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STUDY OF THE RATE OF CORROSION OF METALS BY A FARADAIC DISTORTION METHOD, III

DETERMINATION OF THE KINETIC PARAMETERS OF THE CORROSION PROCESS BY INTERMODULATION DISTORTION

L. MÉSZÁROS and J. DÉVAY

(*Research Laboratory for Inorganic Chemistry of the Hungarian Academy of Sciences, Budapest*)

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An intermodulation technique based on faradaic distortion has been developed for the study of the kinetics of corrosion processes if both the anodic and the cathodic reaction have Tafel type current-potential characteristics. Formulas have been derived for the harmonic components (having frequencies ω_1, ω_2, $2\omega_1$, $2\omega_2$, $3\omega_1$, $3\omega_2$) and the intermodulation components (having frequencies $\omega_1 \pm \omega_2$, $\omega_1 \pm 2\omega_2$, $\omega_2 \pm 2\omega_1$) of the current flowing through the electrode polarized by the sum of two different sinusoidal alternating voltages superimposed on the polarizing direct voltage as functions of the direct voltage and the amplitudes of the alternating voltages.

The corrosion current and the Tafel slopes can be determined from data of the harmonic and intermodulation components at one potential in the cathodic and anodic Tafel ranges, respectively. A method has been developed for the determination of the kinetic parameters of the corrosion process by the measurement of the harmonic and/or intermodulation current components at the corrosion potential. The equations can be considerably simplified if a small amplitude alternating voltage is employed. The measurement of the intermodulation components is more advantageous than that of the harmonic components as the distortion of the sine-wave generators does not interfere.

In our previous communication [1] a new a.c. method has been presented for the determination of the rate of electrochemical corrosion of metals. The potential dependence of the harmonic components of the current flowing through the electrode under the effect of a sinusoidal voltage has been studied in order to determine the kinetic parameters of the corrosion process. Both the anodic and the cathodic reactions of the corrosion process have been assumed to exhibit Tafel type current-voltage characteristics. Relationships have been established between the kinetic parameters of the corrosion process (corrosion current density, Tafel slopes) and the harmonic components of the a.c. On the basis of these relationships, the kinetic parameters of the corrosion process can be determined by means of the measurement of the harmonic components at a single potential namely either at the corrosion potential or at one potential of the anodic or cathodic Tafel ranges of the polarization curves.

The present communication is related to the study of the components of the current flowing through the non-linear faradaic impedance under the effect of intermodulation distortion. Intermodulation distortion is observed when two or more alternating voltages of different angular frequencies (ω_1, ω_2, . . .) are simultaneously connected to a circuit having non-linear current-

voltage characteristics. In this case intermodulation components having $n_1\omega_1 \pm n_2\omega_2 \pm \ldots$ (n_1, $n_2 = 1, 2, 3, 4, \ldots$) frequencies also appear in the current in addition to the fundamental harmonic and higher harmonic components, having $\omega_1, \omega_2, \ldots$ and $n_1\omega_1, n_2\omega_2, \ldots$ frequencies, respectively. The intermodulation components, similarly to the harmonic components, depend on the parameters of the non-linear current-voltage characteristics. This phenomenon can be illustrated by the example of current-voltage characteristics of second degree:

$$I = AU + BU^2. \tag{1}$$

If voltage U is

$$U = U_1 \sin \omega_1 t + U_2 \sin \omega_2 t \tag{1a}$$

where U_1 and U_2 are the amplitudes of the alternating voltages and ω_1 and ω_2 are the corresponding angular frequencies, current I is

$$I = A(U_1 \sin \omega_1 t + U_2 \sin \omega_2 t) + B(U_1 \sin \omega_1 t + U_2 \sin \omega_2 t)^2 . \tag{2}$$

Taking into account well-known trigonometric identities, Eq. (2) can be written in the form

$$I = \frac{B}{2}(U_1^2 + U_2^2) + A(U_1 \sin \omega_1 t + U_2 \sin \omega_2 t) - \tag{3}$$

$$- \frac{B}{2}(U_1^2 \cos 2\omega_1 t + U_2^2 \cos 2\omega_2 t) + BU_1U_2(\cos(\omega_1 - \omega_2)t - \cos(\omega_1 + \omega_2)t).$$

It is apparent that the current contains the intermodulation components of frequencies $\omega_1 \pm \omega_2$ in addition to the fundamental harmonic components of frequencies ω_1 and ω_2 as well as the d.c. component $\frac{B}{2}(U_1^2 + U_2^2)$ generated by rectification and the second harmonic components. When the current-voltage characteristics is a polynomial composed of higher powers of U or an exponential function of U, the current contains higher harmonic components and also intermodulation components having frequencies $n_1\omega_1 \pm n_2\omega_2$ ($n_1, n_2 = 1, 2, 3, \ldots$).

The parameters (A, B) of the current-voltage characteristics can be determined if the amplitudes of the harmonic and intermodulation components are known , as the former parameters appear in the latter.

The above considerations also apply to the case when the circuit having non-linear current voltage characteristics is supplied with a.c. having two or more different frequencies. In this case rectification and distortion is observed in the voltage appearing across the circuit.

Similar effects are encountered also in such cases when the non-linear circuit is supplied with the sum of alternating voltages or of a.c. having frequencies $\omega_1, \omega_2, \ldots$ superimposed on direct voltage or d.c.

However, the current-voltage characteristics observed in the absence of a.c. are altered by the rectification current. The study of the harmonic and of the intermodulation components as functions of the direct voltage or current respectively, offer valuable information on the parameters of the non-linear current-voltage characteristics.

NEEB [2, 3] has introduced the measurement of intermodulation distortion, namely the measurement of current components having $n_1\omega_1 \pm n_2\omega_2$ frequencies in a.c. polarography and tensammetry.

RANGARAJAN [4] has developed an operator method for the study of the non-stationary behaviour of non-linear systems. This method has been applied for the special cases of sinusoidal alternating voltages of ω frequency and amplitude modulated alternating voltages [5]. PRABHAKARA RAO and MISHRA [6] have studied the potential dependence of the fundamental and second harmonic components as well as that of the intermodulation components of $\omega_1 \pm \omega_2$ frequencies flowing through the electrode polarized by a small amplitude alternating voltage, superimposed on the direct voltage in the vicinity of the corrosion potential. The polarization curve has been assumed to be linear with respect to d.c. in the vicinity of the corrosion potential, while it was substituted by a fourth order Taylor polynomial with respect to a.c. The above method permitted the determination of both the corrosion current and the Tafel slopes.

A more detailed consideration of the intermodulation distortion observed on the faradaic impedance permits the determination of the kinetic characteristics of the corrosion process. The intermodulation technique can be regarded as a new possibility for kinetic investigations since in our previous communication [1] only a method based on harmonic distortion has been presented. In the present communication we examined the potential dependence of the a.c. components flowing through the electrode polarized by the sum of sinusoidal alternating voltages of amplitudes U_1 and U_2 and frequencies ω_1 and ω_2, respectively, superimposed on the direct voltage. The effect of the amplitudes of the alternating voltages will also be considered.

Similarly to the assumption already made in our previous communication [1], both the anodic and cathodic reaction of the corrosion process are assumed to exhibit Tafel type current-voltage characteristics and the reversible potentials of the reactions are assumed to differ to a great extent from the corrosion potential.

Harmonic and Intermodulation Components of the Faradaic Current

The polarization curve of the electrode can be given in the present case by the following equation

$$\mathbf{j} = \mathbf{j}_k\left(e^{\frac{\Delta E}{\beta_a}} - e^{-\frac{\Delta E}{\beta_c}}\right), \tag{4}$$

where $\mathbf{j}$ is the current density, $\mathbf{j}_k$ is the corrosion current density, $\Delta E = E - E_k$ is the polarization, *i.e.* the difference of the actual potential and the corrosion potential, while β_a and β_c are parameters proportional to the Tafel slopes, b_a and b_c, of the anodic and cathodic processes respectively

$$\beta_a = \frac{b_a}{\ln 10}, \quad \beta_c = \frac{b_c}{\ln 10}.$$

When the electrode is polarized by alternating voltages of amplitudes U_1 and U_2 and angular frequencies ω_1 and ω_2 respectively, superimposed on direct voltage $\overline{\Delta E}$, having the form

$$\Delta E = \overline{\Delta E} + U_1 \sin \omega_1 t + U_2 \sin \omega_2 t \tag{5}$$

the faradaic current density is given by the following expression

$$\mathbf{j}_F = \mathbf{j}_k\left(e^{\frac{\overline{\Delta E} + U_1 \sin \omega_1 t + U_2 \sin \omega_2 t}{\beta_a}} - e^{\frac{\overline{\Delta E} + U_1 \sin \omega_1 t + U_2 \sin \omega_2 t}{\beta_c}}\right) \tag{6}$$

(the non-faradaic current flowing through the double layer capacity will be considered later).

Separating the exponential expressions of Eq (6) to products the trigonometric terms can be expanded into Fourier series or can be substituted by their third order Fourier polynomials as shown in a previous communication [1]

$$\begin{aligned}
\mathbf{j}_F &= \mathbf{j}_k\left(e^{\frac{\overline{\Delta E}}{\beta_a}} \cdot e^{\frac{U_1 \sin \omega_1 t}{\beta_a}} \cdot e^{\frac{U_2 \sin \omega_2 t}{\beta_a}} - e^{-\frac{\overline{\Delta E}}{\beta_c}} \cdot e^{-\frac{U_1 \sin \omega_1 t}{\beta_c}} \cdot e^{-\frac{U_2 \sin \omega_2 t}{\beta_c}}\right) = \\
&= \mathbf{j}_k \left\{ e^{\frac{\overline{\Delta E}}{\beta_a}} \left[I_0\left(\frac{U_1}{\beta_a}\right) + 2I_1\left(\frac{U_1}{\beta_a}\right)\sin \omega_1 t - 2I_2\left(\frac{U_1}{\beta_a}\right)\cos 2\omega_1 t - 2I_3\left(\frac{U_1}{\beta_a}\right)\sin 3\omega_1 t \right] \cdot \right. \\
&\cdot \left[I_0\left(\frac{U_2}{\beta_a}\right) + 2I_1\left(\frac{U_2}{\beta_a}\right)\sin \omega_2 t - 2I_2\left(\frac{U_2}{\beta_a}\right)\cos 2\omega_2 t - 2I_3\left(\frac{U_2}{\beta_a}\right)\sin 3\omega_2 t \right] - \\
&- e^{-\frac{\overline{\Delta E}}{\beta_c}} \left[I_0\left(\frac{U_1}{\beta_c}\right) - 2I_1\left(\frac{U_1}{\beta_c}\right)\sin \omega_1 t - 2I_2\left(\frac{U_1}{\beta_c}\right)\cos 2\omega_1 t + 2I_3\left(\frac{U_1}{\beta_c}\right)\sin 3\omega_1 t \right] \cdot \\
&\left. \cdot \left[I_0\left(\frac{U_2}{\beta_c}\right) - 2I_1\left(\frac{U_2}{\beta_c}\right)\sin \omega_2 t - 2I_2\left(\frac{U_2}{\beta_c}\right)\cos 2\omega_2 t + 2I_3\left(\frac{U_2}{\beta_c}\right)\sin 3\omega_2 t \right] \right\}.
\end{aligned} \tag{7}$$

By executing the multiplications in the Fourier polynomials and employing the trigonometrical identities

$$\sin \alpha \cdot \sin \beta = \frac{1}{2}[\cos(\alpha - \beta) - \cos(\alpha + \beta)],$$

and

$$\sin \alpha \cdot \cos \beta = \frac{1}{2}[\sin(\alpha + \beta) + \sin(\alpha - \beta)],$$

the faradaic current is obtained in the following form:

$$\mathbf{j}_F = \mathbf{j}_k \left\{ I_0\left(\frac{U_1}{\beta_a}\right) I_0\left(\frac{U_2}{\beta_a}\right) e^{\frac{\Delta E}{\beta_a}} - I_0\left(\frac{U_1}{\beta_c}\right) I_0\left(\frac{U_2}{\beta_c}\right) e^{-\frac{\Delta E}{\beta_c}} \right\} +$$

$$+ 2\mathbf{j}_k \left\{ I_0\left(\frac{U_2}{\beta_a}\right) I_1\left(\frac{U_1}{\beta_a}\right) e^{\frac{\Delta E}{\beta_a}} + I_0\left(\frac{U_2}{\beta_c}\right) I_1\left(\frac{U_1}{\beta_c}\right) e^{-\frac{\Delta E}{\beta_c}} \right\} \sin \omega_1 t +$$

$$+ 2\mathbf{j}_k \left\{ I_0\left(\frac{U_1}{\beta_a}\right) I_1\left(\frac{U_2}{\beta_a}\right) e^{\frac{\Delta E}{\beta_a}} + I_0\left(\frac{U_1}{\beta_c}\right) I_1\left(\frac{U_2}{\beta_c}\right) e^{-\frac{\Delta E}{\beta_c}} \right\} \sin \omega_2 t -$$

$$- 2\mathbf{j}_k \left\{ I_0\left(\frac{U_2}{\beta_a}\right) I_2\left(\frac{U_1}{\beta_a}\right) e^{\frac{\Delta E}{\beta_a}} - I_0\left(\frac{U_2}{\beta_c}\right) I_2\left(\frac{U_1}{\beta_c}\right) e^{-\frac{\Delta E}{\beta_c}} \right\} \cos 2\omega_1 t -$$

$$- 2\mathbf{j}_k \left\{ I_0\left(\frac{U_1}{\beta_a}\right) I_2\left(\frac{U_2}{\beta_a}\right) e^{\frac{\Delta E}{\beta_a}} - I_0\left(\frac{U_1}{\beta_c}\right) I_0\left(\frac{U_2}{\beta_c}\right) e^{-\frac{\Delta E}{\beta_c}} \right\} \cos 2\omega_2 t +$$

$$+ 2\mathbf{j}_k \left\{ I_0\left(\frac{U_2}{\beta_a}\right) I_3\left(\frac{U_1}{\beta_a}\right) e^{\frac{\Delta E}{\beta_a}} + I_0\left(\frac{U_2}{\beta_c}\right) I_3\left(\frac{U_1}{\beta_c}\right) e^{-\frac{\Delta E}{\beta_c}} \right\} \sin 3\omega_1 t -$$

$$- 2\mathbf{j}_k \left\{ I_0\left(\frac{U_1}{\beta_a}\right) I_3\left(\frac{U_2}{\beta_a}\right) e^{\frac{\Delta E}{\beta_a}} + I_0\left(\frac{U_1}{\beta_c}\right) I_3\left(\frac{U_2}{\beta_c}\right) e^{-\frac{\Delta E}{\beta_c}} \right\} \sin 3\omega_2 t +$$

$$+ 2\mathbf{j}_k \left\{ I_1\left(\frac{U_1}{\beta_a}\right) I_1\left(\frac{U_2}{\beta_a}\right) e^{\frac{\Delta E}{\beta_a}} - I_1\left(\frac{U_1}{\beta_c}\right) I_1\left(\frac{U_2}{\beta_c}\right) e^{-\frac{\Delta E}{\beta_c}} \right\} \cos(\omega_1 - \omega_2) t -$$

$$- 2\mathbf{j}_k \left\{ I_1\left(\frac{U_1}{\beta_a}\right) I_1\left(\frac{U_2}{\beta_a}\right) e^{\frac{\Delta E}{\beta_a}} - I_1\left(\frac{U_1}{\beta_c}\right) I_1\left(\frac{U_2}{\beta_c}\right) e^{-\frac{\Delta E}{\beta_c}} \right\} \cos(\omega_1 + \omega_2) t -$$

$$- 2\mathbf{j}_k \left\{ I_1\left(\frac{U_1}{\beta_a}\right) I_2\left(\frac{U_2}{\beta_a}\right) e^{\frac{\Delta E}{\beta_a}} + I_1\left(\frac{U_1}{\beta_c}\right) I_2\left(\frac{U_2}{\beta_c}\right) e^{-\frac{\Delta E}{\beta_c}} \right\} \sin(\omega_1 + 2\omega_2) t -$$

$$- 2\mathbf{j}_k \left\{ I_1\left(\frac{U_1}{\beta_a}\right) I_2\left(\frac{U_2}{\beta_a}\right) e^{\frac{\Delta E}{\beta_a}} + I_1\left(\frac{U_1}{\beta_c}\right) I_2\left(\frac{U_2}{\beta_c}\right) e^{-\frac{\Delta E}{\beta_c}} \right\} \sin(\omega_1 - 2\omega_2) t -$$

$$- 2\mathbf{j}_k \left\{ I_1\left(\frac{U_2}{\beta_a}\right) I_2\left(\frac{U_1}{\beta_a}\right) e^{\frac{\Delta E}{\beta_a}} + I_1\left(\frac{U_2}{\beta_c}\right) I_2\left(\frac{U_1}{\beta_c}\right) e^{-\frac{\Delta E}{\beta_c}} \right\} \sin(\omega_2 + 2\omega_1) t -$$

$$- 2\mathbf{j}_k \left\{ I_1\left(\frac{U_2}{\beta_a}\right) I_2\left(\frac{U_1}{\beta_a}\right) e^{\frac{\Delta E}{\beta_a}} + I_1\left(\frac{U_2}{\beta_c}\right) I_2\left(\frac{U_1}{\beta_c}\right) e^{-\frac{\Delta E}{\beta_c}} \right\} \sin(\omega_2 - 2\omega_1) t. \quad (8)$$

The first term of Eq. (8) yields d.c. component $\bar{\mathbf{j}}$ of the faradaic current

$$\bar{\mathbf{j}} = \mathbf{j}_k \left\{ I_0\left(\frac{U_1}{\beta_a}\right) I_0\left(\frac{U_2}{\beta_a}\right) e^{\frac{\Delta E}{\beta_a}} - I_0\left(\frac{U_1}{\beta_c}\right) I_0\left(\frac{U_2}{\beta_c}\right) e^{-\frac{\Delta E}{\beta_c}} \right\}, \quad (9)$$

while the faradaic rectification term, $\overline{\Delta \mathbf{j}}$, is

$$\overline{\Delta \mathbf{j}} = \mathbf{j}_k \left\{ \left[I_0\left(\frac{U_1}{\beta_a}\right) I_0\left(\frac{U_2}{\beta_a}\right) - 1 \right] e^{\frac{\overline{\Delta E}}{\beta_a}} - \left[I_0\left(\frac{U_1}{\beta_c}\right) I_0\left(\frac{U_2}{\beta_c}\right) - 1 \right] e^{-\frac{\overline{\Delta E}}{\beta_c}} \right\}. \quad (10)$$

The next six terms of Eq. (8) correspond to the two fundamental frequencies (ω_1 and ω_2) and to the higher harmonic ones ($2\omega_1$, $2\omega_2$, $3\omega_1$, $3\omega_2$). The amplitudes of the harmonic components are denoted by $\hat{\mathbf{j}}$:

$$\hat{\mathbf{j}}(\omega_1) = 2\mathbf{j}_k \left\{ I_0\left(\frac{U_2}{\beta_a}\right) I_1\left(\frac{U_1}{\beta_a}\right) e^{\frac{\overline{\Delta E}}{\beta_a}} + I_0\left(\frac{U_2}{\beta_c}\right) I_1\left(\frac{U_1}{\beta_c}\right) e^{-\frac{\overline{\Delta E}}{\beta_c}} \right\}, \quad (11)$$

$$\hat{\mathbf{j}}(\omega_2) = 2\mathbf{j}_k \left\{ I_0\left(\frac{U_1}{\beta_a}\right) I_1\left(\frac{U_2}{\beta_a}\right) e^{\frac{\overline{\Delta E}}{\beta_a}} + I_0\left(\frac{U_1}{\beta_c}\right) I_1\left(\frac{U_2}{\beta_c}\right) e^{-\frac{\overline{\Delta E}}{\beta_c}} \right\}, \quad (12)$$

$$\hat{\mathbf{j}}(2\omega_1) = 2\mathbf{j}_k \left| I_0\left(\frac{U_2}{\beta_a}\right) I_2\left(\frac{U_1}{\beta_a}\right) e^{\frac{\overline{\Delta E}}{\beta_a}} - I_0\left(\frac{U_2}{\beta_c}\right) I_2\left(\frac{U_1}{\beta_c}\right) e^{-\frac{\overline{\Delta E}}{\beta_c}} \right|, \quad (13)$$

$$\hat{\mathbf{j}}(2\omega_2) = 2\mathbf{j}_k \left| I_0\left(\frac{U_1}{\beta_a}\right) I_2\left(\frac{U_2}{\beta_a}\right) e^{\frac{\overline{\Delta E}}{\beta_a}} - I_0\left(\frac{U_1}{\beta_c}\right) I_2\left(\frac{U_2}{\beta_c}\right) e^{-\frac{\overline{\Delta E}}{\beta_c}} \right|, \quad (14)$$

$$\hat{\mathbf{j}}(3\omega_1) = 2\mathbf{j}_k \left\{ I_0\left(\frac{U_2}{\beta_a}\right) I_3\left(\frac{U_1}{\beta_a}\right) e^{\frac{\overline{\Delta E}}{\beta_a}} + I_0\left(\frac{U_2}{\beta_c}\right) I_3\left(\frac{U_1}{\beta_c}\right) e^{-\frac{\overline{\Delta E}}{\beta_c}} \right\}, \quad (15)$$

$$\hat{\mathbf{j}}(3\omega_2) = 2\mathbf{j}_k \left\{ I_0\left(\frac{U_1}{\beta_a}\right) I_3\left(\frac{U_2}{\beta_a}\right) e^{\frac{\overline{\Delta E}}{\beta_a}} + I_0\left(\frac{U_1}{\beta_c}\right) I_3\left(\frac{U_2}{\beta_c}\right) e^{-\frac{\overline{\Delta E}}{\beta_c}} \right\}. \quad (16)$$

The components having fequencies $\omega_1 \pm \omega_2$, $\omega_1 \pm 2\omega_2$ and $\omega_2 \pm 2\omega_1$ respectively, correspond to six other terms of Eq. (8) however, the amplitudes of these components are identical in pairs and can be written in a concise form

$$\hat{\mathbf{j}}(\omega_1 \pm \omega_2) = 2\mathbf{j}_k \left| I_1\left(\frac{U_1}{\beta_a}\right) I_1\left(\frac{U_2}{\beta_a}\right) e^{\frac{\overline{\Delta E}}{\beta_a}} - I_1\left(\frac{U_1}{\beta_c}\right) I_1\left(\frac{U_2}{\beta_c}\right) e^{-\frac{\overline{\Delta E}}{\beta_c}} \right|, \quad (17)$$

$$\mathbf{j}(\omega_1 \pm 2\omega_2) = 2\mathbf{j}_k \left\{ I_1\left(\frac{U_1}{\beta_a}\right) I_2\left(\frac{U_2}{\beta_a}\right) e^{\frac{\overline{\Delta E}}{\beta_a}} + I_1\left(\frac{U_1}{\beta_c}\right) I_2\left(\frac{U_2}{\beta_c}\right) e^{-\frac{\overline{\Delta E}}{\beta_c}} \right\}, \quad (18)$$

$$\mathbf{j}(\omega_2 \pm 2\omega_1) = 2\mathbf{j}_k \left\{ I_1\left(\frac{U_2}{\beta_a}\right) I_2\left(\frac{U_1}{\beta_a}\right) e^{\frac{\overline{\Delta E}}{\beta_a}} + I_1\left(\frac{U_2}{\beta_c}\right) I_2\left(\frac{U_1}{\beta_c}\right) e^{-\frac{\overline{\Delta E}}{\beta_c}} \right\}. \quad (19)$$

The signs indicated in Eq. (8) are disregarded in Eqs (13)—(17), as is the phase reversal of the second harmonic components and that of the inter-

modulation components of frequencies $\omega_1 \pm \omega_2$ since the amplitudes are defined as positive quantities.

Simpler relationships are obtained if we confine our investigations to small amplitudes U_1 and U_2, permitting to substitute the Bessel functions in the above equations by the first term or the first two ones of the respective Taylor polynomials.

Using the approximate expressions derived in our previous communication [1] Eqs (9)—(19) can be rewritten in simpler forms:

$$\bar{\mathbf{j}} = \mathbf{j}_k \left\{ \left[1 + \frac{U_1^2 + U_2^2}{4\beta_a^2} \right] e^{\frac{\overline{\Delta E}}{\beta_a}} - \left[1 + \frac{U_1^2 + U_2^2}{4\beta_c^2} \right] e^{-\frac{\overline{\Delta E}}{\beta_c}} \right\}, \tag{20}$$

$$\overline{\Delta \mathbf{j}} = \mathbf{j}_k \left\{ \frac{1}{\beta_a^2} e^{\frac{\overline{\Delta E}}{\beta_a}} - \frac{1}{\beta_c^2} e^{-\frac{\overline{\Delta E}}{\beta_c}} \right\} \frac{U_1^2 + U_2^2}{4}, \tag{21}$$

$$\hat{\mathbf{j}}(\omega_1) = \mathbf{j}_k \left\{ \left[1 + \left(\frac{U_2}{2\beta_a} \right)^2 \right] \frac{1}{\beta_a} e^{\frac{\overline{\Delta E}}{\beta_a}} + \left[1 + \left(\frac{U_2}{2\beta_c} \right)^2 \right] \frac{1}{\beta_c} e^{-\frac{\overline{\Delta E}}{\beta_c}} \right\} U_1, \tag{22}$$

$$\hat{\mathbf{j}}(\omega_2) = \mathbf{j}_k \left\{ \left[1 + \left(\frac{U_1}{2\beta_a} \right)^2 \right] \frac{1}{\beta_a} e^{\frac{\overline{\Delta E}}{\beta_a}} + \left[1 + \left(\frac{U_1}{\beta_c} \right)^2 \right] \frac{1}{\beta_c} e^{-\frac{\overline{\Delta E}}{\beta_c}} \right\} U_2, \tag{23}$$

$$\hat{\mathbf{j}}(2\omega_1) = \mathbf{j}_k \left| \left[1 + \left(\frac{U_2}{2\beta_a} \right)^2 \right] \frac{1}{\beta_a^2} e^{\frac{\overline{\Delta E}}{\beta_a}} - \left[1 + \left(\frac{U_2}{\beta_c} \right)^2 \right] \frac{1}{\beta_c^2} e^{-\frac{\overline{\Delta E}}{\beta_c}} \right| \frac{U_1^2}{4}, \tag{24}$$

$$\hat{\mathbf{j}}(2\omega_2) = \mathbf{j}_k \left| \left[1 + \left(\frac{U_1}{2\beta_a} \right)^2 \right] \frac{1}{\beta_a^2} e^{\frac{\overline{\Delta E}}{\beta_a}} - \left[1 + \left(\frac{U_1}{2\beta_c} \right)^2 \right] \frac{1}{\beta_c^2} e^{-\frac{\overline{\Delta E}}{\beta_c}} \right| \frac{U_2^2}{4}, \tag{25}$$

$$\hat{\mathbf{j}}(3\omega_1) = \mathbf{j}_k \left\{ \left[1 + \left(\frac{U_2}{2\beta_a} \right)^2 \right] \frac{1}{\beta_a^3} e^{\frac{\overline{\Delta E}}{\beta_a}} + \left[1 + \left(\frac{U_2}{2\beta_c} \right)^2 \right] \frac{1}{\beta_c^3} e^{-\frac{\overline{\Delta E}}{\beta_c}} \right\} \frac{U_1^3}{24}, \tag{26}$$

$$\hat{\mathbf{j}}(3\omega_1) = \mathbf{j}_k \left\{ \left[1 + \left(\frac{U_1}{2\beta_a} \right)^2 \right] \frac{1}{\beta_a^3} e^{\frac{\overline{\Delta E}}{\beta_a}} + \left[1 + \left(\frac{U_1}{2\beta_c} \right)^2 \right] \frac{1}{\beta_c^3} e^{-\frac{\overline{\Delta E}}{\beta_c}} \right\} \frac{U_2^3}{24}, \tag{27}$$

$$\hat{\mathbf{j}}(\omega_1 \pm \omega_2) = \mathbf{j}_k \left| \frac{1}{\beta_a^2} e^{\frac{\overline{\Delta E}}{\beta_a}} - \frac{1}{\beta_c^2} e^{-\frac{\overline{\Delta E}}{\beta_c}} \right| \frac{U_1 U_2}{2}, \tag{28}$$

$$\hat{\mathbf{j}}(\omega_1 \pm 2\omega_2) = \mathbf{j}_k \left\{ \frac{1}{\beta_a^3} e^{\frac{\overline{\Delta E}}{\beta_a}} + \frac{1}{\beta_c^3} e^{-\frac{\overline{\Delta E}}{\beta_c}} \right\} \frac{U_1 U_2^2}{8}, \tag{29}$$

$$\hat{\mathbf{j}}(\omega_2 \pm 2\omega_1) = \mathbf{j}_k \left\{ \frac{1}{\beta_a^3} e^{\frac{\overline{\Delta E}}{\beta_a}} + \frac{1}{\beta_c^3} e^{-\frac{\overline{\Delta E}}{\beta_c}} \right\} \frac{U_1^2 U_2}{8}. \tag{30}$$

Thus we obtained the d.c. components, the amplitudes of the harmonic and intermodulation components of the faradaic current flowing through the electrode polarized by the sum of the alternating voltages having amplitudes U_1 and U_2 and angular frequencies ω_1 and ω_2, respectively, superimposed on direct voltage $\overline{\Delta E}$. The equations represent the components of the current as functions of the direct voltage $\overline{\Delta E}$ and amplitudes U_1 and U_2 of the alternating voltages. It is noteworthy that the above equations relate to the faradaic current exempt from a capacitive component and they can be applied only in such cases when the ohmic drop on the resistance of the solution is compensated by an adequate potentiostat, *i.e.* $\overline{\Delta E}$, U_1 and U_2 are the voltages actually branched to the electrode impedance proper as mentioned in a previous communication [7]. The capacity of the double layer can be considered as a linear circuit element, thus it causes neither harmonic nor intermodulation distortion. Capacitive current is only observed in the fundamental harmonic components. In our previous communication [7] the method of the elimination of the capacitive current has also been reported.

Determination of the Corrosion Current and the Tafel Slopes

The kinetic parameters of the corrosion process ($\mathbf{j}_k$, β_a, β_a) can be determined by the intermodulation method in much the same manner as in the case of harmonic distortion, reported in a previous communication [1]. However, the intermodulation effect offers also a new possibility for the determination of the kinetic parameters since both the harmonic and the intermodulation current components depend on the amplitudes of both alternating voltages and thus the independent variation of the latter provides further information.

Let us consider first the application of the methods reported in a previous communication [1] to intermodulation distortion.

The following equations are related to the harmonic and intermodulation components of the faradaic current observed on the electrode polarized in the range of validity of Tafel's equation for the anodic reaction in the case of an anodic polarization sufficiently large as to have $\frac{\overline{\Delta E_a}}{\beta_a} > 1$ according to Eqs (11)—(19).

$$\hat{\mathbf{j}}_a(\omega_1) = 2\mathbf{j}_k I_0 \left(\frac{U_2}{\beta_a}\right) I_1 \left(\frac{U_1}{\beta_a}\right) e^{\frac{\overline{\Delta E_a}}{\beta_a}}, \tag{31}$$

$$\hat{\mathbf{j}}_a(\omega_2) = 2\mathbf{j}_k I_0 \left(\frac{U_1}{\beta_a}\right) I_1 \left(\frac{U_2}{\beta_a}\right) e^{\frac{\overline{\Delta E_a}}{\beta_a}}, \tag{32}$$

$$\hat{\mathbf{j}}_a(2\omega_1) = 2\mathbf{j}_k I_0\left(\frac{U_2}{\beta_a}\right) I_2\left(\frac{U_1}{\beta_a}\right) e^{\frac{\overline{\Delta E}}{\beta_a}}, \tag{33}$$

$$\hat{\mathbf{j}}_a(2\omega_2) = 2\mathbf{j}_k I_0\left(\frac{U_1}{\beta_a}\right) I_2\left(\frac{U_2}{\beta_a}\right) e^{\frac{\overline{\Delta E_a}}{\beta_a}}, \tag{34}$$

$$\hat{\mathbf{j}}_a(3\omega_1) = 2\mathbf{j}_k I_0\left(\frac{U_2}{\beta_a}\right) I_3\left(\frac{U_1}{\beta_a}\right) e^{\frac{\overline{\Delta E_a}}{\beta_a}}, \tag{35}$$

$$\hat{\mathbf{j}}_a(3\omega_2) = 2\mathbf{j}_k I_0\left(\frac{U_1}{\beta_a}\right) I_3\left(\frac{U_2}{\beta_a}\right) e^{\frac{\overline{\Delta E_a}}{\beta_a}}, \tag{36}$$

$$\hat{\mathbf{j}}_a(\omega_1 \pm \omega_2) = 2\mathbf{j}_k I_1\left(\frac{U_1}{\beta_a}\right) I_1\left(\frac{U_2}{\beta_a}\right) e^{\frac{\overline{\Delta E_a}}{\beta_a}}, \tag{37}$$

$$\hat{\mathbf{j}}_a(\omega_1 \pm 2\omega_2) = 2\mathbf{j}_k I_1\left(\frac{U_1}{\beta_a}\right) I_2\left(\frac{U_2}{\beta_a}\right) e^{\frac{\overline{\Delta E_a}}{\beta_a}}, \tag{38}$$

$$\hat{\mathbf{j}}_a(\omega_2 \pm 2\omega_1) = 2\mathbf{j}_k I_1\left(\frac{U_2}{\beta_a}\right) I_2\left(\frac{U_1}{\beta_a}\right) e^{\frac{\overline{\Delta E_a}}{\beta_a}}. \tag{39}$$

Parameter β_a can be determined by successive approximation from one of the following quotients

$$\frac{\hat{\mathbf{j}}_a(\omega_i)}{\hat{\mathbf{j}}_a(2\omega_i)} = \frac{I_1\left(\frac{U_i}{\beta_a}\right)}{I_2\left(\frac{U_i}{\beta_a}\right)}, \qquad (i = 1, 2) \tag{40}$$

$$\frac{\hat{\mathbf{j}}_a(2\omega_i)}{\hat{\mathbf{j}}_a(3\omega_i)} = \frac{I_2\left(\frac{U_i}{\beta_a}\right)}{I_3\left(\frac{U_i}{\beta_a}\right)}, \qquad (i = 1, 2) \tag{41}$$

$$\frac{\hat{\mathbf{j}}_a(\omega_1 \pm \omega_2)}{\hat{\mathbf{j}}_a(\omega_1 \pm 2\omega_2)} = \frac{I_1\left(\frac{U_2}{\beta_a}\right)}{I_2\left(\frac{U_2}{\beta_a}\right)}, \tag{42}$$

$$\frac{\hat{\mathbf{j}}_a(\omega_1 \pm \omega_2)}{\hat{\mathbf{j}}_a(\omega_2 \pm 2\omega_1)} = \frac{I_1\left(\frac{U_1}{\beta_a}\right)}{I_2\left(\frac{U_1}{\beta_a}\right)}, \tag{43}$$

However, successive approximation can be avoided by applying the recursion formula

$$\frac{2n}{x} I_n(x) = I_{n-1}(x) - I_{n+1}(x)$$

valid for modified first order Bessel Functions for the case of $n = 2$ and $x = \frac{U_i}{\beta_a}$ $(i = 1, 2)$ (*Cf.* [1]). Thus β_a can be expressed by the amplitudes of the harmonic and intermodulation components

$$\beta_a = \frac{U_i}{4}\left(\frac{I_1\left(\frac{U_i}{\beta_a}\right)}{I_2\left(\frac{U_i}{\beta_a}\right)} - \frac{I_3\left(\frac{U_i}{\beta_a}\right)}{I_2\left(\frac{U_i}{\beta_a}\right)}\right), \qquad (i = 1, 2), \tag{45}$$

or

$$\beta_a = \frac{U_1}{4}\left(\frac{\hat{\mathbf{j}}_a(\omega_1)}{\hat{\mathbf{j}}_a(2\omega_1)} - \frac{\hat{\mathbf{j}}_a(3\omega_1)}{\hat{\mathbf{j}}_a(2\omega_1)}\right) = \frac{U_2}{4}\left(\frac{\hat{\mathbf{j}}_a(\omega_2)}{\hat{\mathbf{j}}_a(2\omega_2)} - \frac{\hat{\mathbf{j}}_a(3\omega_2)}{\hat{\mathbf{j}}_a(2\omega_2)}\right) =$$

$$= \frac{U_1}{4}\left(\frac{\hat{\mathbf{j}}_a(\omega_1 \pm \omega_2)}{\hat{\mathbf{j}}_a(\omega_2 \pm 2\omega_1)} - \frac{\hat{\mathbf{j}}_a(3\omega_1)}{\hat{\mathbf{j}}_a(2\omega_1)}\right) = \frac{U_2}{4}\left(\frac{\hat{\mathbf{j}}_a(\omega_1 \pm \omega_2)}{\hat{\mathbf{j}}_a(\omega_1 \pm 2\omega_2)} - \frac{\hat{\mathbf{j}}_a(3\omega_2)}{\hat{\mathbf{j}}_a(2\omega_2)}\right). \tag{46}$$

It is noteworthy that the last two terms of identities (46) only contain intermodulation and higher harmonic components. The latter can be determined by direct measurement as they are exempt from capacitive current contrary to the fundamental harmonic components having frequencies ω_1 and ω_2, respectively, which can only be substituted in expression (46) after the elimination of the capacitive current by extrapolation [7].

If amplitudes U_1 and U_2 are sufficiently small as to permit to neglect I_3 in comparison to I_1, $\left(I_3\left(\frac{U_i}{\beta_a}\right) \ll I_1\left(\frac{U_i}{\beta_a}\right);\ i = 1, 2\right)$ Eq. (46) is obtained in a simplified form

$$\beta_a \simeq \frac{U_1}{4}\frac{\hat{\mathbf{j}}_a(\omega_1)}{\hat{\mathbf{j}}_a(2\omega_1)} = \frac{U_2}{4}\frac{\hat{\mathbf{j}}_a(\omega_2)}{\hat{\mathbf{j}}_a(2\omega_2)} = \frac{U_1}{4}\frac{\hat{\mathbf{j}}_a(\omega_1 \pm \omega_2)}{\hat{\mathbf{j}}_a(\omega_2 \pm 2\omega_1)} = \frac{U_2}{4}\frac{\hat{\mathbf{j}}_a(\omega_1 \pm \omega_2)}{\hat{\mathbf{j}}_a(\omega_1 \pm 2\omega_2)}. \tag{47}$$

Corrosion current density $\mathbf{j}_k$ can be determined by any one of Eqs (31)—(39) if β_a is known.

Parameter β_c and corrosion current density $\mathbf{j}_k$ can similarly be determined by applying the above considerations to the cathodic reaction in the case when $-\frac{\overline{\Delta E_c}}{\beta_c} > 1$, *i.e.* the measurement is performed at a potential $\overline{\Delta E_c}$ in

the cathodic Tafel range. The equations relating to cathodic polarization are identical to Eqs (31)—(34) and (45)—(47) except for the subscripts.

The equations can considerably be simplified if quotients (40)—(43) are calculated by employing relations (22)—(30) for the case of anodic $\left(\frac{\overline{\Delta E}_a}{\beta_a} > 1\right)$ and cathodic $\left(-\frac{\overline{\Delta E}_c}{\beta_c} > 1\right)$ polarization, respectively, since successive approximation on the basis of Eqs (40)—(43) can be avoided and β_a or β_c can be expressed directly by the amplitudes of the harmonic and intermodulation components.

$$\beta_a = \frac{U_i}{4} \frac{\hat{\mathbf{j}}_a(\omega_i)}{\hat{\mathbf{j}}_a(2\omega_i)}, \qquad (i = 1, 2) \tag{48}$$

$$\beta_a = \frac{U_i}{6} \frac{\hat{\mathbf{j}}_a(2\omega_i)}{\hat{\mathbf{j}}_a(3\omega_i)}, \tag{49}$$

$$\beta_a = \frac{U_2}{4} \frac{\hat{\mathbf{j}}_a(\omega_1 \pm \omega_2)}{\hat{\mathbf{j}}_a(\omega_1 \pm 2\omega_2)} = \frac{U_1}{4} \frac{\hat{\mathbf{j}}_a(\omega_1 \pm \omega_2)}{\hat{\mathbf{j}}_a(\omega_2 \pm 2\omega_1)}. \tag{50}$$

Similar relationships are obtained for the parameters of the cathodic reaction when the harmonic and intermodulation components are measured at potential $\overline{\Delta E}_c$ in the cathodic Tafel range.

$$\beta_c = \frac{U_i}{4} \frac{\hat{\mathbf{j}}_c(\omega_i)}{\hat{\mathbf{j}}_c(2\omega_i)}, \qquad (i = 1, 2) \tag{51}$$

$$\beta_c = \frac{U_i}{6} \frac{\hat{\mathbf{j}}_c(2\omega_i)}{\hat{\mathbf{j}}_c(3\omega_i)} \qquad (i = 1, 2) \tag{52}$$

$$\beta_c = \frac{U_2}{4} \frac{\hat{\mathbf{j}}_c(\omega_1 \pm \omega_2)}{\hat{\mathbf{j}}_c(\omega_1 \pm 2\omega_2)} = \frac{U_1}{4} \frac{\hat{\mathbf{j}}_c(\omega_1 \pm \omega_2)}{\hat{\mathbf{j}}_c(\omega_2 \pm 2\omega_1)}. \tag{53}$$

Corrosion current density $\mathbf{j}_k$ can be expressed from one of Eqs (22)—(30) applied for the case when $\frac{\overline{\Delta E}_a}{\beta_a} > 1$, or $-\frac{\overline{\Delta E}_c}{\beta_c} > 1$, if β_a or β_c, respectively, have been determined from the above equations.

$$\mathbf{j}_k = \frac{\hat{\mathbf{j}}_a(\omega_1)\,\beta_a}{\left[1 + \left(\frac{U_2}{2\beta_a}\right)^2\right] U_1} e^{-\frac{\overline{\Delta E}_a}{\beta_a}} = \frac{\hat{\mathbf{j}}_a(\omega_2)\,\beta_a}{\left[1 + \left(\frac{U_1}{2\beta_a}\right)^2\right] U_2} e^{-\frac{\overline{\Delta E}_a}{\beta_a}} =$$

$$= \frac{4\hat{\mathbf{j}}_a(2\omega_1)\,\beta_a^2}{\left[1 + \left(\frac{U_2}{2\beta_a}\right)^2\right] U_1^2} e^{-\frac{\overline{\Delta E}_a}{\beta_a}} = \frac{4\hat{\mathbf{j}}_a(2\omega_2)\,\beta_a^2}{\left[1 + \left(\frac{U_1}{2\beta_a}\right)^2\right] U_2^2} e^{-\frac{\overline{\Delta E}_a}{\beta_a}} =$$

$$= \frac{24\hat{\mathbf{j}}_a(3\omega_1)\,\beta_a^3}{\left[1+\left(\frac{U_2}{2\beta_a}\right)^2\right]U_1^3}\,e^{-\frac{\overline{\Delta E_a}}{\beta_a}} = \frac{24\hat{\mathbf{j}}_a(3\omega_2)\,\beta_a^3}{\left[1+\left(\frac{U_1}{2\beta_a}\right)^2\right]U_2^3}\,e^{-\frac{\overline{\Delta E_a}}{\beta_a}} =$$

$$= \frac{2\hat{\mathbf{j}}_a(\omega_1 \pm \omega_2)\,\beta_a^2}{U_1 U_2}\,e^{-\frac{\overline{\Delta E_a}}{\beta_a}} = \frac{8\hat{\mathbf{j}}_a(\omega_1 \pm 2\omega_2)\,\beta_a^3}{U_1 U_2^2}\,e^{-\frac{\overline{\Delta E_a}}{\beta_a}} =$$

$$= \frac{8\hat{\mathbf{j}}_a(\omega_2 \pm 2\omega_1)\,\beta_a^3}{U_1^2 U_2}\,e^{-\frac{\overline{\Delta E_a}}{\beta_a}}. \qquad (54)$$

In the case of cathodic polarization $\left(-\frac{\overline{\Delta E_c}}{\beta_c} > 1\right)$ subscript c is used in Eq. (54) and $-\overline{\Delta E_c}$ is inserted instead of $\overline{\Delta E_a}$.

Thus it can be concluded that parameters β_a and β_c as well as corrosion current density $\mathbf{j}_k$ can also be determined by the intermodulation technique from data obtained at potentials $\overline{\Delta E_a}$ and $\overline{\Delta E_c}$ in the validity range of Tafel's equation for the anodic and cathodic reaction, respectively.

The extrapolation to $\omega = 0$ for the elimination of the capacitive current (observed in the fundamental harmonic current components) can be avoided if the higher harmonic and/or the intermodulation components are only employed for the evaluation of the kinetic parameters.

Corrosion current density $\mathbf{j}_k$ and parameters β_a and β_c can also be calculated from data at corrosion potential $\overline{\Delta E} = 0$ by introducing $\overline{\Delta E} = 0$ in Eqs (10)–(19).

$$\overline{\Delta \mathbf{j}_0} = \mathbf{j}_k\left\{I_0\left(\frac{U_1}{\beta_a}\right)I_0\left(\frac{U_2}{\beta_a}\right) - I_0\left(\frac{U_1}{\beta_c}\right)I_0\left(\frac{U_2}{\beta_c}\right)\right\}, \qquad (55)$$

$$\hat{\mathbf{j}}_0(\omega_1) = 2\mathbf{j}_k\left\{I_0\left(\frac{U_2}{\beta_a}\right)I_1\left(\frac{U_1}{\beta_a}\right) + I_0\left(\frac{U_2}{\beta_c}\right)I_1\left(\frac{U_1}{\beta_c}\right)\right\}, \qquad (56)$$

$$\hat{\mathbf{j}}_0(\omega_2) = 2\mathbf{j}_k\left\{I_0\left(\frac{U_1}{\beta_a}\right)I_1\left(\frac{U_2}{\beta_a}\right) + I_0\left(\frac{U_1}{\beta_c}\right)I_1\left(\frac{U_2}{\beta_c}\right)\right\}, \qquad (57)$$

$$\hat{\mathbf{j}}_0(2\omega_1) = 2\mathbf{j}_k\left|I_0\left(\frac{U_2}{\beta_a}\right)I_2\left(\frac{U_1}{\beta_a}\right) - I_0\left(\frac{U_2}{\beta_c}\right)I_2\left(\frac{U_1}{\beta_c}\right)\right|, \qquad (58)$$

$$\hat{\mathbf{j}}_0(2\omega_2) = 2\mathbf{j}_k\left|I_0\left(\frac{U_1}{\beta_a}\right)I_2\left(\frac{U_2}{\beta_a}\right) - I_0\left(\frac{U_1}{\beta_c}\right)I_2\left(\frac{U_2}{\beta_c}\right)\right|, \qquad (59)$$

$$\hat{\mathbf{j}}_0(3\omega_1) = 2\mathbf{j}_k\left\{I_0\left(\frac{U_2}{\beta_a}\right)I_3\left(\frac{U_1}{\beta_a}\right) + I_0\left(\frac{U_2}{\beta_c}\right)I_3\left(\frac{U_1}{\beta_c}\right)\right\}, \qquad (60)$$

$$\hat{\mathbf{j}}_0(3\omega_2) = 2\mathbf{j}_k\left\{I_0\left(\frac{U_1}{\beta_a}\right)I_3\left(\frac{U_2}{\beta_a}\right) + I_0\left(\frac{U_1}{\beta_c}\right)I_3\left(\frac{U_2}{\beta_c}\right)\right\}, \qquad (61)$$

$$\hat{\mathbf{j}}_0(\omega_1 \pm \omega_2) = 2\mathbf{j}_k \left| I_1\left(\frac{U_1}{\beta_a}\right) I_1\left(\frac{U_2}{\beta_a}\right) - I_1\left(\frac{U_1}{\beta_c}\right) I_1\left(\frac{U_2}{\beta_c}\right) \right|, \tag{62}$$

$$\hat{\mathbf{j}}_0(\omega_1 \pm 2\omega_2) = 2\mathbf{j}_k \left\{ I_1\left(\frac{U_1}{\beta_a}\right) I_2\left(\frac{U_2}{\beta_a}\right) + I_1\left(\frac{U_1}{\beta_c}\right) I_2\left(\frac{U_2}{\beta_c}\right) \right\}, \tag{63}$$

$$\hat{\mathbf{j}}_0(\omega_2 \pm 2\omega_1) = 2\mathbf{j}_k \left\{ I_1\left(\frac{U_2}{\beta_a}\right) I_2\left(\frac{U_1}{\beta_a}\right) + I_1\left(\frac{U_2}{\beta_c}\right) I_2\left(\frac{U_1}{\beta_c}\right) \right. . \tag{64}$$

The corrosion current density can readily be expressed from any one of the above equations if β_a and β_c are known. It is noteworthy that Eqs (55), (58), (59) and (62) can only be used if $\overline{\Delta \mathbf{j}_0}$, $\hat{\mathbf{j}}_0(2\omega_1)$, $\hat{\mathbf{j}}_0(2\omega_2)$ and $\hat{\mathbf{j}}_0(\omega_1 \pm \omega_2)$, respectively, differ from zero.

However β_a, β_c and $\mathbf{j}_k$ can also be calculated by using three linearly independent equations from among Eqs (45)—(64) and writing a suitable computer program.

β_a and β_c and $\mathbf{j}_k$ can also be expressed in an explicit form if small amplitude alternating voltages are employed. In this case Eqs (21)—(30) are utilized by introducing $\overline{\Delta E} = 0$:

$$\overline{\Delta \mathbf{j}_0} = \mathbf{j}_k \left\{ \frac{1}{\beta_a^2} - \frac{1}{\beta_c^2} \right\} \frac{U_1^2 + U_2^2}{4}, \tag{65}$$

$$\hat{\mathbf{j}}_0(\omega_1) = \mathbf{j}_k \left\{ \left[1 + \left(\frac{U_2}{2\beta_a}\right)^2 \right] \frac{1}{\beta_a} + \left[1 + \left(\frac{U_2}{2\beta_c}\right)^2 \right] \frac{1}{\beta_c} \right\} U_1, \tag{66}$$

$$\hat{\mathbf{j}}_0(\omega_2) = \mathbf{j}_k \left\{ \left[1 + \left(\frac{U_1}{2\beta_a}\right)^2 \right] \frac{1}{\beta_a} + \left[1 + \left(\frac{U_1}{2\beta_c}\right)^2 \right] \frac{1}{\beta_c} \right\} U_2, \tag{67}$$

$$\hat{\mathbf{j}}_0(2\omega_1) = \mathbf{j}_k \left| \left[1 + \left(\frac{U_2}{2\beta_a}\right)^2 \right] \frac{1}{\beta_a^2} - \left[1 + \left(\frac{U_2}{2\beta_c}\right)^2 \right] \frac{1}{\beta_c^2} \right| \frac{U_1^2}{4}, \tag{68}$$

$$\hat{\mathbf{j}}_0(2\omega_2) = \mathbf{j}_k \left| \left[1 + \left(\frac{U_1}{2\beta_a}\right)^2 \right] \frac{1}{\beta_a^2} - \left[1 + \left(\frac{U_1}{2\beta_c}\right)^2 \right] \frac{1}{\beta_c^2} \right| \frac{U_2^2}{4}, \tag{69}$$

$$\hat{\mathbf{j}}_0(3\omega_1) = \mathbf{j}_k \left\{ \left[1 + \left(\frac{U_2}{2\beta_a}\right)^2 \right] \frac{1}{\beta_a^3} + \left[1 + \left(\frac{U_2}{2\beta_c}\right) \right] \frac{1}{\beta_c^3} \right\} \frac{U_1^3}{24}, \tag{70}$$

$$\hat{\mathbf{j}}_0(3\omega_2) = \mathbf{j}_k \left\{ \left[1 + \left(\frac{U_1}{2\beta_a}\right)^2 \right] \frac{1}{\beta_a^3} + \left[1 + \left(\frac{U_1}{2\beta_c}\right)^2 \right] \frac{1}{\beta_c^3} \right\} \frac{U_2^3}{24}, \tag{71}$$

$$\hat{\mathbf{j}}_0(\omega_1 \pm \omega_2) = \mathbf{j}_k \left| \frac{1}{\beta_a^2} - \frac{1}{\beta_c^2} \right| \frac{U_1 U_2}{2}, \tag{72}$$

$$\hat{\mathbf{j}}_0(\omega_1 \pm 2\omega_2) = \mathbf{j}_k \left\{ \frac{1}{\beta_a^3} + \frac{1}{\beta_c^3} \right\} \frac{U_1 U_2^2}{8}, \tag{73}$$

$$\hat{\mathbf{j}}_0(\omega_2 \pm 2\omega_1) = \mathbf{j}_k \left\{ \frac{1}{\beta_a^3} + \frac{1}{\beta_c^3} \right\} \frac{U_1^2 U_2}{8}. \tag{74}$$

The expressions related to the amplitudes of the harmonic components assume the simple forms given by Eqs (50)—(52) of our previous communication [1] if the bracketed expressions of Eqs (66)—(71) are approximately equal to unity. The latter condition is fulfilled if the amplitudes of the alternating voltages are properly selected. In this case corrosion current density $\mathbf{j}_k$ and parameters β_a and β_c can be calculated using Eqs (53), (58), (59), (60) and (61) given in our previous communication [1]. Equations (72)—(74) relating to the intermodulation components can readily be employed in the expressions used for the calculation of β_a and β_c and the corrosion current density, instead of Eqs (68)—(71) relating to the higher harmonic components since in the case if $1 + \left(\frac{U}{2\beta}\right)^2 \approx 1$

$$\hat{\mathbf{j}}_0(2\omega_1) = \frac{U_1}{2U_2}\,\hat{\mathbf{j}}_0(\omega_1 \pm \omega_2)\,, \tag{75}$$

$$\hat{\mathbf{j}}_0(2\omega_2) = \frac{U_2}{2U_1}\,\hat{\mathbf{j}}_0(\omega_1 \pm \omega_2)\,, \tag{76}$$

$$\hat{\mathbf{j}}_0(3\omega_1) = \frac{U_1^2}{3U_2^2}\,\hat{\mathbf{j}}_0(\omega_1 \pm 2\omega_2)\,, \tag{77}$$

$$\hat{\mathbf{j}}_0(3\omega_2) = \frac{U_2^2}{3U_1^2}\,\hat{\mathbf{j}}_0(\omega_2 \pm 2\omega_1)\,. \tag{78}$$

Thus the kinetic parameters of the corrosion process are given by the following relationships containing the harmonic and intermodulation components of the faradaic current measured at the corrosion potential:

$$\mathbf{j}_k = \frac{\hat{\mathbf{j}}_0^2(\omega_1)}{\sqrt{48}\,\sqrt{2\hat{\mathbf{j}}_0(\omega_1)\,\hat{\mathbf{j}}_0(3\omega_1) - \hat{\mathbf{j}}_0^2(2\omega_1)}} = \frac{\hat{\mathbf{j}}_0^2(\omega_2)}{\sqrt{48}\,\sqrt{2\hat{\mathbf{j}}_0(\omega_2)\,\hat{\mathbf{j}}_0(3\omega_2) - \hat{\mathbf{j}}_0^2(2\omega_2)}} =$$

$$= \frac{U_2}{U_1}\,\frac{\hat{\mathbf{j}}_0^2(\omega_1)}{2\sqrt{8\hat{\mathbf{j}}_0(\omega_1)\,\hat{\mathbf{j}}_0(\omega_1 \pm 2\omega_2) - 3\hat{\mathbf{j}}_0^2(\omega_1 \pm \omega_2)}} =$$

$$= \frac{U_1}{U_2}\,\frac{\hat{\mathbf{j}}_0^2(\omega_2)}{2\sqrt{8\hat{\mathbf{j}}_0(\omega_2)\hat{\mathbf{j}}_0(\omega_2 \pm 2\omega_1) - 3\hat{\mathbf{j}}_0^2(\omega_1 \pm \omega_2)}}\,, \tag{79}$$

$$\frac{1}{\beta_a} = \frac{1}{2U_1}\left(\frac{\hat{\mathbf{j}}_0(\omega_1)}{\mathbf{j}_k} \pm 4\,\frac{\hat{\mathbf{j}}_0(2\omega_1)}{\hat{\mathbf{j}}_0(\omega_1)}\right) = \frac{1}{2U_2}\left(\frac{\hat{\mathbf{j}}_0(\omega_2)}{\mathbf{j}_k} \pm 4\,\frac{\hat{\mathbf{j}}_0(2\omega_2)}{\hat{\mathbf{j}}_0(\omega_2)}\right) =$$

$$= \frac{1}{2U_1}\left(\frac{\hat{\mathbf{j}}_0(\omega_1)}{\mathbf{j}_k} \pm 2\,\frac{U_1}{U_2}\,\frac{\hat{\mathbf{j}}_0(\omega_1 \pm \omega_2)}{\hat{\mathbf{j}}_0(\omega_1)}\right) =$$

$$= \frac{1}{2U_2}\left(\frac{\hat{\mathbf{j}}_0(\omega_2)}{\mathbf{j}_k} \pm 2\,\frac{U_2}{U_1}\,\frac{\hat{\mathbf{j}}_0(\omega_1 \pm \omega_2)}{\hat{\mathbf{j}}_0(\omega_2)}\right), \tag{80}$$

$$\frac{1}{\beta_c} = \frac{1}{2U_1}\left(\frac{\hat{\mathbf{j}}_0(\omega_1)}{\mathbf{j}_k} \mp 4\frac{\hat{\mathbf{j}}(2\omega_1)}{\hat{\mathbf{j}}_0(\omega_1)}\right) = \frac{1}{2U_2}\left(\frac{\hat{\mathbf{j}}_0(\omega_2)}{\mathbf{j}_k} \mp 4\frac{\hat{\mathbf{j}}(2\omega_2)}{\hat{\mathbf{j}}_0(\omega_2)}\right) =$$

$$= \frac{1}{2U_1}\left(\frac{\hat{\mathbf{j}}_0(\omega_1)}{\mathbf{j}_k} \mp 2\frac{U_1}{U_2}\frac{\hat{\mathbf{j}}_0(\omega_1 \pm \omega_2)}{\hat{\mathbf{j}}_0(\omega_1)}\right) =$$

$$= \frac{1}{2U_2}\left(\frac{\hat{\mathbf{j}}_0(\omega_2)}{\mathbf{j}_k} \mp 2\frac{U_2}{U_1}\frac{\hat{\mathbf{j}}_0(\omega_1 \pm \omega_2)}{\hat{\mathbf{j}}_0(\omega_2)}\right). \tag{81}$$

The upper signs of Eqs (80) and (81) refer to the case when $\beta_a < \beta_c$, while the lower signs are valid when $\beta_a > \beta_c$. $\beta_a < \beta_c$ when $\overline{\Delta \mathbf{j}_0} > 0$, according to Eq. (65), while $\beta_a > \beta_c$ when $\overline{\Delta \mathbf{j}_0} < 0$, when $\overline{\Delta \mathbf{j}_0} = 0$. $\beta_a = \beta_c$ and can be calculated using any one of Eqs (66), (67), (70), (71), (73) and (74).

Except for minor modifications, the above method can be considered essentially identical to the method based solely on harmonic distortion as presented in a previous report [1] However, the intermodulation effect offers new possibilities for the determination of the kinetic parameters of the corrosion process which are based on the fact that amplitudes U_1 and U_2 of the alternating voltages, having different frequencies, can be varied independently from one another and the amplitudes of the harmonic components of the current are affected by both U_1 and U_2. (This effect is also encountered in the case of intermodulation components but it does not lead to a new evaluation method.).

The dependence of the harmonic components of the current on amplitudes U_1 and U_2 of the alternating voltages are given by Eqs (31)—(36) at a polarizing potential $\overline{\Delta E_a}$ in the anodic Tafel range where $\frac{\overline{\Delta E_a}}{\beta_a} > 1$. The following ratios permit to calculate β_a using tables of Bessel functions when the current components of frequency ω_1, $2\omega_1$, $3\omega_1$ and ω_2, $2\omega_2$, $3\omega_2$ are also measured in the case of $U_2 = 0$ and $U_1 \neq 0$ or $U_1 = 0$ and $U_2 \neq 0$, respectively:

$$\frac{\hat{\mathbf{j}}_a(\omega_1)}{[\hat{\mathbf{j}}_a(\omega_1)]_{U_2=0}} = \frac{\hat{\mathbf{j}}_a(2\omega_1)}{[\hat{\mathbf{j}}_a(2\omega_1)]_{U_2=0}} = \frac{\hat{\mathbf{j}}_a(3\omega_1)}{[\hat{\mathbf{j}}_a(3\omega_1)]_{U_2=0}} = I_0\left(\frac{U_2}{\beta_a}\right), \tag{82}$$

$$\frac{\hat{\mathbf{j}}_a(\omega_1)}{[\hat{\mathbf{j}}_a(\omega_2)]_{U_1=0}} = \frac{\hat{\mathbf{j}}_a(2\omega_2)}{[\hat{\mathbf{j}}_a(2\omega_2)]_{U_1=0}} = \frac{\hat{\mathbf{j}}_a(3\omega_2)}{[\hat{\mathbf{j}}_a(3\omega_2)]_{U_1=0}} = I_0\left(\frac{U_1}{\beta_a}\right). \tag{83}$$

[Note that $I_0(0) = 1$].

The approximation $I_0(x) \approx 1 + \frac{x^2}{2}$ can be employed when the amplitudes of the alternating voltages are small and β_a can be expressed from Eqs

(83) and (82) by algebraic calculation

$$\frac{1}{\beta_a^2} = \frac{4}{U_2^2}\left(\frac{\hat{\mathbf{j}}_a(\omega_1)}{[\hat{\mathbf{j}}_a(\omega_1)]_{U_2=0}} - 1\right) = \frac{4}{U_2^2}\left(\frac{\hat{\mathbf{j}}_a(2\omega_1)}{[\hat{\mathbf{j}}_a(2\omega_1)]_{U_2=0}} - 1\right) =$$

$$= \frac{4}{U_2^2}\left(\frac{\hat{\mathbf{j}}_a(3\omega_1)}{[\hat{\mathbf{j}}_a(3\omega_1)]_{U_2=0}} - 1\right), \tag{84}$$

$$\frac{1}{\beta_a^2} = \frac{4}{U_1^2}\left(\frac{\hat{\mathbf{j}}_a(\omega_2)}{[\hat{\mathbf{j}}_a(\omega_2)]_{U_1=0}} - 1\right) = \frac{4}{U_1^2}\left(\frac{\hat{\mathbf{j}}_a(2\omega_2)}{[\hat{\mathbf{j}}_a(2\omega_2)]_{U_1=0}} - 1\right) =$$

$$= \frac{4}{U_1^2}\left(\frac{\hat{\mathbf{j}}_a(3\omega_2)}{[\hat{\mathbf{j}}_a(3\omega_2)]_{U_1=0}} - 1\right). \tag{85}$$

We note that voltage U_2 of frequency ω_2 has to be small in Eq. (84) while this applies to voltage U_1 of frequency ω_1 in Eq. (85).

The corrosion current density can be expressed from one of Eqs (31)—(39) if β_a has been determined in the above manner.

Similar relationships are obtained using the harmonic components of the current measured on an electrode polarized to potential $\overline{\Delta E_c}$ in the cathodic Tafel range, where $-\frac{\overline{\Delta E_c}}{\beta_c} > 1$. In this case Eqs (82)—(85) are modified by changing subscripts a to *c*.

Thus it can be concluded that the kinetic parameters of a corrosion process characterized by Tafel type cathodic and anodic reactions can be determined by the study of harmonic and intermodulation distortion caused by the non-linearity of the faradaic impedance. The methods presented in this communication permit the determination of the kinetic parameters on the basis of the measurement of the harmonic and/or intermodulation components at one potential (at one potential either in the cathodic or the anodic Tafel range or at the corrosion potential).

The intermodulation effect has another advantage in addition to those mentioned in the first report of this series [1]. Namely, frequencies $\omega_1 \pm \omega_2$ $\omega_2 \pm 2\omega_1$ and $\omega_1 \pm 2\omega_2$ of the intermodulation components do not coincide with the higher harmonics of fundamental frequencies ω_1 and ω_2 if the latter are properly selected and thus the distortion of the signal generators producing the fundamental harmonic voltages does not interfere in the measurement of the intermodulation components. However, the distortion of the signal generators can affect the measurement of the higher harmonic components and consequently, in the latter case it is advisable to use generators having very small distortion.

The experimental verification of the above methods will be presented in a later communication.

REFERENCES

[1] DÉVAY, J., MÉSZÁROS, L.: Magy. Kém. Folyóirat (In press): Acta Chim. Acad. Sci. Hung., **100,** 183 (1979)
[2] NEEB, R.: Naturwissenschaften, **49,** 447 (1962)
[3] NEEB, R.: Z. Anal. Chem., **208,** 168 (1965)
[4] RANGARAJAN, S. K.: J. Electroanal. Chem., **56,** 1 (1974)
[5] RANGARAJAN, S. K.: J. Electroanal. Chem. **56,** 27 (1974)
[6] PRABHAKARA RAO, G., MISCHRA, A. K.: J. Electroanal. Chem., **77,** 121 (1977)
[7] DÉVAY, J., MÉSZÁROS, L.: Magy. Kém. Folyóirat **85,** 218 (1979); Acta Chim. Acad. Sci. Hung. (In press)

Lajos MÉSZÁROS
József DÉVAY
} H-1112 Budapest, Budaörsi út 45.

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STUDIES ON 1-ARYLOXYSILATRANES, I

KINETICS OF THE HYDROLYSIS OF 1-(2′,4′,6′-TRIMETHYLPHENOXY)SILATRANE

J. ŁUKASIAK and Z. JAMRÓGIEWICZ

Department of Physical Chemistry, Institute of Chemistry and Analytics, Medical Academy, 80—416 Gdansk, Poland)

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A UV spectroscopic method has been developed for studying the kinetics of hydrolysis of 1-(2′,4′,6′-trimethylphenoxy)silatrane. The effect of temperature and pH on the rate constant of hydrolysis has been determined and a mechanism of the reaction proposed.

The kinetics of hydrolysis of 1-alkyl- and 1-alkoxysilatranes has been studied by VORONKOV *et al.* [1]. The course of the reaction was monitored by titration with standard hydrochloric acid solution. The authors suggested a mechanism for this reaction. In 1975 VORONKOV *et al.* [2] found that the titration technique did not afford accurate results and employed the polarographic method for kinetic studies. By this method the kinetics of hydrolysis of 1-alkoxy-, 1-aryloxy- and 1-(1′-chloroalkyl) silatranes was investigated.

Our interest in 1-aryloxysilatranes dates back to 1973. In this work we wish to report on a UV spectrophotometric study of the hydrolysis kinetics of these compounds.

Experimental

Preparation of 1-(2′,4′,6′-trimethylphenoxy)silatrane

The reaction was carried out in an assembly consisting of a 250 cm^3 round-bottomed flask, reflux condenser and a calibrated receiver. An equimolar mixture (0.1 mol each) of triethanolamine (14.8 g), tetraethoxysilane (20.8 g) and 2,4,6-trimethylphenol (13.6 g) was placed in the flask and refluxed. Ethanol, liberated during the reaction:

$$(C_2H_5O)_4Si + N(CH_2CH_2OH)_3 + (CH_3)_3C_6H_2OH = (CH_3)_3C_6H_2OSi(OCH_2CH_2)_3N + 4\ C_2H_5OH$$

was continuously distilled of and its volume measured. The crude product was shaken with 500 cm^3 of ethyl ether, filtered dried and crystallized from isooctane to give 12 g (48%) of the silatrane, mp. 180—184 °C.

$C_{15}H_{23}NO_4Si$ (309.408). Calcd. C 58.22, H 7.50, Si 9.08, found C 58.30, H 7.60, Si 8.64% Mol. wt. 364. Molecular weight was assessed cryometrically in nitrobenzene. An increased value of the molecular weight may be indicative of intermolecular Si ← N interaction.

IR (cm^{-1}): 2950 m ($\nu_{as}CH_3$), 2860 m (ν_sCH_3), 1485 m, 1460 m (νC—C, aromatic), 940 m (νSi—OAr), 1150 s (νSi—OCH_2), 1460 w (δCH_2), 1020 m (ν_{as}C—N), 800 s (ν_sCN).

The IR spectra were taken on a Perkin-Elmer Model 357 spectrophotometer in KBr pellets.

NMR (τ, ppm): 7.94 (s) o-CH_3, 7.91 (s) p-CH_3, 3.44 (s) m-H_{Ar}, 7.40 (6 H) (t) N—CH_2, 6.36 (6 H) (t) O—CH_2.

The NMR spectra were recorded on an 80 MHz Tesla BS 487C spectrometer using $CDCl_3$ as solvent.

Thin layer chromatographic (TLC) investigations

Qualitative analysis of the hydrolysis products was accomplished by TLC on glass plates (150×75 mm) coated with silica gel 60 G (Merck) taken in an amount of 1.8 g per 3.5 cm^3 of water. The plates were dried for 24 hrs in air followed by 1.5 hrs at 105 °C. A mixture of benzene, methanol and chloroform (2 : 3 : 5 by vol.) was used as the mobile phase. Spots were detected in iodine vapours.

Kinetic measurements

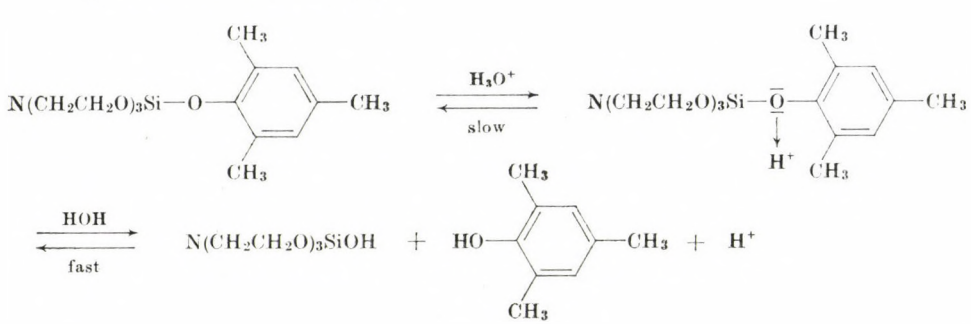
In kinetic measurements, use was made of a Pye Unicam SP 1750 A spectrophotometer with a thermostated cuvette holder. The temperature was maintained constant within ±0.1 °C. As solvents, 0.04, 0.01 and 0.004 *M* HCl solutions, distilled water and 0.04, 0.01 and 0.004 *M* NaOH solutions were employed. Kinetic curves ($A = f(\tau)$, where A is the absorbance and τ is time) were recorded at wavelengths of the maximum absorption of the liberated 2,4,6-trimethylphenol at 25 °C. At pH 11.6, measurements at 20, 34 and 40 °C were also performed.

The kinetic curves were recorded until a constant absorbance reading was attained (A_∞). Based on these data, the rate constant was calculated.

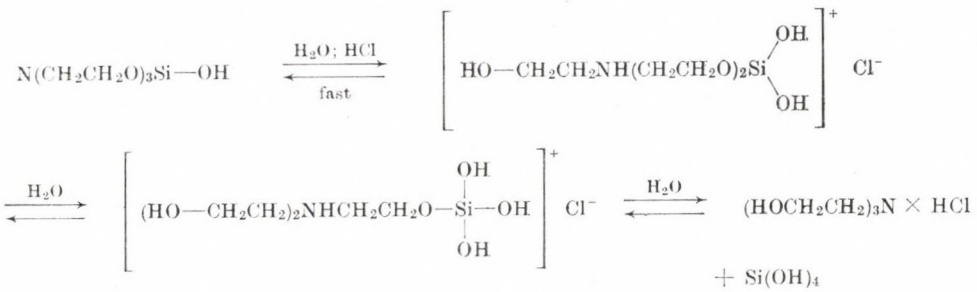
Results

Preliminary investigations of the mechanism of hydrolysis of the silatrane were based on TLC evidence. Assuming that the final products of hydrolysis of 1-(2′,4′,6′-trimethylphenoxy) silatrane are 2,4,6-trimethylphenol, triethanolamine and orthosilicic acid, aqueous solutions of the silatrane were separated by TLC along with triethanolamine, 2, 4,6-trimethylphenol and 1-(2′,4′,6′-trimethylphenoxy)silatrane as standards. On the basis of the R_f values and the colour of individual spots in the chromatograms, 1-(2′,4′,6′-trimethylphenoxy)silatrane (R_f 0.58), 2,4,6-trimethylphenol (R_f 0.68), triethanolamine (R_f 0.10) and an unidentified substance remaining on the starting line were found to form in solution during hydrolysis. Moreover, TLC analyses of aqueous solutions of the silartrane, made at various time intervals, showed that the decrease of the amount of silatrane occurred at a rate comparable with that of the increase of 2,4,6-trimethylphenol and triethanolamine. These results allowed the following mechanism of hydrolysis of 1-(2′,4′,6′-trimethylphenoxy)-silatrane to be advanced:

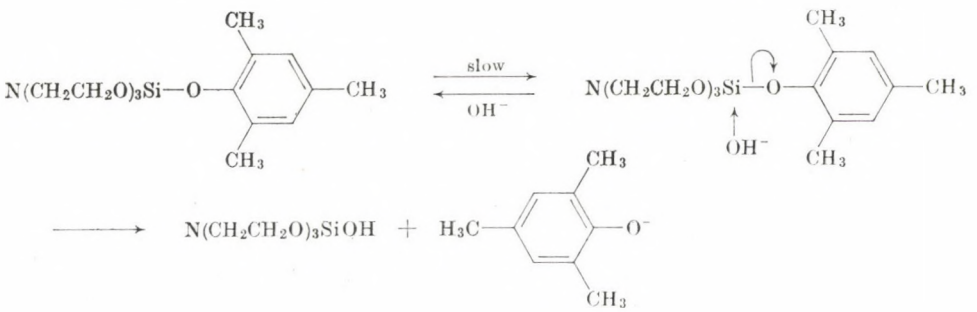
(i) In acidic medium [3]



followed by the spectrophotometrically undetectable decomposition of 1-hydroxysilatrane



(ii) In basic medium



The TLC evidence showed that at the first stage of hydrolysis, 2,4,6-trimethylphenol or the corresponding phenoxide (during alkaline hydrolysis) were produced. In the UV spectra of 1-(2′,4′,6′-trimethylphenoxy)silatrane taken in alkaline, acidic and aqueous media, the maximum absorbance occurred at 280 nm. Exactly at this wavelength a maximum in the spectra of acidic and aqueous solutions of 2,4,6-trimethylphenol was observed. On the other hand in alkaline solutions the maximum of 2,4,6-trimethylphenol occurred at 298.5 nm. Further, the concentration of hydrochloric acid was found not to affect the quantitative and qualitative characteristics of the spectrum of 2,4,6--trimethylphenol.

In alkaline medium, 2,4,6-trimethylphenol was converted to 2,4,6--trimethyl phenoxide which affected much both the position and intensity of the maximum absorbance. A closer investigation of this effect was made by taking the spectra of 2,4,6-trimethylphenol in 10^{-3}—8×10^{-3} *M* NaOH solutions. A spectrum of the phenol in 10^{-3} *M* NaOH displayed two maxima at 285 and 298.5 nm. A spectrum of the phenol in the 4×10^{-3} *M* NaOH solution had only one maximum at 298.5 nm. The 285 nm band has been assigned to undissociated 2,4,6-trimethylphenol and that at 298.5 nm to its anion.

The Lambert—Beer law was found to be obeyed at 2,4,6-trimethylphenol concentrations of 10^{-2}, 4×10^{-2} and 4×10^{-3} M in NaOH and HCl solutions and over the concentration range of 7.4×10^{-5}—6.3×10^{-4} M in aqueous solutions.

Clear-cut differences in the molar absorption coefficients (ε_{max}) of 1-(2′,4′,6′-trimethylphenoxy) silatrane and 2,4,6-trimethylphenol in the hydrochloric acid medium (λ_{max} 280 nm) and in NaOH solutions (λ_{max} 298.5 nm) permitted to follow directly the concentration of the hydrolysis product (2,4,6-trimethylphenol) in time. On the other hand, the similarity of spectra

Table I

Rate constant of hydrolysis, k (s^{-1}), as a function of the pH at 25 ± 0.1 °C and as a function of the temperature at pH 11.6

pH	t = 25 ± 0.1 °C	Temp. (°C)	pH 11.60
1.40	$k = (57.3 \pm 1.13)\times10^{-4}$ $S_r = 5.42$ $S_x = 0.56\times10^{-4}$ $t_{1/2} = 2.0$ min	20	$k = (5.01 \pm 0.05)\times10^{-4}$ $S_r = 2.65$
2.00	$k = (14.9 \pm 0.30)\times10^{-4}$ $S_r = 5.47$ $S_x = 0.15\times10^{-4}$ $t_{1/2} = 7.8$ min		$S_x = 0.03\times10^{-4}$ $t_{1/2} = 20.9$ min
2.40	$k = (5.6 \pm 0.10)\times10^{-4}$ $S_r = 5.17$ $S_x = 0.05\times10^{-4}$ $t_{1/2} = 20.4$ min		$k = (7.5 \pm 0.17)\times10^{-4}$ $S_r = 6.06$
5.60	$k = (5.9 \pm 0.37)\times10^{-7}$ $S_r = 8.66$ $S_x = 0.16\times10^{-7}$ $t_{1/2} = 14.3$ days	25	$S_x = 0.08\times10^{-4}$ $t_{1/2} = 15.6$ min
11.60	$k = (7.5 \pm 0.17)\times10^{-4}$ $S_r = 6.06$ $S_x = 0.08\times10^{-4}$ $t_{1/2} = 15.6$ min	34	$k = (12.5 \pm 0.10)\times10^{-4}$ $S_r = 2.25$
12.00	$k = (13.0 \pm 0.11)\times10^{-4}$ $S_r = 2.58$ $S_x = 0.06\times10^{-4}$ $t_{1/2} = 8.9$ min		$S_x = 0.05\times10^{-4}$ $t_{1/2} = 9.3$ min
12.60	$k = (36.0 \pm 0.43)\times10^{-4}$ $S_r = 3.06$ $S_x = 0.21\times10^{-4}$ $t_{1/2} = 3.0$ min	40	$k = (17.5 \pm 0.08)\times10^{-4}$ $S_r = 1.39$ $S_x = 0.04\times10^{-4}$ $t_{1/2} = 6.6$ min

S_r = relative standard error of a single determination (%),
S_x = standard error of the arithmetic mean,
$t_{1/2}$ = half-time of the reaction.
The confidence interval for k was calculated at the probability level of 0.95

of 2,4,6-trimethylphenol and 1-(2′,4′,6′-trimethylphenoxyl)silatrane in aqueous medium prompted us to employ another method for the determination of momentary concentrations c_t, or the corresponding absorbances A_t. By this method, appropriate amounts of NaOH were added to the aqueous silatrane solution after time t to convert the phenol to phenoxide. After addition of the hydroxide, the kinetic curve was recorded at 298.5 nm. Based on this curve, the half-time $\tau_{0.5}$, of the alkaline hydrolysis was determined. The $\tau_{0.5}$ value was then utilized to determine $A_{\tau 0.5}$ *i.e.* the absorbance after time $\tau_{0.5}$ from the addition of NaOH to the aqueous silatrane solution. The rate constant k, of hydrolysis was calculated from the equation

$$k = \frac{2.303}{t} \log \frac{A_\infty}{2(A_\infty - A_{\tau_{0.5}})}$$

where k is the rate constant of hydrolysis in aqueous medium, t is the time elapsed between the dissolution of the silatrane in water and the addition of NaOH, A_∞ is the absorbance after $8t_{0.5}$ (degree of hydrolysis 99.6%), $A_{\tau_{0.5}}$ is the absorbance after $\tau_{0.5}$ of alkaline hydrolysis.

During kinetic measurements, the dependence between the rate constant and pH was investigated as well as that between the rate constant and temperature at a fixed pH. The results are shown in Table I.

Based on the data of Table I, $\log k$ was plotted against $1/T$ as well as $\log (k/T)$ against $1/T$. Both curves are in accord with the Arrhenius (curve 1, Fig. 1) and Eyring (curve 2, Fig. 1) equations.

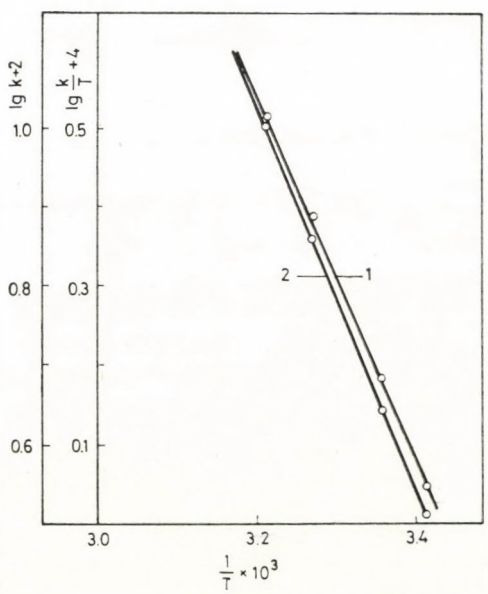


Fig. 1. Graphs of the dependence of $\log k$ on $1/T$ and $\log (k/T)$ on $1/T$

The activation energy, E_A, was calculated from coordinates of two points of the function $\log k = f(1/T)$, using the Arrhenius equation. Its value is 10.50 kcal/mol. Also a graph of the function $\log k = f(pH)$ has been made and is shown in Fig. 2.

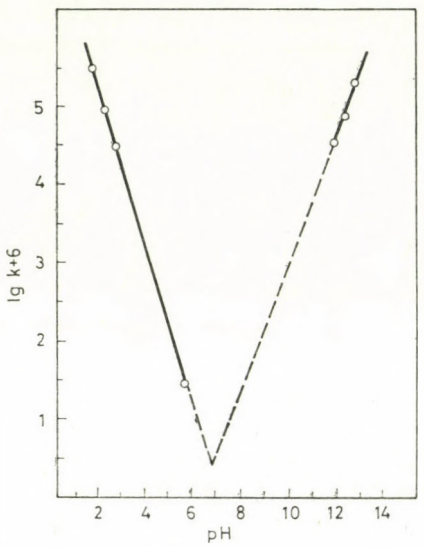


Fig. 2. Graph of the function $\log k = f(pH)$

Conclusions

1. The UV spectroscopic method was found to be suitable for studying the kinetics of hydrolysis of 1-aryloxysilatranes.

2. The hydrolysis of 1-(2′,4′,6′-trimethylphenoxy)silatrane was found to occur as a pseudo-first roder reaction, the rate constant depending on the concentration of both the hydrogen and hydroxyl ions.

3. The activation energy of 10.50 kcal/mol reveals the comparatively poor hydrolytic stability of the ArO—Si bond.

4. The results of the TLC experiments performed at various stages of the hydrolysis show that the cleavage of the ArO—Si bond is the rate-determining step.

5. A plot of $\log k$ *vs.* pH shows that the hydrolysis is effectively catalyzed by both hydrogen and hydroxide ions, the reaction being the slowest in the pH range of 6—7.

REFERENCES

[1] VORONKOV, M. G., ZELCHAN, G. I.: Khim. Geterotsikl. Soed., **1969,** 450
[2] VORONKOV, M. G., EMELYANOV, S. Z., ZELCHAN, G. I., DYAKOV, B. M., KUZNETSOV, G. I.: Khim. Geterotsikl. Soed., **1975,** 35
[3] VORONKOV, M. G., EMELYANOV, S. I., DYAKOV, V. M., VITKOVSKII, V. Yu., KAPRANOVA, L. V., BARYSHOK, V. P.: Khim. Geterotsikl. Soed., **1976,** 1344

Jerzy ŁUKASIAK
Zygmunt JAMRÓGIEWICZ
Institute of Chemistry and Analytics,
Al. K. Marksa 107 80—416 Gdansk 6, Poland

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UNIMOLECULAR H_2 ELIMINATION DURING THE LIQUID PHASE RADIOLYSIS AND PHOTOLYSIS OF ALKANE—ALKANE MIXTURES

L. WOJNÁROVITS and G. FÖLDIÁK

(Institute of Isotopes of the Hungarian Academy of Sciences)

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Unimolecular H_2 elimination from alkanes was investigated in cyclopentane–cyclohexane, *n*-hexane–cyclohexane and cyclohexane–cyclooctane mixtures during radiolysis and 7.6 eV photolysis. During the radiolysis of all systems, and when the fluorescence shift law allowed it, during the photolysis as well, inhibited H_2 detachment was observed from the first component and sensitized hydrogen molecule elimination from the second. It has been concluded that the same excited state (the lowest singlet, S_1) is responsible for the H_2 elimination during radiolysis and photolysis and this is that one that gives rise to fluorescence in the experiments of other authors. The H_2 and H elimination from alkanes generally have different excited precursors. The direct population of S_1 by γ-irradiation is of limited importance and this intermediate is mainly produced in "charge neutralization" processes.

Introduction

Although numerous papers have been published on the nature and reactions of electrons and positive ions produced during radiolysis in saturated hydrocarbon systems, much less work has been concerned with the formation and decay of alkane excited states [1—4]. Some part of the higher singlet excited states produced initially undergoes internal conversion to the first singlet excited state (S_1) and the electron–ion recombination also contributes to the formation of molecules in the S_1 state.

The excitation energy of alkane molecules (with the exception of the C_1—C_4 ones) to the S_1 state is around 7 eV [5—8] and, therefore, by the photons of some photolysis lamps (for instance Br 7.6 eV, Xe 8.4 eV), these states can be selectively produced, thereby providing a means of studying their reactions [9—11]. The basic decomposition pathway of molecules in the *n*-alkane series and that of cyclopentane and cyclohexane in gaseous and liquid phases excited by photons near the absorption onset is unimolecular H_2 elimination [12]. As is known from the literature, H_2 elimination also occurs in the course of radiolysis of these compounds.

In this study we investigate unimolecular H_2 elimintation during the radiolysis of cyclopentane–cyclohexane, *n*-hexane–cyclohexane and cyclohexane–cyclooctane mixtures and compare the results with the data obtained

during 7.6 eV photolysis in order to get a deeper insight into the processes taking place during radiolysis.

The radiolysis of cyclopentane–cyclohexane mixtures has been investigated by several research groups [13–16], but none of them investigated the full spectra of dehydrogenation products. Therefore, they could not clarify the details of product formation mechanism. Some of the authors [15] supposed an activity transfer from cyclopentane to cyclohexane, while others [13,14, 16] tried to explain the product distribution (usually that of dimers), taking into account radical exchange reactions.

Experimental

Cyclopentane, cyclohexane and cyclooctane were obtained from Fluka and purified by sulfuric acid treatment and distillation to attain a purity better than 99.95%; *n*-hexane was Merck gas chromatographic grade (>99.9) and further purification was unnecessary. Biphenyl was a Fluka product.

The samples were irradiated by the ^{60}Co γ-radiation source of the Institute of Isotopes. The dose rate was 6.4 Gy s^{-1} (4×10^{16} eV $g^{-1}s^{-1}$) and the dose 16 kGy (1×10^{20} eV g^{-1}). The irradiation temperature was 25 °C.

The electrodeless discharge bromine lamp was constructed at the Tokyo Institute of Technology in a manner similar to that described in Refs. [10]. The discharge was powered by a stabilized microwave generator operating at a power input of 60 W. The side arm of the lamp was immersed into a dry ice-methanol slush and the lamp was thermostated during operation at 100 °C by a heating tape. The light spectra obtained with a vacuum-UV spectrometer consisted of a very intense line at 163 nm (7.6 eV, $\geq$98%) and several other weak lines. The solution was stirred during photolysis and the temperature of the irradiation cell was kept constant at 25 $\pm$ 2 °C. The reaction cell was connected to a vacuum line and a Toepler pump and the gases noncondensable at −196 °C after photolysis were collected and measured volumetrically. The actinometry was based on the yield of hydrogen formed during the photolysis of pure cyclohexane, taking the quantum yield as unity [10,12]. The photon intensity was 1×10^{16} s^{-1}.

The liquid fraction was analyzed by gas chromatography on *n*-octane/Porasil C and silicone grease packed columns and on a squalane capillary column.

Results and Discussion

Unimolecular cyclopentene and cyclohexene formation during the radiolysis and photolysis of cyclopentane–cyclohexane mixtures

Our detailed analysis of dehydrogenation products, in agreement with the results obtained by MUCCINI and SCHULER [14], revealed the preferred formation of cyclopentyl over cyclohexyl radicals in the system (Fig. 1). On this basis, however, it cannot be understood why cyclohexene formation is relatively high in the mixtures. To explain this behaviour we suggest a mechanism that takes into account both activity transfer and radical exchange reactions:

$$c\text{-}C_5H_{10}^* \rightarrow c\text{-}C_5H_8 + H_2 \qquad (1a)$$

$$c\text{-}C_5H_{10}^* \rightarrow c\text{-}C_5H_9 + H \qquad (1b)$$

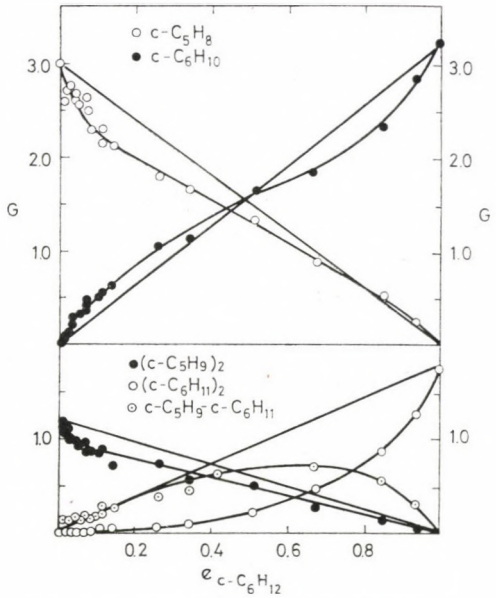

Fig. 1. *G*-values of dehydrogenation products as a function of cyclohexane electron fraction in the radiolysis of cyclopentane–cyclohexane mixtures

$$c\text{-}C_6H_{12}^* \rightarrow \begin{cases} c\text{-}C_6H_{10} + H_2 & (2a) \\ c\text{-}C_6H_{11} + H & (2b) \end{cases}$$

$$c\text{-}C_5H_{10}^* + c\text{-}C_6H_{12} \xrightarrow{k_t} c\text{-}C_5H_{10} + c\text{-}C_6H_{12}^* \quad (3)$$

$$H + c\text{-}C_5H_{10} \longrightarrow H_2 + c\text{-}C_5H_9 \quad (4)$$

$$H + c\text{-}C_6H_{12} \longrightarrow H_2 + c\text{-}C_6H_{11} \quad (5)$$

$$c\text{-}C_6H_{11} + c\text{-}C_5H_{10} \longrightarrow c\text{-}C_6H_{12} + c\text{-}C_5H_9 \quad (6)$$

$$2\ c\text{-}C_5H_9 \rightarrow \begin{cases} c\text{-}C_5H_8 + c\text{-}C_5H_{10} & (7a) \\ (c\text{-}C_5H_9)_2 & (7b) \end{cases}$$

$$c\text{-}C_5H_9 + c\text{-}C_6H_{11} \rightarrow \begin{cases} c\text{-}C_5H_8 + c\text{-}C_6H_{12} & (8a) \\ c\text{-}C_5H_{10} + c\text{-}C_6H_{10} & (8b) \\ c\text{-}C_5H_9\text{-}c\text{-}C_6H_{11} & (8c) \end{cases}$$

$$2\ c\text{-}C_6H_{11} \rightarrow c\text{-}C_6H_{10} + c\text{-}C_6H_{12} \quad (9a)$$

$$2\ c\text{-}C_6H_{11} \rightarrow (c\text{-}C_6H_{11})_2 \quad (9b)$$

where the asterisk indicates molecules activated by radiation. The high yield of cyclopentyl radicals may be a result of the higher rate of reaction (4) than that of reaction (5), or the radical exchange reaction between cyclohexyl radicals and cyclopentane molecules (reaction (6)).

On dissolving small amounts of iodine (3 mM) to scavenge the free radicals produced in the mixtures, it was found that the cyclopentyl and cyclohexyl iodide yields were approximately linearly dependent on the electron fractions of the components cited in the experiments of MUCCINI and SCHULER [14]. Because the presence of radical acceptors considerably shortens the average lifetime of intermediate radicals, this experimental finding may be explained by the suppression of the radical exchange reaction.

Another possible explanation may be the reaction of low energy (thermal) hydrogen atoms ($G = 1.6$ [17] and 1.47 [18]) with I_2 in the hydrogen abstraction reactions of which, owing to the differences in C—H bond strengths in cyclohexane and cyclopentane molecules ($\Delta D_{C-H} \sim 4$ kJ mol^{-1}), a selectivity could be expected. Combining our results with those of MUCCINI and SCHULER we can deduce that transfer reaction (3) does not influence noticeably the decomposition into H atom and cycloalkyl radical.

If the rates of recations between radicals are determined by the statistics of encounters, the following equation should be valid:

$$\frac{G(8)}{\sqrt{G(7)}\sqrt{G(9)}} = \frac{[1 + (k_{8a} + k_{8b})/k_{8c}]\,G(c\text{-}C_5H_9\text{-}c\text{-}C_6H_{11})}{\sqrt{[1 + k_{7a}/k_{7b}]G[(c\text{-}C_5H_9)_2]}\sqrt{[1 + k_{9a}/k_{9b}]G[(c\text{-}C_6H_{11})_2]}} = 2 \quad (10)$$

Since the k_{7a}/k_{7b} and k_{9a}/k_{9b} ratios (1.0 and 1.1) are known from the literature [17, 19], the above equation gives a possibility to calculate the $(k_{8a} + k_{8b})/k_{8c}$ ratio. The latter value was found to be constant (1.1 ± 0.2) for all compositions investigated. On the basis of considerations concerning the distribution of products, the most probable values of k_{8a}/k_{8c} and k_{8b}/k_{8c} are 0.7 and 0.4.

The G-values of cyclopentene and cyclohexene formation consist of the following terms according to the reaction sequence given above:

$$G(c\text{-}C_5H_8) = G(1a) + G(7a) + G(8a) = G[(c\text{-}C_5H_8)]_u + k_{7a}/k_{7b}G[(c\text{-}C_5H_9)_2] + k_{8a}/k_{8c}G(c\text{-}C_5H_9\text{-}c\text{-}C_6H_{11}) \quad (11)$$

$$G(c\text{-}C_6H_{10}) = G(2a) + G(9a) + G(8b) = G[(c\text{-}C_6H_{10})]_u + k_{9a}/k_{9b}G[(c\text{-}C_6H_{11})_2] + k_{8b}/k_{8c}G(c\text{-}C_5H_9\text{-}c\text{-}C_6H_{11}) \quad (12)$$

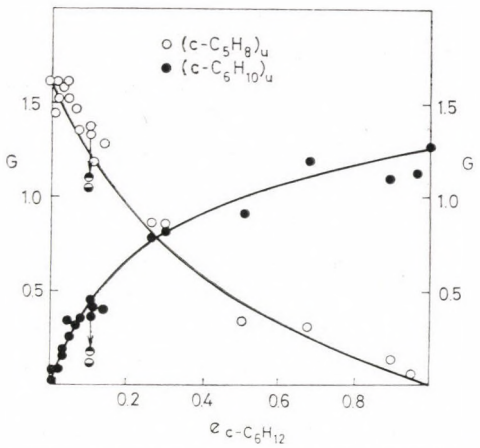

Fig. 2. *G*-values of unimolecular cyclopentene and cyclohexene formation as a function of cyclohexane electron fraction in the radiolysis of cyclopentane, cyclohexane and their mixtures; ◓ and ◒ represent yields determined in the presence of 20 and 50 mM biphenyl

These equations provide an opportunity to calculate the yields of unimolecular cyclopentene and cyclohexene ($G[(c\text{-}C_5H_8)_u] = G(1a)$ and $G[(c\text{-}C_6H_{10})_u] = G(2a)$) formation. The yield of unimolecular cyclopentene formation decreases on adding cyclohexane to the samples (Fig. 2): at the same time the sensitized unimolecular formation of cyclohexene occurs. Consequently, contrary to the hydrogen atom yielding decompositions, in unimolecular H_2 elimination we do observe the effect of transfer reaction (3).

The photolysis of cyclopentane, cyclohexane and their mixtures yields mainly hydrogen and cycloalkenes (Table I). The photoabsorption coefficient of cyclohexane is approximately twice that of cyclopentane at 163 nm [20].

Table I

Quantum yields observed during photolysis of cyclopentane–cyclohexane mixtures

Cyclohexane, M	—	0.25	0.26	0.33	9.25
Hydrogen	0.96[a]	0.97	0.97	0.99	1.0
Cyclopentene	0.92	0.87	0.88	0.85	—
Cyclohexene	—	0.05	0.064	0.067	0.93
Bicyclopentane	0.04	0.04	0.04	0.045	—
Cyclopentylcyclohexane	—	0.0023	0.0037	0.0028	—
Bicyclohexane	—	5×10^{-4}	4×10^{-4}	6×10^{-4}	0.07
$\text{Cyclopentene}_{u,\,corr.}$[b]	0.88	0.87	0.88	0.85	
$\text{Cyclohexene}_{u,\,corr.}$[b]	—	0.01	0.02	0.01	0.86

[a] Some C—C bond rupture product formation was also observed
[b] Unimolecular cycloalkene formation, corrected for direct photon absorption in cyclohexane

If we make a correction for the higher rate of production of excited cyclohexane molecules, it can be concluded that during photolysis there is only a very limited if any transfer reaction leading to enhanced unimolecular cyclohexene formation.

At this point we may conclude that the transfer reaction found during radiolysis is similar to that observed formerly [17] when positive charge acceptors were dissolved in cyclopentane. This idea gains support from the decrease of the $G[(c\text{-}C_5H_8)_u]$ and $G[(c\text{-}C_6H_{10})_u]$-values in the presence of 20 and 50 mM biphenyl ($e_{c\text{-}C_6H_{12}} = 0.1$) since this additive captures some of the electrons and positive ions produced during radiolysis in the system (Fig. 2). The recombination of charged entities with biphenyl cations and anions may lead to dissipation of the energy liberated upon recombination and, consequently, does not result in the formation of excited cycloalkane suitable for unimolecular H_2 elimination.

Radiolysis and photolysis of n-hexane–cyclohexane mixtures

If the cyclohexane content in *n*-hexane–cyclohexane mixtures is increased the *G*-value of cyclohexene produced during radiolysis rises much more quickly than in the cyclopentane–cyclohexane system (Fig. 3). Calculations

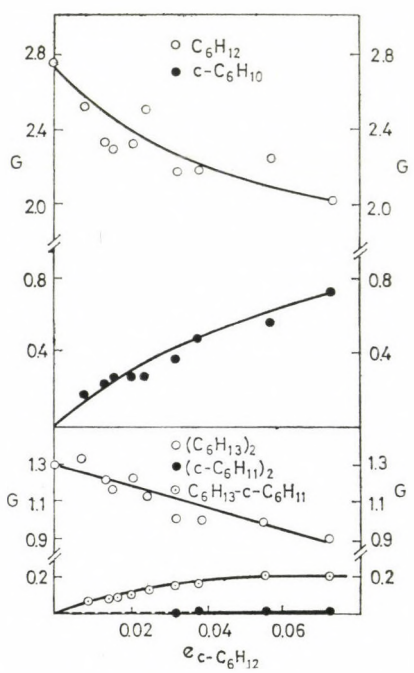

Fig. 3. G-values of dehydrogenation products as a function of cyclohexane electron fraction in the radiolysis of *n*-hexane–cyclohexane mixtures

similar to those used previously, applied to the *n*-hexane–cyclohexane system, show the existence of sensitized unimolecular cyclohexene and inhibited unimolecular hexene formation (Fig. 4). (For the disproportionation to recombination ratio of hexyl radicals, $k_d/k_c = 1.08$ [21] was accepted). The yields of unimolecular and atomic H_2 productions during the photolysis of pure *n*-hexane liquid were found to be 0.9 and 0.1, respectively. On adding cyclohexane to

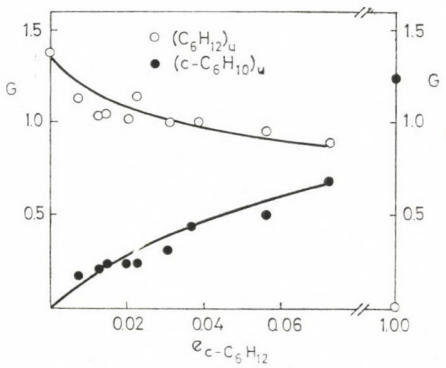

Fig. 4. G-values of unimolecular hexene and cyclohexene formation in the radiolysis of *n*-hexane, cyclohexane and their mixtures as a function of cyclohexane electron fraction

n-hexane the yields of products of *n*-hexane and cyclohexane decreased or increased non-linearly. As the photoabsorption coefficient of cyclohexane is about 3.5 times higher than that of *n*-hexane in the liquid phase at 7.6 eV [22], after correction for differences in the absorbances, the same result was obtained as in the cyclopentane–cyclohexane system: there is practically no energy transfer between the components involving excited states populated by 7.6 eV photons.

Radiolysis and photolysis of cyclohexane–cyclooctane mixtures

Previously published results [23] showed that during the radiation-induced dehydrogenation of cyclooctane besides the usual products (cycloalkene and bicycloalkane), a bridged saturated hydrocarbon — perhydropentalene (bicyclo[3.3.0]octane) — was also found, which, according to the radical scavenging experiments, was observed to be formed via an unimolecular path. In the mixtures the yields of both cyclooctene and perhydropentalane increased strongly with the cyclooctane content (Fig. 5). After correction for alkene formation *via* the radical path, the results in Figs 6 and 7 reveal sensitized unimolecular H_2 production from cyclooctane and inhibited H_2 detachment from cyclohexane in radiolytic as well as photolytic experiments. (The k_d/k_c ratio for cyclooctyl radicals was taken as 0.9 [23], the ratio

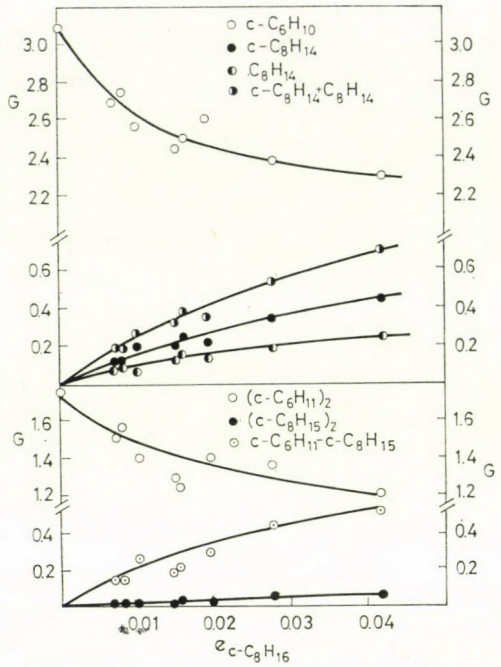

Fig. 5. **G-values of dehydrogenation products as a function of cyclooctane electron fraction in the radiolysis of cyclohexane–cyclooctane mixtures (C_8H_{14} stands for perhydropentalene)**

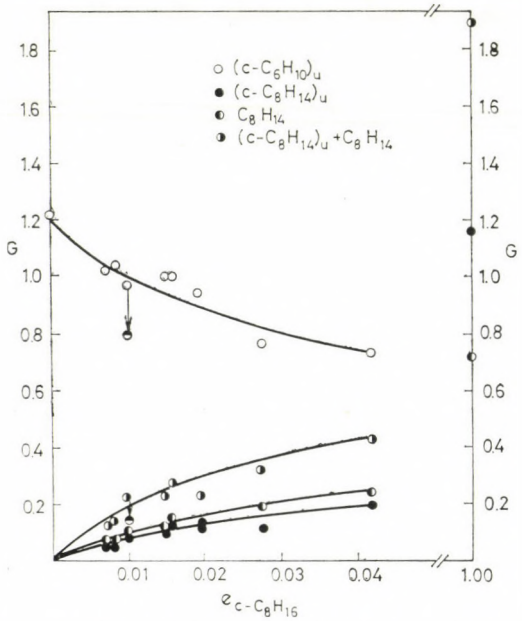

Fig. 6. **G-values of unimolecular cyclohexene, cyclooctene, perhydropentalene, and cyclooctene + perhydropentalene formation in the radiolysis of cyclohexane, cyclooctane and their mixtures as a function of cyclooctane electron fraction; ◓ represents yields determined in the presence of 20 mM biphenyl**

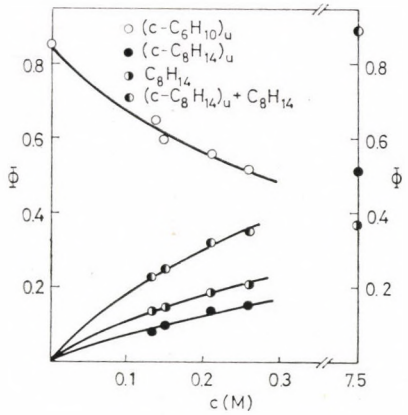

Fig. 7. Quantum yields of unimolecular dehydrogenation products in the photolysis of cyclohexane, cyclooctane and their mixtures as a function of cyclooctane concentration

of photoabsorption coefficients of cyclooctane and cyclohexane was accepted as 1.6 [20]).

As expected from the usual Stern-Volmer analysis of energy transfer processes the concentration dependences should obey the equations:

$$\frac{1}{D} = \frac{1}{{}^0D} + \frac{\alpha}{{}^0D} c \tag{13}$$

$$\frac{c}{A} = \frac{1}{{}^0A\alpha} + \frac{1}{{}^0A} c \tag{14}$$

where

D and ${}^0D$ are the yields of products of donor molecules (here $(c\text{-}C_6H_{10})_u$) formed in the mixtures and extrapolated to the pure solvent;

A and ${}^0A$ represent the actually measured and the extrapolated maximum yield of products of acceptor molecules (here $(c\text{-}C_8H_{14})_u$ and C_8H_{14}) formed as a consequence of the transfer reaction;

c is the concentration of acceptor molecules (M);

α is a reactivity parameter in M^{-1} ($\alpha = k_t\tau$, where k_t is the rate constant of the transfer reaction and τ is the lifetime of the excited state).

The $1/D$ or c/A-values plotted against concentration c give straight lines (Fig. 8), as expected from Eqs (13) and (14). A least-squares treatment of the individual lines yields α-values not differing very much from each other: $\alpha = 2.5 \pm 0.4\ M^{-1}$. This is indicative of the fact that the mechanism of the transfer reaction is the same during radiolysis and photolysis.

In such a large molecule as cyclohexane the excitation levels are densely populated and therefore the internal conversion between the states possessing

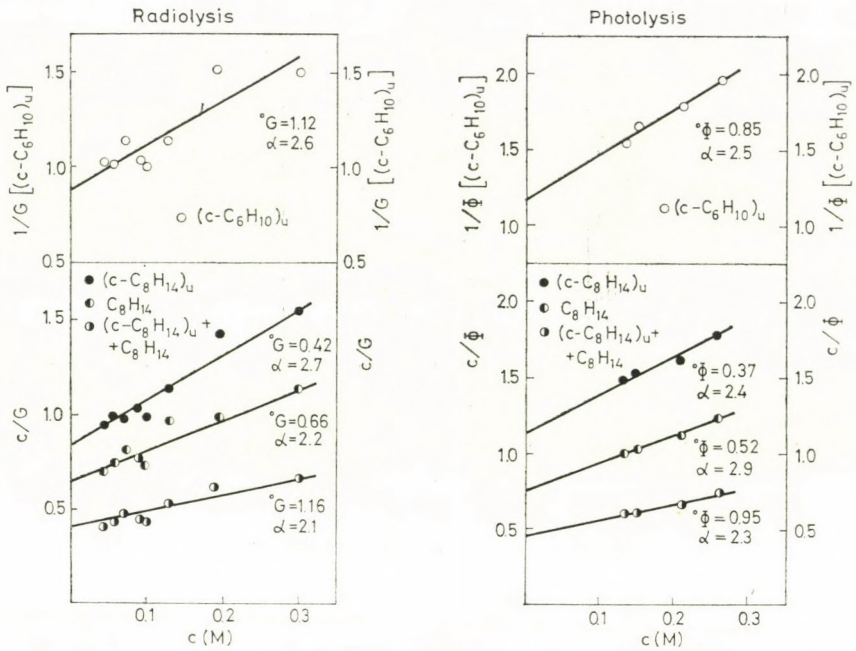

Fig. 8. Stern—Volmer kinetic plots of dehydrogenation products formed in cyclohexane–cyclooctane mixtures

the same multiplicity to the lowest one (S_1) is very fast (10^{-12}—10^{-11} s [24]). Consequently, transfer most probably takes place from the S_1 state of cyclohexane. The yields of unimolecular cyclohexene production established in the Stern—Volmer analysis applied to mixtures and found in neat cyclohexane coincide ($^0G = 1.12$ and 1.26, $^0\Phi = 0.85$ and 0.86), and these values are not far from the overall maximum yield of unimolecular cyclooctene and perhydropentalene formation ($^0G = 1.16$ and $^0\Phi = 0.95$). These findings may be traced back to the fact that every S_1 excited cyclohexane molecule can transfer its energy to cyclooctane and the probabilities of unimolecular H_2 elimination from the excited states of cyclohexane and cyclooctane are practically identical, as found in the course of the photolysis of the pure liquids ($\Phi = 0.86$ and 0.89).

Nature of the transfer reaction

As has been shown above, during the radiolysis of cyclopentane–cyclohexane, *n*-hexane–cyclohexane and cyclohexane–cyclooctane systems the extent of unimolecular H_2 detachment from the first component is lower and that from the second one is higher than could be calculated on the basis of simple additivity. In the photolytic experiments performed with the first two mixtures, however, only a very slight deviation from the additivity rule

can be observed; this means that there is practically no energy transfer between the components. When studying fluorescence in hydrocarbons, ROTHMAN *et al.* [7] discovered that the rate of energy transfer from the fluorescing state (in their opinion S_1) is closely related to the energy difference between the fluorescence peak energy (characterized by its intensity maximum and the halfwidth) of the transferring and the absorption onset of the accepting compound. As the intensity maximum of *n*-hexane fluorescence is at 6.02 eV (halfwidth 1.0 eV) and the absorption onset of cyclohexane is at 7.0 eV, the large difference means that energy transfer from the fluorescing state is not to be expected. The same reasoning has to hold for the cyclopentane–cyclohexane system.

The absorption onset of liquid cyclooctane (6.93 eV) is just within the fluorescence band of cyclohexane (maximum 6.17, halfwith 0.95 eV), pointing to the possibility of energy transfer from cyclohexane to cyclooctane in agreement with the experimental findings discussed above. The very close relationship between the present photolytic results and the fluorescence experiments of ROTHMAN *et al.* may suggest that the same excited state is responsible for fluorescence and H_2 detachment.

In the cyclopentane–cyclohexane and *n*-hexane–cyclohexane systems we have seen that transfer cannot be the result of energy transfer from the low energy excited states (S_1) of the first components. Therefore, in line with the experiments done in the presence of biphenyl, the conclusion can be drawn that the transfer is similar to that observed when so-called positive charge acceptors are present in alkanes. The transfer operating in the cyclohexane–cyclooctane system has an energy transfer type character and not a charge transfer or mixed character. This finding may be explained by the ionization energies of the compounds being very close to each other [25]. The presence of biphenyl causes in that system also substantial reduction of the unimolecular H_2 elimination product yields, pointing to a similar precursor of the low energy excited states to that in the other two systems.

In the preceding paragraphs we have given evidence for the identical precursors of unimolecular H_2 detachment observed during the radiolysis and photolysis of the alkanes investigated. On this account the *G*-value of the low energy excited states of *n*-hexane, cyclopentane, cyclohexane and cyclooctane radiolysis can be estimated to be 1.6 ± 0.5, 1.8 ± 0.5, 1.5 ± 0.4 and 2.2 ± 0.5, respectively. The *G*-value given for cyclohexane agrees well with the *G*-value of the first singlet excited state formation ($G = 1.4 - 1.7$) established in fluorescence measurements by WALTER and LIPSKY [3]. Further *G*-values of the low energy excited states for a large number of alkanes have been obtained and the theoretical discussion of the results is currently under preparation.

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REFERENCES

[1] BAXENDALE, J. H., MAYER, J.: Chem. Phys. Lett., **17**, 458 (1972)
[2] BECK, G., THOMAS, J. K.: J. Phys. Chem., **76**, 3856 (1972)
[3] WALTER, L., LIPSKY, S.: Int. J. Radiat. Phys. Chem., **7**, 175 (1975)
[4] WALTER, L., HIRAYAMA, F., LIPSKY, S.: Int. J. Radiat. Phys. Chem., **8**, 237 (1976)
[5] ROBIN, M. B.: Higher Excited States of Polyatomic Molecules, Vol. **1**, Chapter III A, Academic Press, New York 1974
[6] SAATZER, P. M., KOOB, R. D., GORDON, M. S.: J. Chem. Soc. Faraday Trans. II, **73**, 829 (1977)
[7] ROTHMAN, W., HIRAYAMA, F., LIPSKY, S.: J. Chem. Phys., **58**, 1300 (1973)
[8] LIPSKY, S.: Chemical Spectroscopy and Photochemistry in the Vacuum Ultraviolet (Eds SANDORFY, C., AUSLOOS, P., ROBIN, M. B.), p. 495. Reidel, Dordrecht 1974
[9] a) HOLROYD, R. A., YANG, J. Y., SERVEDIO, F. M.: J. Chem. Phys., **46**, 4540 (1967); **48**, 1331 (1969)
b) HOLROYD, R. A.: Advan. Chem. Ser., **82**, 488 (1969)
c) HOLROYD, R. A.: J. Amer. Chem. Soc., **91**, 2208 (1969)
[10] a) NAFISI-MOVAGHAR, J., HATANO, Y.: J. Phys. Chem., **78**, 1899 (1974)
b) WADA, T., HATANO, Y.: J. Phys. Chem., **79**, 2210 (1975); **81**, 1057 (1977)
[11] a) PICHUZHKIN, V. I., ANTONOVA, E. A.: Vestn. Mosk. Univ., **16**, 302 (1975)
b) ANTONOVA, A. E., PICHUZHKIN, V. I.: Khim. Vysok. Energ., **11**, 242 (1977)
c) ANTONOVA, E. A., PICHUZHKIN, V. I., BAKH, N. A.: Vestn. Mosk. Univ., **19**, 45 (1978)
[12] AUSLOOS, P., LIAS, S. G.: Chemical Spectroscopy and Photochemistry in the Vacuum Ultraviolet (Eds SANDORFY, C., AUSLOOS, P., ROBIN, M. B.), p. 465. Reidel, Dordrecht 1974
[13] SCHULER, R. H., MUCCINI, G. A.: J. Amer. Chem. Soc., **81**, 4115 (1959)
[14] MUCCINI, G. A., SCHULER, R. H.: J. Phys. Chem., **64**, 1436 (1960)
[15] TOMA, S. Z., HAMILL, W. H.: J. Amer. Chem. Soc., **86**, 4761 (1964)
[16] YANG, Y. Y., MARCUS, I.: J. Phys. Chem., **69**, 3113 (1965)
[17] KESZEI, Cs., WOJNÁROVITS, L., FÖLDIÁK, G.: Acta Chim. (Budapest), **92**, 329 (1977); Khim. Vysok. Energ., **11**, 316 (1977)
[18] ASMUS, K. D., WARMAN, J. M., SCHULER, R. H.: J. Phys. Chem., **74**, 246 (1970)
[19] CRAMER, W. A.: J. Phys. Chem., **71**, 1171 (1967)
[20] RAYMONDA, J. W., SIMPSON, W. T.: J. Chem. Phys., **47**, 430 (1967)
[21] GÄUMANN, T.: in Aspects of Hydrocarbon Radiolysis (Eds GKUMANN, T., HOIGNÉ, J.), p. 213. Academic Press, New York, 1968
[22] SOWERS, B. L., WILLIAMS, M. W., HAMM, R. N., ARAKAWA, E. T.: J. Chem. Phys., **57**, 167 (1972)
[23] FÖLDIÁK, G., WOJNÁROVITS, L.: Acta Chim. (Budapest), **82**, 269 (1974)
[24] PLOTNIKOV, V. G., OVCINNIKOV, A. A.: Usp. Khim., **47**, 444 (1978)
[25] PUTTEMANS, J. P.: Ing. Chim. (Brussels), **56**, 64 (1976)

László WOJNÁROVITS
Gábor FÖLDIÁK
H-1525 Budapest, P.O.B. 77

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SYNTHETIC LINEAR POLYMERS, XXXVI*

DEPENDENCE OF THE SPECIFIC PROPERTIES OF OLIGO–(TETRAFLUOROETHYLENE) HOMOLOGUES ON THE MOLECULAR SIZE AND THE PHYSICAL STATE**

I. GÉCZY and K. MEDVE-SZABAD

(College of Commerce and Catering Trade, Chair for Knowledge of Goods, Budapest)

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Changes of the refractive index at 20 and 70 °C, specific volume, specific refractivity, specific mean square dipole moment of tetrafluoroethylene oligomers with F and I end-groups, as well as changes of the specific mean square dipole moment with H end-groups, and that of the specific magnetic susceptibility of ethylene oxide oligomers were investigated as a function of the reciprocal molecular weight. In case of the refractive index measured at 20 °C, the specific volume, specific refractivity and specific magnetic susceptibility for both liquid and solid state members can be described — in spite of the existing linear relationship — by straight lines with different slopes and intercepts. With the refractive index measured at 70 °C, along with the specific dipole moment, differences in the physical state disappear and all points fall on the same line; this indicates the dependence of the effect upon the physical state. The dipole moment for the repeating unit $-(CF_2-CF_2)-$ was found to be 0.64 D (2.13×10^{-30} Cm) in CCl_4 at 20 °C and 0.59 D (1.97×10^{-30} Cm) in benzene at 25 °C.

Introduction

It has been shown earlier [1] that for linear polymer homologous oligmeric compounds represented by the general formula

$$X - (M)_n - Y$$

(where X and Y are identical or different end-groups, M is the repeating unit, n the degree of polymerization) the following general relationship is valid, which can also be verified by deduction:

$$\varphi_{sp} = \frac{a}{M} + b \qquad (1)$$

where φ_{sp} is some specific property (*e.g.* specific refraction, specific volume, *etc.*), M is the molecular weight, while a and b are constants. The former is

* Part XXXV.: Kolorisztikai Értesítő, **21,** 134 (1979); Acta Polymerica, **30,** 634 (1979).
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implicitly characteristic of the end-groups, the latter explicitly of the units within the chain. Later the validity of the equation was extended to specific properties to be determined only by indirect measurements in solvents ($\frac{\mu^2}{M}$ — specific mean square dipole moment [2–6]; [α] — specific rotation [4, 7, 8]).

It is characteristic of the studies carried out so far that within the polymer homologous series in the range investigated the physical state of the individual members was constantly identical (already solid from the first member on or *e.g.* in case of silicones the highest molecular weight investigated was still liquid).

Recent investigations

In the course of our experiments some specific properties of oligo-(tetrafluoroethylene) homologues of general formula $F-(CF_2-CF_2)_n-I$ ($n = 2$ up to 5) were investigated as a function of the molecular weight.

The first three members of the series investigated were liquid, while the fourth was solid.

Table I shows the measured data for the individual members. Also the mean square ($\overline{\mu}^2$) and specific mean square ($\overline{\mu}^2/M$) dipole moments — and the values needed for their calculation — are given in the Table.

Table I

Measured data for oligomers of general formula $F-(CF_2-CF_2)_x-I$ calculated as a function of the molecular weight

x	M	n_D^{20}	n_D^{70}	d_4^{20}	$1/M$	$1/d$	$\frac{n^2-1}{n^2+2}\frac{1}{d}$
2	345.9	1.3275	1.3058	2.0497	0.00289	0.4878	0.09884
3	445.9	1.3289	1.3091	2.0564	0.00224	0.4862	0.09890
4	546.0	1.3291	1.3110	2.0710	0.00183	0.4828	0.09829
5	646.0	1.33	1.3105	2.0913	0.00155	0.4784	0.09759
∞		1.376*		2.3*		0.4348	

x	α	β	R_2	$P_{x(\infty)}$	$\overline{\mu}$**	$\overline{\mu}^2$	$\overline{\mu}^2/M$
2	0.0323	0.0030	34.14	63.428	1.19	1.41	0.00409
3	0.0392	0.0034	43.37	81.663	1.36	1.84	0.00413
4	0.0485	0.0038	52.72	99.915	1.50	2.25	0.00412
5	0.0524	0.0056	63.05	118.031	1.62	2.62	0.00406
∞							

* See Ref. [10].
** D, 1 $D = 3.336 \times 10^{-30}$ Cm

Experimental

The refractive index (n_D) was measured by a Zeiss-Abbé type refractometer, the density (d_4^{20}) by means of a pycnometer. The dielectric constant (ε) was determined using a RADELKISZ type "Universal Dielectrometer" at 20 °C in *p.a.* CCl_4. The dipole moment was determined by the (so called) HEDESTRAND method [9] (for the description of the method, *c.f.* Ref. [6]). With the exeption of one series ($n_D^{70°}$) all measurements were carried out at 20 °C with FORAFAC oligomers (produced by Ugine Kuhlmann). We wish to express our thanks to the Firm Ugine Kuhlmann (France, Paris) for supplying the samples.

Discussion

Similarly to our method applied earlier on the basis of data given in Table I, the refractive index, specific volume as well as the specific refraction calculated from the two latter are plotted as a function of the reciprocal molecular weight in Figs 1, 2 and 3.

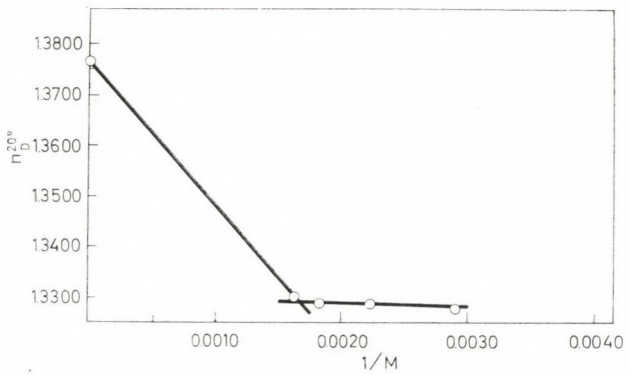

Fig. 1. Refractive index of oligo(tetrafluoroethylenes) at 20 °C as a function of the reciprocal molecular weight

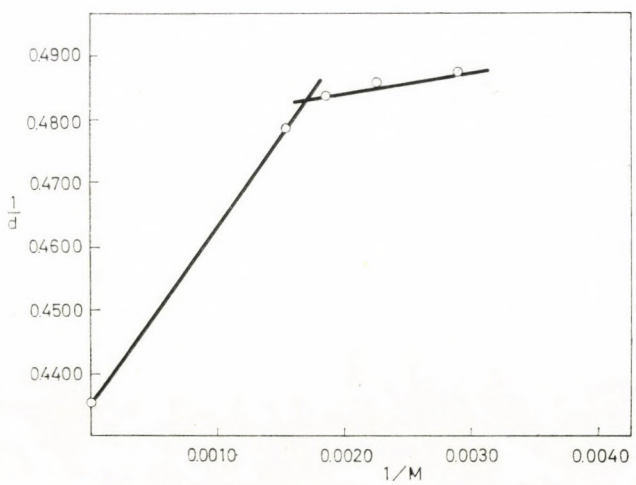

Fig. 2. Specific volume of oligo(tetrafluoroethylenes) as a function of the reciprocal molecular weight

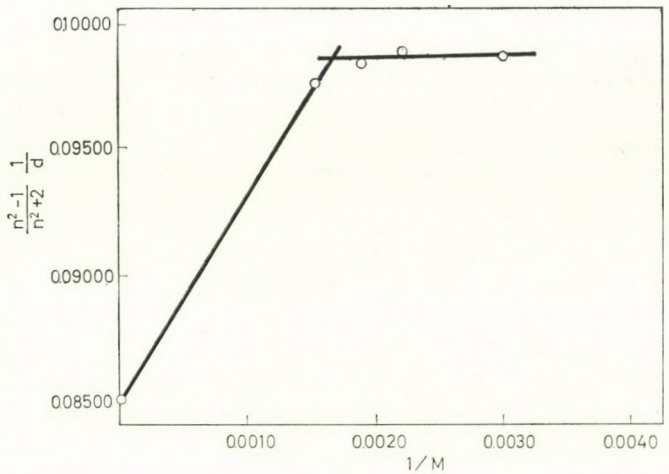

Fig. 3. Specific refraction of oligo(tetrafluoroethylenes) as a function of the reciprocal molecular weight

It can be seen that these may be described — unlike our former results — only by a straight line which breaks above a certain molecular weight (or below the corresponding value of $1/M$). This deviation occurs around the range where the physical state of oligomers turns into solid from liquid within the homologous series. In case of the oligomers investigated this phenomenon occurs also with specific refraction, though in most cases the value of this is practically independent of the physical state. The phenomenon indicates that, within the polymer homologous series, variation of the physical state is accompanied also by the change of molecular state. It is well known that, of the additive properties, the molar magnetic susceptibility is highly sensitive to the physical state [11]. If the break of the straight lines is due to the change of the physical state, then the phenomenon observed by us must appear also in the specific magnetic susceptibility of polymer homologous compounds.

For this reason we have plotted — using the data of BALTÁ—CALLEJA [12] — the specific magnetic susceptibility of polyethylene oxides (*d.p.* = 4—130) as a function of the reciprocal molecular weight. The results are shown in Fig. 4. It can be seen that for both liquid and solid members lines with different slope and intrecept are valid.

Furthermore, we have determined the refractive index of tetrafluoroethylene oligomers at 70 °C since all of the compounds examined are fluid at this temperature. Data given in Table I, plotted as a function of the reciprocal molecular weight are shown in Fig. 5. It can be seen that the points thus obtained are on one single straight line, proving that the effect observed can be attributed to the change of the physical state.

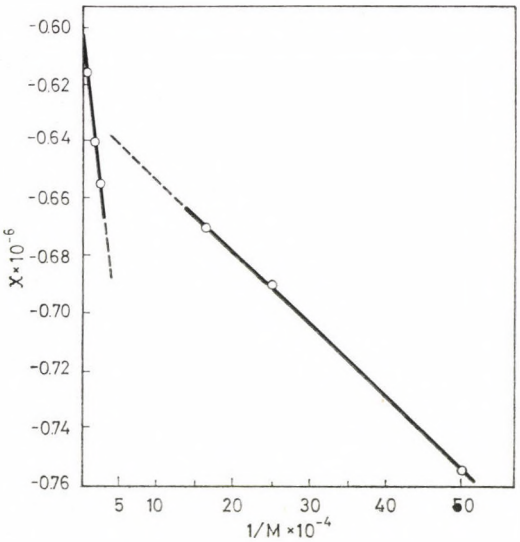

Fig. 4. Specific magnetic susceptibility of poly(ethyleneoxides) as a function of the reciprocal molecular weight

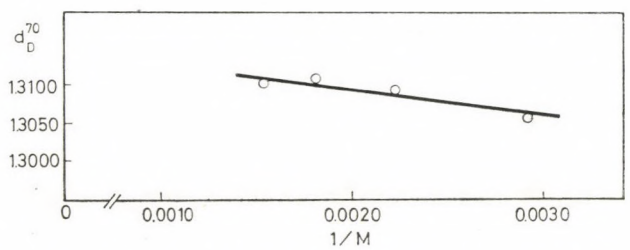

Fig. 5. Refractive index of oligo(tetrafluoroethylenes) at 70 °C as a function of the reciprocal molecular weight

Finally, dipole moments of the oligomers were determined at 20 °C in *p.a.* CCl_4.

Since such measurements are carried out in a solvent, the difference in physical state disappears during the course of measurements. Results obtained on the basis of Table I are given in Fig. 6.

Here the specific mean square dipole moment ($\overline{\mu}^2/M$) is plotted as a function of the reciprocal molecular weight ($1/M$). The points thus obtained again fall onto one single straight line. Reality of value of the intercept of the straight line was confirmed by additional investigations.

It is well known that this value is identical for polymer homologous series where repeating units are the same and only the end-groups differ. Therefore, we determined, using the data of BATES and STOCKMAYER [13], the specific

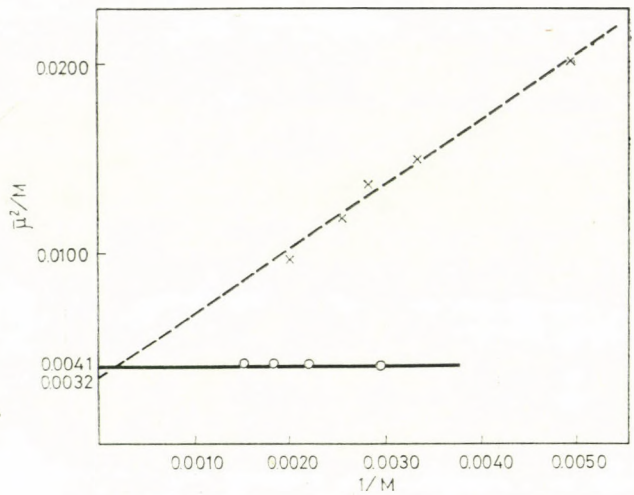

Fig. 6. Specific mean square dipole moment of oligo-F-$(CF_2)_n$-I (o, full line) and H-$(CF_2)_n$-H(x, dotted line) as a function of the reciprocal molecular weight, at 20 °C in CCl_4 (o) and 25 °C in benzene (x)

mean square dipole moment of oligomers of general formula $H-(CF_2)_n-H$ ($n = 4-10$) as a function of the molecular size. The results obtained are shown in Table II and Fig. 6.

It can be seen that the intercept of the straight line obtained has on the whole the very same values. In addition, it is evident from the results that single members of these two oligomer homologous series are present in the form of random coils under the given experimental conditions and do not form a secondary structure. The dipole moment for the repeating unit $-(CF_2-CF_2)-$ ($\bar{\mu} = \sqrt{bM_0}$) is 0.64 D (2.13×10^{-30} Cm) in case of F and I terminated oligomers, and 0.59 D (1.97×10^{-30} Cm) in case of H end-groups. The small differ-

Table II

Dipole moment, mean square and specific mean square dipole moment of oligomers of general formula $H-(CF_2)_x-H$ as a function of the molecular weight (25 °C in benzene)

x	M	$\langle\mu^2\rangle^{\frac{1}{2}}$ D*	$1/M$	$\bar{\mu}^2$	$\bar{\mu}^2/M$
4	202	2.02 ± 0.01	0.00495	4.08	0.0202
6	302	2.12 ± 0.01	0.00331	4.49	0.0149
7	352	2.20 ± 0.02	0.00284	4.84	0.0137
8	402	2.19 ± 0.01	0.00249	4.80	0.0119
10	502	2.21 ± 0.02	0.00199	4.88	0.0097

* Data of Ref. [13] (*c.f.* remark of Table I)

ence can be attributed to the measurements carried out in different solvents and temperatures. The results show that specific properties of the $F-(CF_2)_n-I$ polymer homologous series depend highly upon the physical state and, although varying linearly with the reciprocal molecular weight, the behaviour of liquid and solid members are described by straight lines of different slopes and intercepts. The occurrence of this phenomenon is predictable in all cases where members of a polymer homologous series are solid above a given molecular size and the actually investigated additive property depends already to a non-negligible extent on the physical state. Additional investigations should be carried out in ordei to determine the physical meaning of the parameters of the straight lines obtained.

REFERENCES

[1] See *e.g.*: GÉCZY, I.: MTA Kém. Tud. Oszt. Közl., **23**, 285 (1965), and references cited therein
[2] GÉCZY, I.: Magy. Kém. Folyóirat, **71**, 216 (1965); Acta Chim. Acad. Sci. Hung., **45**, 131 (1965)
[3] GÉCZY, I.: Magy. Kém. Folyóirat, **71**, 551 (1965); Polymer Reviews, **2**, 556 (1966); J. Pol. Sci., [C], **16**, 2991 (1967)
[4] GÉCZY, I.: Kolor. Ért., **10**, 237 (1968); Acta Chim. Acad. Sci. Hung., **66**, 77 (1970)
[5] GÉCZY, I.: Magy. Kém. Folyóirat, **80**, 237 (1974); Acta Chim. Acad. Sci. Hung., **84**, 289 (1975)
[6] GÉCZY, I.: Magy. Kém. Folyóirat, **81**, 177 (1975); Tenside, **14**, 64 (1977)
[7] GÉCZY, I.: Kolor. Ért., **8**, 221 (1966); Cellulose Chem. & Techn., **4**, 245 (1970)
[8] GÉCZY, I.: Kolor. Ért., **21**, 134 (1979); Acta Polymerica, **30**, 634 (1979)
[9] HEDESTRAND, G.: Z. physik. Chem., **B2**, 428 (1929)
[10] HONN, F. J.: in KIRK, R. E.—OTHMER, D. F.: Encyclopedia of Chemical Technology, 2nd ed., Vol. **11**, p. 689. Interscience Publ. New York (1958)
[11] FARQHUARSON, J.: Trans. Faraday Soc., **32**, 219 (1936)
[12] BALTÁ-CALLEJA, F. J.: Faserforsch. ů. Textiltechn., **15**, 575 (1964)
[13] BATES, T. W., STOCKMAYER, W. H.: Macromolecules, **1**, 12 (1968)

István GÉCZY
Katalin MEDVE-SZABAD } H-1054 Budapest, Alkotmány u. 9—11.

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SOME OBSERVATIONS ON OSCILLATORY PHENOMENA IN ANODIC OXIDATION

M. NOVÁK and Cs. VISY

(Institute of General and Physical Chemistry of Attila József University, Szeged)

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Potential oscillations during galvanostatic oxidation of simple organic substances have been related to changes in the amount of strongly bound species. Relation regarding the necessary current range and desorption is discussed.

Potential oscillations occurring in the galvanostatic oxidation of organic compounds have been observed for over fifty years [1]. Since then numerous papers have been published dealing with this phenomenon (a survey is given in [2]). CONWAY *et al.* [3] have shown several possibilities giving rise to an autocatalytic effect which was a requirement for the development of oscillation. WOJTOWICZ's [4] contribution increased these possibilities by taking into consideration the effect of change of sorption of strongly bonded species. Recently HORÁNYI [5] gave data about these changes during oxidation of glycol by applying radiotracer method.

The present-day knowledge about the nature of the processes leading to the decrease in potential is still scarce primarily because the experimental background is not sufficient to decide which systems might lead to the occurrence of periodic changes in potential [6, 7].

In this paper some results of experiments are reported which were carried out in connection with the study of the role of strongly bonded species in the potential oscillation.

Experimental

The equipment used was practically the same as previously described [8]. A bright Pt rotating disc electrode (0.7 cm in diam. and with a roughness factor of 5.71) was used. It was cleaned by anodic and cathodic potential impulses and was rotated by 1000 rpm. Hydrogen electrode in the same solution was used as a reference.

For the polarization a special instrument containing galvanostat as well as potentiostat was applied which was constructed in the electronic workshop of the Institute. Change in its mode of operation could be achieved automatically at previously set parameter of starting instrument *i.e.* galvanostat to potentiostat or potentiostat to galvanostat at preset potential or current, respectively. The working parameters of mode of operation following the switching could be set independently. The organic substances used were of analytical grade purity and were distilled on reduced pressure in N_2 atmosphere then the purity was checked on a gas chromatograph. Suprapur grade (Merck) H_2SO_4 and $HClO_4$ and triply distilled water were used, the third distillation was carried out by pyrolytic process proposed by Conway [9].

Results and Discussion

1. *The occurrence of potential oscillations*

The possibilities of occurence and the behaviour of potential oscillations were studied in the case of methanol, formaldehyde, formic acid, ethanol, acetaldehyde, 1-propanol, 1-butanol, propione aldehyde, 2-chloro-ethanol, 2,2,2-trichloro-ethanol and 2,2,2-trifluoro-ethanol. By varying the concentration and the polarizing galvanostatic current density in a broad range, the galvanostatic oxidation process led to oscillation only in case of substances containing one carbon atom as well as the unsubstituted alcohols. The other compounds did not exhibit such behaviour. The appearance of potential oscillation is in good agreement with the theoretical prediction of CLARKE [10] since the rate of oxidation and the sensitivity to perturbation of the compounds leading to oscillation is much higher than that of the others [11, 12].

The change in potential was quite characteristic and with the exception of formic acid well reproducable (Fig. 1). In case of formic acid the drop in potential occurred suddenly without any rest as the potential reached a (certain) critical value. In case of formaldehyde the potential changes were well defined. As the potential attained its upper limit the drop was not sudden but for a short period of time a section of larger capacity could be observed which caused a small potential step on the $E-t$ curve. In the case of methanol the transition from the increase to the decrease of potential was not sharp. With the increase of number of C-atoms in the molecule this pattern remained and the frequency of oscillation decreased. Thus, it seems that a well defined transition of potential change appears going from formic acid to the alcohols containing more than one C-atom.

2. *Changes in coverage during potential oscillations*

The change in the amount of strongly bonded species should be taken into account among the probable causes of oscillations [4, 5]. Therefore measurements were carried out concerning the coverage of electrode and its changes during oscillations. Having ensured the reproducibility of the phenomenon the amount of adsorbate was measured within one cycle of the oscillation at the characteristic potential values indicated in Fig 1. The determination of coverage was carried out in different later cycles as well, to get information whether the coverage changed in the next cycles. As it can be seen in Table I within one cycle the change in coverage was not larger than $\Delta\Theta \leq 0.1$. Thus, a very small change on the surface can produce and maintain the oscillations. The absolute value of coverage is rather different for the various substances: for formic acid and methanol $\Theta \leq 0.1$, for formaldehyde $\Theta \approx 0.5-0.65$ and for ethanol or 1-propanol $\Theta \approx 0.25-0.4$ values were observed during the oscillations. With increasing number of cycles the coverage decreases.

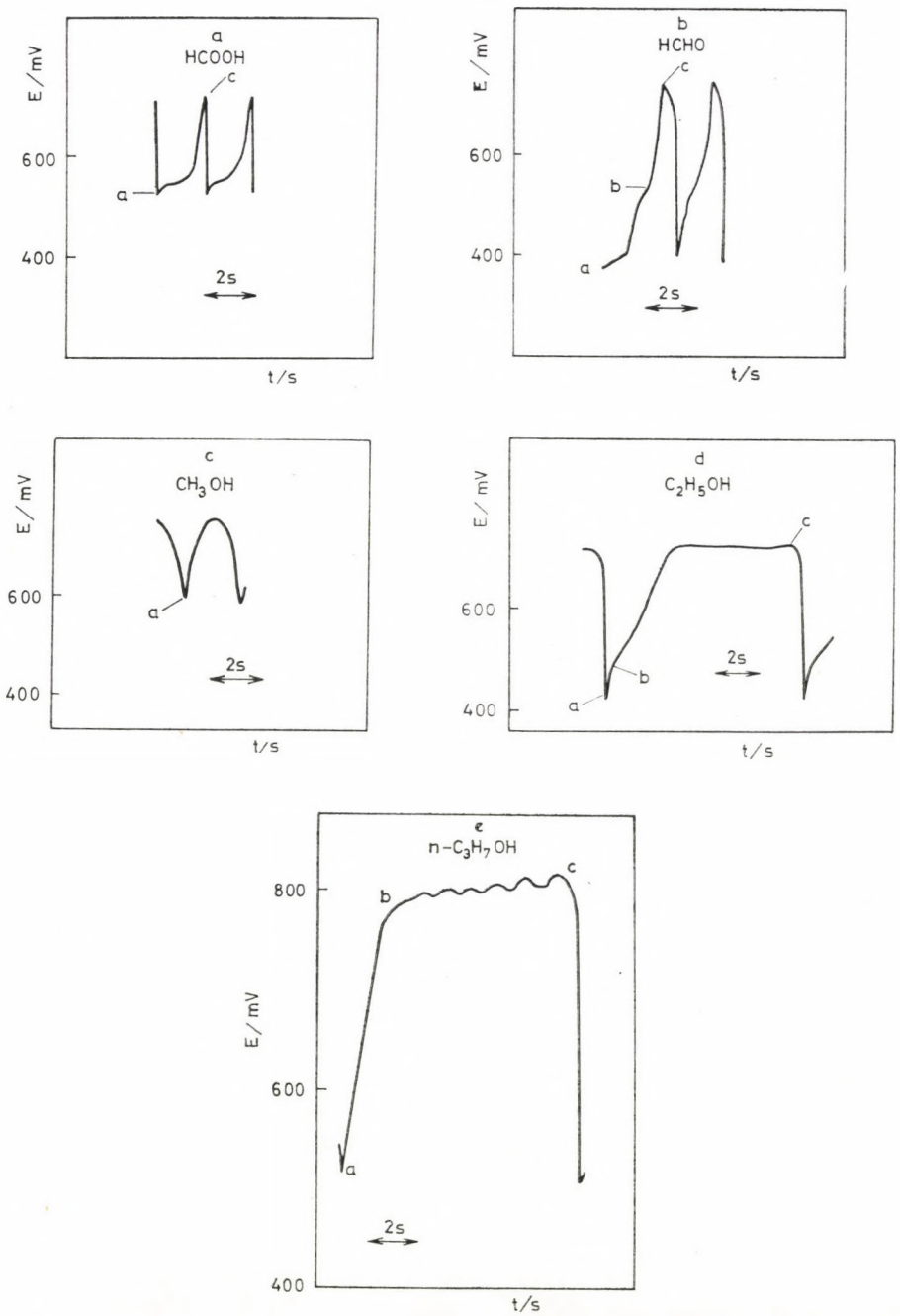

Fig. 1. Parts of potential-time curves under galvanostatic conditions; $c = 3 \times 10^{-2}$ mol dm^{-3}. a — HCOOH; $i = 0.17$ mA cm^{-2}, b — HCHO; $i = 0.175$ mA cm^{-2}, c — CH_3OH(MOH); $i = 1.31$ mA cm^{-2}, d — C_2H_5OH(EtOH); $i = 0.17$ mA cm^{-2}, e — C_3H_7OH(POH); $i = 5.91 \times 10^{-2}$ mA cm^{-2}

Table I

n	Θ coverage				
Number of cycle	MOH $HClO_4$ $i = 1.31$ mAcm^{-2}	HCHO H_2SO_4 $i = 0.175$ mAcm^{-2}	HCOOH $HClO_4$ $i = 0.17$ mAcm^{-2}	EtOH $HClO_4$ $i = 0.17$ mAcm^{-2}	POH H_2SO_4 $i = 5.91 \cdot 10^{-2}$ mAcm^{-2}
1.a			0.08	0.39	0.36
c			0.02	0.29	
2.a	0.07				0.35
b					0.33
c					0.31
3.a					0.33
5.a		0.64	0.02	0.36	
c		0.635	0.00	0.27	
6.a		0.63			
10.a				0.33	
c				0.265	
15.a				0.325	
c				0.26	
20.a				0.32	
c				0.26	
25.a		0.58			
b		0.565			
c		0.55			

3. *The effect of adsorbate on the oscillations*

Differences observed considering either the potential-time curves (*i.e.* the formal characteristics) or the coverage values call the attention, that while in the case of formic acid the surface state necessary for the potential break seems to be already present, in case of the other compounds some "organizing" period strongly affected by the number of C-atoms was needed. This period of "organization" might be connected to the transformation of adsorbed species. To get informations on that the following measurements were carried out.

In one series of the experiments with propanol in 1 mol dm^{-3} H_2SO_4 solution the galvanostatic polarization ($5.83 \cdot 10^{-2}$ mA/cm^2) was started after the preadsorption period of 10 s at $E = 0.4$ V. The value of coverage was then $\Theta^\circ = 0.41$. In this case, oscillations of three cycles were observed around 0.75 V and at about 26 s, 36 s and 51 s after the switching on the galvanostatic polar-

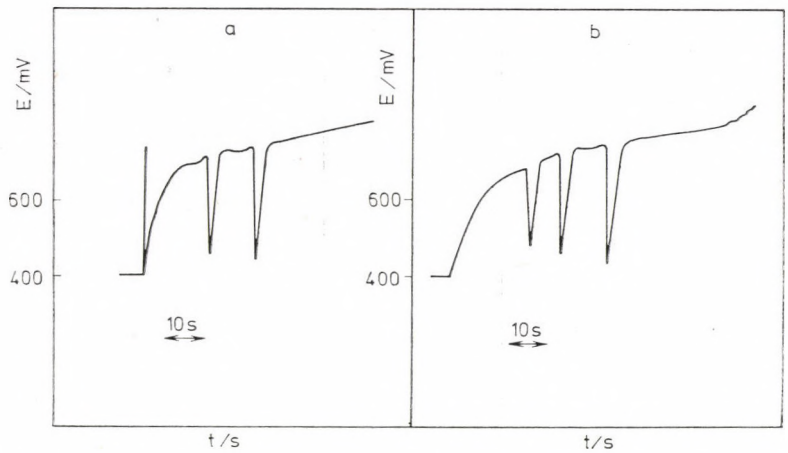

Fig. 2. Potential-time curves with propanol; $c = 3 \times 10^{-2}$ mol dm^{-3}, $i = 5.91 \times 10^{-2}$ mA cm^{-2}. a — after $t = 10$ s preadsorption at $E = 0.4$ V and switching to $E = 0.75$ V for $t = 0.1$ s, b — after $t = 10$ s preadsorption at $E = 0.4$ V

ization (Fig. 2/b). In the other series of experiments the potential was switched to $E = 0.75$ V after the same (10 s) preadsorption time at $E = 0.4$ V and the galvanostatic polarization started just after the switching. This potential step to 0.75 V for about 100 ms before switching to galvanostatic polarization resulted in two cycles at 20 s and 35 s. Thus the anodic potential impulse reduced the time of waiting period before the potential drop and at the same time it shortened the total time of oscillations (Fig. 2a).

4. *The effect of transformation of adsorbed species on oscillations*

To reveal the relation between the oscillations and the transformation of the preadsorbed substances at $E = 0.75$ V, the following method was used: having formed $\Theta^\circ = 0.41$ coverage at $E = 0.4$ V the potential was switched to $E = 0.75$ V and was kept there for a period then the galvanostatic polarization was started. The oscillation resulted showed different number of cycles (Table II) before the potential increased into the oxide region. It might be seen that the number of cycles decreased with the increasing time of potentiostatic polarization at $E = 0.75$ V ($t_{p,0.75}$). The sum of time of the potentiostatic polarization ($t_{p,0.75}$) and the time of oscillation ($t_{g,\mathrm{osc.}}$) proved to be constant:

$$\Sigma t = t_{p,0.75} + t_{g,\mathrm{osc.}} \approx 40 \text{ s}.$$

Thus the increase in potentiostatic period proportionally decreased the overall period of oscillations. Apparently, besides decreasing the amount of sorbate

Table II

$t_{p,0.75\,V}$ / s	Number of cycles	$\Sigma t = t_{p,0.75} + t_{g,osc.}$ / s
0.1	2	35
1	2	37
2	2	40
3	2	43
5	1	40
15	1	38
20	0	
30	0	

capable of leading to oscillations, the potentiostatic period contributes to the shortening of the waiting period by accumulating and/or preorganizing the adsorbate involved in the fast reaction triggering the potential change.

5. *State of oxidation of adsorbate* ($\Theta°$) *after transformation at* 0.75 V

In order to see the state of sorbate, the charge Q_{ox} needed to oxidize the surface after preadsorption at $E = 0.4$ V ($\Theta° = 0.41$) and after switching to 0.75 V was determined. This was carried out by the means of anodic sweeps $\left(\frac{dE}{dt} = 20\ V\ s^{-1}\right)$ and the current was integrated between 0.75 and 2.1 V. In Fig. 3a it can be seen that after switching the potential, first a decrease in coverage occurs which is followed by an increase while the charge of oxidation monotonously decreases. The decrease in coverage takes place in $t_{0.75} \approx \approx 40$ s, which is close to the time period of occurrence of oscillations (Σt). Thus, the phenomenon is in connection with the diminution of coverage (see part 4). The slope of $Q_{ox} - \Theta$ curves (Fig. 3b) shows that the sorbate at 0.75 V requires ~ 2 e/centre to oxidize while the sorbate at 0.4 V ($\Theta°$) required 1 e/centre.

Taking into consideration these observations together with the experimental findings in [13], one might assume that a transformation of sorbate takes place via C—C bond rupture.

6. *The current range of galvanostatic polarization leading to oscillations*

It is well known that potential oscillations occur only in a defined current range. Although there was some attempts to connect this range with other properties of the system studied (for example with the peak currents of the potentiodynamic curves [14]) no closer relationship has been yet given.

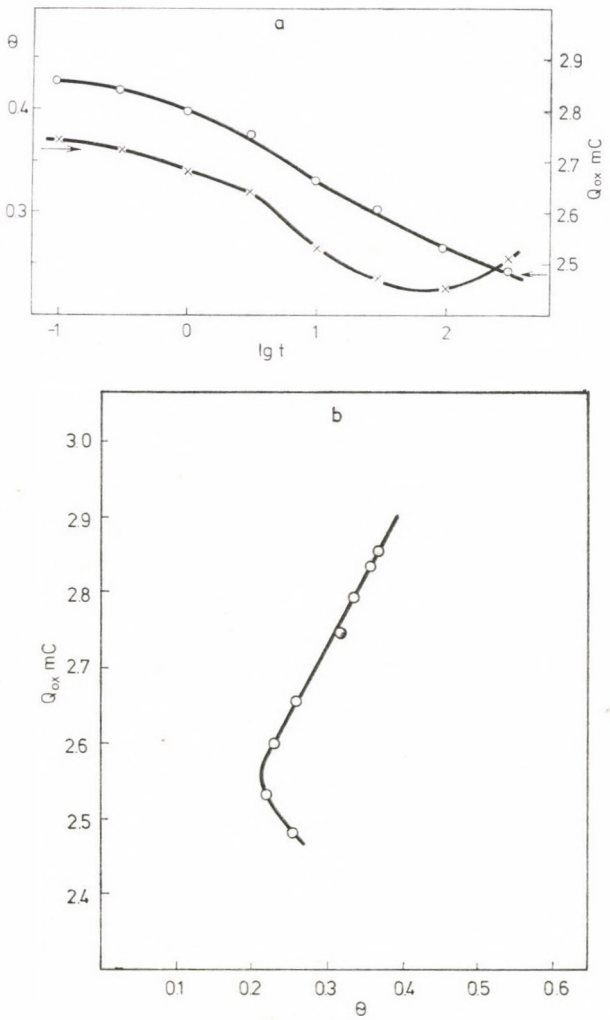

Fig. 3. a — time dependence of charge of oxidation (Q_{ox}) and of coverage (θ) at $E = 0.75$ V, $\theta^{\circ} = 0.41$; b — Q_{ox} values plotted against θ at $E = 0.75$ V, $\theta^{\circ} = 0.41$

It is obvious that at relatively small current densities the increase in potential during the galvanostatic charging comes to an end and a stationary potential arises. It might mean that the coverage too, arrived to a stationary value. Taking this into consideration, the increasing charging current might give rise to a decrease in coverage. The coverage along the potential-time curve at different galvanostatic currents was determined in $3 \cdot 10^{-2}$ mol dm^{-3} solution of propanol.

After cleaning the surface, galvanostatic polarizations with different currents were started and at potentials set previously potentiodynamic opera-

tion was switched automatically to determine the coverage of electrode. As it can be seen on Fig. 4 the coverage goes through a maximum as a function of potential. This maximum is at $E \approx 0.68$ V. Oscillations were observed in $i = 0.17-0.4$ mA cm^{-2} current-density range. This means that oscillations are observed only in cases when desorption takes place to a relatively large extent. Thus, it seems that either the oxidative desorption leaves free sites capable of supplying the necessary zone for the catalytic reaction, or the desorption itself takes place with a rate sufficient to drop the potential. If the rate of electron withdrawing is too large, it might drive the potential to the oxide formation which ends the oscillations at 0.85 V at all currents used. Apparently the largest current yet permitting the phenomenon is the one at which the sorption is sufficiently large below 0.68 V to ensure fast desorption.

An apparently important part of the phenomenon is the "waiting" period before the potential drop occurs. It is zero at formic acid and increases with the hydrogen content and the C-atoms of the molecules. Therefore it is assumed that the oscillation might be in connection with a one C-atom group.

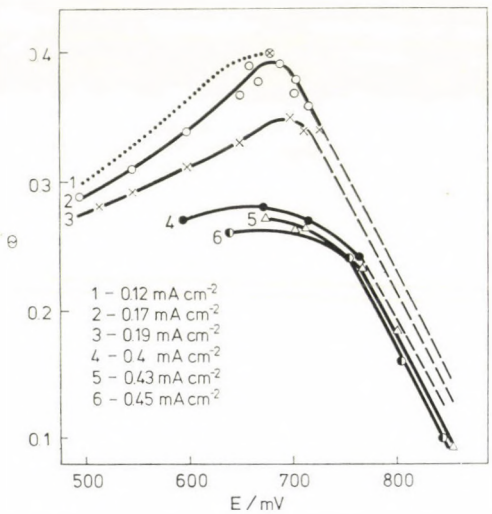

Fig. 4. Potential dependence of adsorption (θ) in propanol; $c = 3 \times 10^{-2}$ mol dm^{-3}. (1) — $i = 0.12$ mA cm^{-2}, (2) — $i = 0.17$ mA cm^{-2}, (3) — $i = 0.19$ mA cm^{-2}, (4) — $i = 0.40$ mA cm^{-2}, (5) — $i = 0.43$ mA cm^{-2}, (6) — $i = 0.45$ mA cm^{-2}

The potential of the "waiting" period is constant or increases depending on the current. If it is constant, the corresponding coverage is constant and if it increases, the corresponding coverage decreases. In this second case the zone of reaction of desorption involves new areas of the surface. The decreasing part of curves on Fig. 4 shows that the coverage is a linear function of the potential. It means that the desorption is not disturbed by oscillations but for a

short period of time which is in agreement with the monotonous increase in potential from cycle to cycle in $E-t$ curve in Fig. 5.

Since the change in the amount of adsorbate is connected to the reaction between the water and the organic substance, one might assume that during the "waiting" period an accumulation of the species occurs. The potential value of this process at a given current depends on the zone of the reaction

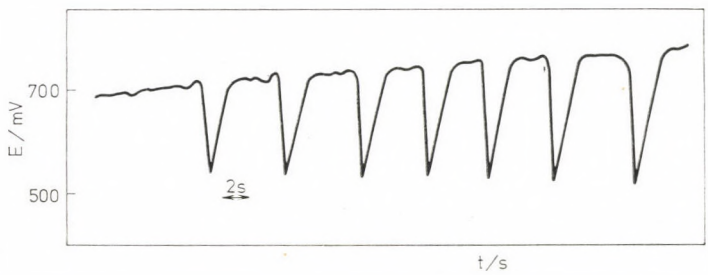

Fig. 5. $E - t$ curve in 3×10^{-2} mol dm^{-3} propanol during galvanostatic polarization; $i = 0.19$ mA cm^{-2}

i.e. the coverage. Since the $\Theta-E$ relationship is linear at the desorption, it seems that in the reaction a surface heterogeneity effect appears and the potential required to ensure the same amount of species leading to the potential drop, increases accordingly.

Working with various anions our experiments showed that they might effect the oscillation similarly as in [3, 6, 7].

Conclusion

On the basis of the observations described it might be concluded that the oscillations arise with substances capable of large catalytic current and sensitivity to perturbances. The formal appearance of the phenomenon in the series of the substances suggests that in the oscillations, species of one C-atom might play a decisive role.

Apparently, the amount participating in the reaction leading to the phenomenon is very small involving $\Theta \leq 0.1$.

The oscillations are closely related to the oxidative desorption of the strongly bonded species. They occur only if necessary amount of sorbate accumulated. The drop in potential is due to the fast catalytic reaction occurring on the surface zone freed by desorption or to the fast desorption. It is believed that in case of substances oxidized by dehydrogenation, the first possibility is more probable.

REFERENCES

[1] MÜELLER, E., HINDEMITH, G.: Z. Elektrochem., **33,** 562 (1927)
[2] WOJTOWITZ, J.: Modern Aspects of Electrochemistry, **8,** 47, Plenum Press, New York (1972)
[3] CONWAY, B. E., NOVAK, D. M.: J. Phys. Chem., **81,** 1459 (1977)
[4] WOJTOWITZ, J., MARTINIC, N., CONWAY, B. E.: J. Chem. Phys., **48,** 4333 (1968)
[5] HORÁNYI, G., INZELT, G.: Acta Chim. Acad. Sci. Hung., **100,** 229 (1979)
[6] SIDHESWARAN, P.: Ind. J. Chem., **16/A,** 69 (1978)
[7] NOVÁK, M., VISY, Cs.: Ind. J. Chem. **16/A,** 172 (1979)
[8] NOVÁK, M., LANTOS, J., MÁRTA, F.: Acta Phys. Chem. Szeged, **18,** 147 (1972)
[9] CONWAY, B. E., ANGERSTEIN-KOZLOWSKA, H., SHARP, W. B. A., CRIDDLE, E. E.: Anal. Chem., **45,** 1331 (1973)
[10] CLARKE, B. L.: J. Chem. Phys., **62,** 3726 (1975)
[11] NOVÁK, M.: Thesis, University of Szeged (1973)
[12] NOVÁK, M., VISY, Cs., Vassiliev, Yu. B.: Elektrokhimiya (in press)
[13] PODLOVCHENKO, B. I., GLABISHEVA, T. D., STENIN, V. F., LEVINA, V. I.: Elektrokhimiya, **9,** 1680 (1973)
[14] GEYER, R., BORMANN, H. D., HUNDHAMMER, B.: Z. Chem., **16,** 158 (1976)

Mihály NOVÁK
Csaba VISY
H-6701 Szeged, P.O. Box 105.

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INVESTIGATION OF THE SORPTION PHENOMENA OF POLYACRYLAMIDES IN POROUS MEDIA UNDER DYNAMIC CONDITIONS, I

EFFECT OF THE POLYMER TYPE AND CONCENTRATION, AND FOREIGN ELECTROLYTES ON THE AMOUNT OF ADSORBED POLYMER

I. LAKATOS and J. LAKATOS-SZABÓ

(Petroleum Engineering Research Laboratory of the Hungarian Academy of Sciences, Miskolc)

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The sorption phenomena of different polyacrylamides under dynamic conditions in non-consolidated porous media of silica sand have been studied. The amount of adsorbed polymer was found to decrease slightly with increasing average molecular mass of the polymer, and to a great extent with the increase of the degree of hydrolysis. Dissolved inorganic salts, although to different extents, increase the adsorbed amount of hydrolyzed and unhydrolyzed polymers. The concentration of polymer beyond a critical concentration, also tends to increase the adsorbed amount. These phenomena have been traced back to the structures of the solution and the coil (gel concentration, coil density, coil diameter), noting that, owing to the simultaneity of sorption phenomena and mechanical polymer retention, it is very difficult to give an exact descritption of adsorption phenomena in natural porous systems under dynamic conditions.

Introduction

The improvement of the areal and vertical (volumetric) sweep efficiency of conventional waterflooding has a central role in enhanced oil recovery. One widespread and promising method for the above purpose is the mobility control by polymer solutions, primarily by dilute aqueous solutions of different polyacrylamides [1, 2]. At the beginning of the 1960's, some authors, including PYE [3] and SANDIFORD [4], who laid down the fundations of polymer flooding, were of the opinion that the increase in the sweep efficiency of waterflooding is due completely to the viscosity enhancing effect of chain like polymers and to the non-Newtonian flow of polymer solutions. However, MUNGAN [5, 6], GOGARTY [7], and DAUBEN and MENZIE [8] have pointed out that sorption phenomena are also responsible for the decrease in the mobility of the polymer solution and of the polymer-free connate waters following this solution. Thereafter, the comprehensive papers dealing with polymer flooding and the flow phenomena of polymer solutions in porous media (*e.g.* SMITH [9], SAREM [10], SZABÓ [11—13] and CHAUVETEAU and KOHLER [14]) all deal with the adsorption of polyacrylamides on rock media, and attribute a decisive role to it in the displacement mechanism.

Although the papers cited above contain several valuable data and observations appropriate in the given case on sorption phenomena, there is no work in which the polymer-rock interaction is investigated in full detail.

In the Petroleum Engineering Research Laboratory of HAS much attention has been devoted to the study of factors which may affect the adsorption of polymers in a rock/oil/water system [2, 15, 16]. Following the practice of the displacement of petroleum with dilute polyacrylamide solutions, the first part of our paper is concerned with the effect of the average molecular mass, the degree of hydrolysis, the concentration of the polymer and the quality and quantity of foreign electrolytes on the amount of adsorbed polymer.

Nature of polymer retention by porous media

The adsorption phenomena of polyacrylamides under static conditions were studied by MUNGAN [6], SMITH [9], SCHAMP and HUYLEBROECK [17], SZABÓ [12] and DAWSON and LANTZ [18]. Their results can be summarized as follows.

1) The sorption phenomena can be described by a Langmuir type isotherm. In these isotherms the adsorbed amount hardly changes with the concentration of polymer above 100—200 ppm.

2) The sorption phenomena are highly irreversible. According to MICHAELS and MORELOS [19], the main role in the adsorption mechanism is played by hydrogen bonds between the positively charged amide groups and some rock zones of negative charge. According to generally accepted views, the sorption phenomena can be attributed primarily to the chemical bonds between the carboxyl groups of hydrolyzed polyacrylamides and the multivalent metals (calcium, magnesium, *etc.*) on the pore surfaces of the natural rock.

3) The amount of adsorbed polymer measured under static conditions may be smaller by several orders of magnitudes than under dynamic conditions.

The differences between the data obtained under static and dynamic conditions can be interpreted on the basis of various factors. On one hand, the specific surface areas of consolidated and non-consolidated models formed from adsorbents identical in weight and grain size are different. On the other hand, the total surface of the porous model is not accessible for the polymer solution [18]. For the flooding of a given hydrocarbon field it is preferable to choose a polymer for which the ratio of the mean pore diameter of the rock and the mean equivalent diameter of the polymer in solution is between 3 and 10 [20]. In such a case the pore distribution curves of the rock and the relative molecular mass of the polymer necessarily overlap to some extent. The greater the overlap of the distribution curves, the greater the pore volume and pore surface area inaccessible for the random gel coils in the solution.

Consequently, under real conditions, during the flooding of porous models with a polymer solution, the sorption phenomena are accompanied by a dynamic and irreversible mechanical entrapment of the polymer. The sorption and mechanical losses cannot be separated exactly in the given case, and thus it is practical to use the concept of specific polymer retention instead of the specific amount of sorption. Moreover owing to the difficulties in determining the pore space and pore surface area accessible for the polymer solution, the authors usually avoid to refer the amount of adsorbed polymer to unit area.

In our investigations we tried to apply a compatible polymer-rock system for which mechanical polymer retention is not characteristic. Therefore, the adsorbed amount is referred to unit weight of the porous model. It is emphasized however, that in certain cases, mainly in the study of solvent-deficient solutions with high polymer concentration, the polymer loss occurring in the model is due not only to sorption but to mechanical retention as well.

Experimental

As a result of a cooperation between this Laboratory and Nitrochemical Works, the laboratory measurement were carried out with polyacrylamides prepared experimentally for oil displacement purposes. The polymers were obtained in gel form with active contents of 20—30%. The degrees of hydrolysis varied between 0 and 40%, and the average molecular mass were between 0.7×10^6 and 4.8×10^6. Partly as model and partly as reference, two polymers (Separan) of Dow Chemical were also studied.

The most important characteristics of the porous model prepared from natural silica sand, 100—200 μm in grain size, were as follows:

Length of model	213 mm
Diameter	49 mm
Porosity	38—42%
Permeability	1.7—2.0 μm^2
Weight of adsorbent	610—620 g

Polymer solutions of appropriate compositions were prepared at 40—50 °C, under slow stirring. After one day of a standing the solutions were filtered through a G4 sintered glass filter. These solutions were passed through the porous system at a linear flow rate of 150 cm/day. From the model 5 cm^3 samples were taken, and the polymer concentrations were determined by turbidimetric methods after calibration. The mass of the polymer remaining on the model and adsorbed amounts were calculated from the saturation curves by planimetry.

The specific surface area of the sand used to prepare the model was 0.18 m^2g^{-1} as calculated by the BET method from a krypton adsorption isotherm. Permeometric methods, for which the calculations were performed according to the Kozeny—Carman equation modified by KUMAR and FATT [21]., gave a much smaller surface area, *ca.* 0.1 m^2g^{-1}. When a polymer solution was used instead of water as moving phase, even lower specific areas were obtained, and they varied as a function of the type of polymer.

Results and Discussion

Data published by MARTIN and SHERWOOD [22] indicate that the amount of adsorbed polymer decreases with increasing degree of hydrolysis. On this basis the authors assumed that an increase in the average molecular mass must

have the same effect. Of our experimental results, therefore, the effect of the relative molecular mass and the degree of hydrolysis will be presented first as the most important factors characteristic of the polymer. The measurements were carried out with polymer solutions of 0.5 g dm^{-3} concentration, which, in order to simulate the ionic strength of connate waters, also contained sodium chloride in a concentration of 2 g dm^{-3}. These solutions were injected into the porous model with a linear velocity of 150 cm/day, which is close to the average fluid rates characteristic of hydrocarbon fields. The adsorbed amount calculated from the saturation curves were plotted against the average molecular mass and the degree of hydrolysis of the polymers. The curves are shown in Figs 1 and 2.

It can be seen from Fig. 1 that the amount of adsorbed polymer in the porous medium slightly decreases with increasing average molecular mass. The figure shows only the data obtained for unhydrolyzed polyacrylamides and copolymers (acrylamide — acrylic acid) hydrolyzed to a degree of 30%. The shapes of the two curves already forecast the conclusions proved by Fig. 2, *i.e.* the increase in the degree of hydrolysis reduces polymer adsorption substantially, even by an order of magnitude. The polymers did not include samples identical in average molecular mass and, within this, similar in molecular mass distribution but different in degree of hydrolysis. Therefore, the specific data obtained for polymers with the same degrees of hydrolysis are given in the figure with deviation limits. Nevertheless, the mean values within the deviation

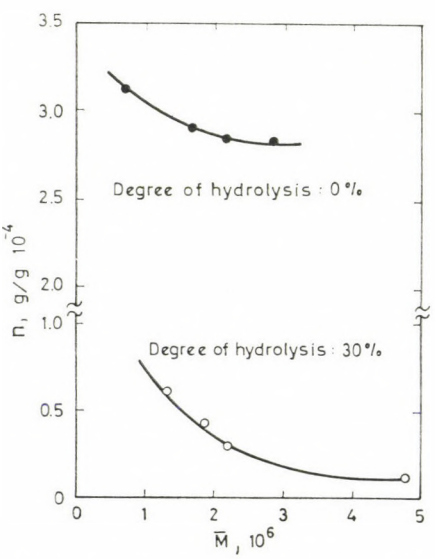

Fig. 1. Variation of the adsorbed amount of polyacrylamides having various degrees of hydrolysis with the average molecular mass

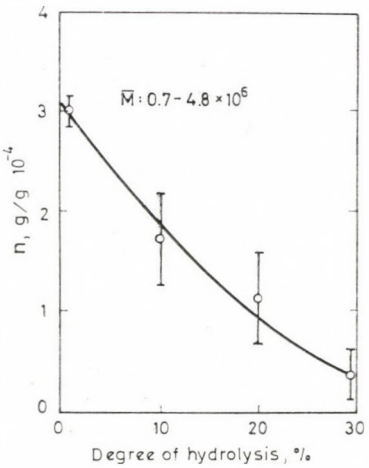

Fig. 2. Variation of the adsorbed amount of polyacrylamides having various average molecular mass with the degree of hydrolysis

are well fitted on the curve. This may be due to the fact that the deviations arising from differences in molecular mass are insignificant (Fig. 1).

In practice the areal flooding is usually performed with polymer solutions of 0.2—1.5 g dm^{-3} concentration. Taking into account that, according to the laboratory measurements, under static conditions the adsorbed amount hardly depends on the concentration in the range of 0.1—0.2 g dm^{-3}, our experiments under dynamic conditions were performed with distilled water solutions of 0.1—2.0 g dm^{-3} concentration containing 2 g dm^{-3} of sodium chloride.

The polymer adsorption of two polymers representing two limiting cases, *i.e.* a low molecular mass unhydrolyzed and a high molecular mass hydrolyzed polymer, is shown in Figs. 3 and 4 as a function of the polymer concentration of the solution.

Despite a difference of almost one order of magnitude between the adsorbed amounts obtained for the two polymers, it can be found that the value of n increases with increasing polymer concentration. Within this general tendency, however, there is a steep increase with both polymers, both in ion-free and in salt solutions, only above a certain polymer concentration. Below these values similarly to the saturation sections of isotherms measured under static conditions, n hardly depends on the polymer concentration of the solution. The characteristic concentration at which the steep change starts is about twice as high for low molecular mass unhydrolyzed polyacrylamide as for the high molecular mass hydrolyzed polymer.

It can also be observed that for solutions also containing foreign electrolyte the range of concentration independence is much wider.

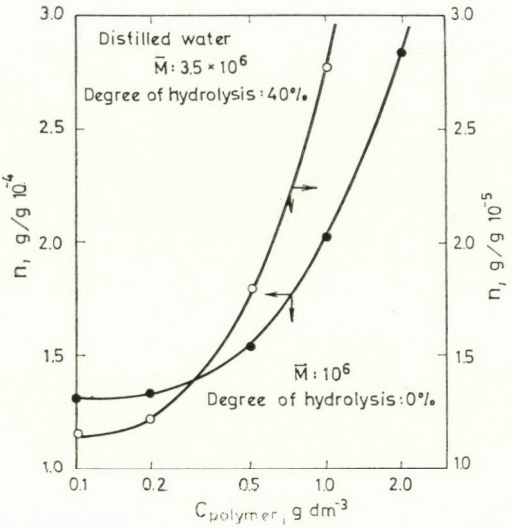

Fig. 3. Variation of the adsorbed amount of different polyacrylamides with concentration

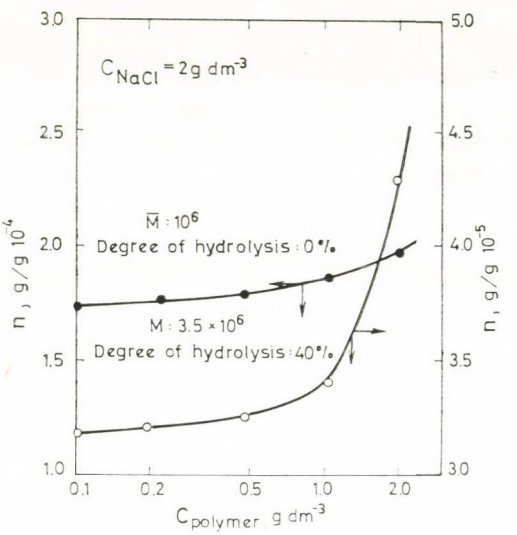

Fig. 4. Variation of the adsorbed amount of different polyacrylamides with concentration

A comparison of the two figures shows that solutions which also contain sodium chloride have a higher adsorption at the same polymer concentration than in the absence of foreign ions. The variation of adsorbed amount with electrolyte concentration is clearly proved by Fig. 5, in which the values of n obtained for the two polymers mentioned are plotted as a function of the sodium chloride concentration of the solution.

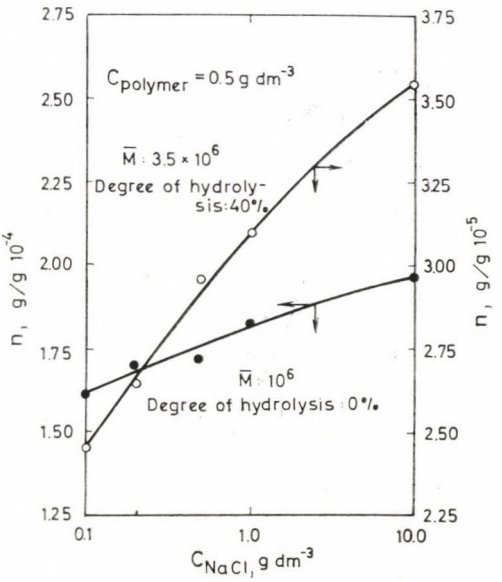

Fig. 5. Variation of the adsorbed amount of different polyacrylamides with salt concentration

Although there is a difference of one order of magnitude between the right and left ordinates of the figure, the scale is the same. Therefore, in addition to reflecting the direction of the n *vs.* c_{NaCl} correlation, the figure also shows that the specific adsorption of unhydrolyzed polyacrylamide depends much less on the concentration of salt than of the hydrolyzed polymer: the change is 1.2 for the former and 1.45 for the latter.

A comprehensive interpretation of the experimental data presented is possible only through the structures of solutions, on a molecular basis, taking into account gel concentration, the density and size of random coils, the interactions of random coils, and the reversible changes thereof under the given conditions.

Such attempts were published by WILLHITE and DOMINGUEZ [23, 24], but these papers attach importance only to the association phenomena which play a role in the mechanical polymer retention by the porous medium.

From dynamic invetigations on a large number of polymers it appears that there is a correlation between adsorption and viscosity, particularly the intrinsic viscosity of the solution. Let us assume that for dilute polymer solutions not the polymer chain but the statistical or random molecular coil, freely floating in the solution, takes part in the adsorption. Therefore, as a first step, a correlation is set up between the adsorbed amount and intrinsic viscosity and the equivalent coil diameter calculated from molecular mass and coil density. Plotting the n against equivalent coil diameter and coil density, re-

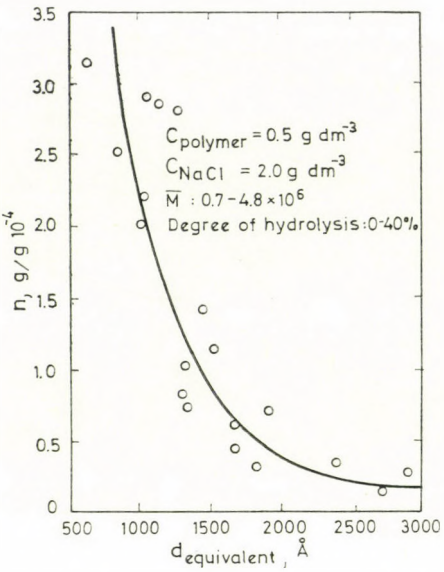

Fig. 6. **Variation of the adsorbed amount of the polymer with the equivalent diameter of random coils**

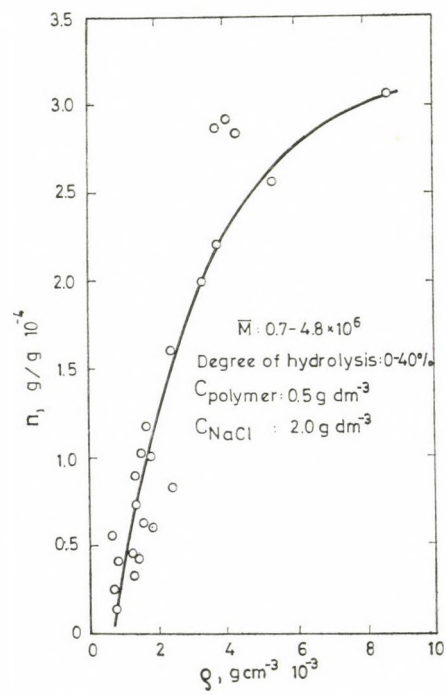

Fig. 7. **Variation of the adsorbed amount of different polyacrylamides with coil density**

spectively, Figs 6 and 7 can be obtained. Incidentally, it is noted that in the solutions prepared from *ca.* 20 different polymers, gel concentration varied between 15 and 50%, *i.e.* the polymer solutions had substantial amounts of free solvent in excess.

The equivalent coil diameter of polymer molecules measured in solution is proportional to the cubic root of intrinsic viscosity and average molecular mass. However, the coil density changes in an opposite way: the disorder (tangle) of the molecule and therefore the coil density decreases slightly with relative molecular mass and substantially with the degree of hydrolysis. According to our calculations, there is almost one order of magnitude difference between the coil densities of polymers with equal molecular mass but with hydrolysis degrees of 0 and 30%. As a result of the increase in relative molecular mass and degree of hydrolysis, the amount of the polymer retained by the porous model and thus the adsorption decreases since the volume of random coils increases, which is also accompanied by a substantial decrease in coil density. Since the coil density is determined primarily by the number of negatively charged carboxy groups, it is clear that adsorbed amount depends basically on the degree of hydrolysis, and the average relative molecular mass of the polymer plays only a secondary role (Figs 1 and 2).

In order to illustrate the effect of polymer concentration, data are given for two different types of polymer. The characteristic changes cannot be interpreted in terms of coil density and the volume or size of the molecule, since these factors hardly change with polymer concentration. (According to our measurements, the equivalent coil diameter decreased in some cases to a negligible extent with increasing polymer concentration.) There are, however, much stronger changes in the structure of solution; with increasing polymer concentration much larger portions of the solvent can be regarded as part of the coil. According to the curves shown in Fig. 8, the critical polymer concentration above which the solution can already be regarded as solvent deficient, is 0.57 g dm^{-3} for unhydrolyzed polyacrylamide and 0.14 g dm^{-3} for the hydrolyzed polymer in distilled water solution. Owing to the contracting effect of foreign electrolytes these data change to 2 and 0.95 g dm^{-3} in saline water.

Referring in part to unpublished data, WILLHITE and DOMINGUEZ [23] state that above these concentrations the interactions between the solute molecules already cannot be neglected, *i.e.* aggregates start to form. Near and above the critical polymer concentration there is no solution in the conventional sense, the whole system can be regarded as a gel, in which the molecular coils are not separated from one another. In adsorption studies carried out in porous media under dynamic conditions, these facts have the following consequences. In the adsorption on rock surfaces molecular aggregates, rather than coils, take part, the pore volume or pore surface available for the polymer decreases owing to the increasing size of the species, and the dynamic and irreversible

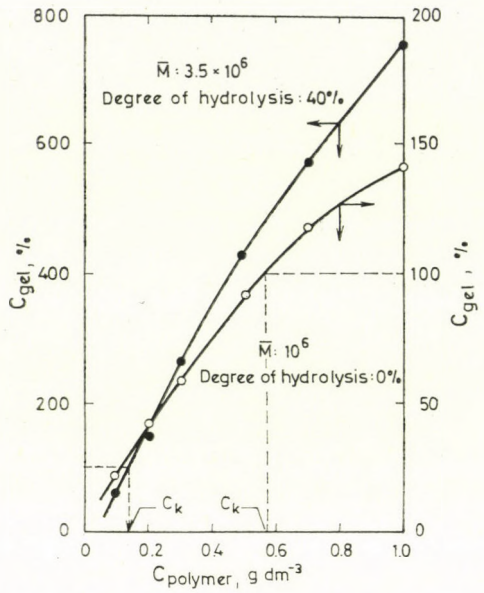

Fig. 8. Variation of gel concentration with polymer concentration

polymer retention or filtering sets in. The decrease in accessible pore volume is far overcompensated by the effect of the two other factors, primarily by the mechanical entrapment and retention of the polymer, which is also proved by the steady increase in the pressure gradient measured on the porous model. Consequently, the steep increase in the adsorbed amount vs. polymer concentration curve occurs in the vicinity of the critical polymer concentration, and it can be traced back basically to mechanical retention and not to sorption phenomena.

In connection with the structure of the adsorption layer, many authors [12, 25, 26] are of the opinion that it is usually monomolecular, noting that the calculated coverage is generally higher than unity. It has been shown by GREENE [27] on methacrylates that this coverage arises from the fact that the calculated volume of the molecular coil is larger than the true value, and mutual chain penetration of neighbouring coils may also occur.

We should add to this reasoning that in a porous system, even if highly compatible, certain degree of mechanical retention cannot be excluded, and this also contributes to the increase of coverage. For the approximately linear sections of the curves in Fig. 4, we have calculated the values of coverage on the basis of the specific surface area measured by permeometry, and they were found to be 2.21 for the unhydrolyzed polymer and 1.98 for hydrolyzed polyacrylamide, in constrast with the literature data cited. These values show

a slight increase with polymer concentration, and a steep increase starting at the critical concentration.

The formation of an adsorption multilayer, which is more appropriately characterized by segment density according to SILBERBERG [28], can be explained not only by the adsorption of molecular aggregates. According to the convincing experiments of THOMAS [26] in glass capillaries, further layers can be built on the polymer monolayer when the ratio of the diameter of capillary and the random coil is smaller than 4. In these capillaries or pores the motion of the liquid slows down, and if a sufficiently long contact time is available, the freely floating coil is bound via chain penetration on the first layer.

Since for the flooding of natural hydrocarbon-containing porous media it is preferable to apply a polymer solution in which the average coil size is close to the average pore size (ratio *ca.* 10), it should be taken into account that the major part of pore surface is covered by a polymer multilayer in the first place, *i.e.* literature data suggesting monomolecular coverage under natural conditions should be accepted with criticism. Consequently, adsorption models (*e.g.* HIRASAKI and POPE [29]) that calculate the permeability against water from the flow cross-section reducing effect of the monomolecular layer should be modified, or their validity restricted.

The effects of inorganic salt in natural connate waters on polymer adsorption were investigated by several authors [9—11, 13, 30]. They have unambiguously established that adsorbed amount increases with the concentration of foreign electrolytes. We have found [31] that in the presence of mono- or divalent salts the dissociation of polyelectrolytes is suppressed, and thus the contraction of random coils is responsible for the adverse changes in the rheological properties of polymer solutions (*e.g.* viscosity).

Figures 9 and 10 show the variation of the coil diameters and densities of the two different polymers investigated as a function of the sodium chloride concentration of the solution. It can be seen from the figures that the equivalent coil diameter and coil density change at first abruptly with salt concentration, and then, from *ca.* 2 g dm^{-3} concentration, the structure of the solution hardly changes. A comparison of the value also shows that despite the nearly identical relative changes, the salt concentration has a much larger effect on the structure of the solution of hydrolyzed polyacrylamide than on that of the unhydrolyzed low molecular mass polymer. This is easy to understand if it is taken into account that in the former case the size of the molecule in solution is affected not only by the molecular mass but also by the degree of hydrolysis. (In the electron micrographs of HERR and ROUTSON [32], the rigid chains of hydrolyzed polyacrylamide in ion-free solutions are well observable, whereas in a solution containing 0.5 *M* sodium chloride, the spherical coil is the dominant species.) The changes in the density and size of random coil thus explain the phenomenon shown in Fig. 5, namely that specific adsorp-

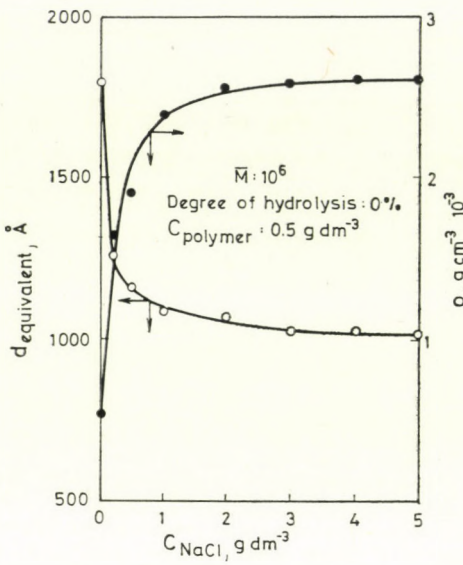

Fig. 9. Variation of the equivalent diameter and density of random coils with the sodium chloride concentration

tion varies more strongly with salt concentration for hydrolyzed than for unhydrolyzed polyacrylamides.

On this basis, however, it is difficult to explain why the two curves shown in Fig. 5 still increase above a salt concentration of 2 g dm^{-3}, although according to Figs 9 and 10, the structure of the solution hardly changes above this ion concentration. It should be noted, however, that the shape of the curves in the region of low salt concentrations is determined presumably not only by adsorption phenomena but also by the decrease of the electrokinetic potential of quartz and mechanical retention as well. Since we studied polymer solutions of 0.5 g dm^{-3} concentration, the value of n at the origin of the curves corresponds unambiguously to a polymer solution in the gel state with the hydrolyzed polymer (more than three times higher than the critical polymer concentration), and it is close to the critical state with the unhydrolyzed polymer. The magnitude of the excess loss arising from dynamic and irreversible polymer retention cannot be determined under the given conditions, but it has been found by SZABÓ [13] that these two factors, similarly to specific sorption, greatly depend on the salt concentration.

From the aspects of sorption, the nature of electrolytes is also relevant. The salts of multivalent metals contract the coils by 10—30% more than the salts of alkali metals [31]. Therefore, in the presence of di- and multivalent cations, adsorbed amount increases with decreasing valence number of the cation.

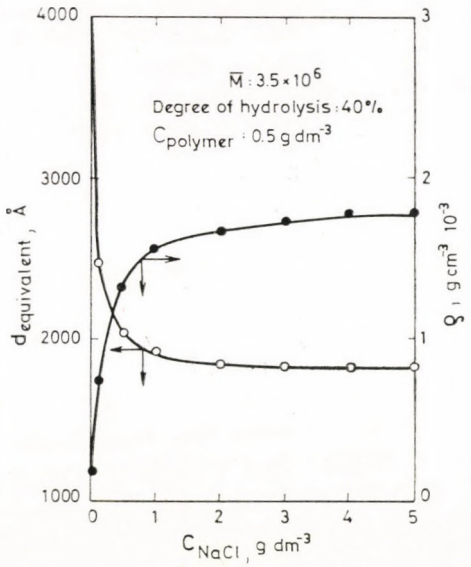

Fig. 10. Variation of the equivalent diameter and density of random coil with the sodium chloride concentration

The so-called salt effect as a whole has an adverse influence on the mechanism of polymer displacement, and therefore on the economy of the process based thereon. It increases the adsorption and mechanical losses on the porous medium, decreases the viscosity of the solution and increases the risk of *in situ* barrier formation. The maximum salt concentration of connate water at which the process is still applicable is usually estimated as 20—25 g dm^{-3}. If connate water is particularly rich in calcium and magnesium salts, this concentration may not exceed 10 g dm^{-3}. The presence of salts has, however, a certain stabilizing effect as well. This arises from the fact that the salt concentration of connate water is rarely less than 1—2 g dm^{-3}, which is usually enough to decrease the gel concentration of the solution below 100%. It is therefore possible to carry out the flooding with non-gellified solution, except for the head-front of slug with programmed concentration profile, in which the polymer concentration is generally 1—1.5 g dm^{-3}. This is a precondition of compatibility, and also of the situation in which the interaction of the rock and the freely floating random coils is the dominant factor in polymer retention by the porous system.

The experimental data and the above considerations show that in natural, consolidated porous systems sorption phenomena may never take place alone. Let us take for instance the structure of a porous rock from Csongrád-South (Hungary) area. The pore size distribution (determined by mercury porosimetry) of the rock with the relatively low but not uncommon permeability of *ca.*

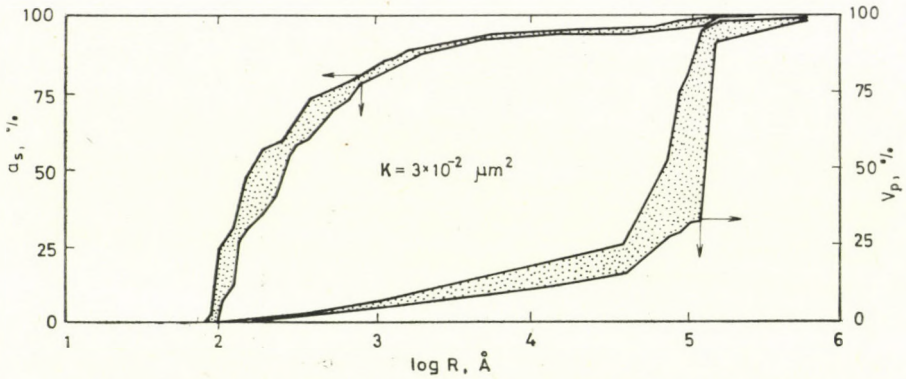

Fig. 11. The pore size distribution of a rock of low permeability, from Algyő, as a function of percent specific surface area (a_s) and pore volume (V_p) (shaded areas include the data for three samples)

3.0×10^{-2} μm^2 as a function of pore volume and specific surface area is shown in Fig. 11. It can be seen that 80% of the pore volume is represented by pores greater than 10^3 nm in radius whereas 80% of the specific surface area of *ca.* 7×10^3 cm^2g^{-1} arises from pores smaller than 10^2 nm in radius. This pore surface is inaccessible even for the coils of the unhydrolyzed polymer with low relative molecular mass. Although the fluid flows almost exclusively in the large pores, due to the filtering effect of the smaller pores representing only 20%, so much polymer may be retained in the system that the polymer loss in the model apparently corresponds to multilayer adsorption when referred to specific surface area, and it substantially changes the parameters of flow (resistance factor, residual resistance factor, *etc.*).

A consequence of the simultaneous processes mentioned is that for the polyacrylamides used in oil displacement the exact description of the adsorption phenomena in porous systems under dynamic conditions is generally impossible or possible only to a limited extent.

Conclusions

Investigating the sorption phenomena of different polyacrylamides under dynamic conditions in porous media made of silica sand we have found that

a) the adsorbed amount slightly decreases with increasing relative molecular mass of the polymer and strongly decreases with increasing degree of hydrolysis;

b) the effect of the molecular mass and degree of hydrolysis can be traced back to variations in density, accompanying the changes in the random coil size;

c) up to the critical polymer concentration the amount of adsorbed polymer is practically independent of the polymer concentration, and above this concentration it sharply increases owing to mechanical polymer retention by the porous medium;

d) with increasing concentration of dissolved inorganic salts the adsorbed amount also increases, due to increasing coil density;

e) the adsorption behaviour of hydrolyzed polymers, due to the structural differences between the solution and the coil, depend on the salt concentration to a greater extent than the behaviour of unyhodrolyzed polymers;

f) in polymer flooding under approximately compatible conditions with usual polymer and salt concentrations, the interaction of the rock and the freely floating polymer coil is dominant in the sorption phenomena, but the calculated coverage is always greater than unity;

g) in programmed flooding or in the case of low pore size/coil size ratio, the adsorbed polymer film is a multilayer, which can be attributed to the simultaneous effect of the adsorption of coil aggregates, chain penetration of random coils and mechanical polymer retention; and

h) in the flooding of natural, consolidated porous rocks the calculated multilayer adsorption is due primarily to the overlap between the distribution curves of pore size and molecular mass and to mechanical polymer retention, of filtering, arising therefrom.

Due to the simultaneous nature of sorption phenomena and mechanical polymer retention, the exact description of adsorption processes in natural porous rocks under dynamic conditions is at present very complicated.

REFERENCES

[1] Shah, D. O., Schechter, R. S.: Improved Oil Recovery by Surfactant and Polymer Flooding, Academic Press Inc., New York 1977
[2] Lakatos, I., Munka, M.: Theory and Practice of Polymer Flooding, Part I (in Hungarian) Bányászati Szakirodalmi Tájékoztató, NIMDOK, Budapest, 1978
[3] Pye, D. J.: J. Pet. Tech., **8,** 911 (1964)
[4] Sandiford, B. B.: J. Pet. Tech., **8,** 917 (1964)
[5] Mungan, N., Smith, F. W., Thompson, J. L.: J. Pet. Tech., **9,** 1143 (1966)
[6] Mungan, N.: Can. J. Pet. Tech., **2,** 45 (1969)
[7] Gogarty, W. B.: Soc. Pet. Eng. J., **6,** 161 (1967)
[8] Dauben, D. L., Menzie, D. E.: J. Pet. Tech., **8,** 1065 (1967)
[9] Smith, F. W.: J. Pet. Tech., **2,** 148 (1970)
[10] Sarem, A. M.: SPE preprint No. 3002 (1970)
[11] Szabó, M. T.: SPE preprint No. 4668 (1970)
[12] Szabó, M. T.: Soc. Pet. Eng. J., **8,** 333 (1975)
[13] Szabó, M. T.: SPE preprint No. 6601-B (1976)
[14] Chauveteau, G., Kohler, N.: SPE preprint No. 4745 (1974)
[15] Lakatos, I., Lakatos-Szabó, J.: Kőolaj és Földgáz, **106,** 336 (1973)
[16] Lakatos I.: Kőolaj és Földgáz, **108,** 215 (1975); Acta Geodaet. Geophys. Montanist. (Budapest), **13,** 325 (1978)
[17] Schamp, N., Huylerbroeck, J.: J. Polym. Sci., **42,** 553 (1973)
[18] Dawson, R., Lantz, R. B.: Soc. Pet. Eng., J. **12,** 448 (1972)

[19] MICHAEL, A. S., MORELOS, O.: Ind. Eng. Chem., **47**, 1801 (1955)
[20] THOMAS, C. P.: SPE preprint No. 5556 (1975)
[21] KUMAR, J., FATT, I.: Soc. Pet. Eng. J., **10**, 4 (1970)
[22] MARTIN, F. D., SHERWOOD, N. S.: SPE preprint No. 6339 (1975)
[23] WILLHITE, G. P., DOMINGUEZ, J. G.: Mechanism of Polymer Retention in Porous Media, in Shah and Schechter: Recovery by Surfactant and Polymer Flooding, Academic Press, New York 1977
[24] DOMINGUEZ, H. G. WILLHITE, G. P.: SPE preprint No. 5835 (1976)
[25] THAKUR, G. C.: SPE preprint No. 4956 (1974)
[26] THOMAS, C. P.: SPE preprint No. 5556 (1975)
[27] GREENE, B. W.: J. Coll. Interface Sci., **37**, 144)1971)
[28] SILBERBERG, A.: J. Coll. Intreface Sci., **38**, 217 (1972)
[29] HIRASAKI, G. J., POPE, G. A.: Soc. Pet. Eng., J. **14**, 337 (1974)
[30] MUNGAN, N.: SPE preprint No. 3521 (1971)
[31] LAKATOS, I., LAKATOS-SZABÓ, J.: Kőolaj és Földgáz, **106**, 309 (1973)
[32] HERR, J. W., ROUTSON, W. G.: SPE preprint No. 5098 (1974)

István LAKATOS
Júlianna LAKATOS-SZABÓ
} H-3515 Miskolc, Egyetemváros, P.O.B. 2.

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COMPLEX INVESTIGATIONS ON RANEY NICKEL CATALYSTS, IX

HYDROGEN ADSORPTION ON DRIED RANEY NICKEL

A. TUNGLER,[1] S. BÉKÁSSY,[2] J. PETRÓ[2] and T. MÁTHÉ[1]

([1]*Research Group for Organic Chemical Technology,*
[2]*Department of Organic Chemical Technology, Technical University, Budapest*)

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The adsorption of hydrogen on partly dehydrogenated, dried Raney nickel has been studied by magnetic and dynamic microcalorimetric methods. It has been found that the high hydrogen content of Raney nickel in comparison with other nickel catalysts is stabilized by the liquid, primarily water, covering the catalyst. On dry catalyst, upon repeated hydrogen adsorption, one order of magnitude less gas is bound, but with high bond strength. Hydrogen determined by thermodesorption (detectable with certainty up to 500 K) is desorbed from the catalyst and does not arise from the possible water-metal reactions.

Our investigations on this special catalyst type by several methods have been reported in a series of publications [1—9].

These measurements were carried out to clarify how the structure, activity and hydrogen content of the active catalyst are interrelated and how these properties can by influenced by the methods of catalyst preparation and promotion.

As a conclusion on the hydrogen content of the catalysts, we have established that there is a dynamic interaction between the various types of hydrogen bound on Raney nickel. A major part of hydrogen is released from the catalyst already at lower temperatures, upon flushing with inert gas. By comparing the thermodesorption behaviour of dry catalysts and those flushed with argon at room temperature for a couple of 10 hours we have found that during this treatment, while the catalysts become dry, their hydrogen content is lost. According to our assumptions, Raney nickel, unlike other catalysts, is able to retain hydrogen in amounts greater by one order of magnitude only if covered with water, and hydrogen is also released simultaneously with drying when the catalyst is flushed with argon.

The repeated measurement of the hydrogen sorption capacity of the dried catalyst, which was released most of its hydrogen content, may unambiguously prove the correctness of the above assumption: if it is substaintially lower than the original, our assumption is correct. Re-moistened Raney nickel is again able to adsorb higher amounts of hydrogen. This is, however, insufficient for proving that the presence of a liquid shell is necessary for binding

larger amounts of hydrogen, since in the hydrogenation of dry catalysts the amount of repeatedly adsorbed hydrogen is unknown. This cannot be determined by thermodesorption, since during the replacement of hydrogen with argon, there is a partial desorption and thus the amount of repeatedly adsorbed hydrogen cannot be mesaured accurately. Gas adsorption can be measured reproducibly by volumetric or gravimetric methods if the sample is treated in vacuum for a sufficiently long time at high temperature (>423 K). However, in the case of Raney nickel this would involve a change in structure and therefore the information obtained would not reflect the original state.

Accordingly, the repeated adsorption of hydrogen was studied by magnetic and microcalorimetric methods [10], in order to obtain at least indirect data on the quantity and quality of adsorbed hydrogen.

Experimental

Raney nickel catalysts were prepared by a special method [11] from an alloy containing 50 wt.% of Ni and 50 wt.% of Al. The catalyst was washed to neutral and stored under distilled water.

Magnetization was measured on a Faraday type apparatus [7].

The dynamic microcalorimetric measurements were performed on a DuPont 990 Thermal analyzer.

Results

To determine the thermomagnetic curve, magnetization was measured as a function of temperature, in argon at a heating rate of 10°/min, and then, with the catalyst heat treated at the maximum temperature (673 K), the measurement was continued at decreasing temperatures. The curve is shown in Fig. 1.

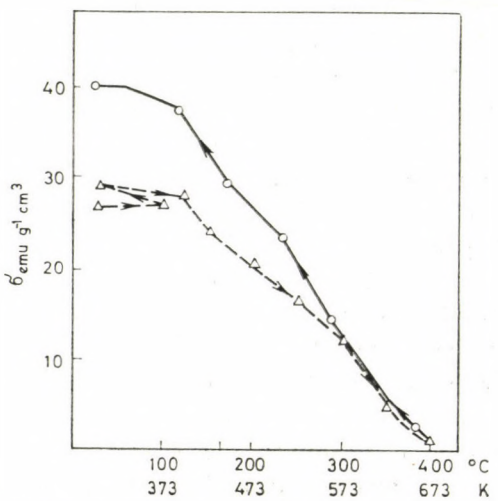

Fig. 1. Thermomagnetic curve of Raney nickel in argon

The further thermomagnetic curves, more precisely their parts corresponding to rising temperature, were obtained in argon under the conditions given in Table I. The parameters varied were the temperature of drying under argon (373 and 403 K), the time of drying (1200—3600 s), the temperature (298—323 K) and time (3600—5400 s) of hydrogenation and the time and temperature of heat treatment in argon.

As can be seen from the data of Table I (columns 2—6), during drying at 373 K a substantial amount of hydrogen is desorbed ($\Delta\sigma_{25}i = 3—6$ emu $g^{-1}cm^{-3}$, and only a fraction of this amount can be resorbed by the catalyst in a repeated hydrogenation ($\Delta\sigma_{250} = 0.6—2$). (1 emu = $10^3/4\pi$ Am^{-1}).

On flushing the catalyst with argon (Table I, column 6) at 323 K, the magnetization reaches that of the catalysts treated at higher temperatures within 2 hrs.

The samples dried at 373 K for 1 hr (columns 4, 5) have higher magnetization after heat treatment than those dried for shorter times (columns 1, 2, 3), *i.e.* containing more water.

The time and temperature of heat treatment at higher temperature have less influence on the magnetization of the catalyst measured after a heat. treatment at 298 K than does the time of drying at 373 K.

In the dynamic microcalorimetric measurements the catalyst sample was heated under an argon flow of 25 cm^3/h at a rate of 10°/min, and the thermal effect was recorded (Fig. 2). At the beginning of measurement, up to 373 K, a strong thermal effect can be observed, which corresponds to the, release of water. Between 373 and 673 K a flat, drawn-out exothermic effect appears (its presumable shape is indicated by the dashed line in the figure with a maximum at 493—503 K. On this exothermic signal, a sharp endother-

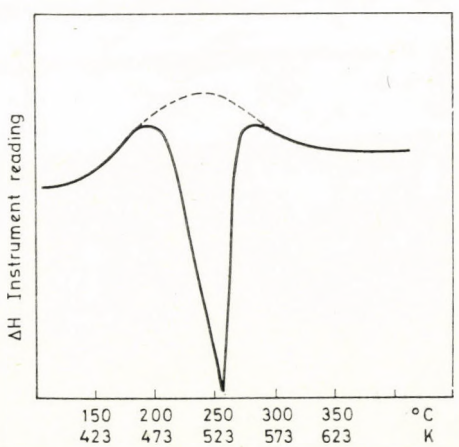

Fig. 2. Microcalorimetric curve of Raney nickel

Table I

Magnetization of Raney nickel on drying, hydrogenation and heat treatment in argon

Conditions of measurement				Conditions of measurement				Conditions of measurement			
T (°C)	Gas	(t/min)	σ (emu g^{-1}cm$_3$)	T (°C)	Gas	(t/min)	σ (emu g^{-1}cm^3)	T(°C)	Gas	(t/min)	σ (emu g^{-1}cm^3)
25	Ar	—	26.9	25	Ar	—	26.9	25	Ar	—	26.9
130		* 0	26.7	100		0	26.0	100		0	26.3
		↓20	27.5			↓30	27.6			↓20	27.3
50	H_2	90	30.3	25		—	30.7	25	H_2	60	28.0
50	Ar	0	30.9	25	H_2	0	28.8	25	Ar	120	29.9
		20	31.5			60	28.8	115	Ar	0	26.6
130		0	28.0	230	Ar	0	21.7			20	27.4
		20	28.5			50	23.8	175		0	21.4
220		0	18.6	300	Ar	0	7.2			25	22.3
		30	20.1			10	8.4	230		0	16.7
				350		0	8.5			30	18.6
						10	7.0	290		0	11.3
				400		0	2.3			20	12.0
						10	2.4	365		0	1.5
										15	2.4
								290	Ar	—	14.3
								230			23.5
								175			29.4
								115			37.1
25			40.4	25			41.1	25			40.1
25		—	26.9	25	Ar	—	26.9	25	Ar	—	26.9
100	Ar	0	23.6	100	Ar	0	24.1	100	Ar	↓60	30.6
		2	24.3			2	24.3	50	Ar	—	36.5
		5	27.1			↓60	28.1	50	H_2	60	34.7
		10	28.5	25	Ar		31.1	50	Ar	5	34.7
		20	29.0	25	H_2	60	30.5			10	34.9
		30	29.9	25	Ar	0	30.6			20	36.4
		↓60	31.2			2	30.6			45	40.1
25			33.0			40	31.1			60	41.5
25			31.1	100		0	28.1			120	42.0
25	Ar	0	31.5			2	28.3				
		10	31.9			40	28.7				
		30	32.5	200		0	23.8				
		60	32.6			2	23.8				
100		0	29.1			20	24.1				
		20	29.5	250		0	18.7				
		30	29.8			2	18.7				
200		0	23.2			20	19.6				
		20	24.1	300		0	12.7				
250		0	18.9			2	14.0				
		20	19.9			20	14.6				
300		0	13.2	350		0	7.1				
		20	13.7			2	7.2				
350		0	6.3			20	7.0				
		20	7.4								
25			44.2	25			43.3	25			42.7

* Data marked with arrow refer to drying
(1 emu = $10^3/4\pi$ Am^{-1})

mic peak is superimposed at 523 K. This is the thermal effect of alumina present in the form of hydrargillite in the catalyst [12].

On admitting hydrogen to the sample dried at 373 K under argon flow an exothermic peak, indicating adsorption, can be observed. When hydrogen is replaced by argon, a more prolonged endothermic process takes places. By exchanging the gases several times, this effect can be reproduced. After calibrating the instrument, the magnitude of the exothermic peak can be determined from the integrated area of the peak.

The thermal effect of adsorption was found to be around 12.6 mJ/mg. Regarding the heat of adsorption of hydrogen on nickel as 105×10^3 J/mol [13], the above effect corresponds to a hydrogen amount of 3 cm^3/g catalyst.

Discussion

According to our investigations reported in previous publications [2, 7], with the so-called highly active Raney nickel catalysts the amount of hydrogen desorbed at lower temperatures (<373 K) is 20—40 cm^3/g, and the increase in Bohr magnetons on desortpion is between 0.2 and 0.3. The data of Table I show that upon drying at 373 K, this type of hydrogen is most probably completely released, but, as estimated from microcalorimetric measurements, in a repeated treatment with hydrogen only one tenth of this amount is resorbed.

The decrease in Bohr magnetons caused by the adsorption of one hydrogen atom is 0.5—1.5. Accordingly, this type of hydrogen interacts with nickel more strongly, *i.e.* it behaves as the second type of hydrogen determined by thermodesorption.

It is clear from the results that the dry catalyst adsorbs substantially less hydrogen.

In agreement with the result of thermodesorption measurements, on flushing with argon, the catalyst releases its hydrogen content almost completely within 2 hrs, since its magnetization approaches that of the catalysts heat treated at higher temperatures. This also proves that a large part of hydrogen detected by thermodesorption is sorbed on the catalyst, and does not arise from a reaction between water bonded in aluminium hydroxides and the aluminium and nickel metal content of the unleached alloy. As hydroxides release their water content only above 473 K, the water + Al reaction becomes possible only above this temperature.

On the other hand, the aluminium and nickel metal content of the catalyst may react at higher temperatures with the water present, since the magnetization measured after heat treatment of samples dried for shorter times at 373 K is lower than that of the samples subjected to more prolonged drying.

Consequently, magnetic and dynamic microcalorimetric measurements on dried catalyst samples support our previous hypothesis, according to which, the high hydrogen content of Raney nickel is stabilized by the liquid covering the catalyst, and on dry catalysts the amount of gas bonded during repeated hydrogen adsorption is one order of magnitude lower, but its bond strength is higher.

Hydrogen detected by thermodesorption detectable with certainty up to 500 K is sorbed on the catalyst, and does not arise from the possible water-metal reactions.

REFERENCES

[1] HEISZMAN, J., PAYER, K., BÉKÁSSY, S., PETRÓ, J.: Acta Chim. (Budapest), **84**, 431 (1975)
[2] HEISZMAN, J., PETRÓ, J., TUNGLER, A., MÁTHÉ, T., CSŰRÖS, Z.: Acta Chim. (Budapest), **86**, 117 (1975)
[3] HEISZMAN, J., BÉKÁSSY, S., PETRÓ, J.: Acta Chim. (Budapest), **86**, 347 (1975)
[4] TUNGLER, A., BÉKÁSSY, S., PETRÓ, J.: Acta Chim. (Budapest), **86**, 359 (1975)
[5] BÉKÁSSY, S., PETRÓ, J., LIPTAY, G.: Thermochim. Acta, **11**, 45 (1975)
[6] BÉKÁSSY, S., PETRÓ, J., KRISTYÁK, E., CSANÁDY, A., KÁLMÁN, A.: Acta Chim. (Budapest), **88**, 375 (1976)
[7] TUNGLER, A., PETRÓ, J., MÁTHÉ, T., HEISZMAN, J., BÉKÁSSY, S., CSŰRÖS, Z.: Acta Chim. (Budapest), **89**, 31 (1976)
[8] HEISZMAN, J., BÉKÁSSY, S., PETRÓ, J., BIDLÓ, G., BEZUR, L.: Magyar Kém. Foly., **81**, 558 (1975)
[9] TUNGLER, A., PETRÓ, J., MÁTHÉ, T., HEISZMAN, J., BUELLA, F., CSŰRÖS, Z.: Acta Chim. (Budapest), **89**, 151 (1976)
[10] BÉKÁSSY, S., GÁL, S., STATIS, J.: to be published
[11] HUNGARIAN Patent No. 162,281
[12] CSŰRÖS, Z., PETRÓ, J., KÁLMÁN, V., ERDEY, L., PAULIK, F.: Magyar Kém. Foly., **70**, 337 (1964)

Antal TUNGLER
Sándor BÉKÁSSY
József PETRÓ
Tibor MÁTHÉ
H-1521 Budapest, Műegyetem

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INVESTIGATION OF SILATRANES BY ^{29}Si NMR SPECTROSCORY

(PRELIMINARY COMMUNICATION)

P. HENCSEI[1] and H. C. MARSMANN[2]

([1]*Institute of Inorganic Chemistry, Technical University, Budapest,* [2]*Laboratorium für Anorganische und Analytische Chemie der Gesamthochschule Paderborn, Paderborn, B. R. D.*)

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The first paper on the investigation of silatranes ($\overbrace{RSi(OCH_2CH_2)_3N}$) by ^{29}Si NMR spectroscopy was published in 1977 [1]. In communications published since that time [2—5] the ^{29}Si NMR spectra of 36 various silatranes and further 8 ring substituted silatranes have been reported. To study the bond structure of silatranes, we determined the ^{29}Si chemical shifts for several silatranes and triethoxysilane molecules. The data of our measurements together with data measured by other authors for the investigated compounds are summarized in Table I.

The spectra were recorded on a WP 60 DS (Brucker) instrument in $CDCl_3$ solutions; TMS was used as reference material. The ^{29}Si frequency was 11.919 MHz, the reproducibility of data was ± 0.1 ppm.

As can be seen from Table I, our data are in good agreement with the results of other authors. The data of aryloxysilatranes indicate that the effect of substituent in para position on the ^{29}Si chemical shift can be practically neglected. In Table II the ^{29}Si chemical shifts of silatranes and triethoxysilanes with identical substituents are compared.

In each case the δ^{29}Si value is significantly more negative in the silatrane derivative than in the corresponding triethoxysilane. This marked difference also supports the existence of an Si $\leftarrow$ N dative bond in silatranes. For the methyl and phenyl derivatives, where the molecules contain Si—C bonds, the $\Delta\delta^{29}$Si value is approximately 21 ppm; in the case of alkoxy and aryloxy derivatives containing Si-O bonds the $\Delta\delta^{29}$Si value is about 12 ppm. This finding is supported by data in [5], where a study for 10 pairs of compounds with Si-C bonds provided 22.2 ppm for the mean value of $\Delta\delta^{29}$Si.

The difference in $\Delta\delta^{29}$Si values can be explained by the different Si$\leftarrow$N distances and bond strengths. In the methyl- and phenylsilatranes the Si$\leftarrow$N distance is short, a strong dative bond is formed, the environment of the silicon atom is changed, thus the $\Delta\delta^{29}$Si value will be large. In the alkoxy and aroxy

Table I

^{29}Si *Chemical Shifts of Silatranes and Triethoxysilanes* (in ppm)

Compounds	This work	[5]	[4]	[1]	[3]
$CH_3Si(OCH_2CH_2)_3N$	—65.1	—65.7	—64.8	—65.7	—65.7
$C_6H_5Si(OCH_2CH_2)_3N$	—80.3	—80.5	—81.7		
$C_2H_5OSi(OCH_2CH_2)_3N$	—94.7	—94.7			
$C_6H_5OSi(OCH_2CH_2)_3N$	—98.4	—99.3			
$4\text{-}ClC_6H_4OSi(OCH_2CH_2)_3N$	—98.6	—99.7			
$4\text{-}NO_2C_6H_4OSi(OCH_2CH_2)_3N$	—98.6	—99.6			
$4\text{-}FC_6H_4Si(OCH_2CH_2)_2(OCOCH_2)N$	—84.2				
$3\text{-}CF_3C_6H_4Si(OCH_2CH_2)_2(OCOCH_2)N$	—86.3				
$C_6H_5OSi(OC_2H_5)_3$	—86.6				
$4\text{-}ClC_6H_4OSi(OC_2H_5)_3$	—86.7				

Table II

Comparison of ^{29}Si *Chemical Shifts of Silatranes and Triethoxysilanes* (δ^{29}Si, ppm)

R	$RSi(OCH_2CH_2)_3N$	$RSi(OC_2H_5)_3$	$\Delta\delta^{29}$Si
CH_3	—65.1	—44.21 [6]	20.9
C_6H_5	—80.3	—58.4 [4]	21.9
C_2H_5O	—94.7	—82.40 [6]	12.3
C_6H_5O	—98.4	—86.6	11.8
$4\text{-}ClC_6H_4O$	—98.6	—86.7	11.9

derivatives the bond lengths can be assumed to be larger, resulting in smaller $\Delta\delta^{29}$Si values.

To draw further conclusions concerning the bond structure of the investigated compounds, the determination of molecular geometries by X-ray diffraction is necessary. In the knowledge of these data the connection between the ^{29}Si chemical shifts and bond distances (particularly Si-N bond length)

could be investigated and quantumchemical calculation could be carried out. Since only a few X-ray diffraction data are available, a more detailed evaluation of our findings can be carried out later.

*

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REFERENCES

[1] TANDURA, S. N., PESTUNOVICH, V. A., VORONKOV, M. G., ZELCHAN, G. I., BARYSHOK, V. P., LUKINA, J. A.: Dokl. Akad. Nauk SSSR, **235**, 406 (1977)
[2] TANDURA, S. N., PESTUNOVICH, V. A., VORONKOV, M. G., ZELCHAN, G. I., SOLOMENNIKOVA, I. I., LUKEVICS, E. I.: Khim. Geterots. Soed., **1977**, 1063
[3] PESTUNOVICH, V. A., TANDURA, S. N., VORONKOV, M. G., BARYSHOK, V. P., ZELCHAN, G. I., GLUKHIKH, V. I., ENGELHARDT, G., WITANOWSKI, M.: Spectr. Lett. **11**, 339 (1978)
[4] HARRIS, R. K., JONES, J., NG, S.: J. Magn. Resonance, **30**, 521 (1978)
[5] PESTUNOVICH, V. A., TANDURA, S. N., VORONKOV, M. G., ENGELHARDT, G., LIPPMAA, E., PEHK, T., SIDORKIN, V. F., ZELCHAN, G. I., BARYSHOK, V. P.: Dokl. Akad. Nauk SSSR, **240**, 914 (1978)
[6] HARRIS, R. K., KIMBER, B. J.: Org. Magn. Resonance, **7**, 460 (1975)

Pál HENCSEI H-1521 Budapest, Gellért tér 4.
Heinrich C. MARSMANN D-4790 Paderborn, Wartburger Str. 100.

RECENSIONES

Crystals. Growth, Properties, and Application. Vol. 1.

Crystals for Magnetic Applications C. J. M. ROOIJMANS,

Springer-Verlag, Berlin—Heidelberg—New York 1978

Lately, increasing interest has been focused on studies that deal with the preparation, formation and nature of crystals. Several features on crystals, allowed to rest in obscurity up to now, and only briedly mentioned in some earlier books on mineralogy or crystallography have been brought into the foreground. Research and electronice industry, laser techniques and crystal optics require a variety of crystals whose production is responsible for evolution of a new branch of science. In view of these developments, Springer Verlag started a new series of books entitled "Crystals. Growth, Properties, and Application."

Well known representatives of the various fields were invited to from the editorial committee partly from Universities, partly from industrial R & D departments, thus harmony between pure and applied aspects of the subject has been provided for.

The introduction to this series clearly states its aim, which is to offer a critical survey of recent progress in the field. It is intended to describe the theory and practice of the growing of crystals and to discuss the relevant studies.

The first volume in this series carries the title "Crystals for Magnetic Applications" and contains five papers on the production and growth of magnetic garnets.

The introductory paper in one by W. TOLKSDORF, and F. WELZ, entitled "Crystal Growth of Magnetic Garnets from High-Temperature Solutions". 52 pages are assigned to this topic. First the history of the discovery of magnetic garnets is described, then the crystallographic characteristics of the yttrium-iron garnets $Y_3Fe_5O_{12}$ are discussed. A treatment of the phase-diagram is followed by a critical evaluation of the properties of the lead oxide bath. Subsequently a detailed description of the way of how to grow these crystals, of the apparatus, of the material and shape of the crucible, of the optimization of agitation, of the temperature of the formation of crystal nuclei is given.

Three melting experiments are discussed. In the first a 250 g garnet was obtained from 3 kg the raw material; a single crystal of 605 g formed from an 8 kg batch of the raw materials in the second experiment; in the third a seed-crystal was also used and thus the demand of energy for spontaneous formation of a nucleus was diminished substantially. Among the impurities in the crystals lead (0.042 wt.%) and fluorine (0.042 wt.%) were prominent. The amount of Fe^{II} was between 0.04 and 0.08 wt.%.

Defective growth was studied separately. The faces of the (111) form show up on (211) planes in a disoriented state and this causes magnetic anisotropy.

Other garnets could also produced by this method.

Very thorough and well-founded considerations form the basis of the experiments done by these authors: good quality garnets in good yields were the result. It is well to point out that 120 references to the literature are given. The date of the receipt of this paper is June 9, 1978, and on January 11, 1979 this book was already in Hungary!

F. J. BRUNI: Gadolinium Gallium Garnet (GGG). This is the most satisfactory monocrystal substance used the world over. In the 17 pages paper the crystallographic data of the garnet with the composition $Gd_3Ga_5O_{12}$ are noted by way of introduction; then the methods of growing are mentioned. The furnace designed by CZOCHRALSKI is used; the garnet crystal is drawn from the melt by means of slow rotation because rapid turning leads to faulty crystals. A great proportion of the crystal defects in the garnets is due to the material of the iridium crucible, inclusions of the size of 0.2 to 20 microns of this substance are found within the crystal lattice.

Most of the crystal defects develop in the course of crystal growth and are due to the incorporation of iridium, which settles on surfaces and separates the layers from one another.

Further lattice defects result from faulty seed crystals, leading to dislocations of various types. Also fibrillar structures may develop in the course of crystal growth because also here the (211) form is evident besides the faces characteristic of garnet crystals.

49 references are added, among these several personal communications.

M. H. RANDLES: Liquid Phase Epitaxial Growth of Magnetic Garnets. This 25 pages essay deals with the method of how to grow garnet films needed for bubble memory. The development and the first results of the liquid phase epitaxy (LPE) technique are described by way of introduction. Initially, thin slices of magnetic garnets were used in bubble memories in 1970 epitaxial growth was introduced as the regular course of preparation. The chemistry of rare-earth garnets is discussed, then the features of growth baths of $PbO-B_2O_5$ are explained. Data on the composition of magnetic garnet films and their lattice constants are given.

The furnace allowing a fluctuation of the temperature within not more than ± 1 °C, was suitable for isothermal growth. Growing was effected upon GGG which was carefully purified first in order to prevent the occurrence of lattice defects. The growing of quite satisfactory garnet films is reported. The final chapter deals with the kinetics of crystal growth.

The paper is complete with 103 references.

N. L. DEMIANETS: Hydrothermal Crystallization of Magnetic Oxides. The hydrothermal method of the preparation of metal oxides is reviewed here in a 25 page paper. First the Fe_2O_3 group is discussed: the conditions of the formation of haematite and of goethite are described together with the possibilities of transformation of these into magnetite. Then the properties and the conditions of the production of orthoferrite ($YFeO_3$) are explained; also the properties of ferrite garnets. In the second part, the characteristics of the MnO_2 group dealt with, though only too briefly. The third part is devoted to the TiO_2 group. The method of the epitaxial growth of magnetic garnets completes this paper: the conclusion is that the hydrothermal method is quite suitable for the preparation of oxides as well as for epitaxial growing.

74 references complete this paper.

"Magnetic Spinel Single Crystals by Bridgman Technique", by Mitsuo SUGIMOTO, is the concluding paper in this volume. The phase equilibrium of the Fe—Ni—O ternary system and the thermal dissociation of Fe_2O_3 are discussed in this 13 pages survey. A description of the furnace used in this Bridgman method and the results of crystallization are included.

In summary, the reviewer feels that, first of all, one should welcome the fact that crystal growth and properties of crystals have found a new forum, and one of such high standard. The papers present from all over the world careful experimental work undertaken after profound theoretical considerations.

The time of printing of this book was extremely short. Production, illustrations, quality of printing praise the usual, careful workmanship of Springer-Verlag. The next volume in this series is eagerly awaited.

G. BIDLÓ

J. C. JOHNSON: *Emulsifiers and Emulsifying Techniques* (p. 447)

Noyes Data Corp., Park Ridge, New Jersey, 1979

The study of emulsions as that of crude dispersed systems is generally coeval with the chemistry of colloids, and particularly with the steadily spreading practical utilization of knowledge gained by colloid chemistry.

This propagation of the use of natural and anciently known emulsions like milk, lates, as well as that of other partly or wholly artificial ones, rests upon the realization that heterogeneous systems of mutually insoluble components: one being water or an aqueous solution, the other being an apolar or only slightly polar liquid, can be united, under certain circumstances, into a "homogeneous" medium that carries the useful propreties of both phases.

A fundamental task, from the scientific point of view, was the elucidation of the dispersion process, and of the roles played by the most important factors in the maintenance of the dispersed state. In recent decades Soviet, British, American, and other schools have shown that the efficient performance of dispersing as well as the stabilizing of the dispersed state are decisively affected by the technique (apparatus) used for dispersing itself on the one hand, and by the emulsifier, mostly surfactant, additives which help the formation and the stability of emulsions, on the other. Especially informative research done in the Soviet Union helped to understand correlations between the structure of the adsorption layer at phase boundaries and the stability of the emulsion.

Fundamental research has furnished important directives concerning the preparation of emulsions, nevertheless the preparation of a certain emulsion for a specific purpose is still a matter of trial and error. At the same time, emulsions rapidly tend to become ubiquitous in practice, from pharmaceuticals through food industry to paper manufacture, to give but a scanty enumeration.

Considering all this it is no wonder that there exists a substantial body of patent literature on emulsions, besides the scientific literature proper in this domain.

The author of this book undertook the descriptive compilation of U.S.A. patents concerning emulsions, beginning with 1973; this already implies the high professional level of this work.

It is more than a collection according to some system, of patent specifications. The available literature has been elaborated by J. C. JOHNSON in such a way that the most important technological information is given prominence, and the pitfalls of patent terminology are skilfully evaded. As the author points out in the preface to his book: many patents from among the ones here mentioned have been realized in industrial practice and the ones successfully applied furnish a groundwork for further development.

The first chapter deals with the preparation of emulsifiers, and mostly with that of the less known ones, *e.g.* borane derivatives, or various derivatives of *iso*-cyanic acid.

The second part is about emulsifiers used in the production of margarine and similar products, with special reference to low-calorie. and soft or liquid varieties.

In a separate part, other emulsions in connexion with milk products are dealt with; also with those used in cheese manufacture, and in that of various whipped cream types and foods by freezing techniques.

The next part, about various types of emulsions used in the preparation of goods processed by baking, is especially noteworthy from the point of view of food production.

Valuable information is offered, in the chapter on other emulsions involved in food technologies, about emulsifiers applicable in the preparation of mayonnaise and other dressings with similar consistency, in the dispersing of flavouring substances, and in the manufacture of special food porducts.

In a relatively comprehensive part emulsions which contain chemicals, and emulsions for cosmetical of pharmaceutical purposes are discussed. The descriptions of the not easily realizable preparation of hydrazine emulsions, interesting from the point of view of rocketry, and those of a concentrated emulsions of bromine applicable in chemical analyses and syntheses, are most interesting. Among the products to be used in cosmetics, the poly-amino acids, in the role of emulsifiers are worth noticing, but so are the emulsifier mixtures for the processing of di-organo-siloxanes, and the emulsions of alcohols with petroleum products.

The preparation of the emulsions of hydrocarbons, vitamins, and vaccines is described in the part which treats of relevant pharmaceutical products.

The practical importance of the chapters about emulsion-polymerization and polymer emulsions is greater than made to appear through the prescriptions published.

The author offers a detailed discussion of macromolecular and other types of emulsifiers applicable in the process of emulsion-polymerization. In this part about polymer emulsions we find how to make thermosetting polyester emulsions, W/O type, cross-linked emulsions suitable for coatings, and various other types, *e.g.* elastomeric latexes applicable as top-dressings on road surfaces.

The next chapter discusses emulsions suitable for the cleaning, burnishing of surfaces, for purposes of the paper- and textile industries; then bituminous and asphaltic emulsions in the building and kindred industries are discussed.

The last three parts of this book deal with the production of emulsion for well-boring, petroleum industries, and of some for peculiar uses. Among the emulsions for the petroleum industry special mention is made of bio-degradable varieties which are very important from the point of view both of economic and environmental aspects.

M. NAGY

Andor HAJÓS: *Complex Hydrides and related reducing Agents in Organic Synthesis*

Akadémiai Kiadó, Budapest, 1979

Complex hydrides as reducing agents have been applied for about 100 years. Their importance is so great today that they are no longer curious laboratory reagents, even the number of commercially available reducing agents of this type is so great now that proper

choice of the reducing agent for a given task is not at all easy, as the author states in the preface. One main objective of the book is to provide help in choice of reagents.

This purpose is reflected in the way of discussing the individual hydrides and hydride families. After reviewing the physical and chemical properties, the field of application is demonstrated on several functional groups, compound types and examples systematically, and the most important characteristics of operations are described (Chapter 11 also treats the processing of reaction mixtures).

The book consists of the following chapters.

1. Introduction
2. Alkali metal and alkaline earth metal hydrides (2 pages),
3. Boranes and their derivatives (9 pages),
4. Aluminium hydride and its derivatives (5 pages),
5. Metal borohydrides (42 pages),
6. Metal aluminium hydrides (84 pages),
7. Silanes (34 pages),
8. Organotin hydrides (30 pages),
9. Hydrides of transition metals (39 pages),
10. Analysis of complex hydrides (5 pages),
11. Technique of selective reductions with complex hydrides (11 pages),
12. Mechanism of reduction with complex hydrides (26 pages).

The book includes an Appendix, Authors List and Subject Index; the total volume is 370 pages.

At the end of each chapter ample references can be found, including the data published until the end of 1977.

In this topic, a comprehensive work has not been published in the last 20 years and, since development has greatly accelerated, much information waited for systematic discussion. In this respect, the book satisfies the needs. It gives an excellent review of the field and provides a great help for experts dealing with hydride reductions.

J. PETRÓ

Advances in Polymer Science, 32

(Fortschritte der Hochpolymeren-Forschung) Vol. 32 Springer-Verlag, Berlin—Heidelberg—New York, 1979, 158 pages

The volume contains three review articles, discussed separately below.

S. CESCA, A. PRIOLA and M. BRUZZONE: *Synthesis and modification of polymers containing a system of conjugated double bonds*

The paper of 67 pages is written in English. It contains 34 figures, 26 tables and 97 references.

EPDM rubbers, prepared by random terpolymerization of ethylene, propylene and an unconjugated diene, have found important applications especially where resistance to oxygen and ozone is required. However, blends of diene based — either natural or synthetic — elastomers and (low unsaturated) EPDM rubbers were not covulcanizable so far, owing to the large difference in their double bond concentrations and thus in reactivity.

Recently a new type of hydrocarbon monomers has been synthesized, which is characterized by the presence of a double bond suitable for copolymerization or terpolymerization, and of a system of multi-conjugated double bonds, the reactivity of which makes them competitive with conventional diene rubbers in sulfur vulcanization, despite their low concentration.

A similar situation exists in the case of copolymerization of *iso*-olefins with suitable trienes. The results permit to compare the behaviour of these two classes of copolymers which display several analogies.

The whole field is still in rapid development, and there has been no up-to date summary of the investigations in this area.

The aim of the review is to fill this gap and to get acquainted the reader with recent developments in this field.

EPDM terpolymers can be obtained by means of coordination catalysts displaying low acidity, while cationic catalysts are used for the synthesis of triene — isobutene copolymers.

The polymers thus obtained posses a reactivity which is qualitatively and quantitatively different from that of the corresponding polymers containing only one single double bond.

The diene double bonds can have different structures.

Conjugated diene systems in these polymers display considerable reactivity not only in sulfur vulcanization, but also toward free radicals, oxygen, chlorinating agents, *etc.* In the latter case the reaction takes place mainly through 1,4-addition. The refore, the resulting polymer which contains very reactive chloride atoms in allylic positions, is suitable for curing processes.

The presence of the conjugated double bond system makes thus possible several post-modification reactions, which widely extend the classes of these synthetic elastomers; thereby new polymers and materials can be made for useful and specific applications.

V.T. STANNETT, W. J. KÖRÖS, D. R. PAUL, H. K. LONDSDALE and R. W. BAKER: *Recent advances in membrane science and technology*

The paper of 53 pages is written in English. It containes 18 figures, 12 tables and 210 references.

A membrane is — as defined by the authors — any medium which acts as a barrier to transport into or out of a region, providing selective transfer of one species over another, regulating the transport of a material to its environment at a controlled rate.

Membranes are high polymers. Their common usage includes many fields such as ultrafiltration (UF), gas separation, microfiltration (MF), reverse osmosis, the application of hydrophobic liquid membranes with outstanding permselective properties which can be taylored, controlled release of chemicals, removal of volatile residual monomers from polymers such as PVC and PAN, *etc.*

The search for polymeric materials with favourable transport properties has been entirely empirical in the past. Two materials are mainly in use today: cellulose acetate, with a degree of acetylation 2.5—2.8, and aromatic polyamides.

The migration of small molecules in high polymers has been successfully exploited for gas separations, water purification and controlled release. In the latter use a drug concentration may be maintained constant at the optimal level for prolonged periods. This is useful in the field of medicine (*e.g.*, the release of pilocarpine to control glaucoma, or of progesterone to effect birth control) and in agriculture (*e.g.* controlled release of pesticides, fertilizers and herbicides in microcapsules with less environmental side effects; release of pheromones: sex attractants for insects); other uses are in antifouling coatings for ships, *etc.*

Examples of the applications which can be accomplished by UF are the separation of oil from emulsified oil wastes, recovery of paint from electro-coat paint rinse tanks, and concentration of whey, a by-product of cheese making.

The most important utilization of MP is sterile filtration. Bacteria can be removed from drinking water, solutions for intravenous or parenteral injection, from heat-sensitive liquid food, *etc.*

G. HENRICI-OLIVÉ and S. OLIVÉ: *Molecular interactions and macroscopic properties of polyacrylonitrile and model substances*

The paper of 30 pages is in English. It contains 9 figures, 8 tables and 104 references.

At present acrylic fibres have a market share of about 20% in the production of synthetic fibres. Despite the large volume production of these fibres, much of their chemistry and physics is still far from being fully understood.

In the review article an attempt is made to collect, and interpret on a molecular basis what is known thus far about the interactions of polyacrylonitrile molecules with each other and with other molecules, and to relate these interactions to macroscopic properties of polymer and fibre.

For the interactions of PAN the polar nitrile groups are responsible. All characteristic properties of the polymer and of fibres therefrom, such as the high polymerization rate constant in water, the dissolution of the polymer in concentrated inorganic salt solutions, the high melting point, the depression of melting point and glass transition temperature by water, the plasticization by polar additives, *etc.*, can be traced back to such interactions.

These can be divided in dipole-dipole interactions, hydrogen bonding and EDA-complex formation. The effect of these factors are discussed separately. The electrostatic forces play the predominant part in dipole-dipole interactions, hydrogen bonding and weak to medium EDA-complexes. In the case of transition metal complexes, also charge transfer has a dominant role in non-covalent bonding.

To facilitate an easier survey, a *cumulative author index* of the volumes published so far (1—32) has been added to the volume.

To sum up the 32nd volume of "Advances in Polymer Science" contains three reviews the topics of which are at present in the foreground of reaserach. The authors of the compilations are scientists of international reputation in their special fields. The editing of the book is careful, misprints are very rare, and the typography of the figures and tables is also unobjectionable. The volume is a valuable contribution to the literature of high polymer chemistry.

I. GÉCZY

Topics in Current Chemistry

Manag. Ed.: F. L. BOSCHKE

Vol. 81: *Large Amplitude Motion in Molecules* I (p. 180)
Vol. 82: *Large Amplitude Motion in Molecules* II (p. 184)

Springer-Verlag, Berlin—Heidelberg—New York, 1979

It is increasingly realized that the intramolecular motion is a very important part of the molecular structure especially when the molecules undergo large-amplitude motion. Modern experimental and theoretical tools are utilized in the investigation of large-amplitude motion of non-rigid molecules and outstanding scientists address themselves to these problems. The area is quickly developing and the series Topics in Current Chemistry has proved once again its timeliness with the appearance of the two volumes reviewed here. There are altogether four papers in the two volumes presenting four subareas of the studies of large-amplitude motion using very different approaches. The four papers are as follows:

Part I (Volume 81)

H. FREI, A. BAUDER, Hs. H. GÜNTHARD: The Isometric Group of Nonrigid Molecules (pp 1—97)

O. BASTIANSEN, K. KVESETH, H. MØLLENDAL: Structure of Molecules with Large Amplitude Motion as Determined from Electron-Diffraction Studies in the Gas Phase (pp 99—172)

Part II (Volume 82)

L. A. CARREIRA, R.C. LORD, T. B. MALLOY, Jr.: Low-Frequency Vibrations in Small Ring Molecules (pp 1—95)

G. O. SØRENSEN: A New Approach to the Hamiltonian of Nonrigid Molecules (pp 99—175)

The paper by FREI *et al.* presents a rigorous mathematical method devised by the authors to treat the molecular structure or rather the nuclear configuration of non-rigid molecules. The description of the isometric group is followed by a presentation for semirigid nuclear configurations. The relation between the isometric groups and the permutation-inversion groups is discussed. Next the application of isometric groups is shown to large-amplitude internal motion and examples related to stereochemical problems are given.

BASTIANSEN *et al.* collected a large body of electron diffrection results referring mainly to conformational analysis with some emphasis on rotational barrier determinations. Electron diffraction clearly emerges as a powerful tool of studying large-amplitude motion and further extension of its scope may be expected as its up-to-date techniques provide more and finer information than was thought possible earlier.

The possibilities of spectroscopy is demonstrated in the investigation of large-amplitude motion of small ring molecules by CARREIRA *et al.* Far and mid infrared spectroscopy, Raman spectroscopy and microwave spectroscopy are covered.

In the concluding paper SØRENSEN summarises some theoretical studies on large-amplitude motion aiming at the standardization of the treatment of non-rigid molecules similarly to that of rigid molecules.

The contribution by FREI *et al.* is an original investigation in itself rather than a review and no immediate proliferation of their not-easy-to-digest treatment is anticipated. The other theoretical study by SØRENSEN seems to be more related to the recent experimental development of the field of the large-amplitude motion by non-rigid molecules. The achievements of experimental techniques as well as the interpretation of the experimental data are well demonstrated by the reviews on the electron diffraction and spectroscopic results.

Although the four papers cannot be considered as fully composing a comprehensive picture, they convey an adequate impression of the state of art of the large-amplitude motion studies. As comprehensive reviews let alone monographs have been lacking on the subject, the two volumes mark an important step in the direction of establishing the necessary literature for this very important field.

I. HARGITTAI

J. S. ROBINSON: *Corrosion Inhibitors, Recent Developments* (p. 305)

Noyes Data Corp., Park Ridge, New Yersey; 1979

This book gives short expositions of all the patent specifications on corrosion inhibitors accepted by the U.S.A. Patent Office since July 1976. The patents granted in this field before this date are dealt with in a work: Corrosion Inhibitors, Manufacture and Technology, published in 1976. Within the domain of corrosion inhibitors, the 290 expositions treat of the following applications of corrosion inhibitors: application in water supply (cooling, boiler feed water, descaling and other acid treatments, heat exchange, communal supplies), in oil-drilling and -refining (mud flushes, exploitation of secondary production wells, pipelines and tank parks, degassing plant, petroleum refinery), in building and construction (cement, concrete, gypsum; primers, pigments, resins, and rust converters; electric contacts; marine projects), in fuels and lubricants (motor fuels, hydraulic fluids, lubricating oils and greases), in the treatment of metal surfaces with inorganic substances, and inorganic coating materials (phosphatation, pickling, anodic and other electrochemical treatment, coatings on zinc basis, chromate treatment, silicon-containing coating, other inorganic treatments and coatings), in the treatment of metal surfaces with organic substances, in organic coatings (tannic acid treatment of aluminium, amines, organis acids, rubbers and polymers, other organic treatments and coatings), in other fields of application (detection and determination of corrosion processes; protection during transport and storage, chlorinated hydrocarbons; reactors and other apparatus for chemical technologies; pipelines for the transport of gases and of coal-washings or -sludges; detergents; tooth-pastes). This matter is completed by lists, respectively, of patentees, inventors, and the patents themselves.

The expositions of the patents are short and lucid: they contain the necessary information on technological aspects, and happily eschew the jargon proper to patent specifications. This is a useful book also because it communicates data very often not published in journals, and because it discusses situations which had existed before relevant patents were issued. In a number of instances the patents deal with problems previously solved, but of which those solutions became unacceptable or impracticable owing to environmental effects or other risks involved.

This book lists the patents without selection and without criticism, and does not take into account whether or not they have been realized in practice; thus no responsibility is assumed in regard to the applicability of the methods and substances described.

This compilation is a useful book in the hands of professionals charged with development work and technologies, since it may engender perhaps similar yet novel idea or may point toward novel fields of application; besides this it is a source of information useful for those who might contemplate the acquisition of a licence. No fundamental research data or theoretical considerations are included, but even without these this book might be full of seminal ideas to be utilized by the expert.

J. DÉVAY

J. C. JOHNSON: *Immobilized Enzymes, Preparation and Engineering*

Recent Advances

Chemical Technology Review No. 133.

Noyes Data Corporation, Park Ridge, New Jersey, USA, 1979. 383 + XII pages

The information offered in this book is based solely on U.S. patents, issued since July 1974, that deal with immobilized enzymes. The book can be used as a guide to the U.S. patent literature, which is a large collection of technical information in the West. However, it is far from being complete, as indicated by the fact that of the 89 patent owner companies in this field only 40 are American, the others being Japanese, French, West-German, English, Swiss-Swedish, Dutch, Israelian, Danish, Czechoslovakian and Hungarian. Consequently, the infor, mation contained in this book is limited.

It is true that the patent literature covers a substantial amount of information not available in the journal literature. However, the opposite applies even more, and this book presents very little material from the scientific literature, either from journals or books.

The topics covered are: immobilization of enzymes by adsorption, by ionic and metal bonding, entrapment, cross-linking, polymerizing and copolymerizing, as well as by covalent bonding to inorganic supports, to proteins, carbohydrates or to synthetic polymers. The book deals with the application of immobilized enzymes for affinity chromatography, analytical processes, in sugar production, chemical processes, or for pharmacological uses, for food and feed uses, and for detergent action.

The book contains a company index, an inventor index and a U.S. patent number index. No subject index is included which makes the use of the book practically impossible in some respect. The reader may be interested *e.g.*, to find a possibility of immobilizing penicillin-amidase or glucose oxidase, or to learn which enzymes can be immobilized by covalent bonding on Sepharose, but it is very much less likely that somebody is interested to known which patent exists under the number 3 966 580. In the foreword the author states that the table of contents is organized in such a way as to serve as a subject index, but the reviewer cannot agree with this. The table of contents is only a simple, usual, traditional one.

Despite these insufficiencies, the book contains a great deal of useful information and it is a prime source of basic, commercially utilizable data. It can serve to avoid duplication in research work, and as a source of new ideas in related fields. The most important merit of the book is that it eliminates legal jargon and juristic phraseology thus rendering the practical and scientific contents of the patents comprehensible and utilizable.

T. KELETI

Application of Zeolites in Catalysis

Herausgegeben von G. K. BORESKOV und Kh. M. MINACHEV Akadémiai Kiadó, Budapest, 1979, 179 Seiten

Zeolithe haben in den letzten zwei Jahrzehnten als Katalysatoren eine außerordentlich große technische und wissenschaftliche Bedeutung erlangt und — nicht zuletzt wegen ihrer durch die Kristallstruktur bedingten Formselektivität — vor allem auf dem Gebiet der katalytischen Kohlenwasserstoff-Umwandlungen neue Wege erschlossen. Das schnell angewachsene Interesse and den katalytischen, aber auch anderen Eigenschaften der Zeolithe (Adsorption, Ionenaustausch) hat mit sich gebracht, daß — vor allem in den letzten 5 Jahren — eine Reihe von sich mit dieser Thematik befassenden nationalen und internationalen Kongressen und ähnlichen Veranstaltungen abgehalten wurden. Das zu rezensierende Buch enthält die auf der vom 22.—25. März 1976 in Novosibirsk veranstalteten 1. Allunions-Konferenz über "Molekularsiebe in der Katalyse" von namhaften sowjetischen Zeolithforschern gehaltenen Plenarvorträge in englischer Übersetzung.

Im ersten Beitrag gibt Kh. M. MINACHEV eine Übersicht über die mit zeolithischen Katalysatoren ausführbaren Reaktionen von Kohlenwasserstoffen. Es ist dem Verfasser sehr gut gelungen, ein so weites Gebiet unter Berücksichtigung der wichtigsten Literatur in einem

verhältnismäßig engen Rahmen zusammenzufassen. Zugleich vermittelt der Vortrag ein ziemlich komplettes Bild über die von der Schule des Autors geleisteten Beiträge zum seinerzeitigen Wissensstand auf dem behandelten Fachgebiet.

Im zweiten, von Y. M. MIRSKY u. Mitarb. verfaßten Beitrag werden die katalytischen Eigenschaften der in der Sowjetunion im industriellen Maßstab zur Krackung von Erdölfraktionen eingesetzten zeolith-haltigen Katalysatoren eingehend beschrieben.

Im dritten Beitrag faßt K. V. TOPCHIEVA Untersuchungen ihrer Schule über katalytische und Säure-Basen-Eigenschaften von Zeolith-Trägerkatalysatoren zusammen. Zunächst werden die Ionenaustauscheigenschaften des Katalysators sowie die der Matrix und der zeolithischen Komponente und der Übergang von Kationen zwischen Zeolith- und Matrixphase bei thermischer und hydrothermaler Einwirkung behandelt. Im weiteren wird auf Beziehungen zwischen Aktivität und Selektivität bei verschiedenen Kohlenwasserstoffen, der Acidität und der chemischen Zusammensetzung der Zeolith-Katalysatoren eingegangen.

A. Z. DOROGOCHINSKI u. Mitarb. zeigen — in erster Linie an Hand eigener Arbeiten — die Faktoren auf (chemische Zusammensetzung und Kristallinität der Zeolithphase, Porenstruktur des Trägers), die Aktivität und Selektivität von zeolithischen Katalysatoren für die Krackung von Kohlenwasserstoffen bestimmen.

K. G. IONE u. Mitarb. vermitteln eine umfassende Übersicht über die seinerzeit bekannten Wechselwirkungen zwischen Molekülen und durch Ionenaustausch in Zeolithe eingebrachte Übergangsmetallionen und die sich daraus für katalytische Kohlenwasserstoff-Reaktionen (Oxydation, Hydrierung, Hydrokrackung) ergebenden Folgerungen.

Daran schließt sich eine zusammenfassende Darstellung eigener Untersuchungen von V. F. ANUFRIENKO u. Mitarb. aus der gleichen Schule (Katalyseinstitut der Sibirischen Abteilung der Akademie der Wissenschaften der UdSSR) an, in der die Untersuchung des Koordinationszustandes von Ni- und Cu-Ionen in Zeolithen durch spektroskopische Methoden behandelt wird.

In einem weiteren Beitrag berichten Kh. M. MINACHEV u. Mitarb. über Untersuchungen des Bindungs- und Valenzzustandes von Ni-, Co- und Cr-Ionen in Zeolithen mittels Röntgen-Elektronenspektroskopie.

Im letzten Beitrag schließlich wird von M. M. DUBININ die Theorie der Diffusion in biporösen Systemen, wozu im allgemeinen Zeolith-Katalysatoren zu zählen sind, dargelegt und an Hand einiger Beispiele deren Anwendung auf katalytische Probleme aufgezeigt.

Die einzelnen Beiträge vermitteln den Lesern einen guten Überblick über das jeweils behandelte Gebiet. Aus der Fülle von Veröffentlichungen sind im allgemeinen die wichtigsten Publikationen berücksichtigt worden. Es ist — da es sich ja nicht um Monographien, sondern um Plenarvorträge einer sowjetischen Tagung handelt — nur natürlich, ja in einigen Fällen war es sogar beabsichtigt, daß den eigenen Arbeiten der Autoren und ihrer Schulen, darübe r hinaus aber auch den sonstigen in der sowjetischen Fachliteratur erschienenen Publikationen ein größeres Gewicht gegeben wurde. Aber gerade darin dürften viele Leser — nämlich diejenigen, denen die sowjetische Fachliteratur aus sprachlichen Gründen nicht oder nur schwer zugänglich ist, aber auch die, die sich speziell über die sowjetischen Beiträge zum Wissenstand eines engeren Fachgebietes informieren möchten — einen weiteren Vorteil dieses Buches sehen.

In den im zu rezensierenden Buch wiedergegebenen, im März 1976 gehaltenen Plenarvorträgen ist natürlich nur die bis 1975 erschienene Literature aufgearbeitet. Man kann zwar nicht sagen, daß damit der Inhalt des Buches "veraltet" sei, aber man muß sich doch dessen bewußt sein, daß der Wissensstand von vor 5 Jahren widergespiegelt wird. Es ist jedenfalls zu bedauern, daß dieses Buch nicht — sagen wir — 1 Jahr nach der Konferenz im Frühjahr 1977, sondern erst im Herbst 1979 erschienen ist.

Der Umstand, daß in dem Buch Vorträge einer thematisch auf das ziemlich enge Gebiet der Zeolith-Katalyse eingeschränkten Konferenz wiedergegeben sind, bringt natürlich mit sich, daß auch der daran interessierte Leserkreis begrenzt ist. Das Buch sollte aber nicht nur für die Fachleute im engeren Sinne, sondern auch für all diejenigen, die sich vom wissenschaftlichen oder technischen Standpunkt aus mit der heterogenen Katalyse oder unter anderen Gesichtspunkten mit der Chemie und den Eigenschaften der Zeolithe befassen, von Interesse und Nutzen sein.

H. K. BEYER

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SUBSTITUENTENEFFEKTE IN DEN ^{13}C-NMR-SPEKTREN VON DIASTEREOMEREN CHALKONDIHALOGENIDEN, II*

UNTERSUCHUNGEN AN DIASTEREOMEREN CHALKONDICHLORIDEN

R. RADEGLIA[1] und F. G. WEBER[2]**

([1]Zentralinstitut für physikalische Chemie der AdW der DDR und [2]Sektion Chemie der Humboldt-Universität zu Berlin)

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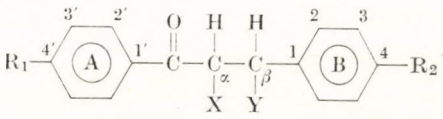
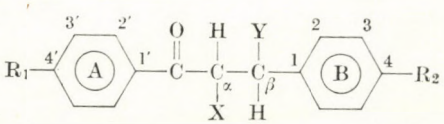
Es werden Fourier-Transform-^{13}C-NMR-Spektren Diastereomerenpaaren sowie von einzelnen Isomeren der Chalkondihalogenide **1** beschreiben. Auf der Basis der chemischen Verschiebungen C_α und C_β kann die Konfiguration sowohl bei den Diastereomerenpaaren als auch bei einzelnen Isomeren eindeutig bestimmt werden. Eine Unterscheidung zwischen verschiedenen Dihalogeniden erfolgt auf der gleichen Grundlage.

In Fortführung unserer Untersuchungen an diastereomeren Chalkondihalogenide [1] haben wir vergleichende Untersuchungen an Diastereomerenpaaren von Chalkondichloriden **1** bezüglich ihrer ^{13}C-NMR-spezifischen Unterschiede vorgenommen. In Übereinstimmung mit den Befunden bei anderen Chalkondihalogeniden (**2, 3**) [1] zeigte sich, daß sich *erythro-* (*e*-**1**) und *threo*-Verbindungen (*t*-**1**) in ihrem spektroskopischen Verhalten so deutlich voneinander unterscheiden, daß eine eindeutige Konfigurationszuordnung möglich wird.



erythro



threo

1: X = Y = Cl **2**: X = Y = Br **3**: X = Br; Y = Cl

(R_1 und R_2 siehe Tabelle I)

* I. Mitt. vgl. l. c. [1]

** Meinem verehrten Lehrer Prof. Dr. L. REICHEL zum 80. Geburtstag gewidmet

Konfigurationszuordnung mittels ^{13}C-NMR-Verschiebung

Die in Tabelle I aufgeführten Signale des Carbonylkohlenstoffes und der Substituenten R_1 und R_2 an den Ringen A und B (gültig für CH_3, C_2H_5 und CH_3O) liegen in charakteristischen Bereichen [2]. Wegen der geringen Verschiebungsdifferenzen zwischen den Signalen der Kholenstoffatome C_α und C_β ist deren Zuordnung mittels üblicher Inkrementsysteme [2] nicht eindeutig. Erst eine vergleichende Betrachtung der Substituenteneffekte, die weiter unten beschrieben wird, ergab zweifelsfrei, daß dem Signal von C_β die größere chemische Verschiebung gegenüber C_α zukommt (Tabelle I).

Vergleicht man die verschiedenen Diastereomerenpaare der **1** miteinander, so wird ersichtlich, daß infolge eines wahrscheinlich unterschiedlichen »steric compression shift« die *e*-**1** sich durch signifikant geringere chemische Verschiebung sowohl des C_α — als auch des C_β-Signales von den *threo*-Isomeren unterscheiden. Danach liegen die ^{13}C-Signale der *t*-**1** bei C_α um 3,7 ppm und bei C_β um 3,5 ppm tieffeld gegenüber den entsprechenden Signalen der *e*-**1** verschoben. Es ist folglich ebenso wie bei den **2** und **3** [1] eine Konfigurationszuordnung allein auf der Basis der C_α- und C_β-Signale möglich, wobei hier für folgende Richtwerte gelten:

erythro-**1**:	C_α:	56,9 ppm	C_β:	60,0 ppm
threo-**1**:	C_α:	60,5 ppm	C_β:	63,2 ppm

(inclusive einer Bandbreite von $\pm$0,5 bis 0,6 ppm)

Substituenteneinflüsse

Die Substituentenabhängigkeiten der ^{13}C-Verschiebungen von CO, C_α und C_β gestalten sich bei den *e*-**1** grundsätzlich so wie in l.c. [1] für die erythro-Isomeren der **2** und **3** dargestellt. Wie dort führt ein Elektronenzug von R_1 bei den *e*-**1** und *t*-**1** zu einer paramagnetischen Verschiebung der Signale von CO und C_α, aber zu einer diamagnetischen Verschiebung des C_β-Signales. Im Gegensatz dazu bewirkt ein elektronenziehender Substituent R_2 eine Hochfeldverschiebung aller drei Resonanzsignale der *e*-**1**. Analoge Ergebnisse wurden allerdings auch bei den *p*-substituierten Alkylbenzenen gefunden [3], [4].

Mit Hilfe dieser Substituenteneinflüsse ist es aber prinzipiell möglich, eine eindeutige Zuordnung der Signale von C_α und C_β vorzunehmen. Dazu wird nur der Einfluß des Substituenten R_2 am B-Ring auf die Signallagen von C_α und C_β in den Verbindungsreihen *e*-**1**, *e*-**2** und *e*-**3** betrachtet. Da die Zuordnung der C_α- und C_β-Signale in der Reihe *e*-**3** wegen $X \neq Y$ eindeutig auf der Grundlage von Inkrementsystemen [2] möglich ist [1], kann für diese Verbindungsreihe der Substituenteneinfluß getrennt für C_α und C_β mit $\Delta = \delta(R_2) - \delta(H)$ bestimmt werden. Es ist zu erwarten, daß die entsprechenden

Tabelle I

^{13}C-NMR-Verschiebungen diastereomerer Chalkondichloride **1** (in ppm)

Nr.	R_1	R_2	Konf.	δ_{CO}	δ_{C_α}	δ_{C_β}	$\delta_{C-1'}$	$\delta_{C-2'}$	$\delta_{C-3'}$	$\delta_{C-4'}$	δ_{C-1}	δ_{C-2}	δ_{C-3}	δ_{C-4}
1a	H	H	*e*	191,2	56,9	60,0	134,5	128 9	128 9	134,2	136 9	128,2	128,7	129,2
1b	F	H	*e*	189,7	56,9	60,0	131,0	131,7	116,2	166,3	136,8	128,2	128,7	129,3[a]
1c	Cl	H	*e*	190,1	56,9	59,9	132,8	130,3	129,3	140,8	136,7	128,2	128,7	129,3
1d	Br	H	*e*	190,3	56,9	59,9	133,3	130,3	132,3	129,6	136,7	128,2	128,8	129,3
	Br	H	*t*	190,6	60,6	63,4	132,9	130,0	132,1	129,5	137,1	127,8	128,8	129,2
1e	CH_3	H	*e*	190,8	56,9	60,1	132,0	129,9	129,6	145,4	137,1	128,2	128,7	129,2[b]
	CH_3	H	*t*	191,0	60,6	63,7	131,6	128,7	129,5	145,2	137,4	127,8	128,7	129,0[c]
1f	C_2H_5	H	*e*	190,8	56,9	60,1	132,3	129,2	128,5	151,5	137,1	128,2	128,7	129,2[d]
	C_2H_5	H	*t*	191,0	60,6	63,7	131,8	128,7	128,5	151,3	137,4	127,8	128,8	129,0[e]
1g	CH_3O	H	*e*	189,6	56,8	60,2	127,4	131,4	114,2	164,4	131,7	128,2	128,6	129,2[f]
	CH_3O	H	*t*	189,0	60,5	63,8	127,0	131,0	114,0	164,2	137,4	127,8	128,7	129,0[g]
1h	NO_2	H	*e*	190,0	57,5	59,9	139,2	130,0	124,1	150,9	136,4	128,3	128,9	129,5
1i	H	Cl	*e*	191,0	56,9	59,3	134,6	129,0	129,0	134,3	135,7	129,7	129,0	135,2
1k	H	Br	*t*	191,1	60,3	62,6	133,8	128,5	128,8	134,2	136,3	129,5	131,9	123,1
1l	H	CH_3	*e*	191,3	56,9	60,0	134,6	128,9	128,9	134,2	134,0	128,1	129,4	139,3[h]
	H	CH_3	*t*	191,4	60,6	63,5	134,1	128,5	128,7	133,9	134,2	127,6	129,4	139,0[i]
1m	H	CH_3O	*e*	191,4	57,1	60,1	134,6	128,9	128,9	134,2	128,9	129,5	114,1	160,2[k]
1n	H	NO_2	*e*	190,4	56,4	58,3	134,1	129,0	129,0	134,5	143,8	129,5	123,9	148,2
1o	Br	Cl	*e*	189,7	56,1	—	133,1	130,3	132,3	129,7				
1p	NO_2	Cl	*e*	189,7	57,2	59,0	138,9	130,0	124,1	150,8	134,9	129,6	129,1	135,3

[a] $^1J_{CF}$ = 257,2 Hz, $^2J_{CF}$ = 21,8 Hz, $^3J_{CF}$ = 9,5 Hz; [b] CH_3 = 21,7 ppm; [c] CH_3 = 21,7 ppm; [d] CH_2 = 29,0 ppm, CH_3 = 15,0 ppm; [e] CH_2 = = 28,9 ppm, CH_3 = 14,9 ppm; [f] OCH_3 = 55,5 ppm; [g] OCH_3 = 55,5 ppm; [h] CH_3 = 21,1 ppm; [i] CH_3 = 21,0 ppm; [k] OCH_3 = 55,2 ppm

Δ-Werte für C_β in den Verbindungsreihen **1** und **3** (mit Y = Cl) bzw. für C_α in den **2** und **3** (mit X = Br) miteinander nahezu identisch sind. Nur wenn die Signale von C_α und C_β in *e*-**1** und *e*-**2** richtig zugeordnet worden sind, bekommt man bei Auftragung von Δ(**1**, C_β) gegen Δ(**3**, C_β) bzw. von Δ(**2**, C_α) gegen Δ(**3**, C_β) eine Gerade, die durch den Koordinatenursprung geht und den Ansteig Eins besitzt, was Bild 1 bestätigt.

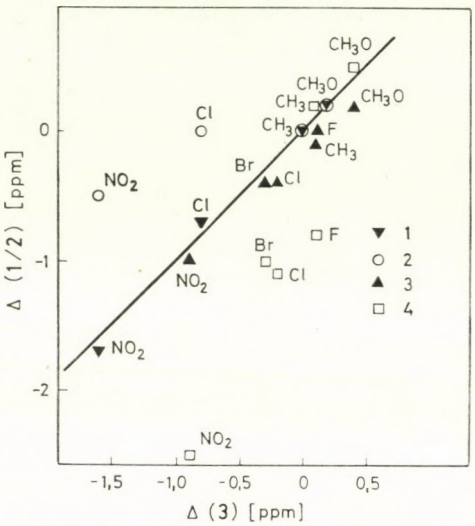


Bild 1. Auftragung der R_2-substituenteninduzierten Verschiebungen Δ (in ppm): (1) C_β-Signal von *e*-**1**; (2) C_α-Signal von *e*-**1**; (3) C_α-Signal von *e*-**2**; (4) C_β-Signal von *e*-**2**, gegen die entsprechenden Δ-Werte von *e*-**3** zur Bestätigung der Zuordnung der C_α- und C_β-Signale in den Verbindungsreihen *e*-**1** und *e*-**2**

Struktur- und Konfigurationszuordnung von Chalkondihalogeniden

Die Kenntnis der Lage der C_α- und C_β-Signale von Chalkondihalogeniden gestattet neben der schon beschriebenen Bestimmung der Konfiguration zugleich aber auch die eindeutige Zuordnung einer vermessenen Verbindung zur jeweiligen Verbindungsklasse **1**, **2** oder **3**:

	C_α	C_β	
e-**1**:	56,9 ppm	60,0 ppm	
t-**1**:	60,5 ppm	63,2 ppm	
e-**2**:	46,8 ppm	49,7 ppm	[1]
t-**2**:	51,3 ppm	54,9 ppm	[1]
e-**3**:	47,4 ppm	59,8 ppm	[1]
t-**3**:	51,0 ppm	63,6 ppm	[1]

Wie Bild 2 deutlich zeigt, lassen sich somit auch solche Fragen wie die nach dem Vorliegen reiner Interhalogenaddukte **3** oder äquimolarer, isomorph kristallisierender Gemische von **1** und **2**, wie sie von uns gleichfalls beobachtet wurden [5], eindeutig entscheiden.

Abschließend kann festgestellt werden, daß der Vorteil der eindeutigen, mit einer Messung erfolgenden Konfigurationsbestimmung von einzelnen Chalkondihalogeniden vermittels der ^{13}C-NMR-Spektroskopie gegenüber der bisher geübten Praxis auf der Basis von ^{1}H-NMR- und Dipolmomentuntersuchungen [6] zwar auf der Hand liegt, letztere jedoch bezüglich der Bestimmung der vorliegenden Vorzugskonformation dennoch nicht überflüssig erscheinen läßt. Das wird besonders dann deutlich, wenn man zu den sogenannten »nichtklassischen« Chalkondihalogeniden mit X = Cl, Br, I und Y = F oder X = Cl und Y = Br bzw. zu den Chalkonhalogenhydrinen (X = OH, Y = Cl, F) übergeht [7]. Über Untersuchungen an diesen Verbindungen werden wir demnächt berichten.

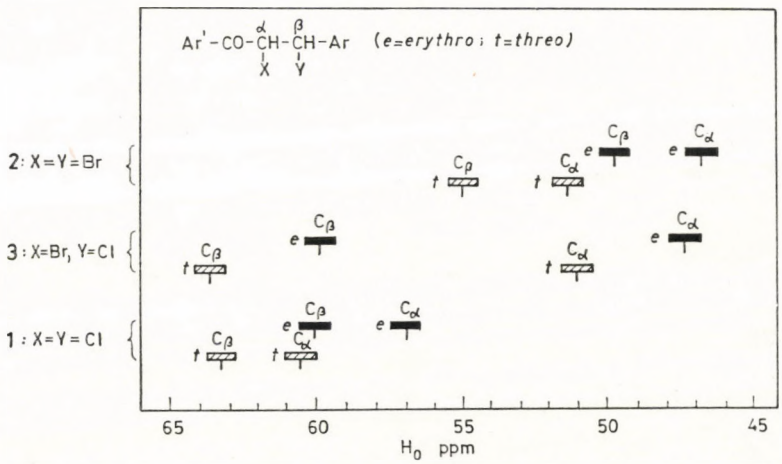


Bild. 2. ^{13}C-chemische Verschiebungen von C_α und C_β verschiedener diastereomerer Chalkondihalogenide

Experimenteller Teil

Die ^{13}C-NMR-Spektren der **1** [8] wurden unter ^{1}H-Breitbandentkopplung mit einem JNM-PFT-100-Spektrometersystem der Fa. JEOL (Japan) bei 25,15 MHz nach dem Fourier-Transform-Prinzip bei Zimmertemperatur (Pulslänge 12 μs, Pulsabstand 3s, 8K-Speicher, Spektralbereich 6 kHz) gemessen.

Zur Untersuchung gelangten gesättigte Lösungen in $CDCl_3$ (D-Lock). Hexamethyldisiloxan diente als innerer Standard, die chemischen Verschiebungen wurden auf TMS umgerechnet.

LITERATUR

[1] WEBER, F. G., RADEGLIA, R.: J. prakt. Chem., **321**, 935 (1979)
[2] CLERC, J. T., PRETSCH, E., STERNHELL, S.: »^{13}C-Kernresonanzspektroskopie«, Bd. 16 der »Methoden der Analyse in der Chemie«, Akademische Verlagsgesellschaft, Frankfurt a.M. 1973
[3] BROMILOV, J., BROWNLEE, R. T. C., CRAIK, D. J.: Austr. J. Chem., **30**, 351 (1977)
[4] ADCOCK, W., KITCHING, W., ALBERTS, V., WICHKAM, G., BARRON, P., DODDRELL, D.: Org. Magn. Resonance, **10**, 47 (1977)
[5] WEBER, F. G., REIMANN, E.: Z. Chem., **12**, 176 (1972)
[6] WEBER, F. G., MÖSCHWITZER, G., REIMANN, E.: Tetrahedron (London), **29**, 2479 (1973)
[7] WEBER, F. G., GIESE, H.: Z. Chem., **15**, 475 (1975); Dissertation H. GIESE, Berlin 1978
[8] WEBER, F. G., BROSCHE, K.: Tetrahedron (London), **27**, 1435 (1971); REIMANN, E., WEBER, F. G., WESTPHAL, G.: Z. Chem., **19**, 56 (1979)

R. RADEGLIA Zentralinstitut für physikalische Chemie der AdW der DDR, 1199 Berlin, Rudower Chaussée

F. G. WEBER Sektion Chemie der Humboldt-Universität zu Berlin, DDR-104 Berlin, Invalidenstr. 42

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SULFENYL CHLORIDES, XII*

BIS-TRICHLOROMETHANESULFENYLATED DITHIOCARBAMATES

G. STÁJER,[1] J. REISCH[2] and A. E. SZABÓ[1]

([1]*Institute of Pharmaceutical Chemistry, Medical University, Szeged, and*
[2]*Institute for Pharmaceutical Chemistry, Westfalian Wilhelms University, Münster, GFR*)

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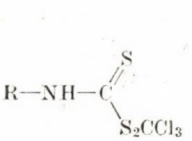
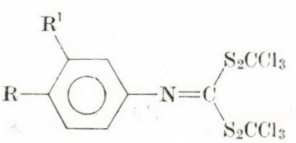
Mono- and bis-trichloromethanesulfenylated derivatives of aryl dithiocarbamates have been prepared. It has been found that the resulting trithiopercarbamates are unstable, and are converted in air by desulfuration into carbamates, particularly during chromatographic purification. The structure of the iminomethane derivatives obtained by sulfenylation has been verified by IR and ^{13}C-NMR spectroscopy.

In an earlier work [1] the stable disulfides **1a, b, c** and the bis-sulfenylated iminomethane derivatives **2a, b, c** have been prepared by the trichloromethanesulfenylation of ammonium dithiocarbamates (Scheme 1).*



1

a R = Ph
b R = *p*-chlorophenyl
c R = *p*-tolyl
d R = benzyl



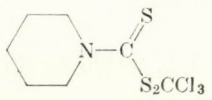
2

a R = R[1] = H
b R = Cl R[1] = H
c R = Me R[1] = H
d R = H R[1] = Me
e R = MeO R[1] = H
f R = EtO R[1] = H

Scheme 1

As a continuation of this work, the compounds **2d, e, f** have now been prepared. However, the bis-sulfenylated derivatives corresponding to **1d, e** could not be obtained, as it is to be expected in the case of **1e.**

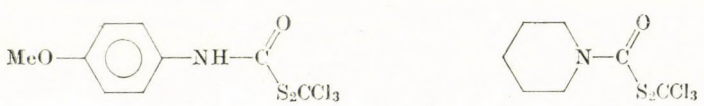
* Part XI: J. PINTYE, G. STÁJER, E. VINKLER: Acta Chim. Acad. Sci. Hung., **95,** 307 (1977)



1e

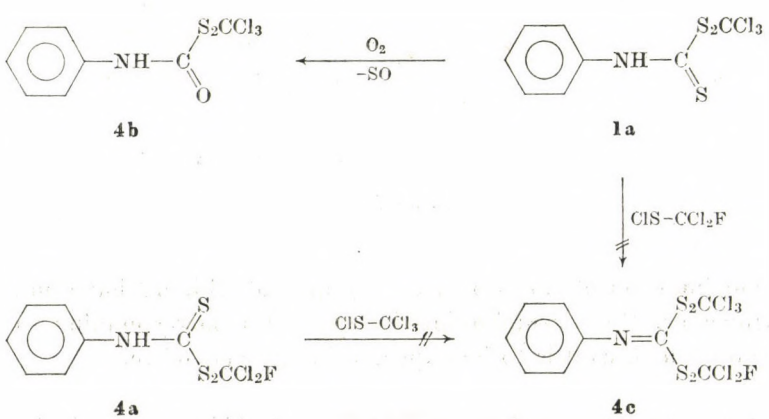
When ammonium benzyldithiocarbamate is allowed to react with 2 moles of trichloromethanesulfenyl chloride, or the further sulfenylation of **1d** is attempted, benzyl isotiocyanate is obtained. The formation of isothiocyanate has been already observed in sulfenylation [1]. It should be noted that the preparation of the **1** derivatives corresponding to compounds **2e, f** remained also unsuccessful, and only the bis-sulfenylated products could be isolated.

On the other hand, when the column chromatographic purification of the reaction product obtained in the preparation of **1e** was attempted, **3b** was obtained (Scheme 2). Similarly, the thiocarbamate ester (**3a**) was isolated as the main product, besides a small quantity of **2e**, on attempted chromatographic purification of this latter compound. Such desulfuration reactions are known in the literature [2, 3]; aliphatic, aromatic and heterocyclic thioketones are unstable when exposed to atmospheric oxygen and light, and in dilute (10^{-2}—10^{-3} molar) solution are rapidly converted into ketones.



3a **3b**

Scheme 2



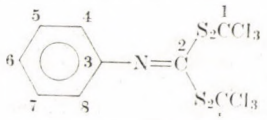
4b **1a**

4a **4c**

Scheme 3

Thus, with trithiopercarbamates desulfuration must also be taken into consideration, which reduces the stability of compounds of type **2**. In certain cases, such as in the attempted further sulfenylation of compound **1a** (Scheme 3), desulfuration is actually the main route of the reaction.

These reactions were performed in order to prove the structure of compounds of type **2**. If, namely, the "mixed" further sulfenylation of **1a** and **4a**



Scheme 4

were successful, both sulfenylations would yield **4c**. However, instead of the desired bis-sulfenylated compound, **4b** was obtained from **1a**, whereas **4a** failed to react with the sulfenyl chloride.

The structure of compounds of type **2** is proved by the IR spectra, in which NH bands are absent, but intensive bands corresponding to νC=N vibrations coupled with aromatic skeletal vibrations appear at a higher frequency as compared to compounds **1**. As further evidence, the C-2 signal, characteristic of compound **1a** and appearing with a very high shift (183.4 ppm), is absent in the ^{13}C-NMR spectrum of **2a** (Scheme 4), and this signal is replaced by a line of smaller shift at 153.7 ppm, corresponding to C=N. The relative intensity of the C-1 signal at 99.5 ppm is doubled, indicating the presence of the new CCl_3 group. The conjugation of C=N and the phenyl ring is reflected partly by the increase in shift (137.2 → 147.0 ppm) of the signal of the substituted aromatic carbon (C-3), and partly by the diminishing of the chemical shift of the *ortho* (C-4, C-8) and *para* (C-6) carbon signals. The latter signals for **1a** are 127.4 and 122.3 ppm, and for **2a** 125.6 and 119.5 ppm, respectively.

Experimental

IR spectra were recorded in KBr pills with a Spectromom 2000 spectrometer, and ^{13}C-NMR spectra with a BRUKER Speetrospin instrument at 22.63 MHz in $CDCl_3$ at room temperature.

Sulfenylation

Method A. A suspension of 0.02 mole of the ammonium aryl dithiocarbamate [4, 5] was prepared in 50 ml of dry ether, and a solution of 3.4 g (0.02 mole) of trichloromethanesulfenyl chloride in 10 ml of ether was added dropwise, while stirring and cooling. After 30 min of stirring the solid material was filtered off, and the solvent was evaporated from the filtrate in vacuum. The residue crystallized on the addition of petroleum ether. The solvent of recrystallization was a 1 : 1 mixture of benzene and petroleum ether.

Method B. Ammonium *N*-aryldithiocarbamate (0.02 mole) was sulfenylated in the presence of 2 g (0.02 mole) of triethylamine with 6.8 g (0.04 mole) of trichloromethanesulfenyl chloride as described under *A*.

Fluorodichloromethyl trithiopercarbanilidate (4a)

Ammonium dithiocarbanilidate (3.7 g; 0.02 mole) was allowed to react according to *Method A* with 3.4 g of fluorodichloromethanesulfenyl chloride [6]. The yield of pale yellow crystals, m.p. 61—63 °C, was 1.8 g (30%).

$C_8H_6NCl_2FS_3$ (302.24). Calcd. C 31.79; H 2.00; N 4.63. Found C 31.95; H 2.08; N 4.83%.

IR: νNH 3220; νNH—C=S 1520, 1490 1390; νC—Cl + νC—F 830, 810, 760; $\gamma C_{Ar}H$ + + $\gamma C_{Ar}C_{Ar}$ 705, 690 cm^{-1}.

S-Trichloromethyl dithiopercarbanilidate (4b)

1a (6.37 g; 0.02 mole) [1] was allowed to react in the presence of 2 g (0.02 mole) of triethylamine with 3.4 g (0.02 mole) of fluorodichloromethanesulfenyl chloride as described above under (*A*), to obtain yellow crystals (4.3 g; 71%), m.p. 94—95 °C.

$C_8H_6NCl_3OS_2$ (302.63). Calcd. C 31.75; H 2.00; N 4.63. Found C 31.55; H 2.13; N 4.50%.

IR: νNH 3250 (?); νNH—C=O 1720—1600; νC—Cl 750, 735; $\gamma C_{Ar}H + \gamma C_{Ar}C_{Ar}$ 700 cm^{-1}.

S-Trichloromethylbenzyl trithiopercarbamate (1d)

Ammonium benzyldithiocarbamate (4.0 g; 0.02 mole) was sulfenylated as above, to obtain colourless needles (1.9 g; 29%), m.p. 82—83 °C.

$C_9H_8NCl_3S_3$ (332.72). Calcd. C 32.49; H 2.42; N 4.21. Found C 32.78; H 2.36; N 4.25%.

IR: νNH 3250; νNH—C=S 1510; νC—Cl 790, 760, 750; $\gamma C_{Ar}H + \gamma C_{Ar}C_{Ar}$ 705 cm^{-1}.

If sulfenylation was carried out according to *Method B*, benzyl isothiocyanate was obtained, which was fractionated in vacuum.

S-Trichloromethylpiperidyl trithiopercarbamate (1e)

Ammonium piperidyldithiocarbamate [7] (3.6 g; 0.02 mole) was sulfenylated according to *(A)*. The yield of colourless needles, m.p. 100—102 °C, was 1.4 g (22%).

$C_7H_{10}NCl_3S_3$ (310.71). Calcd. C 27.06; H 3.24; N 4.50. Found C 26.83; H 3.10; N 4.80%.

IR: νN—C=S 1480, 1430; νC—Cl 790, 780—720 cm^{-1}.

S-Trichloromethyl piperidyldithiopercarbamate (3b)

The reaction mixture from the sulfenylation, as above, of 3.6 g (0.02 mole) of ammonium piperidyldithiocarbamate was washed with water, dried, and the residue obtained on the evaporation of ether was eluted from a silica gel column with a 1 : 2 mixture of benzene--petroleum ether. Recrystallization from benzene-petroleum ether gave colourless crystals (2 g; 33.5%) of **3b**, m.p. 82—84 °C.

$C_7H_{10}NCl_3OS_2$ (294.65). Calcd. C 28.54; H 3.42; N 4.75. Found C 28.40; H 3.70; N 4.74%.

IR: νC=O 1680; νC—Cl 790, 750, 735 cm^{-1}.

Bis(trichloromethyldithio)-*N*-(*p*-methoxyphenyl)-iminomethane (2e)

Ammonium *p*-methoxyphenyldithiocarbamate (4.3 g; 0.02 mole) was sulfenylated according to *(B)*, to obtain pale yellow needles (2.8 g; 28%), m.p. 80—81 °C.

$C_{10}H_7NCl_6OS_4$ (498.15). Calcd. C 24.11; H 1.42; N 2.81. Found C 24.32; H 1.60; N 2.79%.

IR: νC=N + $\nu C_{Ar}C_{Ar}$ 1600; $\gamma C_{Ar}H$ (*p*-di) 815; νC—Cl 700—790 cm^{-1}.

S-Trichloromethyl-*N*-(*p*-methoxyphenyl) dithiopercarbamate (3a)

The reaction mixture from the previous experiment was washed with water, dried over Na_2SO_4 and the ether was evaporated under reduced pressure. The residue was dissolved in benzene, fed onto a silica gel column, and fractionally eluted first with petroleum ether,

then with a 1 : 1 mixture of benzene-petroleum ether. The colourless fractions from the evaporation residues of the eluate were combined and recrystallized from benzene to obtain **3a** (2.1 g; 32%), m.p. 120—122 °C.

$C_9H_8NCl_3O_2S_2$ (332.66). Calcd. C 32.50; H 2.42; N 4.21. Found C 32,85; H 2.67; N 4.57%.
IR: νNH 3220; νNH—C=O 1670; $\gamma C_{Ar}H$ (*p*-di) 825; νC—Cl 780, 760—700 cm^{-1}.

Bis(trichloromethyldithio)-*N*-(*p*-ethoxyphenyl)-iminomethane (2f)

Ammonium *p*-ethoxyphenyldithiocarbamate (4.6 g; 0.02 mole) was sulfenylated according to *(B)*. The product consisted of pale yellow crystals (3.1 g; 30%), m.p. 76—77 °C.

$C_{11}H_9NCl_6OS_4$ (512.17). Calcd. C 25.80; H 1.77; N 2.74. Found C 26.03; H 1.6; N 2.92%.
IR: $\nu C{=}N + \nu C_{Ar}C_{Ar}$ 1620; $\gamma C_{Ar}H$ (*p*-di) 835; νC—Cl 810, 800—740 cm^{-1}.

Bis(trichloromethyldithio)-*N*-(*m*-tolyl)-iminomethane (2d)

Ammonium *m*-tolyldithiocarbamate (4.0 g; 0.02 mole) was sulfenylated as above to obtain colourless crystals of **2d** (1.2 g; 12.5%), m.p. 82—83 °C.

$C_{10}H_7NCl_6S_4$ (482.146). Calcd. C 24.91; H 1.46; N 2.9. Found C 25.20; H 1.62; N 2.99%.
IR: $\nu C{=}N + \nu C_{Ar}C_{Ar}$ 1580; νC—Cl 700—800 (770, 730) cm^{-1}.

REFERENCES

[1] STÁJER, G., KORBONITS, D., SZABÓ, A. E., KLIVÉNYI, F., VINKLER, E.: Acta Chim. Acad. Sci. Hung., **93**, 67 (1977)
[2] RAYEE, R., RAMAMURTHY, V.: Tetrahedron Letters, **51**, 5127 (1978)
[3] ISHIBE, N., ODANI, M., SUNAMI, M.: J. Chem. Soc. (B), **1971**, 1837
[4] HELLER, G., BAUER, W.: Ber., **65**, 369 (1902)
[5] SLOTTA, K. H., DRESSLER, H.: Ber., **63**, 888 (1930)
[6] SHEPPARD, W. A., HARRIS, J. F.: J. Am. Chem. Soc., **82**, 5106 (1960); KOBER, E.: J. Am. Chem. Soc., **81**, 4810 (1959)
[7] LOSANITSCH, S. M.: Ber., **40**, 2970 (1907)

Géza STÁJER
Angela E. SZABÓ } H-6701 Szeged 1, P.O.B. 121.

Johannes REISCH D-44 Münster (Westf.) Hittorfstr. 58—62

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STRUCTURAL INVESTIGATION OF THIOLSULFONIC ESTER DERIVATIVES

(SHORT COMMUNICATION)

E. VINKLER,[1] J. LÁZÁR[1]* and P. SOHÁR[2]

([1]Institute of Pharmaceutical Chemistry, Medical University, Szeged, [2]"EGYT" Pharmacochemical Works, Spectroscopic Department, Budapest)

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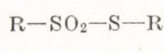
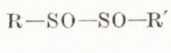
Structure **1** is today generally accepted for thiolsulfonates *(cf.* [1—9]), as this has been confirmed by the spectral data of a number of representatives belonging to this group of compounds. Earlier we proved also by syntheses [10] the correctness of structure **1** for several thiolsulfonates. Formerly, structure **2** was considered acceptable by many researchers; obviously, this has been shown to be erroneous. Yet in a recent review [11] the constitution of thiolsulfonates is still judged to be disputable; the structures of some of the members of this family have not been elucidated at all.



1



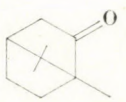
2

a: R = R′ = $-CH_2X$

b: R = $-CH_2X$; R′ = Me

c: R = $-CH_2X$; R′ = *n*-butil

X:



HILDITCH [12], for instance, synthesized three optically active ω-D--camphorthiolsulfonic esters (**a**, **b**, **c**) and supposed that two of them, **a** and **c**, had the disulfoxide structure **2**, on the basis of molecular rotation data. We have repeated the synthesis of these compounds in order to elucidate their structure, *i.e.* to ascertain that their constitution is actually **1**.

* To whom correspondence should be addressed.

In the reproduction of HILDITCH's experiments we obtained compounds **a** and **b** as described, however, the *n*-butyl derivative **c** was not a wax-like, crystalline substance, but an oil. This compound could not be crystallized even after purification by column chromatography, yet, according to TLC and spectroscopy, it was a homogeneous substance. Its optical rotation data significantly deviated from those given in the literature. Using KLIVÉNYI's method [13] we synthesized this compound also from ω-D-camphoryl-sulfinic acid and *n*-butanesulfenyl chloride; this yielded the same product. Hence we conclude that the material isolated by HILDITCH was not ω-D-camphoryl-*n*--butylthiol sulfonate, but some other compound. This is supported by the fact that ω-D-camphoryl-ethyl- and -propylthiol sulfonates are also oils [2].

Structure **1** for compounds **a**—**c** was unequivocally proved by their IR and ^{1}H NMR spectra (Table I). The IR spectra had intensive $\nu_{as}SO_2$ and ν_sSO_2 bands at about 1310 and 1110 cm^{-1}, characteristic of sulfone groups, whereas for sulfoxides only one band, at about 1050 cm^{-1}, is to be expected.

The *AB*-type multiplet of the SO_2CH_2 group and the signal of the SCH_2 group appear separately in the ^{1}H NMR spectrum.

Due to the asymmetric structure of these compounds structure **2** cannot be excluded on the basis of chemical nonequivalence of the two methylene groups

Table I

IR and ^{1}H NMR spectral data of compounds **1a**, **1b** *and* **1c**
(IR spectra were recorded on a Perkin Elmer 577 grating spectrometer in KBr pellet, ^{1}H NMR: spectra were obtained on a Jeol 60-HL instrument at 60 MHz in $CDCl_3$ solution, at room temperature, using TMS as internal standard)

Compound	IR (cm^{-1})			^{1}H NMR ($\delta = 0$ ppm*)			
	νC=O band	$\nu_{as}SO_3$ band	ν_sSO_3 band	δSO_2CH_2 m^x (2×1H)	δSCH_2 (2H)	δCH_3(camphor) 2 x *s* (2×3H)°	δCH_3 (3H)
1a	1720	1310	1120	3.25 3.90	~3.3$^+$	0.90 0.95 1.10 1.15	—
1b	1720	1320 1300	1120	3.28 3.83	—	0.90 1.10	2.75$^{\neq}$
1c	1725	1320	1120	3.28 3.83	3.20$^•$	0.90 1.10	0.95$^•$

* The overlapping multiplets of the methylene and methine protons of the camphor part appear in the range 70—170 Hz; in the case of **1a** overlapped also with the signal of the two "inner" methylenes of the *n*-butyl group: thus the total intensity is 11H for **1a**, and 7H for **1b** and **1c**. ^{x} *AB* multiplet ($J_{AB} = 15$ Hz). $^+$ *AB* multiplet, overlapped with the two lines of the *AB* multiplet of the SO_2CH_2 group. ° In the case of **1a**, 4×*s* (4×3H). $^•$ *n*-Butyl group, *t* ($J = 7$ Hz). $^{\neq}$ SCH_3 group, *s*.

however the significant paramagnetic shift of one of the methylene proton-signals in the case of *one* (and only one) methylene group suggests strongly different neighbouring groups, and hereby the **1**-type structure. Thus it has

been proved that the structures of the three compounds are **1a**, **1b** and **1c**, respectively, in contrast to the disulfoxide structures **2a** and **2c** formerly proposed for compounds **1a** and **1c**.

It is to note that we have now also supported the **1**-type structure of the thiolsulfonate obtained on the peracetic acid oxidation of cystine, as well as that of its acetyl and benzoyl derivatives by ^{1}H NMR spectroscopy. This structure was proved earlier [1, 15], excluding the originally suggested [14] disulfoxide structure **2**. Also in these cases the **1**-type structure can be deduced from the appearance of the $\nu_{as}SO_2$ and ν_sSO_2 IR bands as well as from the chemical shifts of the —CH_2—SO_2—S—CH_2— group in the ^{1}H NMR spectrum, being very similar relative to the corresponding data of compounds **1a—c**.

Experimental

n-Butyl-ω-D-camphorthiolsulfonate, 1c

(*a*) [12] Sodium ω-D-camphorthiolsulfonate [12] (27.34 g; 0.1 mole) was warmed and stirred in *n*-butanol (50 ml) with *n*-butyl iodide (20.24 g; 0.1 mole + 10%) at 60 °C for 24 h. The reaction mixture was evaporated to dryness under reduced pressure, the residue taken up in benzene, washed with water, and dried over anhydrous Na_2SO_4. After the evaporation of the solvent, the residual oil was taken in a mixture of petroleum ether and benzene, and this solution was transferred on to a silica gel column (Merck Kieselgel 40; 0.062—0.20 mm) and chromatographed by eluting first with petroleum ether and then with benzene. The fractions were checked by TLC, using Merck Kieselgel-G adsorbent and a solvent mixture of petroleum ether and benzene (60 : 40) an alkaline solution of potassium permanganate was used for detection of the spots.

After repeated purification by means of column chromatography, the pure *n*-butyl ω-D-camphorthiolsulfonate was isolated from the benzene fraction, to obtain 13.7 g (45.4%) of the product, $n_D^{22.5} = 1.5215$; α_D^{22} +30.15; $M_D^{22} = +90.61$.

$C_{14}H_{24}O_3S_2$ (300.47). Calcd. C 55.96; H 8.05; S 21.34. Found C 55.72; H 7.68; S 21.02%.

(*b*) [13] ω-D-camphorsulfinic acid [12] (21.6 g; 0.1 mole) was dissolved in dry ether (100 ml). To this solution butylsulfenyl chloride was added dropwise at 0 °C, which had been prepared from dibutyl-disulfide (9.98 g; 0.05 mole + 10%) and a calculated amount of chlorine at — 10 °C in carbon tetrachloride (50 ml). On warming to room temperature, the reaction mixture became colourless, with the vigorous evolution of hydrogen chloride. After stirring for 6 h the mixture was washed 5% Na_2CO_3 solution, then with water, and dried (Na_2SO_4). Evaporation of the solvent gave an oil which was dissolved in a mixture of petroleum ether and benzene, and purified as described before under (*a*).

The yield was 17.5 g (58.2%). The product was identical with that described under (*a*), according to the IR spectra and physical constants.

*

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REFERENCES

[1] Sweetman, B. J.: Nature, **183**, 744 (1959)
[2] Oae, S., Kawamura, S.: Bull. Chem. Soc. Japan, **35**, 1156 (1962)
[3] Allen, P., Jr., Berner, P. J., Malinowski, E. R.: Chem. Ind. (London), **1963**, 208; C. A., **58**, 12391 (1963)

[4] WAHL, G. H., Jr., BORDNER, J., HARPP, D. N., GLEASON, J. G.: Acta Crystallogr. Sect. B., **29**, 2272 (1973)
[5] STÁJER, G., SZABÓ, A. E., PINTYE, J., KLIVÉNYI, F., SOHÁR, P.: Chem. Ber., **107**, 229 (1974)
[6] BLOCK, E., BENTLEY, M. D., DAVIS, F. A., DOUGLASS, I. B., LACADIE, J. A.: J. Org. Chem., **40**, 2770 (1975)
[7] CHAU, M. M., KICE, J. L.: J. Am. Chem. Soc., **98**, 7711 (1976)
[8] GIBSON, T. W., STRASSBURGER, P.: J. Org. Chem., **41**, 791 (1976)
[9] TAKATA, T., KIM, Y. H., OAE, S., SUZUKI, K. T.: Tetrahedron Letters, **1978**, 4303
[10] LÁZÁR, J., VINKLER, E.: Acta Chim. Acad. Sci. Hung., **82**, 87 (1974)
[11] KHARASCH, N., ARORA, A. S.: Int. J. Sulf. Chem., **2**, 28 (1976)
[12] HILDITCH, T. P.: J. Chem. Soc., **1910**, 1091
[13] KLIVÉNYI, F.: Magyar Kémiai Folyóirat, **65**, 451 (1959)
[14] LAVINE, T. E.: J. Biol. Chem., **113**, 580 (1936)
[15] VINKLER, E., LÁZÁR, J., KLIVÉNYI, F.: Acta Chim. Acad. Sci. Hung., **30**, 233 (1962)

Elemér VINKLER
János LÁZÁR } H-6701 Szeged 1, Eötvös u. 6.

Pál SOHÁR H-1475 Budapest, P.O.B. 100.

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MASS SPECTROMETRIC STUDIES OF SOME PHENOTHIAZINE-*S*-OXIDES

I. G. TAULOV,[1] J. TAMÁS[2]*, J. HEGEDÜS-VAJDA[2] and D. SIMOV[1]

([1]Faculty of Chemistry, Sofia University, Sofia, Bulgaria, and [2]Central Research Institute for Chemistry, Hungarian Academy of Sciences, Budapest)

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The electron-impact-induced fragmentations of four *N*-alkyl-substituted phenothiazine-*S*-oxides have been investigated. The decomposition pathways show that the tetravalent sulfur atom is the main reaction center in the molecular ions of these compounds and SO, O and OH eliminations represent the main primary decomposition routes. As demonstrated by using the deuterium labelling technique, the abundant $(M—OH)^+$ ions are formed by transannular reactions between the substituents of the S and N atoms in the hetero ring, in accordance with an earlier assumption (Ref. [8]).

Introduction

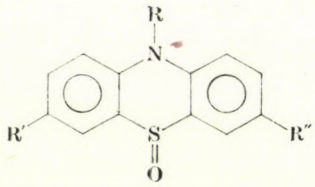
The importance and widespread use of different phenothiazine derivatives in medical practice gave rise to a continuous interest in their mass spectral behaviour, resulting in a well-documented mass spectrometry of these compounds (see *e.g.* [1—12]). However, the same is not true for phenothiazine-*S*-oxides and — *S,S*-dioxides *(i.e.* for cyclic sulfoxides and sulfones), although the significance of these derivatives is now also evident: the metabolic oxidation of phenothiazine drugs to cyclic *S*-oxides has been postulated repeatedly [13, 14] and the formation of sulfone derivatives from chlorpromazine and perazine has been shown recently in man [15].

These facts prompted us to study the details of the electron-impact-induced fragmentation of some phenothiazine sulfoxide and sulfone derivatives.

This paper deals with the mass spectral behaviour of the phenothiazine sulfoxides **I—V:**

This study is a continuation, supporting earlier investigations on 10-methyl- and 10-butyl-phenothiazine-*S*-oxides [8].

* To whom correspondence should be addressed.



	R	R′	R″
I	$-CH_3$	Cl	NO_2
II	$-CH_2-CH_3$	Cl	NO_2
III	$-CD_2-CD_3$	Cl	NO_2
IV	$-CH_2-CH_2-CH_3$	Cl	NO_2
V	$-CH_2-CH=CH_2$	H	H

Results

The 70 eV mass spectra of compounds **I**—**V** are shown as line diagrams in Figs 1—4. The fragmentation pathways, *i.e.* the origin of ions, elucidated by using high resolution mass measurements, as well as by observing the

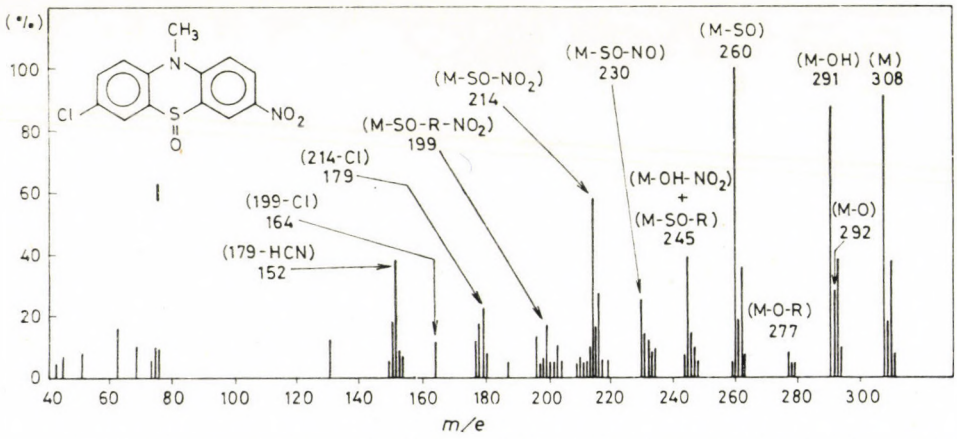
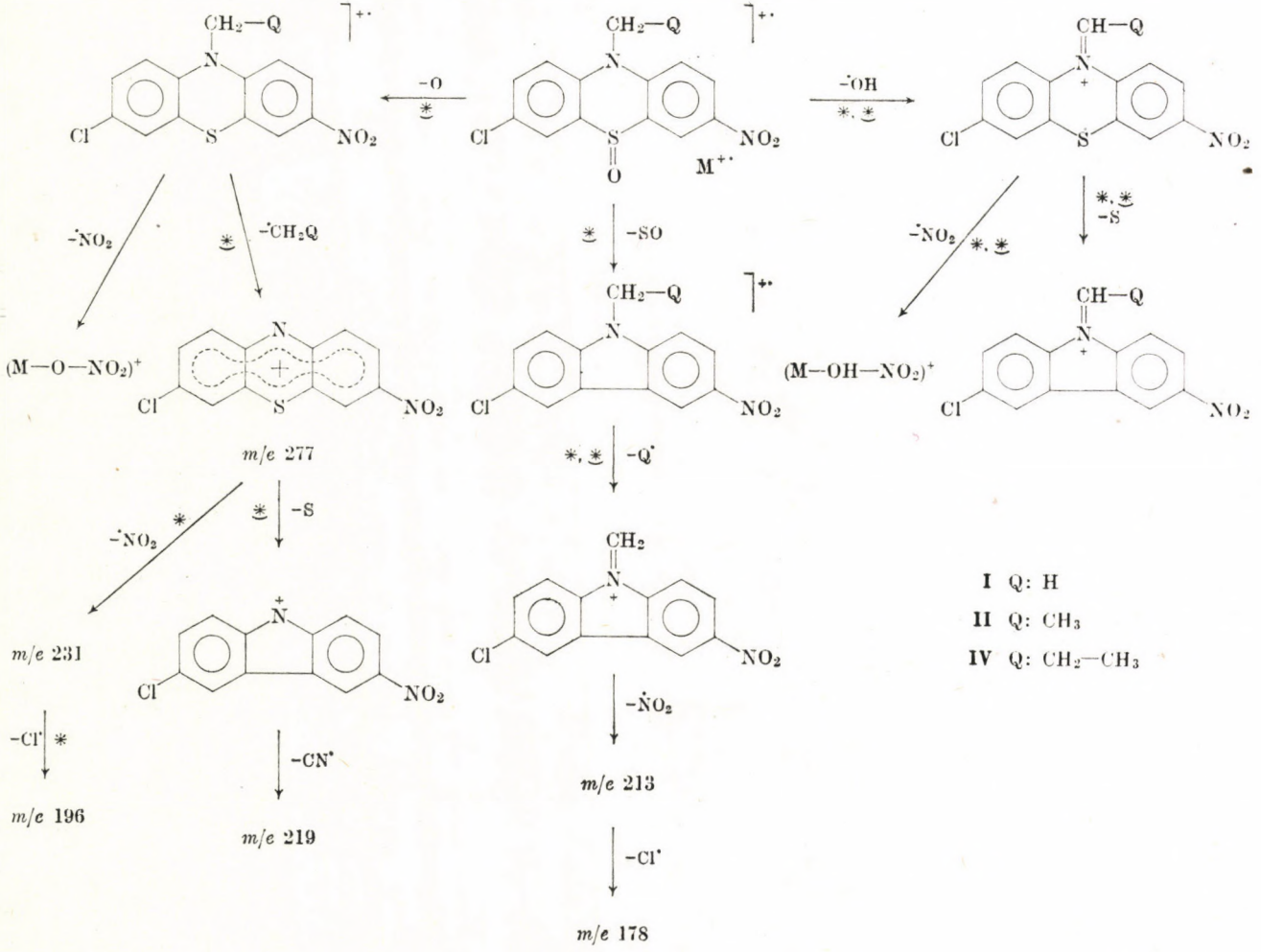


Fig. 1. 70 eV mass spectrum of *N*(10)-methyl-3-nitro-7-chlorophenothiazine-*S*-oxide (**I**)

first and second field free metastables, are presented for significant ions, showing the neutral part(s) lost during the formation of these ions. Common fragmentation processes and suggested structures of the main fragment ions for **I**, **II** and **IV** are shown in Scheme 1. Analogous schemes are valid for **III** and **V**, as well as for 10-methylphenothiazine-*S*-oxide and 10-butyl-3-nitro-7--chlorophenothiazine-*S*-oxide [8].



I Q: H

II Q: CH_3

IV Q: $CH_2—CH_3$

Scheme 1

✳ 1st field free metastables (II)
✳ 2nd field free metastables (I—III)

From the result obtained, some conclusions concerning the main characteristics of the fragmentation of these compounds can be drawn.

The molecular ions of I—V are of medium stability. The main primary fragmentation processes are the loss of OH or SO groups, or the elimination of an O atom, in competing routes.

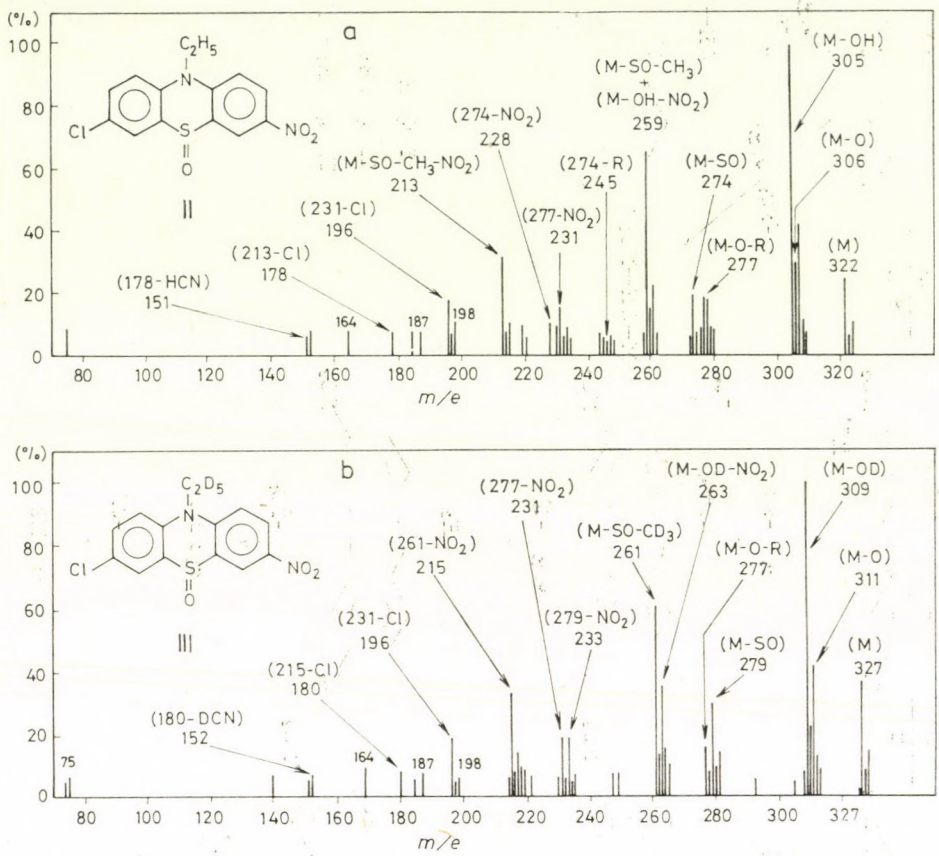


Fig. 2a, b. 70 eV mass spectra of *N*(10)-ethyl-3-nitro-7-chlorophenothiazine-*S*-oxide **(II)** and its ethyl-d_5 analogue **(III)**

Analogously to the mass spectrum of 10-methylphenothiazine-*S*-oxide [8], the base peak in the spectrum of **I** (Fig. 1) is yielded *via* elimination of the SO group from the molecular ion. Competing loss of an OH group leads to $(M-OH)^+$ ions, with an abundance of 85%.

In the mass spectra of **II**—**V** (Figs 2a—4) the base peaks correspond to OH elimination (for **III** an OD group is lost) from the molecular ions, as it was also found in cases of 10-*n*-butyl-3,7-dinitrophenothiazine-*S*-oxide and

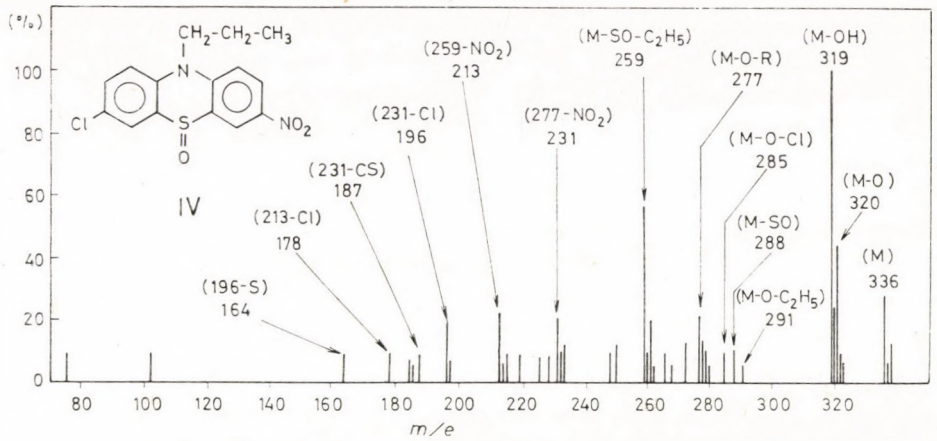


Fig. 3. 70 eV mass spectrum of *N*(10)-*n*-propyl-3-nitro-7-chlorophenothiazine-*S*-oxide (**IV**)

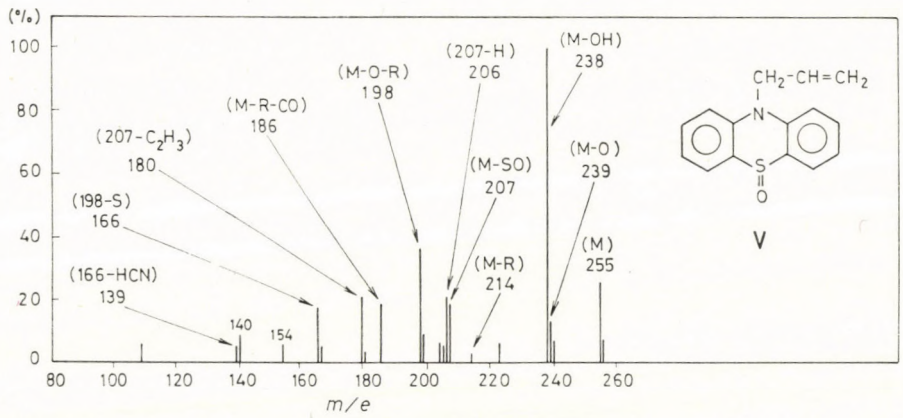


Fig. 4. 70 eV mass spectrum of *N*(10)-allyl-phenothiazine-*S*-oxide (**V**)

10-*n*-butyl-3-nitro-7-chlorophenothiazine-*S*-oxide [8]. These observations indicate that OH elimination is a more favoured process when $R > CH_3$. The competing SO elimination in the cases of **II**—**V** leads to ions with an abundance not exceeding 30%. For **V**, loss of the N(10) substituent from the molecular ion also takes place (allylic effect).

Elimination of an O atom from the molecular ions resulted in low abundant $(M-O)^+$ peaks.

In general, the further fragmentations of compounds **I**—**IV** (Figs 1—3) are very close to that of 10-*n*-butyl-3-nitro-7-chlorophenothiazine-*S*-oxide, and the same applies to that of **V** (Fig. 4) and 10-methylphenothiazine oxide [8]. In this respect it is noted that although $(M-O)^+$ ions appear as weak

peaks in the mass spectra of **I—V** their main further fragmentation, consisting of the loss of the N(10) substituent, leads to abundant $(M-O-R)^+$ peaks. This phenomenon can be due to the high stability of the product ions of heteroaromatic structure (Scheme 1).

Interestingly, the mass spectral behaviour of *N*(10)-alkyl-substituted sulfoxides is very dissimilar to that of phenothiazine sulfoxide (R=H) [5]. With this compound OH elimination is insignificant, and similarly to thianthrene sulfoxide and phenathioxy sulfoxide [16], it has very stable molecular ions, the main fragmentation pathways being expulsion of SO and CO in competing processes. The latter route involves a rearrangement of the —S— group to an —S—O— bridge [17].

α- and β-bond cleavages in the *N*(10)-substituent (R), as well as fragmentation of the other substituents (R′, R″) are significant only as secondary processes, in contrast to analogous phenothiazines, for which these reactions occur as the main primary decomposition pathways.

The above mentioned facts indicate that the main reaction center in the molecular ions of *N*(10)-subtituted phenothiazine sulfoxides is the SO group containing a comparatively unstable, tetravalent sulfur atom; the observed processes lead to the formation of more stable ionic structures. The most interesting reaction is in this respect the OH group elimination from the molecular ion, representing one of the most significant routes of stabilization for **I, II, IV** and **V**. Any further fragmentation of the $(M-OH)^+$ ions has been found almost negligible. OD elimination instead of OH loss in the case of **III**, together with the high abundance of $(M-OH)^+$ ions in the spectrum of **V** (with no other oxygen atoms) indicate that this OH group is formed from the oxygen atom of the SO group and a H atom of the *N*(10)-substituent, as assumed formerly [8]. It follows that this significant OH elimination process represents a reaction between the substituents of the two heteroatoms (S and N) which are in transannular positions of the hetero ring.

Notably, transannular H-rearrangements have also been proposed for the ketene elimination reaction of *N*(10)-acetylphenothiazine-*S*-oxide, followed by OH loss [5], and transannular elimination reactions were indicated for some trimethylsilylated benzhydryl ethers [18].

The higher relative frequency of OH elimination for compounds, with $R > CH_3$ can be interpreted

(*a*) by assuming that the ratio of the "internal" and "external" configurations of R at the N(10) atom are diferent in the molecules examined depending on R [8]; or

(*b*) by supposing a complementary formation of sulfonium ions involving the ethylene (or substituted ethylene) bridge between the two heteroatoms of the ring, as a contributing effect.

For a sure decision between these alternatives, further studies with compounds partially D-labelled in the *N*-alkyl group (CH_2CD_3 and/or CD_2CH_3) seem to be necessary and are planned.

Concerning the first assumption, it is reasonable to suppose that for **II—V**, having large R substituents, the "external" configuration may be predominant, favouring OH elimination. For compound **I** the low abundance of the $(M-OH)^+$ peak can be rationalized by assuming the possibility of both "external" and "internal" configurations, when only the "external" configuration allows OH elimination.

In the case of R=H, the "internal" configuration may be predominant* resulting in a very weak $(M-OH)^+$ peak [5].

Experimental

The mass spectra of the samples were taken by an AEI MS-902 double focussing instrument (Budapest laboratory), using the direct inlet system. The applied ionizing electron energy was 70 eV and the temperature of the ionization chamber was maintained at 170 °C. The accelerating voltage was 8 kV.

High resolution measurements were effected, with an accuracy of 3 ppm. For detecting the first field free metastables, both methods, altering the ESA voltage and change of the accelerating potential, were used.

REFERENCES

[1] Duffield, A. M., Craig, J. C., Kray, L. R.: Tetrahedron, **24**, 7267 (1968)
[2] Audier, L., Cambon, A., Guedi, R., Azzaro, M.: J. Heterocyclic Chem., **5**, 393 (1968)
[3] Audier, L., Azzaro, M., Cambon, A., Guedi, R.: Bull. Soc. Chim. France, **3**, 1013 (1968)
[4] Guedi, R., Cambon, A., Audier, L., Azzaro, M.: Bull. Soc. Chim. France, **3**, 1021 (1968)
[5] Heiss, J., Zeller, K. P.: Org. Mass Spectrom., **2**, 819 (1969)
[6] Gilbert, K. N. T., Millard, B. J.: Org. Mass Spectrom., **2**, 17 (1969)
[7] Mital, R. L., Jain, S. K., Azzaro, M., Cambon, A., Rosset, J. P.: Bull. Soc. Chim. France, **6**, 2195 (1970)
[8] Simov, D., Taulov, I. G.: Org. Mass Spectrom., **5**, 1133 (1971)
[9] Riepe, E., Zander, M.: Z. Naturforsch., **27a**, 170 (1972)
[10] Breyer, U., Gartner, H. J., Prox, A.: Biochem. Pharmacol., **23**, 313 (1974)
[11] Ryhage, R., Brandenberger, H.: Biomed. Mass Spectrom., **5**, 615 (1978)
[12] Pantoretto, C., Belvedere, G., Buoti, L., Frigerio, A.: in Advances in Mass Spectrometry; Biochemistry and Medicine, Vol. **1**, p. 433 and references cited therein, Eds. A. Frigerio and N. Castagnoli, Spectrum Publications, Inc., New York, 1976
[13] Kamm, J. J., Gilette, J. R. Brodie, B. B.: Fed. Proc., **17**, 382 (1958)
[14] Forrest, I. S., Forrest, F. M.: Exp. Med. Surg., **21**, 231 (1963)
[15] Breyer-Pfaff, U., Kreft, H., Roessner, H., Prox, A.: Drug Metabolism and Disposition, **6**, 114 (1978)
[16] Heiss, J., Zeller, K. P., Zech, B.: Tetrahedron, **24**, 3255 (1968)
[17] Bowie, J. H., Williams, D. H., Lawesson, S. O., Madsen, J., Nolde, C., Schroll, G.: Tetrahedron, **22**, 3515 (1966)

* The „internal" orientation of the N—H bond in crystalline phenothiazine was established by Bell *et al.* [19]; on the contrary, "external" position was suggested for *N*-alkyl substituted derivatives by Malrieu and Pullmann [20].

[18] AKKERMAN, O. S., EVERS, E. A. I. M., KERKSTRA, A.: Org. Mass Spectrom., **11**, 57 (1976)
[19] BELL, J. D., BLOUNT, J. F., BRISCOE, O. V., FREEMAN, H. C.: Chem. Commun., **1968**, 1656
[20] MALRIEU, J. P., PULLMAN, B.: Theor. Chim. Acta (Berlin), **2**, 292 (1964)

Dimitur SIMOV
Ivan TAULOV
Faculty of Chemistry, Sofia University, Sofia, Bulgaria

Judit HEGEDÜS-VAJDA
József TAMÁS
H-1025 Budapest, Pusztaszeri út 59/67.

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MASS SPECTROMETRIC STUDIES OF SOME PHENOTHIAZINE-*S*,*S*-DIOXIDES

I. G. TAULOV,[1] J. TAMÁS[2*], J. HEGEDÜS-VAJDA[2] and D. SIMOV[1]

([1]Faculty of Chemistry, Sofia University, Sofia, Bulgaria, and [2]Central Research Institute for Chemistry, Hungarian Academy of Sciences, Budapest)

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The fragmentation processes of seven phenothiazine sulfones have been investigated. The molecular ions were found to be more stable than those of the corresponding sulfoxides. The main decomposition routes consist of losses of small neutrals such as O, OH, SO, SO_2 groups and/or fragments of the *N*(10)-substituent, resulting in heteroaromatization or extension of the π-conjugations in the skeleton. For *N*-ethyl derivatives subsequent eliminations of two OH radicals were observed as significant processes. Deuterium labelling experiments evidenced that both H atoms lost in these reactions originate from the *N*(10)-alkyl group, as assumed earlier for a *N*(10)-propylphenothiazine sulfone derivative (Ref. [1]).

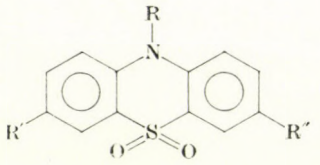
Introduction

In spite of recent interest attached to cyclic sulfone derivatives of phenothiazine drugs as products in the metabolism of these drugs, no systematic studies have been published on their mass spectral behaviour. In an earlier paper [1], a very interesting electron-impact-induced fragment, $(M-H_2O_2)^+$, was observed in the mass spectrum of 10-*n*-propyl-3-amino-7,8-dichlorophenothiazine-*S*,*S*-dioxide; it was proposed to have arisen by the loss of two OH radicals from the molecular ion, similarly to the elimination of one OH radical from that of the corresponding sulfoxides [1, 2]. To elucidate the details of these surprising OH elimination reactions, together with other characteristic decomposition modes occurring under electron impact, the phenothiazine-*S*,*S*-dioxides **I**—**VII** have been studied.

Results and discussion

The 70 eV mass spectra of compounds **I**—**VII** are presented in Figs 1—6. In elucidating the origins of ions, high-resolution mass measurements, as well as observations of first and second field free metastables were extensively applied.

* To whom correspondence should be addressed.



	R	R′	R″
I	H	H	H
II	$-CH_3$	H	H
III	$-CH_2-CH_3$	H	H
IV	$-CH_2-CH=CH_2$	H	H
V	$-C\equiv C-CH_3$	H	H
VI	CH_2-CH_3	Cl	NO_2
VII	CD_2-CD_3	Cl	NO_2

The molecular ions of all studied phenothiazine sulfones form the base peak of the spectrum and decompose in competing routes. In the case of phenothiazine-*S,S*-dioxide (**I**) ,(Fig. 1, Scheme 1 and Ref. [1]) molecular ion undergoes a well-known rearrangement [4, 5, 6], the formation of a C—O bond. Subsequent elimination of SO from this ion yields the ion at *m/e* 183, from which the ions *m/e* 182 and *m/e* 154 arise by successive loss of hydrogen and CO. Expulsion of SO_2 from the molecular ion of *I* leads to the ion at *m/e* 167, while loss of an O and a H atom in a one- or two-step reaction gives rise to the ion *m/e* 214. This latter decomposes, on the one hand, by elimination of

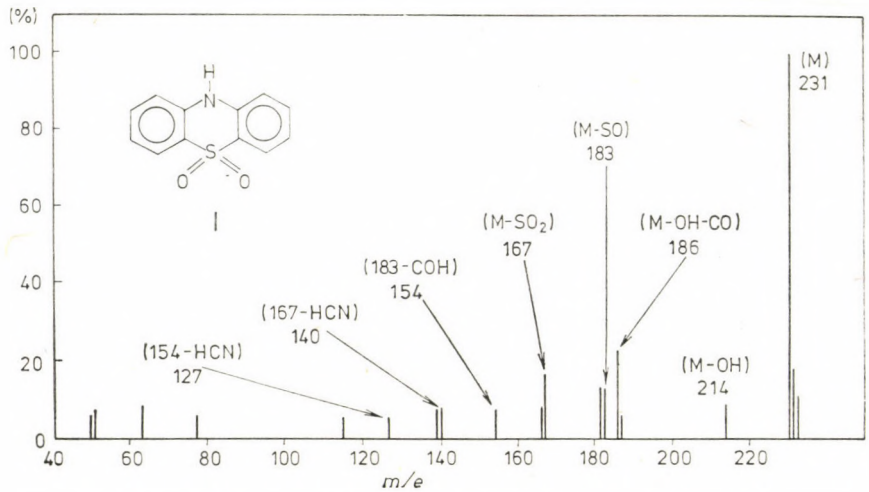
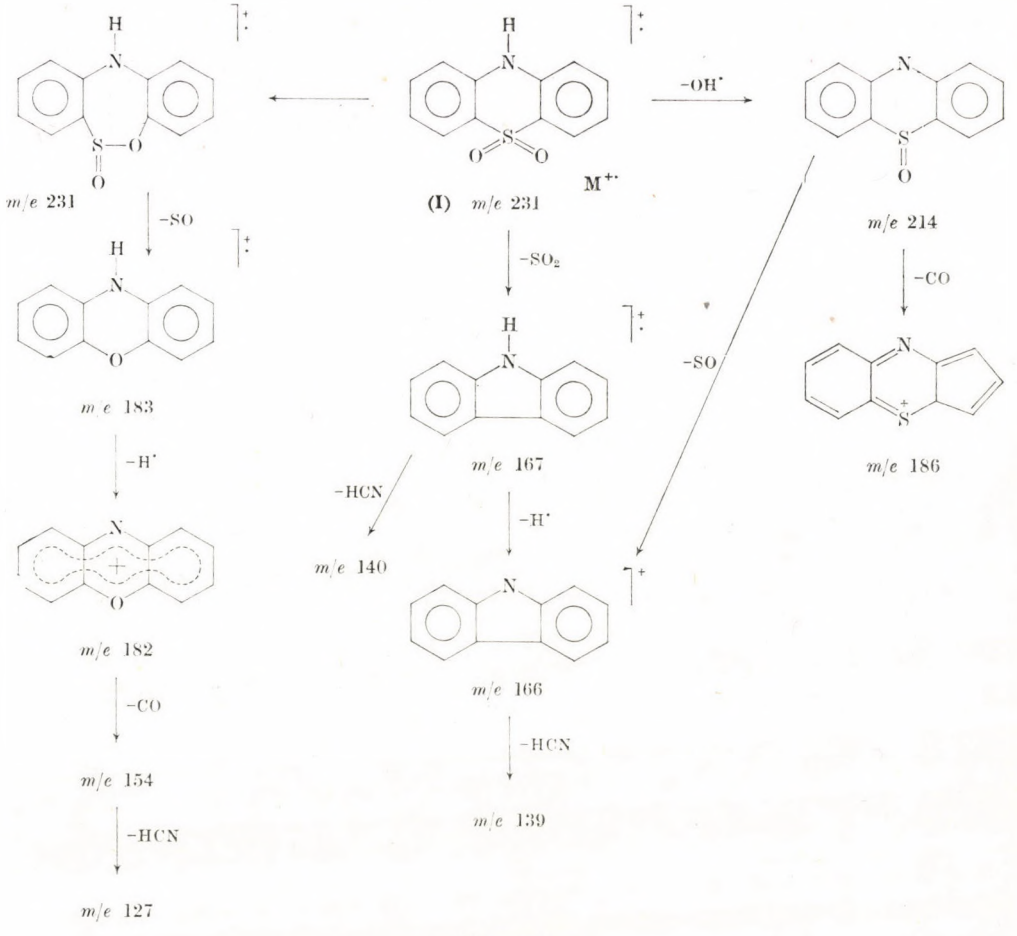


Fig. 1. 70 eV mass spectrum of phenothiazine-*S,S*-dioxide (**I**)



Scheme 1

SO to give the ion *m/e* 166 and, on the other hand, by loss of CO *(via* rearrangement) the ion *m/e* 186, the latter being the second abundant peak in the mass spectrum. The H atom lost in the above mentioned H elimination reactions originates from the N(10) position of **I**, as established from the mass spectrum of the deuterated analogue.

Rather surprisingly, the mass spectrum of 10-methylphenothiazine-*S,S*-dioxide(**II**) (Fig. 2 and Scheme 2) exhibited a very intense peak (30.4%) at *m/e* 198. This ion appeared also in the mass spectra of **III** to **V** and was shifted to *m/e* 277 in the spectra of **VI** and **VII**. Here it should be noted that AUDIER *et al.* [7] observed a peak at *m/e* 198 in the mass spectrum of oxomemazine, but its origin has not been explained.

The peak at *m/e* 186 also appears in the mass spectrum of **II**, as well as in the spectra of **III**, **IV** and **V**, but its intensity is lower than in the case of **I**.

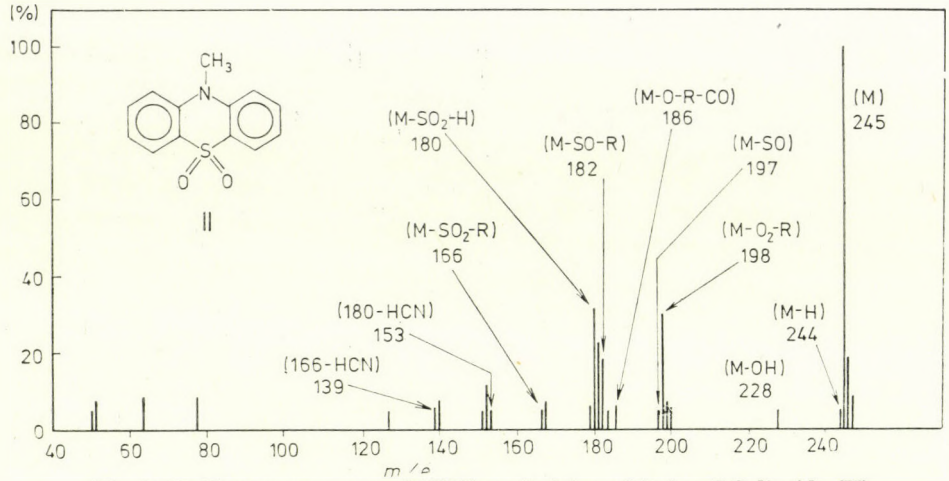
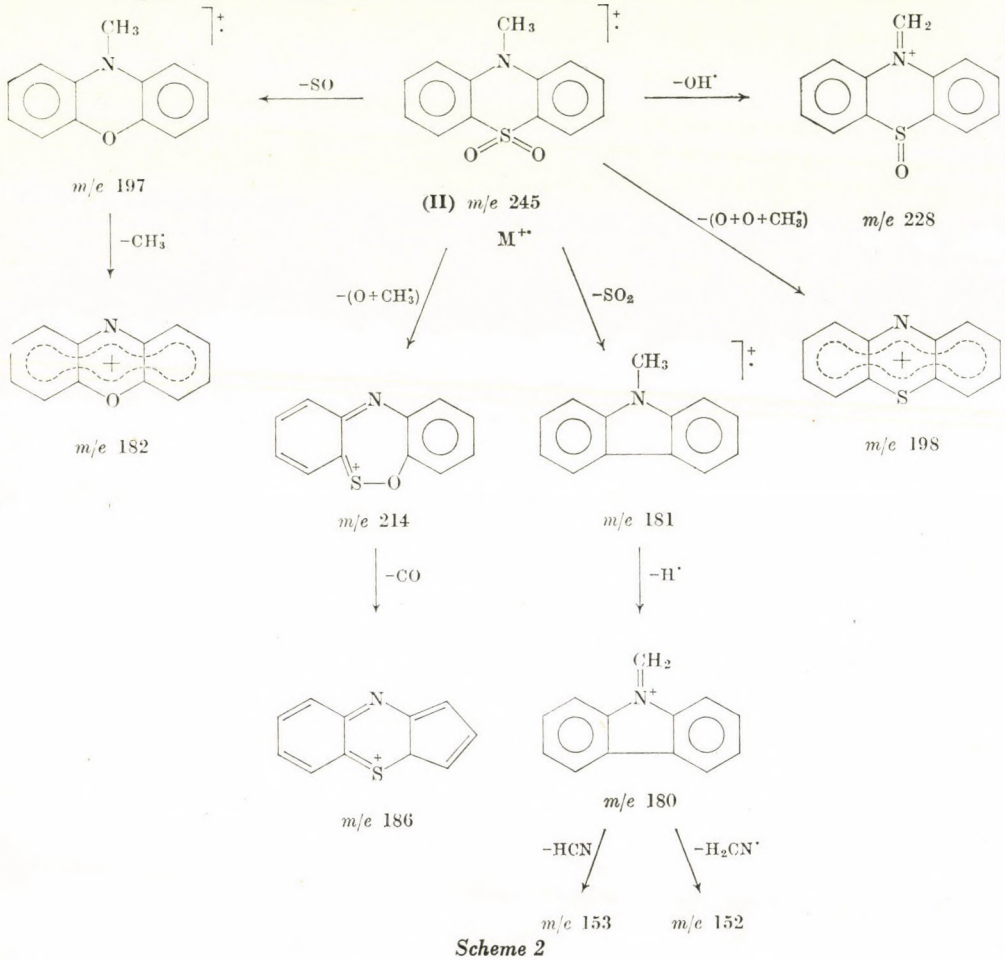


Fig. 2. 70 eV mass spectrum of *N*(10)-methylphenothiazine-*S*,*S*-dioxide **(II)**



Scheme 2

Exact mass measurements have revealed that the *m/e* 198 ion has a chemical composition of $C_{12}H_8NS$, *i.e.* it can be deduced from the molecular ion of **II** by loss of CH_3O_2. Application of the defocussing technique has shown that a pathway leading to this ion from **II** is the successive elimination of two oxygen atoms, followed by that of a methyl group in a very fast process* giving rise to very stable heteroaromatic structure of the product ion (Scheme 2). Interstingly, in the mass spectrum of **II** there is no peak corresponding to the primary loss of a CH_3 group, and, at the same time, the abundance of the $(M-O)^+$ and $(M-O_2)^+$ ions is almost at an undetectable level. This "phenothiazinium ion" was also observed in the case of the sulfoxide analogues [2].

The elemental composition of the *m/e* 186 ion was found to be $C_{11}H_8NS$, *i.e.* it is deducible from the molecular ion of **II** by substracting $C_2H_3O_2$. A possible route to this ion, as detected by the defocussing technique, involves the splitting off of an O atom followed by a very fact elimination of the CH_3 group and a CO molecule.** Thus, similarly to the case of the ion at *m/e* 198 also here only the end-product of a series of reaction steps has a structure stable enough for detection as an abundant peak in the normal spectrum.

The other pronounced feature of the mass spectrum of **II** is the elimination of an SO_2 molecule from the molecular ion and formation of the ion *m/e* 181, from which an ion *m/e* 180 arises by the loss of a hydrogen atom, giving the second abundant peak (40%) in the mass spectrum. Both transitions are confirmed by metastable peaks. Formation of the ion *m/e* 180 also occurs (as displayed by the metastable peak) from the ion of *m/e* 244 $(M-H)^+$ by loss of SO_2. The latter transition was observed in the mass spectrum of oxomemazine [7], too.

The elimination of a methyl group (β-fission at the N(10) atom) and formation of the $(M-CH_3)^+$ ion is the most pronounced primary fragmentation

* Correspondingly, the following first field free metastable transitions were observed:

a one-step processes

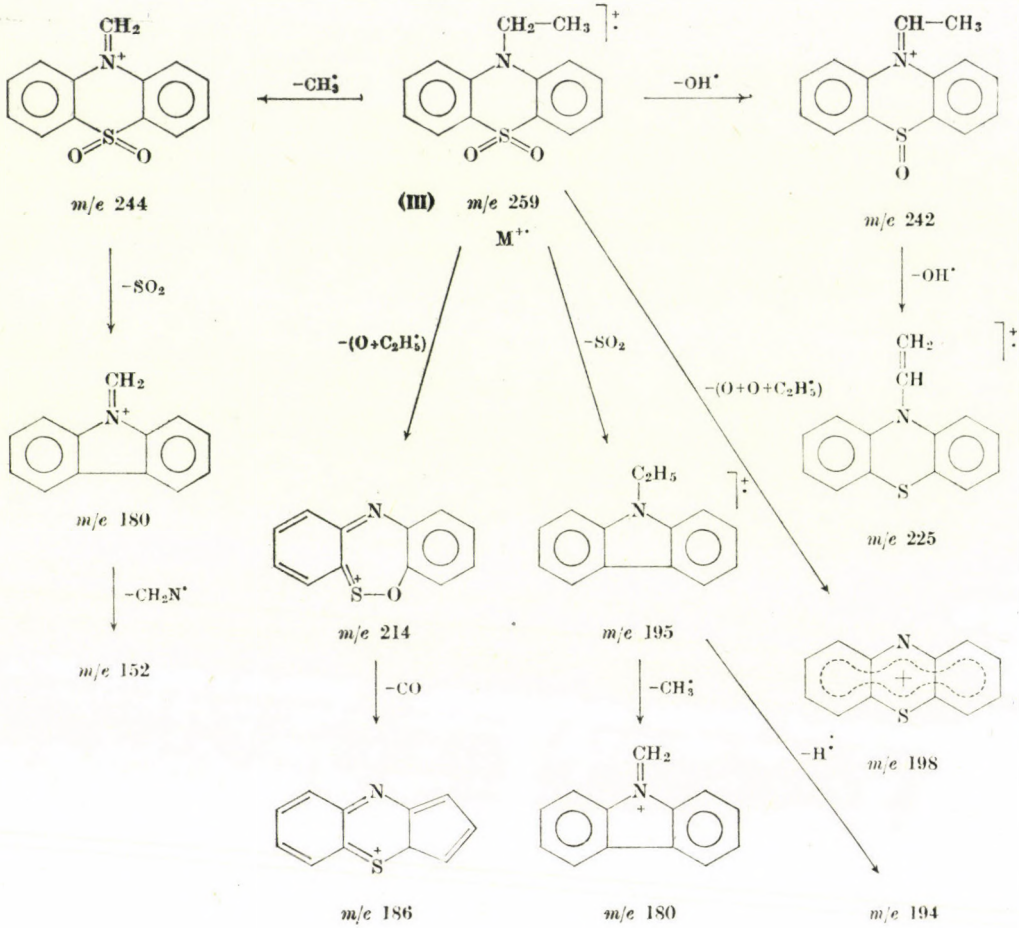
$245 \xrightarrow{-O} 229$	$E/E_0 = 0{,}935;$	$m^* = 214.0$
$229 \xrightarrow{-O} 213$	$E/E_0 = 0{,}930;$	$m^* = 198.1$
$213 \xrightarrow{-CH_3} 198$	$E/E_0 = 0.930;$	$m^* = 184.1$

b multi-step processes:

$245 \xrightarrow{-2\,O} 213$	$E/E_0 = 0.870;$	$m^* = 185.2$
$245 \xrightarrow{-2\,O-CH_3} 198$	$E/E_0 = 0.808;$	$m^* = 160.0$
$229 \xrightarrow{-O-CH_3} 198$	$E/E_0 = 0.865;$	$m^* = 171.2$

** The observed first field free metastables:

$229 \xrightarrow{-CH_3} 214$	$E/E_0 = 0.935;$	$m^* = 200.0$
$214 \xrightarrow{-CO} 186$	$E/E_0 = 0.870;$	$m^* = 161.7$
$229 \xrightarrow{-CH_3-CO} 186$	$E/E_0 = 0.812;$	$m^* = 151.1$
$245 \xrightarrow{-O-CH_3-CO} 186$	$E/E_0 = 0.760;$	$m^* = 141.2$



Scheme 3

process for 10-ethylphenothiazine-*S*,*S*-dioxide (**III**), (*m*/*e* 244 in Fig. 3 and Scheme 3), as well as for 10-ethyl-3-nitro-7-chlorophenothiazine-*S*, *S*-dioxide (**VI**) (*m*/*e* 323 in Fig. 6a) and 10-ethyl(d_5)-3-nitro-7-chlorophenothiazine-*S*,*S*-dioxide (**VII**) (*m*/*e* 325 in Fig. 6b). All these cleavages were confirmed by metastable peaks.

While the mass spectra of **I** and **II** exhibit insignificant elimination of an OH radical from the molecular ion and no peak for loss of two OH groups, in the mass spectrum of **III** (Fig. 3) the ions at *m*/*e* 242 and *m*/*e* 225 correspond to significant elimination of one and two OH groups from the molecular ion, respectively. The mass spectrum of **VI** shows the same behaviour as that of **III** (see peaks at *m*/*e* 321 and *m*/*e* 304 in Fig. 6a). The formation of the ion $(M-2\ OH)^+$ by successive elimination of two OH radicals was supported by

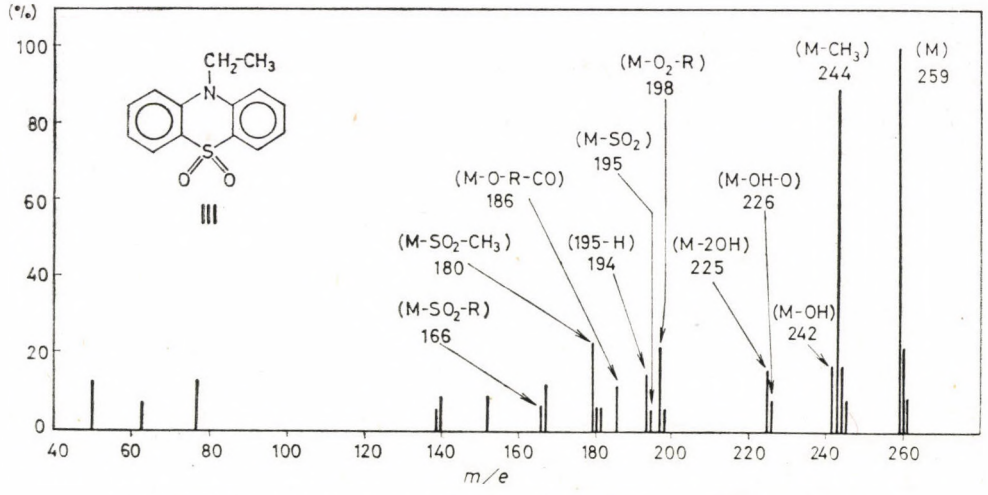


Fig. 3. 70 eV mass spectrum of *N*(10)-ethylphenothiazine-*S*,*S*-dioxide (III)

detecting the appropriate first field free region metastables. Furthermore, the fact that both H atoms lost originated from the *N*(10)-substituent, as it had already been assumed [1], was confirmed by the mass spectrum of **VII**, in which only $(M-2\ OD)^+$ ions were observable, instead of $(M-2\ OH)^+$. The mass spectra of **I**—**IV** and **VI** exhibited well detectable peaks corresponding to $(M-OH)^+$ ions, and analogously, that of **VII** showed an $(M-OD)^+$ peak, too. Their formation from the molecular ion by elimination of an OH(OD) radical was supported by corresponding metastables.

The mass spectrum of **V** (Fig. 5) is very interesting: no peaks either for

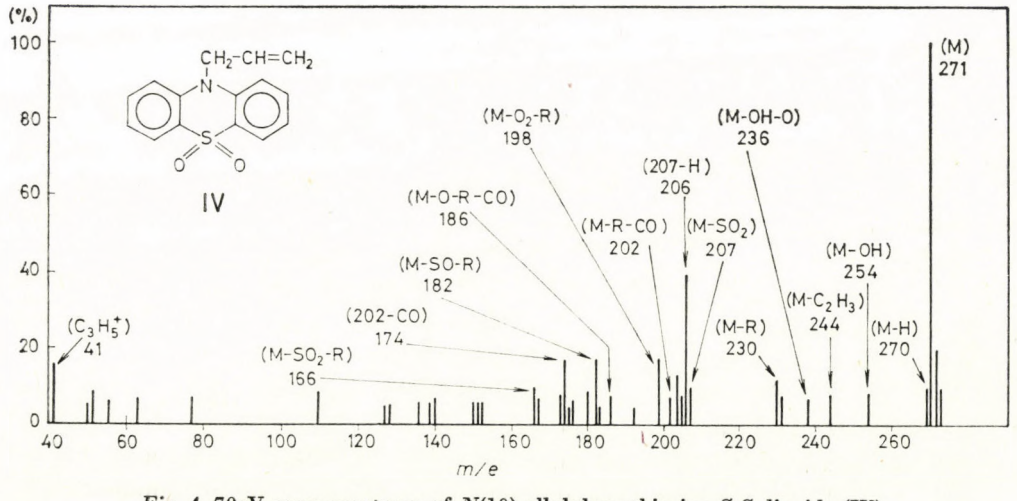


Fig. 4. 70eV mass spectrum of *N*(10)-allylphenothiazine-*S*,*S*-dioxide (IV)

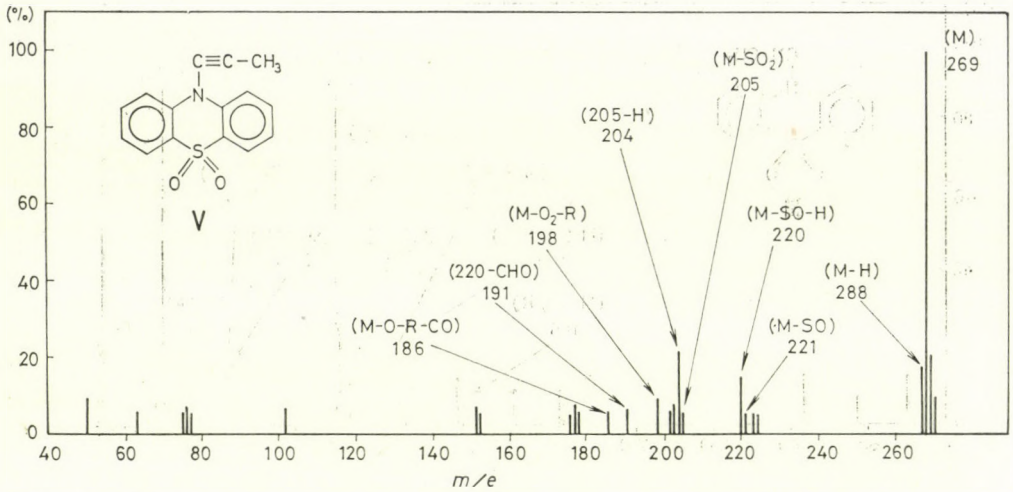


Fig. 5. 70 eV mass spectrum of *N*(10)-1-propynyl-phenothiazine-*S*,*S*-dioxide (**V**)

one or for two OH eliminations were detected at all. The reason for that must be the large distance in this case between the CH_3 group of the rigid R substituent at the N(10) atom and the oxygen atoms.

The above observations and the absence of the $(M-2\ OH)^+$ peak in the mass spectra of **I** and **II** suggest that the hydrogens attached originally to the α and β carbon atoms of the 10-alkyl substituent are lost in these OH elimination reactions. The absence of the $(M-2\ OH)^+$ peak in the spectrum of **IV** (Fig. 4) is another support for this. Elimination of the second OH radical would involve the abstraction of vinyl hydrogen, which seems to be an unfavoured process.

The loss of two OH radicals from the molecular ion of 10-ethylphenothiazine-*S*,*S*-dioxides, as well as from the molecular ion of 10-*n*-propyl-3-amino-7,8-dichlorophenothiazine-*S*,*S*-dioxide, studied earlier [1], may be connected with the "external" configuration of these *N*(10)-alkyl substituents [8], similarly to the OH loss in the analogous sulfoxides [1, 2].

In summing up the fragmentation behaviours of the sulfones examined, it can be concluded that, resembling the cases of the analogous phenothiazines and phenothiazine sulfoxide, the observed decomposition processes lead to stable ionic structures *(a) via* heteroaromatization, or (*b*) by extension of the π-conjugation in the skeleton.

Experimental

The mass spectra were recorded on an AEI MS-902 mass spectrometer (Budapest aboratory). The samples were introduced *via* direct inlet system. The temperature of the onization chamber was maintained at 170 °C; 70 eV ionizing electron energy and 8 kV accelerating voltage were used.

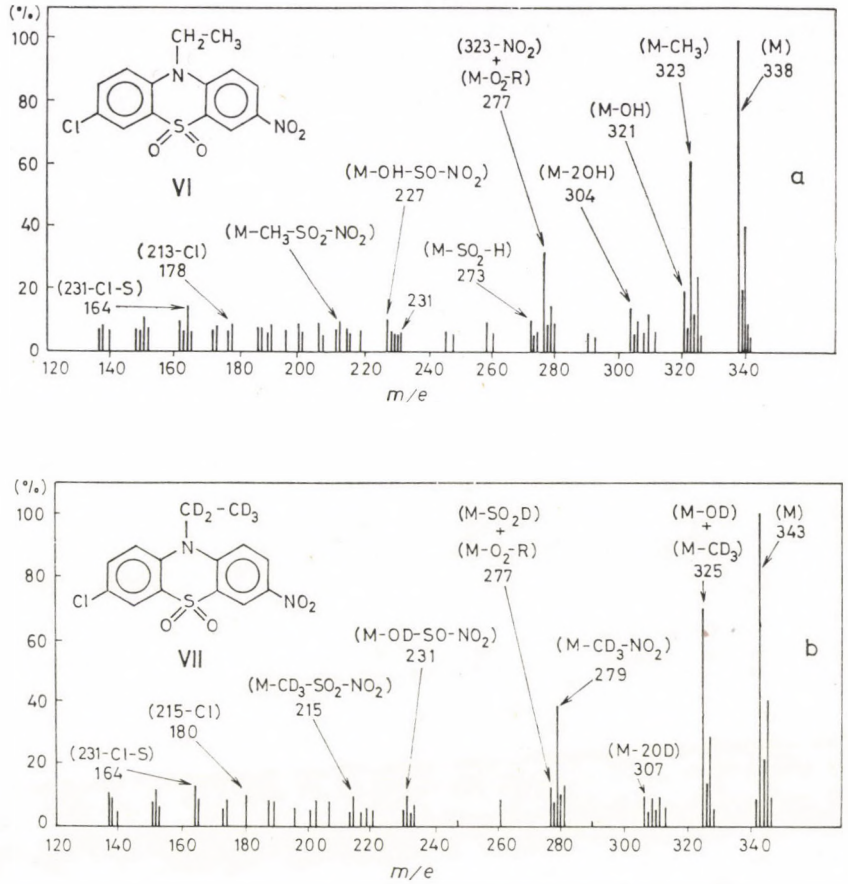


Fig. 6a, b. 70 eV mass spectra of *N*(10)-ethyl-3-nitro-7-chlorophenothiazine-*S*,*S*-dioxide (**VI**) and its ethyl-d_5 analogue (**VII**)

Exact mass measurements were performed at a resolving power of 10,000 with heptacosafluorotributylamine to provide reference masses. Defocussing experiments were carried out by both increasing the accelerating potential and decreasing the ESA voltage.

REFERENCES

[1] Simov, D., Taulov, I. G.: Org. Mass Spectrom., **5**, 1133 (1971)
[2] Taulov, I. G., Tamás, J., Hegedüs-Vajda, J., Simov, D.: Acta Chim. Acad. Sci. Hung. **105**, 109 (1980)
[3] Heiss, J., Zeller K. P.: Org. Mass Spectrom., **2**, 819 (1969)
[4] Bowie, J. H., Williams, D. H., Lawesson, S.-O., Madsen, J., Nolde, C., Schroll, G.: Tetrahedron, **22**, 3515 (1966)
[5] Heiss, J., Zeller, K.-P., Zeeh, B.: Tetrahedron, **24**, 3255 (1968)

[6] PORTER, Q. N.: Austr. J. Chem., **20**, 103 (1967)
[7] AUDIER, L., AZZARO, M., CAMBON, A., GUEDJ, R.: Bull. Soc. Chim. France, **3**, 1013 (1968)
[8] MALRIEU, J.-P., PULLMAN, B.: Theoret. Chim. Acta, **2**, 293 (1964)

Dimitur SIMOV
Ivan TAULOV
Faculty of Chemistry, Sofia University, Sofia, Bulgaria

Judit HEGEDÜS-VAJDA
József TAMÁS
H-1025 Budapest, Pusztaszeri út 59/67.

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VILSMEIER—HAACK REACTION OF 5-AMINO- AND 5-ACYLAMINO-PYRAZOLES*

A. SIMAY, K. TAKÁCS, K. HORVÁTH and P. DVORTSÁK

(Research Department of CHINOIN Pharmaceutical and Chemical Works, Budapest)

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The Vilsmeier-Haack reaction of 5-aminopyrazole derivatives **1** was investigated in view of contradictory literature reports. Structure **2** of the products was proved both chemically and spectroscopically. The mechanism of the reaction was postulated on the basis of isolated intermediates **7** and **8**. 5-Acylaminopyrazoles **9**, **10** and **11** were found to give also **2** (and **7**) under the Vilsmeier conditions by an acyl splitting reaction, proceeding probably via diacylamino derivatives **12**. Compounds **2** provided a simple route to pyrazolo[3,4-*d*]pyrimidine derivatives **13** and **14** as well as to azomethine compounds **15**—**18**.

The Vilsmeier—Haack reaction is a well-known preparative method for the synthesis of certain aldehyde derivatives, based on electrophilic substitution of different substrates [1, 2] including 1-substituted pyrazoles [3], pyrazol-5-ones [4, 5] and 5-aminopyrazoles [6—9]. For the Vilsmeier formylation of compounds **1** all authors reported a double substitution, but different structures, **2** [6, 7] and **3** [8] were postulated for the products obtained. No structural proof was given for **2** and structure **3** was claimed on the basis of some spectroscopic and preparative evidence [8].

In order to elucidate the above structural problem we reinvestigated the Vilsmeier—Haack reaction of differently substituted 5-aminopyrazoles **1a**—**k** with dimethylformamide–phosphoryl-chloride (DMF — $POCl_3$) or *N*-formyl-piperidine–phosphoryl-chloride (NFP — $POCl_3$) as reagents.

The UV, IR and ^{1}H-NMR spectroscopic investigations proved the analogous structure of the reaction products *(cf.* Table I), independently of substituents R^1 and R^2 in **1**, the composition of the reagent and the reaction technique used *(cf.* Experimental). The spectroscopic data, partly shown in Table I, support structure **2** rather than **3**, but for an unequivocal decision we have elaborated a preparative route based on the difference in the functional groups.

In the reaction of **2** (or **3**) **c** and **d** with cyclopentadiene in the presence of a basic catalyst the fulvene derivatives **4c**, **d** were obtained. Alkaline

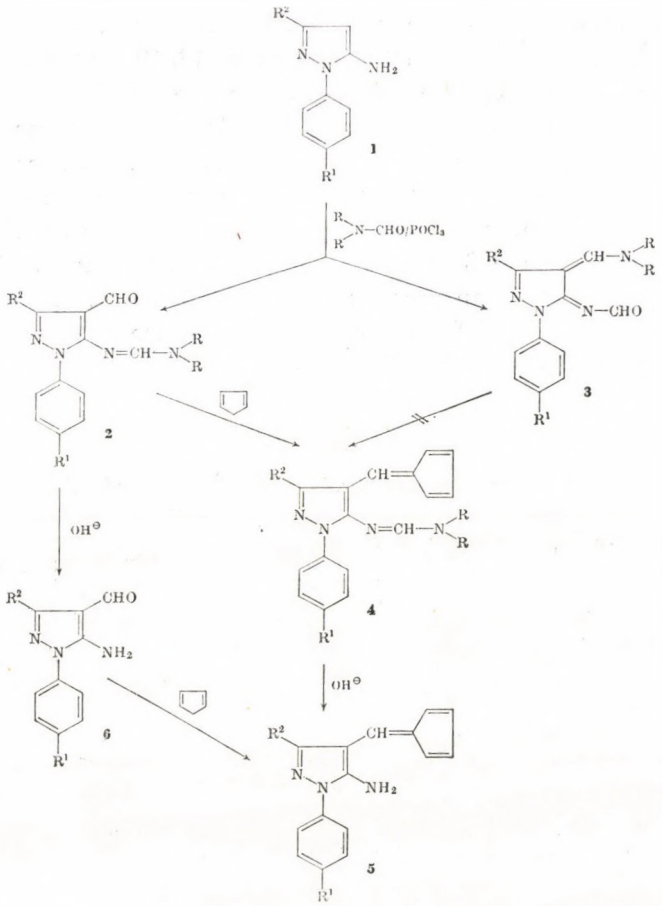
* Part of A. SIMAY's Dr. Techn. Thesis, Budapest, 1978. Presented at the VIth International Symposium on the Chemistry of Heterocyclic Compounds, Brno, 1978.

Table I

Some physical and spectral data of compounds **2**

No.	Yield (%)	M. p. from	Formula[a] Mol. weight	UV	IR		^{1}H-NMR (TFA)	
					C=O	C=N	C*H*O	N=C*H*—N
2a[b]	84	177—80 dec. EtOAc—EtOH (1 : 1)	$C_{13}H_{15}N_4ClO$ 278.74	not measured	not measured		not measured	
2b	83	125—27 EtOH	$C_{19}H_{18}N_4O$ 318.36	251 (4.49) 335 (3.74)	1670s	1616m	10.06s (1H)	8.60s (1H)
2c	70	79—82 C_6H_{12}	$C_{14}H_{16}N_4O$ 256.30	252 (4.39) 338 (3.64)	1665s	1616s	9.99s (1H)	8.46s (1H)
2d	70	138—40 EtOH	$C_{13}H_{13}N_4ClO$ 276.72	258 (4.43) 330 (3.82)	1683s	1618m	9.93s (1H)	8.5[e]
2e	99	179—80 *n*-BuOH	$C_{19}H_{17}N_4ClO$ 352.83	258 (4.48) 338 (3.82)	1670s	1624s	9.97s (1H)	8.64s (1H)
2f	71	144—46 EtOH	$C_{14}H_{15}N_4ClO$ 290.75	260 (4.42) 338 (3.69)	1660s	1628s, br	d	8.62s (1H)
2g	92	200—03 AcOH	$C_{13}H_{13}N_5O_3$ 287.27	240[e] 305	1675s	1612s	d	8.7c
2h	99	200—03 MeCN	$C_{19}H_{17}N_5O_3$ 363.37	246[e] 312	1667s	1626ms	d	8.77s (1H)
2i	80	203—05 MeCN	$C_{14}H_{15}N_5O_3$ 301.30	243[e] 309	1664s	1630s	d	8.65s (1H)
2j	91	180—83 EtOH	$C_{20}H_{26}N_4O$ 332.39	254 (4.46) 335 (3.76)	1675s	1625s	9.97s (1H)	8.61s (1H)
2k	74	147—50 EtOH	$C_{20}H_{20}N_4O_2$ 348.39	252 (4.43) 340 (3.82)	1655s	1622s	d	8.63s (1H)
2l	96	102—04 EtOH	$C_{16}H_{18}N_4O$ 282.33	252 (4.39) 330 (3.85)	1675s	1618s	not measured	
2m	76	84—86 C_6H_{12}	$C_{16}H_{17}N_4ClO$ 316.79	258 (4.44) 333 (3.88)	1668s	1612s	10.15s (1H)	8.50s (1H)

[a] Based on C, H, N, Cl analyses accurate within 0.40%; [b] Isolated as HCl salt only; [c] Overlapping with 3-C*H* signal; [d] Obscured by the signal of TFA; [e] Due to insufficient solubility, lg ε could not be measured



1, 5, 6, 9—18	R^1	R^2	2—4, 7, 8	$(R)_2$
a	**H**	**H**	**a**	$(CH_2)_2$
b	**H**	**Ph**	**b**	$(CH_2)_2$
c	H	**Me**	**c**	$(CH_2)_2$
d	Cl	H	**d**	$(CH_2)_2$
e	Cl	Ph	**e**	$(CH_2)_2$
f	Cl	Me	**f**	$(CH_2)_2$
g	NO_2	H	**g**	$(CH_2)_2$
h	NO_2	Ph	**h**	$(CH_2)_2$
i	NO_2	Me	**i**	$(CH_2)_2$
j	Me	Ph	**j**	$(CH_2)_2$
k	MeO	Ph	**k**	$(CH_2)_2$
	H	H	**l**	$(CH_2)_3$
	Cl	H	**m**	$(CH_2)_3$

Scheme 1

hydrolysis of **4c, d** led to compounds **5c, d,** which could also be synthesised by conducting the reaction via the known **6c** [8, 9] and **d** (Scheme 1). As **3** contains no suitable functional groups to give compound **4**, the latter could only have been formed from structure **2** [10, 11]. This sequence of reactions, supported by the spectroscopic data, proves that the Vilsmeier—Haack reaction of 5-aminopyrazoles **1** results exclusively in the formation of compounds **2**.

Concerning the process **1** → **2**, mechanistic studies were also performed. New intermediates **7** and **8** could be isoleted by modification of the reaction conditions and the work-up procedure *(cf.* Experimental and Table II). The reaction pathway inferred from our observations (see Scheme 2) is different from that reported previously [8].

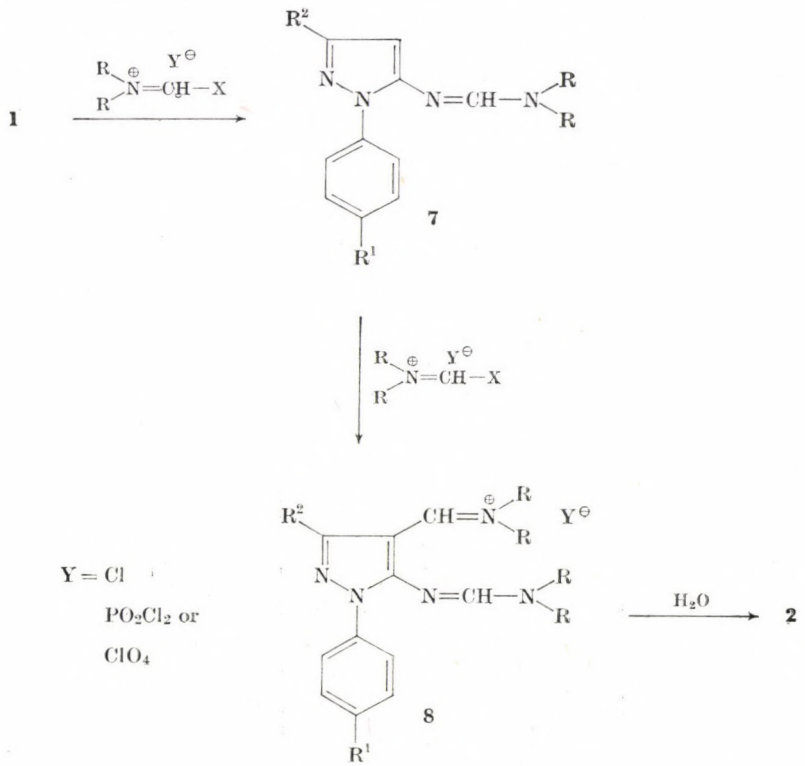
Table II

Some physical and spectral data of compounds **7**

No.	Yield (%)	M. p. from	Formula[a] Mol. weight	UV	IR C=N	^{1}H-NMR (TFA)	
						N=C*H*—N	4-C*H*
7a	89	68—70 C_6H_{12}	$C_{12}H_{14}N_4$ 214.26	250 (4.15) 284 (4.15)	1640s, br	8.62s (1H)	7.14d (1H)
7b	70	118—20 EtOH	$C_{18}H_{18}N_4$ 290.35	272 (4.54)	1650s, br	8.19s (1H)	6.54s (1H)
7c[b]	79	98—100 C_6H_{12}	$C_{13}H_{16}N_4$ 228.29	255 (4.18) 280 (4.17)	1648s, br	8.58s (1H)	6.90s (1H)
7d[c]	68	100—03 C_6H_{12}	$C_{12}H_{13}N_4Cl$ 248.71	255 (4.27) 290 (4.18)	1632s, br	8.59s (1H)	7.10d (1H)
7e	87	120—02 C_6H_{12}	$C_{18}H_{17}N_4Cl$ 324.81	273 (4.49)	1632s, br	8.60s (1H)	7.25s (1H)
7g	75	195—98 MeCN	$C_{12}H_{13}N_5O_2$ 259.26	285[d] 350	1630s, br	8.60s (1H)	7.04d (1H)
7h	75	217—20 MeCN	$C_{18}H_{17}N_5O_2$ 335.36	270 (4.30) 339 (4.23)	1630s, br	8.65s (1H)	7.26s (1H)
7i	57	143—46 MeCN	$C_{13}H_{15}N_5O_2$ 273.29	287 (4.22) 325 (4.19)	1632s, br	8.62s (1H)	6.94s (1H)
7m	40	115—17 C_6H_{12}	$C_{15}H_{17}N_4Cl$ 288.78	254 (4.19) 290 (4.10)	1622s, br	8.55s (1H)	7.11d (1H)

[a] Based on C, H, N, Cl analysis accurate within 0.40%; [b] HCl salt, m.p. 160—2 °C (from EtOH); [c] HCl salt m.p. 207—9 °C (from EtOH); [d] Due to insufficient solubility, lg ε could not be measured

Compounds of type **3** could not be obtained in the Vilsmeier—Haack reaction of 5-acylaminopyrazoles **9, 10** and **11**, either. Even in these cases



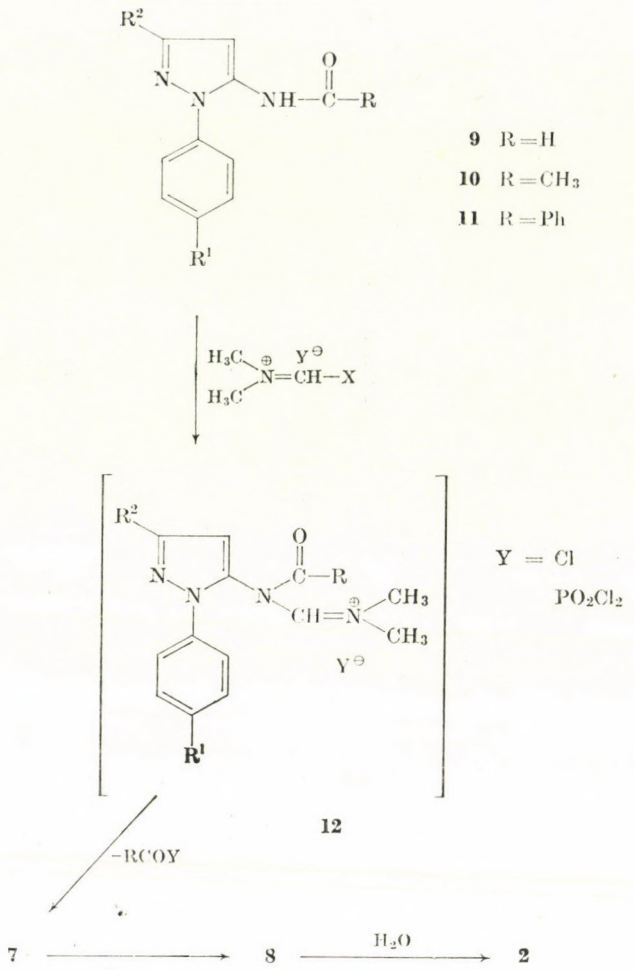
Scheme 2

compounds **2** were obtained and **7** could be isolated as intermediates. Formation of the latter proceeds probably *via* *N,N*-diacyl derivatives **12** by splitting of the original acyl-group (Scheme 3).

The acyl group split off could be detected by esterification followed by gas-chromatographic analysis *(cf.* Experimental). These investigations proved that the acyl splitting takes place very easily even at room temperature without any hydrolytic effect.

Our observations show that in the Vilsmeier—Haack reaction — in contrast to other electrophilic substitutions of aminopyrazoles [12] — protection of the 5-amino group generally cannot be achieved by acylation. In the case of compounds **10**, however, by-products formed without acyl splitting could also be isolated in low yields. Their structures and some chemical transformations will be reported elsewhere [13].

Compounds **2** are proper starting materials for a simple new synthesis [14] of pyrazolo[3,4-*d*]pyrimidine derivatives **13** and **14**, by reacting with ammonium salts and hydroxyammonium salts, respectively. In the absence of acid, however, condensation reactions involving only the aldehyde function take place, resulting in azomethine derivatives **15—18** (Scheme 4).



Scheme 3

Experimental

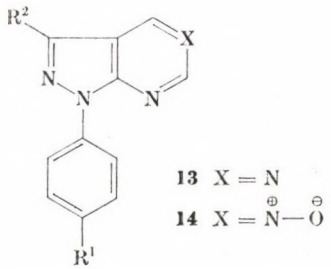
The melting points are uncorrected. All new materials have satisfactory microanalyses.

IR spectra were obtained on a Zeiss UR 20 spectrometer in KBr pellets and UV spectra on a Unicam SP 800A spectrometer in 96% ethanol solutions. The UV data are given as $\lambda_{max}(\lg \varepsilon)$ in nm, the IR data as ν_{max} in cm^{-1}. ^1H-NMR spectra were recorded on a Perkin-Elmer R 12 (60 MHz) instrument. The chemical shifts are given in parts per million (δ) downfield from TMS as internal standard.

Gas-chromatographic analyses were performed on a Packard 7839 type instrument, using a 2 m column (Chromosorb W 60—80, 5% Apiezon, L, at 53 °C, carrier gas N_2 (35 ml/min), FID).

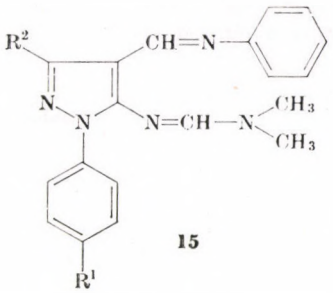
1,3-Disubstituted 5-amino-pyrazoles (1)

1a [15] and **1d** [16] were prepared by methods described by SCHMIDT and DRUEY [15], and ALBERTI and TIRONI [16], respectively.



13 X = N

14 X = $\overset{\oplus}{N}-\overset{\ominus}{O}$



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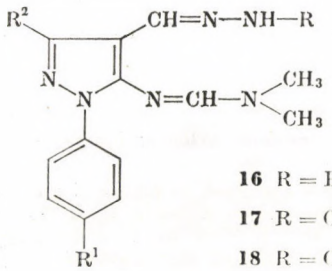

16 R = Ph

17 R = CO—NH_2

18 R = CS—NH_2

Scheme 4

1d [16] and **1g** [16] were prepared by a modification of the above method [16].

0.1 mol of 1-(4-chlorophenyl)- or 1-(4-nitrophenyl)-5-aminopyrazole-4-carbonitrile [17] was refluxed for 5 hrs in 5 *N* hydrochloric acid (80) ml). After purifying with charcoal, the solution was allowed to cool. The crystalline product was dissolved in water and neutralized to give 65% **1d** (m.p. 83—5 °C) or 63% **1g** (m.p. 145—7 °C).

1b [18], **1e** and **1h** were synthesised by the following modification of the method described by GRANDBERG *et al.* [18].

0.1 mol of 4-substituted phenylhydrazine and 0.1 mol of benzoylacetonitrile [19] were refluxed for 3 hrs in a mixture of EtOH (70 ml) and AcOH (3 ml). On cooling, 90% **1b** (m.p. 130—3 °C), 47% **1e** (m.p. 142—4 °C, from EtOH) or 53% **1h** (m.p. 192—4 °C from MeCN) were obtained.

1j (m.p. 145—8 °C, from EtOH) and **1k** (m.p. 160—3 °C, from EtOH) were prepared as follows.

To a suspension of 0.11 mol of 4-substituted phenylhydrazinium chloride in 96% EtOH (50 ml), 10% NaOH solution was added at room temperature until dissolution. After addition of 0.1 mol of benzoylacetonitrile and stirring the mixture for 5 hrs at room temperature, the precipitated product was filtered and recrystallized.

1c [18] (m.p. 113—5 °C), **1f** [20] (m.p. 110—3 °C) and **1i** [16] (m.p. 161—4 °C) were prepared by a modification of the method of ALBERTI and TIRONI [20].

4-Substituted phenylhydrazine and diacetonitrile [21] (0.1 mol of each) were refluxed for 3 hrs in a mixture of EtOH (50 ml) and AcOH (3 ml). After cooling, the crystalline products were filtered and recrystallized.

1,3-Disubstituted-5-disubstituted-aminomethylene-aminopyrazole-4-carbaldehydes (2)

Literature methods (see Refs. 6, 7, 8) gave the very same products (**2c**, **d**, **h**) in the Vilsmeier—Haack reaction of **1c**, **d**, **h**, as did our improved method applied to prepare all compounds **2** listed in Table I.

To 10 mmol of compound **1**, dissolved in 30 mmol of DMF or NFP, 30 mmol of $POCl_3$ was added in small portions at 15—20 °C while shaking and cooling. The mixture was then warmed for 3 hrs on a water bath (60—70 °C) and poured into ice-water (50 g each). The solu-

tion* formed was neutralized with solid Na_2CO_3, the precipitated product filtered off, washed with water and recrystallized (see Table I).

1,3-Disubstituted-5-aminopyrazole-4-carbaldehydes (6)

7,5 g (29 mmol) of **2c** or **d** was refluxed for 1.5 hrs in a mixture of EtOH (75 ml) and 40% NaOH (7.5 ml), then poured into 400 ml of water. The precipitated product was filtered off, washed, dried and recrystallized.

6c: yield 59%; m..p 92—5 °C (CCl_4). *Lit.* [9] m.p. 97 °C.

^{1}H-NMR ($CDCl_3$): 9.64 (s, 1H, C*H*O), 7.48 (s, 5H, Ar*H*), 6.1 (bs, 2H, NH_2, exchangeable with D_2O), 2.36 (s, 3H, CH_3).

6d: yield 58%; m.p. 153—5 °C (EtOH).

UV: 253 (4.26).

IR: 3420ms, 3315m, 3080w, 1618ms (NH_2), 1662s (C=O).

^{1}H-NMR ($CDCl_3$-DMSO-d_6): 9.75 (s, 1H, C*H*O), 7.85 (s, 1H, 3-C*H*), 7.58 (s, 4H, Ar*H*), 6.9 (bs, 2H, NH_2).

1,3-Disubstituted-5-dimethylaminomethyleneamino-4-(6-fulvenyl)-pyrazoles (4)

To 1.36 g (5 mmol) of **2c** or **d**, dissolved in EtOH (7 ml), 0.75 ml (0.60 g; 9 mmol) of freshly distilled cyclopentadiene was added, followed by a NaOEt solution prepared from 0.12 g (5 mg atom) of Na in 3 ml EtOH. After standing for 1 hr at room temperature and cooling overnight, the product was filtered and recrystallized.

4c: yield 70%; m.p. 116—7 °C (MeOH).

UV: 225 (4.24), 255 (4.19), 285 (4.26), 364 (4.18).

IR: 2925w (C-H), 1640s (C=N).

^{1}H-NMR (DMSO-d_6): 7.9—7.1 (m, 6H, Ar*H* + N=C*H*—N), 7.00 (s, 1H, fulvenyl-CH), 6.53 (t, 2H, fulvenyl-C*H*), 6.34 (t, 2H, fulvenyl-C*H*), 3.03, 2.95 (2s, 6H, N(CH_3)$_2$), 2.34 (s, 3H, 3-CH_3).

4d: yield 93%; m.p. 147—8 °C (EtOH).

UV: 228 (4.20), 258 (4.21), 292 (4.26), 365 (4.42).

IR: 2940w (C—H), 1632s (C=N).

^{1}H-NMR (DMSO-d_6): 8.15 (s, 1H, 3-C*H*), 7.88 (s, N=C*H*—*N*), 7.92, 7.53 (2d (J = 9Hz), Ar*H*), 6.87 (bs, 2H, fulvenyl-C*H*), 6.56 (d(J = 5Hz), 1H, fulvenyl-C*H*), 6.37 (t, 2H, fulvenyl-C*H*), 3.14, 3.07 (2s, 6H, N(CH_3)$_2$).

1,3-Disubstituted 5-amino-4-(6-fulvenyl)pyrazoles (5)

Compounds **5c** and **5d** were prepared in 66 and 60% yield, respectively, in the reaction of **6c** and **d** with cyclopentadiene, carried out as given for compounds **4**. The same products (**5c** and **d**) were obtained by alkaline hydrolysis of **4c** and **d** by the method given for compounds **6**, in 67 and 84% yield, respectively.

5c: m.p. 98—100 °C (C_6H_{12}).

UV: 244 (4.10), 303 (3.76), 368 (4.23).

IR: 3428w, 3300w, 3140w, br, 1618s (NH_2).

^{1}H-NMR (DMSO-d_6): 7.7—7.35 (m, 5H, Ar*H*), 7.27 (s, 1H, fulvenyl-C*H*), 6.62 (bd, 2H, fulvenyl-C*H*), 6.37 (t, 2H, fulvenyl-C*H*), 6.09 (bs, 2H, NH_2, exchangeable with D_2O), 2.33 (s, 3H, 3-CH_3).

5d: m.p. 166—7 °C (EtOH or PhH).

UV: 249 (4.10). 286 (3.88), 368 (4.35).

IR: 3455w, 3380w, 3310w, 3180mw, br, 1615s (NH_2).

^{1}H-NMR (DMSO-d_6): 8.08 (s, 1H, 3-C*H*), 7.65 (s, 4H, Ar*H*), 7.35 (s, 1H, fulvenyl-C*H*), 6.86 (d(J = 5Hz), 1H, fulvenyl-C*H*), 6.56 (bs, 3H, fulvenyl-C*H* + NH_2; after addition of D_2O: (d(J = 5Hz), 1H), 6.32 (d, 2H, fulvenyl-C*H*).

* Compounds **2g**, **2h** and **2j** precipitated also in acidic medium.

1,3-Disubstituted 5-disubstituted aminomethylene-aminopyrazoles (7)

To 10 mmol of **1** 10 mmol of DMF or NFP was added followed by enough benzene to form a clear solution (5—40 ml is required). 10 mmol of $POCl_3$ was then added gradually while stirring and cooling at room temperature. After stirring for further 6 hrs at room temperature, the mixture was poured into ice-water (20 g each), the water phase purified with charcoal and neutralized with solid Na_2CO_3. The precipitated product was filtered, washed with water, dried and recrystallized (see Table II).

Alkaline hydrolysis of **7c** and **7d**, carried out as given for the preparation of compounds **6**, gave **1c** and **1d** in 75 and 62% yield, respectively. Vilsmeier formylation of **7b, c** and **d**, carried out at 60—70 °C, however, afforded **2b, c** and **d** in 85, 78 and 72% yield, respectively.

1-(4-Chloro-phenyl)-5-dimethylaminomethyleneamino-4-dimethyliminomethylenepyrazole perchlorate (8d)

To 1.95 g (10 mmol) of **1d**, dissolved in 1.6 ml (1.51 g; 20.7 mmol) of DMF, 1.6 ml (2.68 g; 17.5 mmol) of $POCl_3$ was added gradually at 15—20 °C while shaking. The mixture was warmed for 3 hrs on a water-bath. The resulting oil was dissolved in EtOH (50 ml) and 1 ml of 70% aqueous perchloric acid was added. On cooling, 1.45 g (29%) of **8d**-hydrogen-perchlorate crystallized, which on recrystallization from *abs.* EtOH gave 0.95 g of **8d**.

8d-hydrogen-perchlorate: m.p. 264—6 °C (dec)..
UV: 259 (3.80), 330sh (4.34).
IR: 1715ms, 1685 ms (C=N$^+$), 1635mw (C=N).
8d: m.p. 204—7 °C (EtOH).
UV: 259 (3.77), 330sh (4.31).
IR: 1672s (C=N$^+$), 1635s (C=N).
^{1}H-NMR (TFA): 8.75 (s, 1H, C*H*=N$^+$ or N=C*H*—N), 8.68 (s, 1H, N=C*H*—N or C*H*=*N*$^+$), 8.12 (s, 1H, 3-C*H*), 7.62 (s, 4H, Ar*H*), 3.95, 3.91 (2s, 6H, —N$^+$(C*H*$_3$)$_2$), 3.44, 3.40 (2s, 6H, —N(C*H*$_3$)$_2$).

1,3-Disubstituted 5-acylaminopyrazoles (9—11)

Formylation and acetylation of **1** was carried out at room temperature with excess formyl acetate or Ac_2O, respectively, as described earlier [22] for **10a**. Benzoylation was performed with benzoyl chloride in acetone K_2CO_3 at reflux temperature by a modification of a lit. method [23] (*cf.* Table III).

Vilsmeier—Haack reactions of compounds 9, 10 and 11

(*a*) To 10 mmol of **9, 10** or **11** dissolved or suspended in 30 mmol of DMF, 40 mmol of $POCl_3$ was gradually added and the mixture was warmed on a water-bath for 3 hrs. After pouring into ice-water (50 g each) the insoluble was filtered off and the solution neutralized with solid Na_2CO_3 to yield 67—86% of crude **2**, which after recrystallization were identical with the respective compounds listed in Table I.

(*b*) 10 mmol of **9**, **10** or **11** was dissolved in 50 ml of benzene containing 10 mmol of DMF. While stirring, 10 mmol of $POCl_3$ was added dropwise into the mixture at room temperature and stirring was continued for an additional 6 hrs. During this time a dark, thick oil separated from the mixture. The liquid supernatant was poured into EtOH (20 ml) and after standing for 1 hr at room temperature, the solution was gas-chromatographed. Ethyl formate, acetate and benzoate, respectively, were identified by comparison with authentic samples. Their amount was found to be 85—95% of the theoretical. The thick oil, separated from the reaction mixture was dissolved in 1 *N* HCl, the solution purified with charcoal and neutralized with solid Na_2CO_3 to give 58—76% of crude **7**, which after recrystallization were identical with the respective compounds listed in Table II.

1,3-Disubstituted pyrazolo[3,4-*d*]pyrimidine-5-oxides (14)

To 10 mmol of **2** dissolved in warm EtOH (30 ml) 2.1 g (30 mmol) of HO—NH_2 · HCl was added and the mixture refluxed for 15 min. The products crystallized on cooling (see Table IV).

Table III

Some physical and spectral data of compounds **9—11**

No.	Yield (%)	M. p. from	Formula[a] Mol. weight	IR		^{1}H-NMR			
				amide I	amide II	Solvent	4-C*H*	N*H*	R
9c	49	135—38[b] C_6H_6	$C_{11}H_{11}N_3O$ 201.22	1669s	1560s	DMSO-d_6	6.45s (1H)	10.4—10.8br (1H)	8.28s (1H)
9d	89	105 C_6H_6	$C_{10}H_8N_3ClO$ 221.64	not measured			not measured		
10a	81	90—93[c] EtOAc	$C_{11}H_{11}N_3O$ 201.22	1672s	1550s	$CDCl_3$	6.53d (1H)	8.22s, br (1H)	1.94s (3H)
10b	81	154—56[d] C_6H_6	$C_{17}H_{15}N_3O$ 277.31	1679s	1550s	$CDCl_3$	6.85s (1H)	7.7—8.1br (1H)	1.92s (1H)
10c	78	115—18[e] C_7H_8	$C_{12}H_{13}N_3O$ 215.24	1675s	1548s	$CDCl_3$	6.36s (1H)	8.0s, br (1H)	1.96s (3H)
10d	75	144—46 C_6H_6	$C_{11}H_{10}N_3ClO$ 235.67	not measured			not measured		
10e	79	180 EtOAc	$C_{17}H_{14}N_3ClO$ 311.76	1715ms	1555vs	DMSO-d_6	6.95s (1H)	10.2s, br (1H)	2.07s (3H)
10g	72	197 EtOH	$C_{11}H_{10}N_4O_3$ 246.22	1680s	1550vs[g]	DMSO-d_6	6.54d (1H)	10.4—11.0br (1H)	2.08s (3H)
10h	94	217—20 MeOH	$C_{17}H_{14}N_4O_3$ 322.31	1712s	1553s[g]	DMSO-d_6	7.06s (1H)	10.5s, br (1H)	2.12s (3H)
10i	59	230—32 EtOH	$C_{12}H_{12}N_4O_3$ 260.25	1685s	1540vs[g]	DMSO-d_6	6.33s (1H)	10.3—10.9br (1H)	2.08s (3H)
11a	65	112—15 EtOH	$C_{16}H_{13}N_3O$ 263.28	1665s	1530s	$CDCl_3$	6.70d (1H)	8.6s, br (1H)	7.2—8.9m[h]
11b	89	176 EtOH	$C_{22}H_{17}N_3O$ 339.38	1663s	1540s	DMSO-d_6	7.08s (1H)	11.08s (1H)	7.3—8.9m[h]
11c	51	113[f] CCl_4	$C_{17}H_{15}N_3O$ 277.31	1682s	1550s	$CDCl_3$	6.68s (1H)	8.2br (1H)	7.3—8.1m[h]
11i	67	209—11 EtOAc	$C_{17}H_{14}N_4O_3$ 322.31	1669s	1533s[g]	DMSO-d_6	6.50s (1H)	10.8s, br (1H)	7.6—8.6m[h]

[a] Based on C, H, N, Cl analyses accurate within 0.40%; [b] Reported [24] m.p. 135 °C; [c] Reported [22] m.p. 91—93 °C; [d] Reported [24] m.p. 149 °C; [e] Reported [24] m.p. 110 °C; [f] Reported [24] m.p. 113 °C; [g] Overlapping with the ν_{as} NO_2 signal; [h] 1-Ar*H* signals included

Table IV

Some physical and spectral data of compounds **13, 14**

No.	Yield % Method	M. p. from	Formula[a] Mol. weight	UV	IR aromatic	^{1}H-NMR (TFA)	
						4-C*H*[b]	6-C*H*[b]
13b	87 (*A*) 95 (*B*)	152—54 *n*-BuOH	$C_{17}H_{12}N_4$ 272.30	247 (4.36) 330 (3.72)	1585s, 1565m 1508s	9.35s (1H)	9.68s (1H)
13c	90 (*A*) 97 (*B*) 75 (*C*)	80—3[c] *i*-Pr_2O	$C_{12}H_{10}N_5$ 210.23	245 (4.31) 265 (3.79) 308 (3.27)	1598s, br 1566m 1512s, br	9.30s (1H)	9.65s (1H)
13d	95 (*A*) 84 (*B*) 48 (*C*)	162—65 EtOH or MeOH	$C_{11}H_7N_4Cl$ 230.64	248 (4.48) 270 (3.97) 304 (3.35)	1600s, 1560m 1508vs	9.42s (1H)	9.81s (1H)
14b	88	215—18 EtOH	$C_{17}H_{12}N_4O$ 288.30	260 (4.17) 291 (4.30) 384 (3.66)	1598, 1550w 1508s 1720m (N—O)	9.20d (1H)	9.73d (1H)
14c	73	216 dec. EtOH	$C_{12}H_{10}N_4O$ 226.23	235 (3.77) 270 (3.85) 299 (3.94) 368 (3.44)	1600m, br 1555m, 1515s 1245m, br (N—O)	9.32d (1H)	9.75d (1H)
14d	75	248—50 *n*-BuOH or MeOH	$C_{11}H_7N_4ClO$ 246.66	235 (3.97) 285 (4.38) 360 (3.43)	1600w, 1540m 1508s 1270m (N—O)	9.32d (1H)	9.76d (1H)

[a] Based on C, H, N, Cl analyses accurate within 0.40%; [b] The assignation is arbitrary, though based on literature analogues [25]; [c] Reported [9] m.p. 84 °C (from *i*-PrOH)

1,3-Disubstituted pyrazolo[3,4-*d*]pyrimidines (13)

Method A: 5 mmol of **2** and 0.7 g (13 mmol) of NH_4Cl were refluxed in EtOH (40 ml), for 3 hrs. The products **13** crystallized on cooling.

Method B: To 0.7 g (6.8 mmol) of $(NH_4)_2CO_3$, dissolved in AcOH (10 ml), 5 mmol of **2** was added and the mixture refluxed for 3 hrs. Dilution with water (20 ml) and cooling resulted in crystalline products **13**.

Method C: 2 mmol of **14** and 1.0 ml (1.57 g; 11.5 mmol) of PCl_3, suspended in $CHCl_3$ (20 ml), were warmed on a water-bath for 12 hrs. The solution formed was poured into water (80 ml), the $CHCl_3$ phase separated, dried and evaporated in vacuum. The residue crystallized under water. It was filtered and crystallized (Table IV).

1-(4-Chlorophenyl)-5-dimethylaminomethyleneamino-4-phenyl-iminomethylenepyrazole (15d)

A solution of 2.8 g (10 mmol) of **2d** and 1.0 ml (11 mmol) of aniline in 20 ml of EtOH was refluxed for 5 hrs. The product crystallized on cooling was filtered and recrystallized.

15d: yield 63%; m.p. 132—4 °C (EtOH).

UV: 264 (4.31), 325 (3.95).

IR: 1640s (C=N), 1608s (C=N).

^{1}H-NMR ($CDCl_3$): 8.77 (s, 1H, N=C*H*—N), 8.34 (s, 1H, C*H*=N), 8.08 (s, 1H, 3C*H*), 7.1—8.2 (m, 9H, Ar*H*).

Table V

Some physical and spectral data of compounds **16—18**

No.	Yield (%)	M. p. from	Formula[a] Mol. weight	UV	IR	^{1}H-NMR (DMSO-d_6)		
						CH=N	*NH*	R
16d	86	128—30 EtOH	$C_{19}H_{19}N_6Cl$ 366.85	250 (4.31) 284 (4.39) 341 (4.19)	3312w 1634s	not measured		
16i[b]	51	175—78 EtOH	$C_{20}H_{21}N_7O_2$ 391.43	225 (4.25) 284 (4.27) 301 (4.29) 342 (4.41)	3312m 1626s	7.80s (1H)	c	6.7—7.5m (5H)
17c	63	124—27 EtOAc	$C_{15}H_{19}N_7O$ 313.36	not measured	not measured		not measured	
17d	83	212—15 *n*-BuOH	$C_{14}H_{16}N_7ClO$ 333.79	273 (4.50) 305 (4.22)	3455m 1642s 3420m 3275w 3175m, br	8.1s[d]	10.0br (1H)	6.3br (2H)
17	56	223—25 MeCN	$C_{15}H_{18}N_8O_3$ 358.37	255[e] 301 335	3530w 1645s 3470w 3415w 3120w, br	not measured		
18b	55	191—93 *n*-BuOH	$C_{20}H_{21}N_7S$ 391.50	280 (4.36) 320 (4.11)	3445w 1640s,br 3330vw 3170vw	not measured		
18c	66	133—35 MeCN	$C_{15}H_{19}N_7S$ 329.42	283 (4.43) 323 (4.45)	3310m 1640s,br 3145m, br	not measured		
18d	82	210—12 MeCN	$C_{14}H_{16}N_7ClS$ 349.85	286 (4.49) 327 (4.43)	3430m 1642s,br 3248m 3140m, br	8.03s (1H)	11.1br (1H)	8.0br (2H)

[a] Based on C, H, N, Cl, S analyses accurate within 0.50%; [b] PMR spectrum was obtained in acetone-d_6; [c] Not detected; [d] Overlapping with the *N*=C*H*—N signal; [e] Due to insufficient solubility lg ε cannot be given

1,3-Disubstituted 5-dimethylaminomethyleneamino-4-pyrazolecarbaldehyde hydrazone derivatives 16—18

To 10 mmol of **2**, dissolved in EtOH (20 ml, in the case of **2h** 50 ml), 10.5 mmol of hydrazine derivative (phenylhydrazine, semicarbazide or thiosemicarbazide) was added and the mixture refluxed for 3 hrs. The products crystallized on cooling were recrystallized (Table V).

*

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REFERENCES

[1] OLAH, G. A., KUHN, S. J.: Friedel-Crafts and Related Reactions (Ed. OLAH, G. A.) Vol. **3**, Part 2, p. 1211. Wiley and Sons, New York—London—Sydney 1964
[2] SESHADRI, S.: J. Sci. Ind. Res., **32**, 128 (1973). and references therein
[3] FINAR, I. L., LORD, G. H.: J. Chem. Soc., **1957**, 3314 ; **1959**, 1818
[4] KIRA, M. A., BRUCKNER-WILHELMS, A.: Acta Chim. Acad. Sci. Hung., **56**, 47 (1968); CHANDRAMOHAN, M. R., SARDESSAI, M. S., SHAH, S. R., SESHADRI, S.: Indian J. Chem., **7**, 1006 (1969)
[5] BARNELA, S. B., PANDIT, R. S., SESHADRI, S.: Indian J. Chem., **14B**, 971 (1976)
[6] SWETT, L. R., RATAJCZYK, J. D., YOUNG, P. R.: U. S. 3,544,585; C. A., **74**, 76414 (1971); U. S. 3,686,171; C. A., **77**, 140058 (1972)
[7] STURM, V. J., ARMBRUST, H.: Ger. Offen. 2,008,677; C. A., **76**, 3850 (1972)
[8] KVITKO, I. J., LOGINOVA, T. M.: Zh. Org. Khim., **10**, 1088 (1974)
[9] HÄUFEL, J., BREITMAIER, E.: Angew. Chem., **86**, 671 (1974)
[10] REEVES, R. L.: The Chemistry of the Carbonyl Group (Ed. S. PATAI), p. 593. Interscience, New York, 1970
[11] HOUBEN-WEYL: Methoden der Organischen Chemie, Vol. **VII**/2b, p. 1965, G. Thieme Verlag, Stuttgart 1976
[12] SCHOFIELD, K., GRIMMETT, M. R., KEENE, B. R. T.: Heteroaromatic Nitrogen Compounds: The Azoles. Cambridge University Press, Cambridge 1976
[13] SIMAY, A., TAKÁCS, K. (in preparation)
[14] Preparation of **13c** by reacting **6c** with formamide is reported in Ref. [9]
[15] SCHMIDT, P., DRUEY, J.: Helv. Chim. Acta, **41**, 307 (1958)
[16] ALBERTI, C., TIRONI, C.: Il Farmaco (Ed. Sci.), **22**, 58, 418 (1967)
[17] CHENG, C. C., ROBINS, R. K.: J. Org. Chem. **21**, 1240 (1956)
[18] GRANDBERG, I. I., TING, W-P., KOST, A. N.: Zh. Obshch. Khim., **31**, 2311 (1961)
[19] LONG, R. S.: J. Am. Chem. Soc., **69**, 992 (1947)
[20] ALBERTI, C., TIRONI, C.: Il Farmaco (Ed. Sci.), **19**, 618 (1964)
[21] REYNOLDS, G. A., HUMPHLETT, W. J., SWAMER, F. W., HAUSER, C. R.: J. Org. Chem., **16** 165 (1951)
[22] EICHENBERGER, K., ZÜRCHER, R. F., ROSSI, A., WILHELM, M., SCHMIDT, P.: Helv. Chim. Acta, **48**, 524 (1965)
[23] MICHAELIS, A., SCHÄFER, A.: Liebigs Ann., **397**, 119 (1913)
[24] WILEY, R. H., WILEY, P.: The Chemistry of Heterocyclic Compounds (Ed. A. WEISSBERGER), Vol. **20** Pyrazolones, Pyrazolidinones and Derivatives, p. 236. Wiley-Interscience, New York 1964
[25] ARMAREGO, W. L. F.: The Chemistry of Heterocyclic Compounds (Ed. A. WEISSBERGER), Vol. **24**/1: Quinazolines, pp. 6—37, 450—456. Wiley-Interscience 1967

Antal SIMAY
Kálmán TAKÁCS
Károly HORVÁTH
Péter DVORTSÁK

H-1325 Budapest, P.O.B. 110

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SYNTHESIS OF METHYL 3,6-DIAMINO-2,3,6-TRIDEOXY-β-D-*RIBO*-HEXOPYRANOSIDE, A STRUCTURAL ISOMER OF METHYL NEBROSAMINIDE

(SHORT COMMUNICATION)

I. PELYVÁS and R. BOGNÁR

(Research Group for Antibiotics, Hungarian Academy of Sciences, Debrecen)

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Methyl 3,6-diamino-2,3,6-trideoxy-β-D-*ribo*-hexopyranoside (**I**), a structural isomer of methyl nebrosaminide [1] (methyl tobrosaminide, methyl 2,6-diamino-2,3,6-trideoxy-D-*ribo*-hexopyranoside), has been synthesized from methyl 3-azido-4-*O*-benzoyl-6-bromo-2,3,6-trideoxy-β-D-*ribo*-hexopyranoside (**II**). The latter compound (**II**) was used as a key intermediate in the synthesis [2] of *D*-ristosamine and its derivatives (Fig. 1).

O-Debenzoylation of **II** according to ZEMPLÉN's method gave **III** [2], which was treated with sodium azide in *N*,*N*-dimethylformamide at 120 °C to obtain methyl 3,6-diazido-2,3,6-trideoxy-β-D-*ribo*-hexopyranoside (**IV**) in 92% yield. It is to be noted that the displacement of the bromine atom of the 4-*O*-benzoate (**II**) with azide under similar conditions could only be achieved in moderate (<50%) yields.

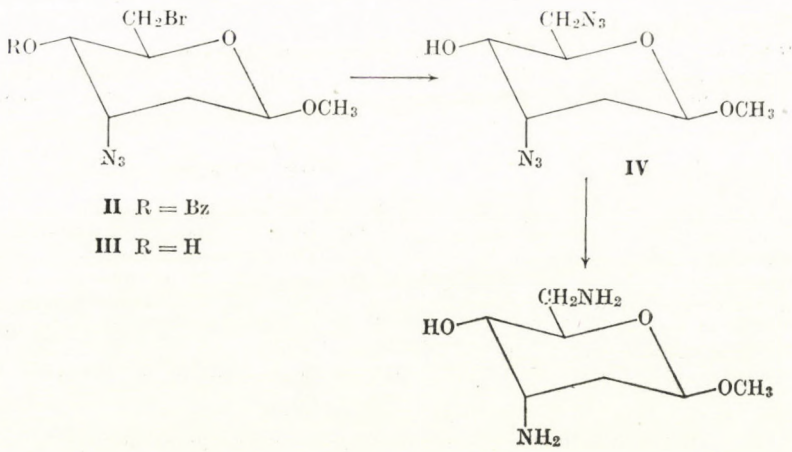

Fig. 1. Synthesis of methyl 3,6-diamino-2,3,6-trideoxy-β-D-*ribo*-hexopyranoside

Hydrogenation of **IV** in the presence of palladium-on-carbon or Raney nickel catalysts failed to give a homogeneous product. However, TLC examinations showed that **IV** readily transformed into the desired methyl 3,6-diamino-2,3,6-trideoxy-β-D-*ribo*-hexopyranoside (**I**) on reduction with lithium aluminium hydride.

According to the ^{1}H-NMR spectra, the $^1C_4$ (D) conformation is strongly favoured for both **I** and **IV** (Table I).

Table I

^{1}H-NMR spectral data of **I** *and* **IV**

Compound	Chemical shifts (δ)								
	H-1	H-2e	H-2a	H-3	H-4	H-5	H-6	H-6'	Others
I[a]	4.77	1.86	1.64	3.26	3.44	3.64	2.98	2.75	3.40 OCH_3
IV[b]	4.67	2.17	1.80	4.09	3.49 →	3.60	—	3.90 →	3.51 OCH_3

Compound	Spin-spin coupling constant $J_{H,H}$ Hz									
	$J_{1,2e}$	$J_{1,2a}$	$J_{2e,2}$	$J_{2a,3}$	$J_{2e,2a}$	$J_{3,4}$	$J_{4,5}$	$J_{5,6}$	$J_{5,6'}$	$J_{6,6'}$
I[a]	1.9	8.7	3.8	4.0	13.7	3.8	8.7	3.8	6.9	13.4
IV[b]	2.5	9.2	3.7	3.2	14.0	3.5	—	—	—	—

[a] Recorded in CD_3OD
[b] Recorded in $CDCl_3$

Recently HORTON et al. [3] synthesized the α-anomer of **I** by the reduction of methyl 3-amino-6-azido-2,3,6-trideoxy-α-D-*ribo*-hexopyranoside.

Experimental

M.p.'s were determined on a Kofler hot-stage apparatus and are uncorrected. ^{1}H-NMR spectra were recorded at 100 MHz with a Jeol MH-100 instrument (tetramethylsilane internal standard). Evaporations were carried out under diminished pressure at 35—40 °C.

Methyl 3,6-diazido-2,3,6-trideoxy-β-D-*ribo*-hexopyranoside (IV)

To a solution of **III** (1.4 g) in *abs.* *N*,*N*-dimethylformamide (8 ml) sodium azide (1.4 g) was added, and the mixture was heated at 120 °C for 10 h. During this period the starting **III** disappeared (TLC in benzene-ethanol 99 : 1) and **IV** appeared. After cooling, the mixture was diluted with water (30 ml) and extracted with ether 3×10 ml. The combined organic layer was washed with water (2×10 ml), dried over $MgSO_4$ and concentrated to give colourless, crystalline **IV** (1.1 g; 91.6%), m.p. 78—79.5 °C, $[\alpha]_D^{25}$ —53.3° (*c* = 0.6, chloroform).

IR (KBr): 2120 cm^{-1} (ν_{C-N} azide); 3410 cm^{-1} (OH).

$C_7H_{12}N_6O_3$ (228.22). Calcd. C 36.83; H 5.30; N 36.83. Found C 37.04; H 5.32; N 36.95%.

Methyl 3,6-diamino-2,3,6-trideoxy-β-D-*ribo*-hexopyranoside (I)

To a cold solution of **IV** (320 mg; 1.4 mmole) in *abs.* ether (20 ml) lithium aluminum hydride (225 mg; 5.91 mmoles) was added and the mixture was refluxed for 2 h under anhydrous conditions. The reaction mixture was cooled to 0 °C and dropwise treated with 5% aqueous

sodium hydroxide solution (2.8 ml) with stirring. Stirring was continued for additional 10 min at room temperature. The mixture was diluted with dichloromethane (20 ml), the organic layer was separated, dried over $MgSO_4$ and concentrated. The syrupy residue was treated with abs. ether to obtain extremely hygroscopic, crystalline **I** (164 mg; 66.4%), m.p. 103—104 °C; $[\alpha]_D^{25}$ —26.8° ($c = 1$, methanol), $[\alpha]_D^{25}$ —44.1° ($c = 1.5$, chloroform).

$C_7H_{16}N_2O_3$ (176.22). Calcd. C 47.71; H 9.15; N 15.90. Found C 47.63; H 9.13; N 15.83%.

*

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REFERENCES

[1] UMEZAWA, S.: Adv. Carbohydr. Chem. Biochem., **30,** 111 (1974)
[2] PELYVÁS, I., SZTARICSKAI, F., SZILÁGYI, L., BOGNÁR, R., TAMÁS, J.: Carbohydr. Res., **68,** 321 (1979)
[3] FUCHS, E. F., HORTON, D., WECKERLE, W., WINTER, B.: J. Antibiotics, **21,** 223 (1979)

István PELYVÁS
Rezső BOGNÁR
H-4010 Debrecen, P.O. Box 20.

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MASSENSPEKTREN ALICYCLISCHER VERBINDUNGEN, VIII*

trans-1-BROM-2-HYDROXYCYCLOALKANE UND *trans*-1-BROM-2-METHOXYCYCLOALKANE

H. REMANE und G. HAUFE

(*Sektion Chemie der Karl-Marx-Universität Leipzig, DDR*)

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Die massenspektrometrische Fragmentierung der *trans*-1-Brom-2-hydroxycycloalkane und der *trans*-1-Brom-2-methoxycycloalkane der Ringgrößen C_5 bis C_8 und C_{12} wird diskutiert und mit der Fragmentierung der Bromcycloalkane, der Hydroxycycloalkane bzw. der Methoxycycloalkane gleicher Ringgröße verglichen.

Die dominierenden Zerfallsreaktionen sind einmal die Abspaltung der funktionellen Gruppen unter Bildung der Fragmente $M—H_2O^{\dagger+}$, $M—HOCH_3^{\dagger+}$ bzw. $M\text{-}Br^{\dagger+}$. Zum anderen der Abbau des Rings unter Bildung der Fragmente $C_3H_4X^{\dagger+}$ (X=Br, OH, OCH_3).

Die Intensitäten der wichtigsten Fragmente zeigen eine deutliche Abhängigkeit von der Ringgröße.

Die Unterschiede in den Intensitäten von *cis*- und von *trans*-1-Brom-2-hydroxycyclododecan sowie von *cis*- und von *trans*-1-Brom-2-methoxycyclododecan erlauben die prinzipielle Unterscheidung der Isomeren an Hand ihrer Massenspektren.

Aus dem Vergleich der Fragmentierung der bifunktionellen 1-Brom-2-hydroxycycloalkane bzw. der 1-Brom-2-methoxycycloalkane mit der Fragmentierung der monofunktionellen Verbindungen kann der Schluß gezogen werden, daß sich die funktionellen Gruppen beim massenspektrometrischen Abbau beeinflussen.

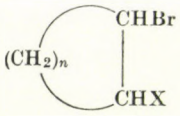
Der massenspektrometrische Abbau von Bromcyclohexan, [2] der Cycloalkanole (C_5 bis C_6) [3] und der Methoxycycloalkane (C_5 bis C_8) [4, 5] ist gut untersucht.

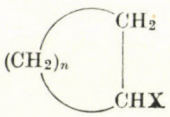
Demgegenüber gibt es zum Fragmentierungsverhalten der homologen Vertreter dieser Verbindungsklassen sowie von gemischt bifunktionellen Cycloalkanen wie den 1-Brom-2-hydroxycycloalkanen und den 1-Brom-2-methoxycycloalkanen kaum Arbeiten [6].

Wir haben daher die Massenspektren der monofunktionellen Cycloalkanole, der Brom- und der Methoxycycloalkane **6** bis **10** sowie der bifunktionellen *trans*-1-Brom-2-hydroxycycloalkane **1a** bis **5a** und *trans*-1-Brom-2-methoxycycloalkane **1b** bis **5b** aufgenommen und diskutiert.

Dabei interessierten neben dem prinzipiellen massenspektrometrischen Abbau Unterschiede und Gemeinsamkeiten im Fragmentierungsverhalten der Verbindungen **1** bis **5** im Vergleich zu den Verbindungen **6** bis **10**. Weiterhin

* VII. Mit.; vgl. [1].





1	$n = 3$	**6**
2	$n = 4$	**7**
3	$n = 5$	**8**
4	$n = 6$	**9**
5 (*cis* + *trans*)	$n = 10$	**10**

a: X = OH
b: X = OCH_3
c: X = Br

sollte die Abhängigkeit der massenspektrometrischen Fragmentierung von der Ringgröße untersucht werden. Im Fallen der Zwölfringverbindungen **5a** und **5b** interessierten Unterschiede in der Fragmentierung der jeweiligen *cis*- und *trans*-Isomeren. Außerdem sollte geprüft werden, ob aus dem massenspektrometrischen Abbau Rückschlüsse auf eine gegenseitige Beeinflussung der beiden funktionellen Gruppen gezogen werden können.

Abbildung 1 zeigt als Beispiel die 70 eV—Massenspektren der untersuchten Cycloheptan-Derivate **3** und **8**. In der Abbildung 2 sind die 70 eV — Massenspektren der Cyclooctan-Derivate **4** und **9** dargestellt. Die mit Hilfe der 12 eV — Spektren ausgewählten Hauptfragmentierungen sind in die abgebildeten Spektren eingetragen worden. Metastabile Übergänge wurden durch* gekennzeichnet.

Eine vergleichende Betrachtung zur Fragmentierung der bifunktionellen Verbindungen *trans*-1-Brom-2-hydroxycycloheptan **3a** und *trans*-1-Brom-2-methoxycyclohepten **3b** mit dem Abbau Cycloheptanol **8a**, von Methoxycyclocheptan **8b** und von Bromcycloheptan **8c** führt zu folgenden Ergennissen:

Die Intensitätswerte für die Molekülionenpeaks von **3a** (0,04%, alle %-Angaben sind auf $\%\Sigma_{39}$ bezogen) und von **3b** (0,2%) liegen zwischen den Werten für die monofunktionellen Verbindungen **8a** (0,4%), **8b** (0,01%) und **8c** (1.3%). In den Spektren der untersuchten bifunktionellen Verbindungen beeinflussen also beide funktionellen Gruppen die Molekülionenstabilität.

Sowohl in den Spektren der Verbindungen **3** als auch **8** sind die dominierenden Primärzerfallsreaktionen einmal die Abspaltung der funktionellen Gruppen und zum anderen die Bildung der Fragmente $C_3H_4X^{1+}$. Der Abbau der funktionellen Gruppe erfolgt im Spektrum von Cycloheptanol **8a** fast ausschließlich durch Eliminierung von H_2O und im Spektrum von Methoxy-

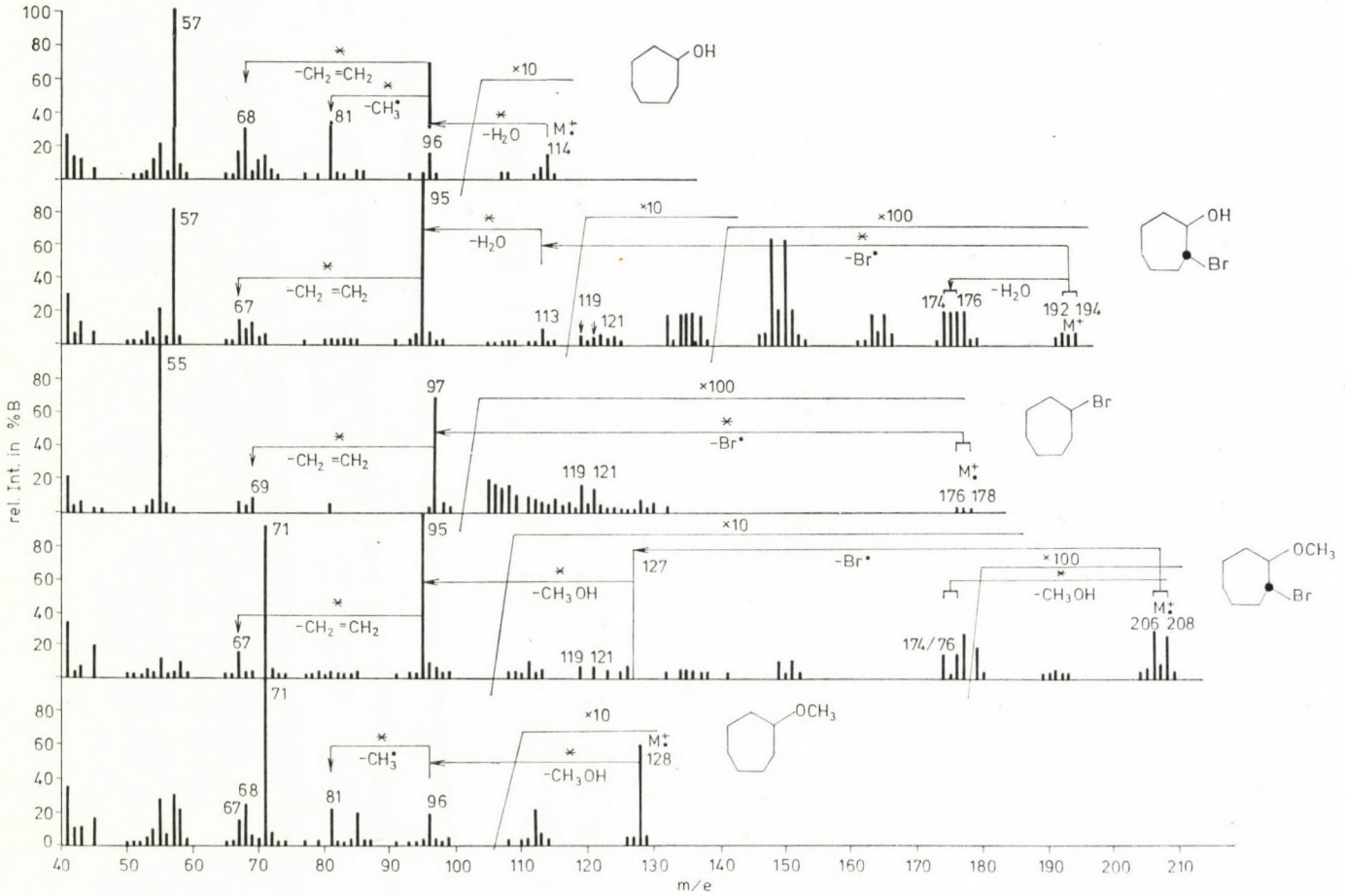


Abb. 1. 70 eV — Massenspektren von Cycloheptanol **8a**, von *trans*-1-Brom-2-hydroxycycloheptan **3a**, von Bromcycloheptan **8c**, von *trans*-1-Brom-2-methoxycycloheptan **3b** und von Methoxycycloheptan **8b**

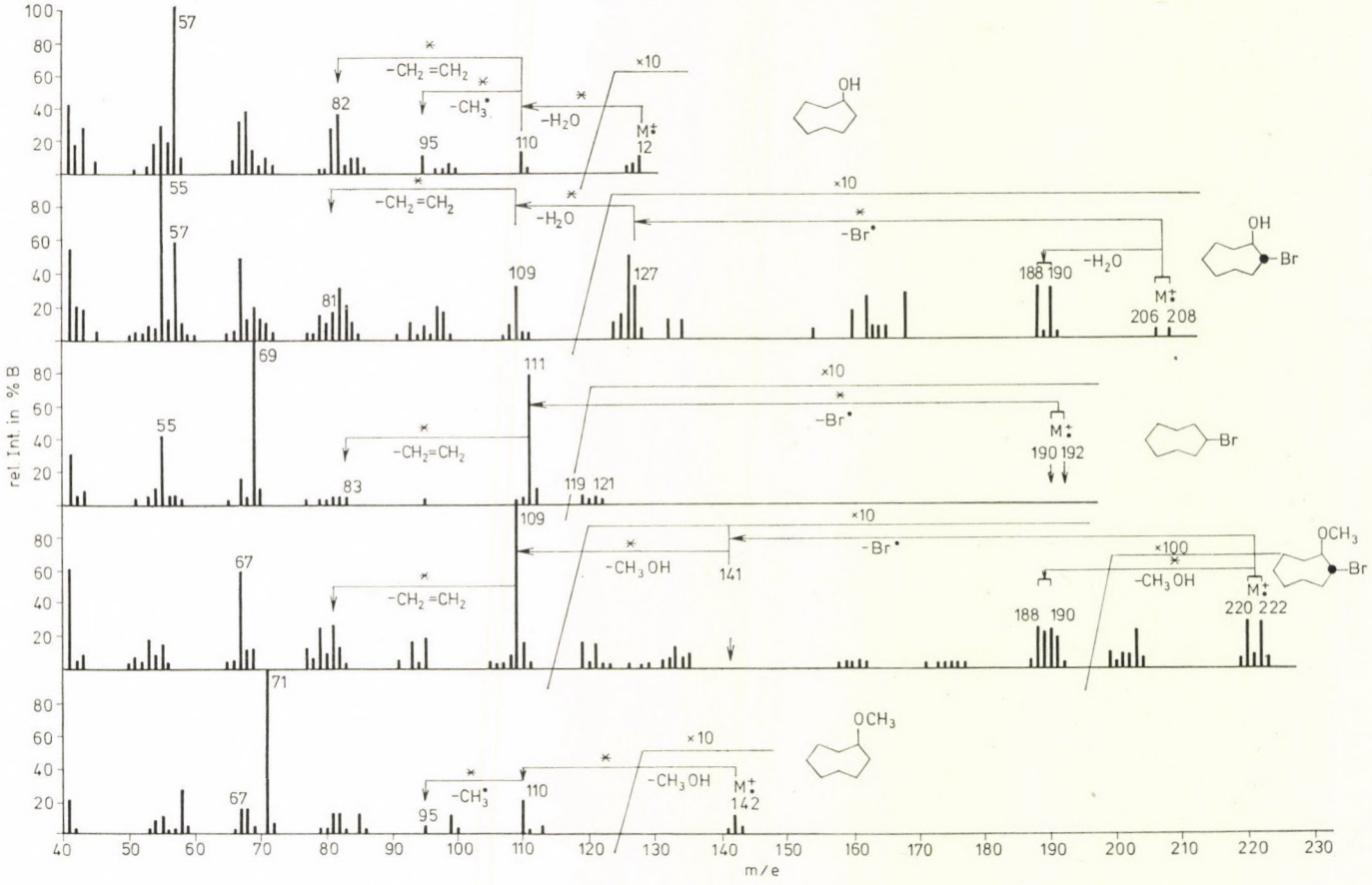
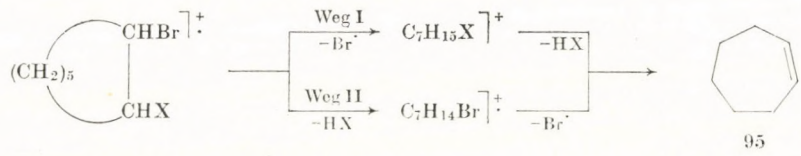


Abb. 2. 70 eV — Massenspektren von Cyclooctanol **9a**, von *trans*-1-Brom -2-hydroxycyclooctan, **4a**, von Bromcyclooctan **9c**, von *trans*-1-Brom-2-methoxycyclooctan **4b** und von Methoxycyclooctan **9b**

cycloheptan **8b** durch Eliminierung von CH_3OH. Im Spektrum von Bromcycloheptan **8c** tritt dagegen die HBr-Eliminierung zugunsten der Bromradikalabspaltung zurück. Die Intensitäten der gebildeten Bruchstücke betragen 4.3% (M—$H_2O^{\urcorner+}$ in **8a**), 4.0% (M—$CH_3OH^{\urcorner+}$ in **8b**), 0.4% (M—$HBr^{\urcorner+}$ in **8c**) und 24.7% (M—$Br^{\urcorner+}$ in **8c**). Die Bromradikalabspaltung ist gegenüber der H_2O- und gegenüber der CH_3OH-Eliminierung stark begünstigt. Die grösseren Intensitätswerte der Fragmente M—$Br^{\urcorner+}$ (2.5% bzw. 2.1% im Vergleich zu M—$H_2O^{\urcorner+}$ (jeweils 0,05%) bzw. M—$CH_3OH^{\urcorner+}$ (jeweils 0,03%) in den Spektren der bifunktionellen Verbindungen **3a** bzw. **3b** bestätigen, daß auch hier diese Tendenz erhalten bleibt. In den Spektren beider bifunktioneller Verbindungen **3a** und **3b** hat jeweils das Fragment 95 die größte Intensität. Es entsteht durch schrittweisen Abbau der funktionellen Gruppen auf folgenden Wegen und hat Cycloheptenyl-Struktur:

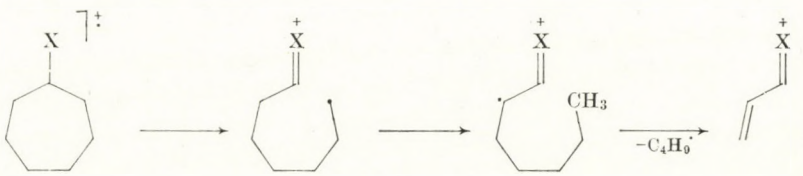
Die größeren Intensitätswerte der M—$Br^{\urcorner+}$-Fragmente gegenüber den M—$HX^{\urcorner+}$-Bruchstücken in den Spektren von **3a** und **3b** weisen darauf hin, daß der Weg I bevorzugt wird.

In den Spektren von **8a** und **8b** hat das Basisfragment die Zusammensetzung $C_3H_4X^{\urcorner+}$ und entsteht in Analogie zum Abbau der vergleichbaren Sechsringverbindungen, vgl. [7], in folgender Weise: Auch das Spektrum von Bromcycloheptan **8c** enthält die vergleichbaren Fragmente (MZ 119 und 121), allerdings mit geringer Intensität. Der Basispeak liegt hier bei der Massenzahl 55 und wird durch das Kohlenwasserstoff-Bruchstück $C_4H_7^{\urcorner+}$ belegt. Aus Abbildung 1 ist ersichtlich, daß auch in den Spektren der bifunktionellen



3a: X = OH

3b: X = OCH_3



8a: X = OH MZ 57 (26,8)

8b: X = OCH_3 MZ 71 (21,8)

8c: X = Br MZ 119/121 (0,1/0,1)

Verbindungen **3a** und **3b** die Bruchstücke $C_3H_4X^{\dagger+}$ vorhanden sind. Die Intensitätswerte, vgl. auch Tabelle I, liegen in der gleichen Größenordnung wie in den entsprechenden monofunktionellen Verbindungen.

Die Fragmentierung der untersuchten Homologen mit 5, 6, 8, vgl. auch Abb. 2, und 12 C-Atomen im Ring erfolgte in prinzipiell gleicher Weise wie bei den vorgestellten Vertretern der Siebenringreihe. Unterschiede bestehen einmal in der Intensitäten der charakteristischen Bruchstücke und zum anderen erwartungsgemäß in der Zunahme der Kohlenwasserstoff-Bruchstücke mit zunehmender C-Zahl. In der Tabelle I sind die Intensitätswerte für $M^{\dagger}$ und einige wichtige Fragmentpeaks zusammengestellt. Fast alle angegebenen Werte nehmen mit steigender Ringgröße ab, z. B. M^+. Fragment 57 und M—$HBr^{\dagger+}$ in den 1-Brom-2-hydroxycycloalkanen **1a** bis **5a**, oder bleiben konstant wie M—$HOCH_3^{\dagger}$ und M—$HBr^{\dagger+}$ in den 1-Brom-2-methoxycycloalkanen **1b** bis **5b** und die Fragmente 119/121 in allen Bromverbindungen. Ausnahmen bilden lediglich die Fragmente M—$H_2O^{\dagger+}$ in den Cycloalkanolen **6a** bis **10a**, M—$HOCH_3^{\dagger+}$ in den Methoxycycloalkanen **6b** bis **10b** und M—$HBr^{\dagger+}$ in den Bromcycloalkanen **6c** bis **10c**.

Zur Klärung der Frage nach den Unterschieden im Fragmentierungsverhalten von *cis*- und von *trans*-1-Brom-2-hydroxycyclododecan **5a** sowie von *cis*- und von *trans*-1-Brom-2-methoxycyclododecan **5b** wurden die Spektren dieser Verbindungen einer vergleichenden Betrachtung unterzogen.

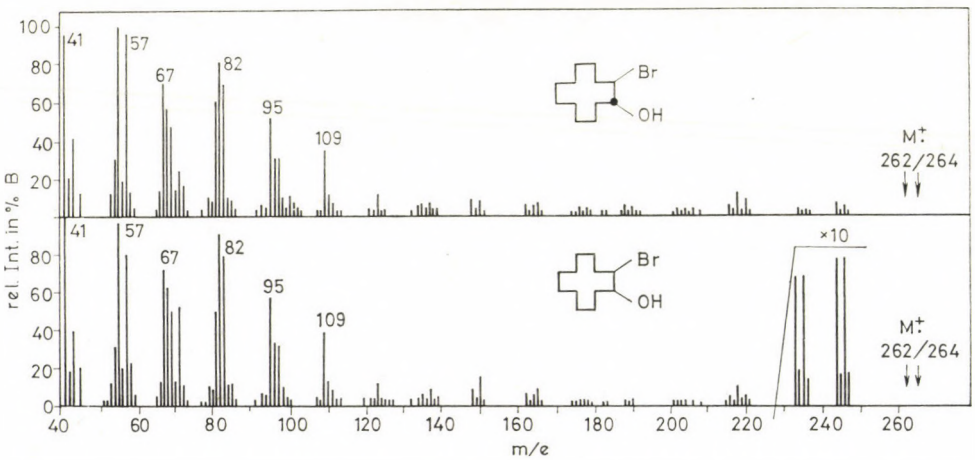


Abb. 3. 70 eV — Massenspektren von *trans*- und von *cis*-1-Brom-2-hydroxycyclododecan **5a**

In der Abbildung 3 sind als Beispiel die 70 eV — Massenspektren von *cis*- und von *trans*-1-Brom-2-hydroxycyclododecan **5a** dargestellt, in der Abbildung 4 werden die entsprechenden 70 eV — Massenspektren von *cis*- und von *trans*-1-Brom-2-methoxycyclocodecan **5b** gezeigt.

Tabelle I

Massenzahlen und Intensitäten (bez. auf % Σ_{39}) wichtiger Peaks in den 70 eV — Massenspektren der Verbindungen **1** *bis* **10**

Verbindungen	Peak	Verbindung **6** bzw. Verbindung **1**	Verbindung **7** bzw. Verbindung **2**	Verbindung **8** bzw. Verbindung **3**	Verbindung **9** bzw. Verbindung **4**	Verbindung **10** bzw. Verb. **5** *(cis)*	Verbindung **10** bzw. Verb. **5** *(trans)*
6a—10a	M^+	86 (4,5)	100 (0,4)	114 (0.4)	128 (0.2)	184 (0.01)	
6b—10b	M^+	100 (5,0)	114 (4,6)	128 (1.3)	142 (0.3)	198 (0.04)	
6c—10c	M^+	148 (0.3)	162 (0,4)	176 (0,003)	190 —	246 —	
		150 (0,3)	164 (0,4)	178 (0,003)	192 —	248 —	
1a—5a	M^+	164 (3,3)	178 (0,5)	192 (0,02)	206 (0,05)	262 —	262 —
		166 (3,3)	180 (0,5)	194 (0,02)	208 (0,05)	264 —	264 —
1b—5b	M^+	178 (3,0)	192 (1,7)	206 (0,1)	220 (0,05)	276 (0,2)	276 (0,3)
		180 (3,0)	194 (1,7)	208 (0,1)	222 (0,05)	278 (0,2)	278 (0,3)
6c—10c	$M—Br^{\cdot}]^+$	69 (47,4)	83 (27,4)	97 (24,7)	111 (22,2)	167 (0,5)	
1a— 5a	$M—Br^{\cdot}]^+$	85 (6.5)	99 (8,8)	113 (2,5)	127 (0,45)	183 (0,1)	183 (0,1)
1b— 5b	$M—Br^{\cdot}]^+$	99 (0,6)	113 (1,5)	127 (2,1)	141 —	197 (0,2)	197 (0,1)
6a—10a	$M—H_2O^{\cdot}]^+$	68 (3,3)	82 (1,8)	96 (4,3)	110 (2,1)	166 (0,5)	
6b—10b	$M—HOCH_3^{\cdot}]^+$	68 (1,8)	82 (6,3)	96 (4,0)	110 (6,1)	166 (1,8)	
6c—10c	$M—HBr^{\cdot}]^+$	68 (3,6)	82 (0,8)	96 (0,4)	110 (0,6)	166 (2,6)	
1a— 5a	$M—H_2O^{\cdot}]^+$	146 (0,5)	160 (0,1)	174 (0,05)	188 (0,3)	244 (0,5)	244 (0,5)
		148 (0,5)	162 (0,1)	176 (0,05)	190 (0,3)	246 (0,5)	246 (0,6)
1a— 5a	$M—HBr^{\cdot}]^+$	84 (0,7)	98 (0,4)	112 (0,4)	126 (0,7)	182 (0,1)	182 (0,1)
1b— 5b	$M—HOCH_3^{\cdot}]^+$	146 (0,2)	160 (0,1)	174 (0,03)	188 (0,4)	244 (0,7)	244 (0,6)
		148 (0,2)	162 (0,1)	176 (0,03)	190 (0,4)	246 (0,7)	246 (0,6)
1b— 5b	$M—HBr^{\cdot}]^+$	98 (0,2)	112 (0,1)	126 (0,1)	140 —	196 (0,2)	196 (0,1)
1a— 5a	$M—Br—H_2O^{\cdot}]^+$	67 (8,3)	81 (28,1)	95 (24,4)	109 (4,4)	165 (0,6)	165 (0,5)
1b— 5b	$M—Br—HOCH_3^{\cdot}]^+$	67 (9,2)	81 (21,0)	95 (26,0)	109 (17,8)	165 (1,9)	165 (1,1)
6a—10a	57	(50,7)	(38,3)	(26,8)	(18,4)	(6,5)	
1a— 5a	57	(38,0)	(21,4)	(19,9)	(1,9)	(5,5)	(7,1)
6b—10b	71	(36,5)	(38,2)	(21,8)	(30,2)	(4,1)	
1b— 5b	71	(43,2)	(26,5)	(24,1)	—	(15,0)	(11,2)
6a—10a	119	(0,1)	(0,1)	(0,1)	(0,1)	(0,1)	
	121	(0,1)	(0,1)	(0,1)	(0,1)	(0,1)	
1a— 5a	119	(0,2)	(0,1)	(0,1)	—	(0,1)	(0,1)
	121	(0,2)	(0,1)	(0,1)	—	(0,1)	(0,1)
1b— 5b	119	(0,3)	(0,1)	(0,1)	(0,3)	(0,1)	(0,1)
	121	(0,3)	(0,1)	(0,1)	(0,3)	(0,1)	(0,1)

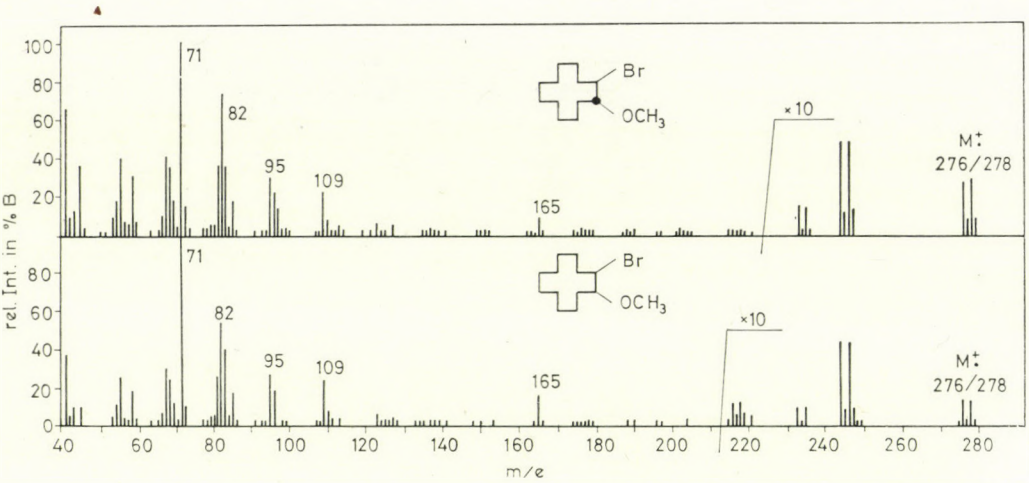


Abb. 4. 70 eV — Massenspektren von *trans*- und von *cis*-1-Brom-2-methoxycyclododecan **5b**

Es läßt sich erkennen, daß in den belegten Massenzahlen kaum Unterschiede zwischen den Spektren der jeweiligen *cis*- und *trans*-Verbindungen bestehen. Demgegenüber unterscheiden sich die Intensitäten der meisten Peaks. Dadurch ist es prinzipiell möglich (wenn Vergleichsspektren vorliegen), die *cis*- und die *trans*- Isomeren mit Hilfe ihrer Massenspektren zu unterscheiden.

Ein Vergleich der Massenspektren der bifunktionellen Verbindungen **1** bis **5** mit den Massenspektren der monofunktionellen Verbindungen **6** bis **10** zeigt, daß beim Abbau von **1** bis **5** sich die funktionellen Gruppen deutlich beeinflussen. So liegen beispielsweise die Intensitätswerte von $M^{+\cdot}$ in **1** bis **5** zwischen denen für die monofunktionellen Verbindungen **6** bis **10**. Weiterhin sind die Intensitäten für $M—H_2O^{+\cdot}$, $M—HOCH_3^{+\cdot}$ und $M—Br^+$ in den Spektren der bifunktionellen Verbindungen kleiner als in den Spektren der monofunktionellen Vertreter gleicher Ringgröße, vgl. auch Tabelle I. Die sonst charakteristischen Bruchstücke $C_3H_4X^+$ (Massenzahl 57, 71 bzw. 119/121) sind dagegen nicht repräsentativ.

Aus unseren Untersuchungen lassen sich folgende Schlüsse ziehen:

Im massenspektrometrischen Abbau der untersuchten bifunktionellen 1-Brom-2-hydroxycycloalkane **1a** bis **5a** und 1-Brom-2-methoxycycloalkane **1b** bis **5b** spiegelt sich die Fragmentierung beider monofunktioneller Verbindungen wider.

Die Unterschiede in den Intensitäten von $M^{+\cdot}$ und von charakteristischen Fragmentpeaks wie z. B. $M—HX^{+\cdot}$ und $M—X^+$ weisen auf eine gegenseitige Beeinflussung der funktionellen Gruppen im Verlauf des massenspektrometrischen Abbaus hin.

Die untersuchten *cis-trans*-isomeren Zwölfring-Verbindungen **5a** bzw. **5b** lassen sich mit Hilfe ihrer Massenspektren unterscheiden. Beim massenspektrometrischen Abbau sowohl der monofunktionellen Verbindungen **6** bis **10** als auch der bifunktionellen Vertreter **1** bis **5** ist eine deutliche Abhängigkeit der Intensität charakteristischer Bruchstücke von der Ringgröße nachweisbar.

Experimenteller Teil

Die *trans*-1-Brom-2-hydroxycycloalkane **1a** bis **5a** und die *trans*-1-Brom-2-methoxycycloalkane **1b** bis **5b** wurden durch Hydroxybromierung bzw. durch Methoxybromierung der entsprechenden Cycloalkene mit *N*-Bromsuccinimid in wäßrigem Dioxan bzw., in absolutem Methanol dargestellt [8, 9]. Die Cycloalkanole **6a** bis **10a** standen als Handelsprodukte zur Verfügung oder wurden aus Cycloalkanonen durch Reduktion erhalten. Die Methoxycycloalkane **6b** bis **10b** sind durch Reduktion entsprechender 1-Brom-2-methoxycycloalkane mit Natrium in flüssigem Ammoniak dargestellt worden.

Die Bromcycloalkane **6c** bis **10c** waren durch Addition von HBr and die Cycloalkene bzw. durch Umsetzen der Cycloalkanole mit HBr oder PBr_3 zugänglich.

Die Struktur der dargestellten Verbindungen wurde durch Vergleich mit Literaturdaten sowie an Hand ihrer IR- und ihrer NMR-Spektren gesichert. Die Werte für die Mikroanalysen (C, H, Br) stimmten mit den berechneten überein.

Die Aufnahme der Massenspektren erfolgte mit einem Massenspektrometer der Firma varian MAT (CH-6) bei 70 eV und bei 12 eV. Ionenquelle IXE 5, Temperetur 200 °C, Emissionsstrom 30 μA, Kathode Re-Draht, indirekt Einlaß.

*

Wir danken Herrn Chem.-Ing. L. Goetz für die Aufnahme der Massenspektren.

LITERATUR

[1] Remane, H., Herzschuh, R.: Organic Mass Spectrom. (im Drück)
[2] Moll, F., Heiss, J.: Dt. Apotheker Ztg., **109**, 1525 (1969)
[3] Natalis, P.: Bull. Soc. Roy. Sci. Liège, **31**, 790 (1962)
[4] Klein, G. W., Smith, V. F. jr.: J. Org. Chem., **35**, 52 (1970)
[5] Jones, R. B., Waight, E. S., Herz, J. E.: Organic Mass Spectrom., **7**, 781 (1973)
[6] Gounelle, Y., Péchiné, J.-M., Solgadi, D.: Organic Mass Spectrom., **7**, 1287 (1973)
[7] Remane, H., Herzschuh, R.: Massenspektrometrie in der organischen Chemie, Akademie-Verlag Berlin 1977, S. 72.
[8] Haufe, G., Mühlstädt, M., Graefe, J.: Mh. Chem., **107**, 653 (1976)
[9] Haufe, G., Mühlstädt, M., Graefe, J.: Mh. Chem., **108**, 803 (1977)

Horst Remane
Günter Haufe
KMU, Sektion Chemie, DDR-701 Leipzig, Liebigstr. 18.

Acta Chimica Academiae Scientiarum Hungaricae, Tomus 105 (2), pp. 155–157 (1980)

SULFENYL CHLORIDES, XIII*

A NEW PROCEDURE FOR THE SYNTHESIS OF SULFONIC ACID THIOL ESTERS FROM THIOLS

J. PINTYE and G. STÁJER

(Institute of Pharmaceutical Chemistry, Medical University, Szeged)

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Chlorination of thiols in alkali carbonate media yielded symmetrically substituted alkyl- and arylsulfonic acid thiol esters (thiosulfonates). The procedure is simple, intermediates need not be isolated.

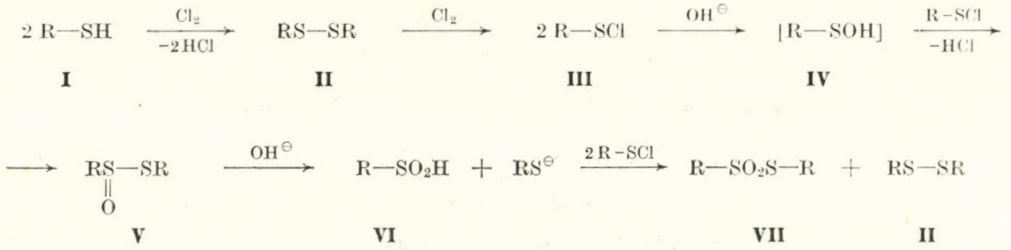
Symmetric thiolsulfonates are usually prepared by the oxidation of disulfides or by the sulfenylation of a sulfinic acid [1, 2, 3]. Besides these the DOUGLASS—FARAH method [4, 5] has been widely applied in practice, consisting in the chlorination of thiols and disulfides in aqueous acetic acid to obtain thiolsulfonates. Just recently a procedure suitable for the direct preparation of thiolsulfonates from thiols has been described, in which the oxidation of thiols is effected by means of nitrogen tetroxide [6]. These procedures involve at least two steps, there are intermediates formed during the oxidation, the product requires chromatographic purification, or the process is slow.

In the present work, aliphatic and aromatic thiols have been converted into symmetrically substituted thiolsulfonates in petroleum ether solutions, in alkaline media containing sodium carbonate, by the introduction of the calculated amount of chlorine (2 moles) at room temperature; the yields are between 70 and 98%. The procedure requires simple reaction conditions. Isolation of the intermediates is unnecessary; in most cases the thiolsulfonate can be separated by filtration.

In respect of the mechanism, it can be assumed that chlorine oxidizes the thiol (**I**) to the disulfide (**II**) this is further converted into sulfenyl chloride (**III**) [7], as indicated by the orange colour of the petroleum ether phase. The colour gradually becomes paler, since the sulfenic acid (**IV**) formed by the hydrolysis of **III** is sulfenylated by the sulfenyl chloride to yield sulfinic acid thiol ester (**V**) (it is possible that **V** is formed from 2 moles of **IV** [8, 9]). The intermediates **II** and **V** can be detected in the reaction mixture by thin-layer

* Part XII: G. STÁJER, J. REISCH and A. E. SZABÓ: Acta Chim. Acad. Sci. Hung. **105**, 99 (1980)

chromatography. Subsequent nucleophilic attack by the OH^- ion [10] at the positively polarized sulfinyl sulfur atom of **V** gives sulfinic acid (**VI**). This is sulfenylated to thiosulfonate (**VII**), while the leaving thiolate anion is converted by **III** into the disulfide (**II**), which takes part again in the process.



a R = Ph
b R = *p*-ClC_6H_4
c R = *p*-$CH_3C_6H_4$
d R = $CH_2C_6H_5$
e R = *p*-$CH_3OC_6H_4$
f R = *p*-$AcNHC_6H_4$
g R = *n*-Bu

The amount of chlorine required was determined experimentally by TLC examinations of samples wich was drawn from the reaction mixture periodically. Optimum yield was attained at the ratio 1 mole of thiol : 2 moles of chlorine; in this case sulfochloride did not appear in the reaction mixture. When using a thiol: chlorine ratio of 2 : 1, only the disulfide was obtained. The reaction on a 0.05 mole scale requires about 30 min. In the majority of cases (**Ib—f**) the thiolsulfonate can be isolated simply by filtration from the heterogeneous reaction mixture. When this is not the case, the petroleum ether phase is separated and the residue recrystallized after evaporation to dryness (**VIIa, g**). The thiolsulfonates obtained were compared with authentic samples [3] and identified by means of m.p., IR, TLC and elemental analysis data. In all cases, the reaction product also contained various amounts of disulfide (**II**), accompanying **VII**. The solubility of the former is, however, significantly higher, thus it remains in the petroleum ether phase. In the case of **VIIa, g**, the majority of the disulfide can be removed by sucking off from the crystalline residue.

Experimental

Preparation of thiosulfonates

A solution of the thiol (0.05 mole) in petroleum ether (50 cm^3) was mixed with 20% sodium carbonate solution (50 cm^3). Chlorine gas (7 g; 0.1 mole), condensed in a vessel cooled by a mixture of carbon dioxide and acetone, was introduced into the reaction mixture at room

temperature, with stirring. In the case of compounds **VIIb—f**, the separated solid was filtered 30 min later, dried and recrystallized. In the preparation of **VIIa, g**, the petroleum ether phase was separated, dried over Na_2SO_4 and evaporated to dryness. The crystalline residue was then recrystallized. The experimental data are given in Table I.

Table I

Preparation of thiosulfonates

Thiol (I)	0.05 mole (g)	Recrystallization	M. p., °C	Yield of thiosulfonate (VII)	
				g	%
a	5.5	Petroleum ether-EtOH (9 : 1)	44— 45	5.5	88
b	7.2	MeOH	133—134	7.7	96
c	6.2	MeOH	76— 77	5.0	72
d	6.2	MeOH-benzene (8 : 2)	107—108	6.8	98
e	7.0	MeOH	94— 95	7.0	90
f	8.35	EtOH	223—224	6.4	70
g	4.5	Petroleum ether-EtOH (8 : 2)	126—127	4.5	86

Thin-layer chromatography

Layer: Kieselgel G (Stahl); developing mixture; benzene-petroleum ether (1 : 1); detection with $KMnO_4$ containing sodium carbonate. The order of distances of the spots from the start was, *e.g.*, in the case of *p*-chlorothiophenol (compound, R_f): **Vb** 0.27; **VIIb** 0.56; **IIb** 0.88.

REFERENCES

[1] Hinsberg, O.: Ber., **41**, 2836 (1908)
[2] Leandri, G., Tundo, A.: Ann. Chim. (Rome), **44**, 74 (1954); C. A., **49**, 4563 (1955)
[3] Klivényi, F.: Magyar Kémiai Folyóirat, **64**, 121 (1958)
[4] Douglass, I. B., Farah, B. S.: J. Org. Chem., **24**, 973 (1959)
[5] Field, L., Parsons, T. F.: J. Org. Chem., **30**, 657 (1965)
[6] Kim, Y. H., Shinhama, K., Fukushima, D., Oae, S.: Tetrahedron Letters, **1978**, 1211
[7] Houben-Weyl: Methoden der org. Chem., **9**, 272 (1955)
[8] Vinkler, E., Klivényi, F.: Acta Chim. Acad. Sci. Hung., **11**, 16 (1957); **22**, 345 (1960)
[9] Vinkler, E., Klivényi, F., Lázár, J., Kozakiewicz, I.: Acta Chim. Acad. Sci. Hung., **60**, 169 (1969)
[10] Oae, S., Takata, T., Kim, Y. H.: Tetrahedron Letters, **1977**, 4219

János Pintye
Géza Stájer
H-6701 Szeged 1, P.O.B. 121.

RECENSIONES

R. C. ELIOT: *Boiler Fuel Additives for Pollution Reduction and Energy Saving*

Energy Technology Review No. 33.
Pollution Technology Review No. 53.
Chemical Technology Review No. 120.

Noyes Data Corporation, Park Ridge 1978, 230 pages

Problems of incomplete combustion, soot deposition and sludge formation are common to most hydrocarbon fuel oils. Thus, boiler fuel additives can be effective means of reducing emissions and, at the same time, increasing overall boiler efficiency.

Various kinds of compounds have shown merit as combustion improvers, including surfactants, organometallics and low molecular weight polymers. Alkaline earth and transition metal additives in concentrations of 20 to 50 ppm of metal in the fuel oil were effective in reducing particulate emissions. For added versatility the organometallic compound is usually blended with dispersants and other ingredients to make a multipurpose product.

The first chapter of the book is based on a report written for the Environmental Protection Agency (EPA) of the U.S.A. and published in January 1977. This chapter is a state-of-the-art review and has the title "Additives for Pollution Control" The reader is given a concise introduction to the

— different kinds of pollutants,
— the mechanism of pollutant formation in combustion process,
— possibilities of controlling combustion-generated emissions by additives,
— scope of experimental investigation (three summary tables showing the quantitative data found in the technical literature for combustion additives),
— effects of the additives on particulate emissions and smoke, on polycyclic organic matter, on sulfur oxides and on nitrogen oxides.

The information reviewed in this chapter was taken from 103 papers, congress proceedings, reports and patents published all over the world.

The longest and perhaps most important chapter in the book is the second one, having the title "Experimental Evaluation of Additives". It is also based on another report written for the Enviromental Protection Agency and the Federal Energy Administration, summarizing the results of an extensive experimental program carried out by the BATTELLE—COLUMBUS Laboratories and published in January 1977. The experimental program was conducted in a commercial fire-tube packaged boiler of 500 kW capacity, generating up to 680 kg/hr of steam at 103 kN/m^2 (15 psig). A total of 24 fuel additives of representative fuels were evaluated when firing residual oils at a continuous rate. Eleven of the additive types were also evaluated when firing distillate oil. In addition, some additives were evaluated under cyclic operation, variable load, and with a detuned burner so that the effectiveness of additives could be assessed as a function of these operating conditions.

A previous EPA program involved tests of numerous commercial additives used with distillate heating oil in a residential oil burner. In general, the additives were found to have a minor effect compare to the opportunity for emission control by proper adjustment and operation of the burner. However, the additives containing manganese, iron or cobalt did reduce the particulate emissions. None of the additives were found to be effective in reducing sulfur oxide emissions or for nitrogen oxides.

This investigation extended the program to larger combustion systems. Of particular interest was the determination of additive effectiveness in reducing smoke and particulate emissions including polycyclic organic matter.

In the second chapter the plan of experimental investigations with description of the experimental facility, experimental procedures, fuel and additive specifications, the experimental results and interpretation of the results are given. It is difficult to summarize the results of such an extensive investigation in a few sentences, but it can be stated that the use of additives with distillate oil firing would allow boilers to be operated at lower excess air levels and

thereby, increase efficiency. In this case, sophisticated controls or manual attention would be required to control the air to fuel ratio precisely, as any slight change in boiler operation could cause a drastic change in the excess air level and the emission of particulates, CO, and unburned hydrocarbons. Only in the largest boilers would these controls be economically feasibe and the larger oil-fired boilers generally are fired with residual oil.

With residual fuels, barium naphthenate was most effective in reducing both smoke and particulate emissions.

In addition to the experimental results and their discussion, the second chapter contains also subchapters on the economics of additive utilization, on the possible mechanisms by which additives affect particulate emissions, on the perspective on fuel additives and a short review of the different types of fuel handling additives. The second chapter is followed by 100 references.

The last three chapters of the book are based entirely on the U.S. patent literature and consist of the detailed and clear description of 52 U.S. Patents issued between January 1970 and 1978. The additives are grouped according to their functions.

Thus, the third chapter is devoted to fuel handling additives. Patents referring to additives for increasing fuel stability, dispersants, flow improvers and pour depressants, corrosion inhibitors and other additives are reviewed.

In the fourth chapter, combustion additives are dealt with. Different types of combustion efficiency improvers, smoke suppresants and additives preventing arsenic sublimation on combustion are described.

The last, short chapter has the title "Post-flame treatment additives". Here different additives and compositions for the reduction of slag build-up, prevention of soot deposition, stabilization of metallic fuel additives, and for prevention of corrosion and ash deposition are reviewed.

In the last three chapters, the patents are simply reviewed but not evaluated in comparison with each other. Nevertheless, the reader gets a good picture of the different types of additives, the possible domain of their applications and their effectiveness.

At the end of the volume, the primary sources on which the book is based, are listed: the two U.S. government reports (chapters one and two) and 52 U.S. patents (chapters 3—5) indexed by company, inventor and patent number.

G. SZÉCHY

M. SITTIG: *Hazardous and Toxic Effects of Industrial Chemicals*

Noyes Data Corp., 1979. p. 460

In the book about 250 entries deal with toxic organic and inorganic substances, starting from acetaldehyde through Portlandcement to zirconium compounds. In fact, far more compounds are dealt with, since the individual groups of compounds appear under one entry, thus, *e.g.*, acetates comprise the properties of 10 acetic acid esters.

The author and the publishing house recommend the work primarily to the attention of industrial hygienic experts, but in the reviewer's opinion, this could be interesting for all researchers and industrial chemical engineers. The reader can get a picture of not only the hazards connected with chemicals known up to now, but the non-confirmed potential harmful effects are also indicated.

The compounds discussed are arranged in alphabetic order and each section has the same structure. *Description* of the compound consists of the molecular formula, a short summary of the physical properties and eventually the way of production, too.

After listing the *synonyms*, there is a summary of syntheses, manufacturing processes, users and application fields, where workers can come into contact with the given compound. The *allowable exposition limits* are values accepted in the USA, given in mg/m^3 and ppm units. The *ways of entering the organism* (Route of Entry) are followed by a detailed discussion of the toxic effects of the compounds: local and systematic harmful effects and eventual mutagenic and carcionogenic effects are listed, together with the potential hazards.

In the section Medical Surveillance, the necessary periodic medical examinations are prescribed, the *special tests* are related with special medical-laboratory examinations. In a separate chapter the *personal protection methods* are discussed.

The minimum one-page entry is finished with a *bibliography*.

L. FENICHEL

Hans-Werner KEMMER und Kurt SCHWABE: *Einführung in die statistische Thermodynamik*

Akademie-Verlag, Berlin 1979. p. 150

Die klassische Thermodynamik liefert in ihrem geschlossenen und strengen System sichere Informationen über die wichtigsten Eigenschaften der in der Natur verlaufenden Vorgänge. Im allgemeinen kann sie jedoch experimentelle Daten nicht entbehren, und die Bestimmung dieser Daten ist — besonders in komplizierten Systemen — keine einfache Aufgabe. Die statistische Thermodynamik gibt uns Mittel, womit die Gesetze der mikroskopischen Welt untereinander verbunden werden können. Zur Zeit stützen sich immer mehr und mehr technische und Hochschulveröffentlichungen auf due Verfahren der statistischen Thermodynamik, und die zunehmende Anzahl der Ergebnisse bestätigt, daß die statistische Thermodynamik bei weitem nicht praxisentfernt ist.

Um das Buch zu-verstehen, sind Kenntnisse über die klassische Thermodynamik sowie elementare Kenntnisse der klassischen und Quantenmechanik nötig. Die Eintellung ist folgende:

Wahrscheinlichkeit und Kombinatorik	10 Seiten
Statistische Beschreibung makroskopischer Systeme	25 Seiten
Gase	49 Seiten
Die spezifische Wärme idealer Kristalle	8 Seiten
Flüssigkeiten	40 Seiten
Anhang	9 Seiten

Das Buch enthält 20 Abbildungen.

Im Abschnitt *Statistische Beschreibung makroskopischer Systeme* werden folgende Probleme behandelt: Makro- und Mikrozustände, statistische Verteilungen, Phasenraum und mikrokanonische Ensemble kanonische und großkanonische Ensemble, Entropie und Temperatur, thermodynamische Potentiale und Verteilungsfunktionen. Der Abschnitt *Gase* behandelt das ideale Gas, die Maxwell-Boltzmannsche Statistik, die kanonische Ensemble, das Fermi- und Bose-Gas, reale Gase, zwischenmolekulare Kräfte, Unordnung und Verteilungsfunktion, Wirkung des Druckes, die Virialgleichung und die Berechnung der Virialkoeffizienten; im Abschnitt *Spezifische Wärme idealer Kristalle* werden das Einsteinsche Modell und das Debyesche Modell erörtert; der Abschnitt *Flüssigkeiten* befaßt sich mit reinen Flüssigkeiten, mit der Zellen-, Löcher- und Tunneltheorie, der Berechnung molekularer Verteilungsfunktionen, mit Störumgstheorien, Mischungen von Nichtelektrolyten, mit regulären Gemischen und der Zellentheorie, mit Lösungen starker Elektrolyte, mit der Debye-Hückelschen Theorie und der Bogoljubows Theorie.

Der *Anhang* behandelt das Liouville-Pinzip und die Rolle der Energie, Quantenstatistik, Zustandsfunktionen und Dichtematrix, sowie das Liouville-Prinzip der in Quantenstatistik.

Aus dem Inhalt und Umfang des Buches ist das Meßhalten der Verfasser ersichtlich: sie bschränken sich auf eine präzise und verständliche Darstellung der wesentlichsten Zusammenhänge. Seit der ersten Ausgabe des Buches wurde besonders der Inhalt des Abschnittes über Flüssigkeiten erweitert, da die Forscher in den letzten Jahren auf diesem Gebiet viel neue und bedeutende Ergebnisse erreicht haben. Nach Meinung des Rezensenten hätten jedoch einige Beispiele den Wert des Buches erhöht und angegeben werden sollen, selbst wenn dadurch eine Vergrößerung des Umfangs notwendig geworden wäre. Da keine numerischen Beispiele enthalten sind, treten in den meisten Fällen keine Maßsystem-Probleme auf. Die Debye-Hückelsche Theorie ist jedoch noch mit den Formeln gemäß dem CGS-System dargestellt.

Von diesen wenigen Unzulänglichkeiten abgesehen ist das Buch eine äußerst nützliche Einleitung für Fachleute, welche die Methoden der statistischen Thermodynamik anzuwenden wünschen.

Gy. VARSÁNYI

NMR: Basic Principles and Progress, Volume 16
Editors: P. DIEHL, E. FLUCK, R. KOSFELD
^{31}P and ^{13}C-NMR of Transition Metal Phosphine Complexes

By Paul S. PREGOSIN and Roland W. KUNZ (Eidgenössische Technische Hochschule, Zürich)
Springer-Verlag Berlin—Heidelberg—New York, 1979. p. 156

For several years, coordination chemists have used phosphorus as a ligand for the stabilization of transition metals in various oxidation states. In spite of this fact, interest has increased towards these complexes; ^{31}P-NMR has been employed as an analytical tool only in relatively few laboratories and, beside ^{1}H- and ^{13}C-NMR, the ^{31}P-NMR properties have hardly been studied at all. The socalled PFT-NMR spectroscopy has developed strongly, and this greatly altered the picture today. Coordination chemists understand the importance of application of the NMR method. For this reason, the authors tried to outline what knowledge is required for the ehmist for effective utilization of the method and they also provide a summary of application of the individual NMR parameters in solving given chemical problems.

The book is divided into two main parts. In the first and larger part (Chapters 1—4) ^{31}P-NMR, in the second part (Chapter 5) ^{13}C-NMR studies of phoshporus-containing complexes are discussed. In the appendix a large number of measured data are given in a clear form.

In Chapter 1, the main data regarding ^{31}P-NMR are summarized. Since the ^{31}P is about 16 times less sensitive for NMR spectroscopy than the proton, the introduction of broad-band ^{1}H-decoupling and PFT-NMR technique, making possible rapid spectrum accumulation, was very important. It is very advantageous that ^{31}P-NMR is usually very simple and covers about 200 ppm, furthermore, the chemical shift of the individual signals is strongly altered by slight changes in the chemical environment of the P-atom. Since, in view of the time of recording and chemical structure, relaxation is very important and informative, this problem is dealt with separately. In the process of relaxation the dipole-dipole mechanism is primarily predominating. It is very advantageous that in complex compounds, in accordance with the reduced mobility of the complex, the above mechanism becomes more emphasized and the relaxation time is significantly shortened. In view of the signal/noise ratio, that is, sensitivity, it is very important that the broad-band ^{1}H-decoupling technique, resulting in the appearance of sharp ^{31}P-NMR signals, is accompanied by a maximum increase of 124% in intensity (Nuclear Overhauser Effect), too.

In the second chapter the coupling between the various transition metals and phosphorus atom attached to them and the coupling between two P-atoms attached to the metal are discussed.

In Chapter 3, chemical shift and the factors affecting it are treated. It is very interesting that beyond the electronegativity of the substituents attached to phosphorus the X-P-X angle also affects significantly the chemical shift, furthermore, similarly to ^{13}C-NMR spectroscopy, substitution at the γ position again the chemical shift 2—6 ppm. A linear correlation was found between the chemical shift characteristic of free phosphine and the change occurring on complex formation. The ^{31}P chemical shift was found to be useful in the determination of the steric structure of complexes and in distinguishing cis and trans isomers.

In Chapter 4, the above statements are illustrated on actual examples and the effectivity of the method is demonstrated. The dynamic NMR studies of the Du Pont group are particularly interesting and provide a picture of the kinetics of intramolecular transformations of pentacoordinated phosphorus compounds.

Although ^{31}P-NMR spectroscopy seems for chemists to be the most direct method of studying metalphosphorus interactions, when the chemical changes occur relatively farther from the phosphorus atoms, ^{13}C- and ^{1}H-NMR can be more suitable for monitoring them. Since several papers have been published on this topics, using ^{1}H-NMR spectroscopy, in Chapter 5 the authors deal only with the ^{13}C-NMR investigation of phosphorus-containing transitions metal complexes. This chapter is followed by the appendix and the tables, which contain the most important data required for understanding the above statements. The book contains 259 references covering the period 1970—1978.

The book presents the applicability of ^{31}P- and ^{13}C-NMR spectroscopy and their effectiveness in the investigation of phosphorus-containing complex at a very high level and still simply and clearly, thus it is strongly recommended the attention of chemists and biologists engaged in this field, as well as of NMR specialists.

G. TÓTH

G. E. SCHULZ and R. H. SCHIRMER: *Principles of Protein Structure*

Springer-Verlag, New York, 1979. p. 314

In the last decades one of the most outstanding achievements of science was the determination of the structure of proteins that provided the basis for the development of molecular biology. Today, the complete structure of nearly one hundred proteins is known, and on the basis of these informations the main lines of the general principles prevailing at the highest level of molecular organization of matter are being revealed. The pathway of the organization of matter into living leads through multimolecular systems of protein and nucleic acid molecules.

The main purpose of the present book is to reveal the principles of the organization of matter into structures of increasingly higher level of complexity manifested in the structure of proteins. It is an excellent summary of the knowledge about the structure of proteins available at the present time. The authors, the one of whom is an expert in X-ray crystallography, the other is a biochemist, do not stop at registering the collected data, but searche primarily for a correlation between the structure and biological function of proteins. Thus the book can be characterised by the synthesis of structural-static and functional-dynamic aspects.

In accordance with its title, the book intends to present the fundamental principles, therefore, it can be regarded neither as a monograph, nor as an introductory text-book. The eleven chapters form separate units dealing with individual problems of the wide-spread topics and, according to the opinion of the authors, they can be read in optional order. None of the chapters is customary. Interesting notes related to the most recent results of protein chemistry can be found in connection with even the simplest problems, *e.g.* the structure of amino acids. The authors often only refer to the well known facts and discuss only the recent results in detail. The physico-chemical, organic chemical, biochemical and genetic aspects of the structure and function of proteins are fused into a common picture in every chapter. It is just this way of treatment that makes the book interesting for the somewhat informed readers, but can involve some drowbacks for those who want to get acquainted with the basic principles of protein chemistry from this book. However, it cannot be said that the book is intended for the specialists, since the emphasis is always on the integration of the wide-spread knowledge and on the comprehensive picture of the protein chemistry as a whole. Therefore, researchers working in different fields of protein chemistry or biochemistry can read this book with great benefit.

In processing the enormous amount of information, the authors attempt to extract general rules from the partial results collected up to now and to establish general principles, even if these are not entirely worked out or generally accepted. By organizing and systematizing the knowledge, they provide an aid for the deeper understanding and a stimulus for further research.

The style of the book is rather concise, but the division of the text into many subchapters, the emphasis of the essence of these smaller units by bold-faced headings and the short summaries at the ends of the individual chapters facilitate the handling. The rich figures and the thorough explanations attached to them also serve better understanding. The appendix at the end of the book provides a deeper statistical mechanical treatment of conformational changes in protein molecules. A list of 805 references complete the book.

M. KAJTÁR

Ch. S. SODANO: *Water and Soil Repellents for Fabrics*; *Chemical Technology Review No. 134*

Noyes Data Corp., Park Ridge, N. J. 1979. p. 395

Volume **134** of the Chemical Technology Review acquaints the reader with patent specifications relevant to the field named in its title, issued in the U.S.A. "Water and Soil Repellents for Fabrics" is a complete collection of such patents granted in the U.S.A., from 1970 through 1978. Two volumes, published in 1970, and entitled, respectively. "Soil Resistant Textiles" and "Waterproofing Textiles" contain earlier U.S. patents of these two fields.

The purpose of the book is to offer detailed information concerning the patents granted, to satisfy technological interest and to eliminate the difficulties, due to patent phraseology, in the way of understanding the originals.

A substantial amount of information, made available here, cannot be found in scientific of professional journals.

The table of contents is constructed so as to serve also as the subject index. The book is complete with lists of patent holders, inventors and patent numbers.

This volume is a source of information valuable for researchers of textile finishing also for organic chemists whose job is to search for, and to manufacture, auxiliary chemicals applicable to fabrics.

The principal chapters are as follows.

— Fluorinated acrylic polymers (17), with nitrogen- or sulfur content; copolymers, graft polymers, and polymer compositions.

— Fluorinated polymers (23), with sulfur content, aminoplasts, nitrogen-containing and other polymers.

— Compositions with fluorinated polymers (14) with acrylic content, applicable for drycleaning other compositions for various purposes.

— Fluorinated compounds with silicon or sulfur (11); perfluoroalkylsilanes; fluorinated sulfates, sulfonates, sulfonamides and sulfones.

— Fluorinated amines (15), pyridinium salts, other quaternary amines, adducts of melamine derivatives, tertiary amine esters.

— Fluorinated amides (13), examples of the preparation of these; aromatic fluorinated amides.

— Other fluorinated compounds (15) with phosphorus content; poly(fluorio-*iso*-alkoxy-alkyl-isocyanates); fluorinated tertiary alcohol intermediates, trimellitates, *etc.*

— Acrylic polymers (27), copolymers, acrylic mixtures with synergetic effects; the method of the application of these in textile finishing, drycleaning and laundering; compositions.

— Aminoplasts (16), preparation, compositions and methods of applications.

— Silicon compounds (6), preparation and compositions.

— Polyesters (8), preparation, compositions and methods of applications.

— Other compounds (51), metal containing ones, styrene, maleic acid and cellulose derivatives; compounds with sulfur and with nitrogen; polyols; cyclic imides, *etc*

The figures in breackets after the headwords indicate the number of patents referred to, 214 altogether in this book. In some of these, surprisingly full particulars are revealed.

I. Rusznák

A. Yehaskel: *Industrial Wastewater: Cleanup Recent Developments*

Noyes Data Corp., Park Ridge, N. J. 1979

This is a book written for experts and researchers active in the field of communal and industrial waste water treatment and in development work bound up with this.

The reader is made acquainted with the patents issued in the waste water treatment field, made available to the public in the U.S.A., in 1977 and 1978. The presentation is such that also readers not familiar with the style of patents will understand the matter easily. Where the specifications reveal characteristic data of relevant processes, these are also reported.

The Author lists fifteen reasons for which the technological information gathered from patents is considered most useful. Such information is concise yet sufficiently detailed to help realization by the expert, and is also commercially exploitable. Patent literature is a storehouse of sound ideas: knowledge of these prevents duplication of research work already done elsewhere; knowledge, at the same time, of accomplishments not yet protected is important help in the elaboration of novel methods. An overall view of alternative methods — amply referred to in patent literature — widens technological choice. Besides all this, and due to efforts for the protection of intellectual property, new scientific results can sooner to be learned from patents than from scientific journals.

The book is structured according to the main titles as follows (these titles also describe the field covered).

— Solid-liquid separation processes.
— Oil—water seperation processes.
— Metals.
— Metal finishing. Pulp and paper.
— Coal, ore and sand processing.
— Chemical and biological treatment.
— Fluorine, phosphorus and polymers.
— Food and other natural products.
— Specific contaminant removal and other processes.

This division seems to be arbitrary in some respects as the headwords selected refer partly to technologies and partly to the origin of waste water. The table of contents, however, is well arranged, information is easily retrievable. The book is complete with the list of patentees and inventors. Patent number, and names of patentee and inventors, respectively, are given as references. This is sufficient if the purchase of licence rights is contemplated.

Among the methods described some are rather peculiar, for example the electrochemical treatment of fatty or oily emulsions, reverse osmosis, activater sludge treatment with active carbon addition, various ion exchange techniques, thermal and oxidative detoxification of various toxie waste waters from the chemical industries.

Of course, it cannot be known yet which of the methods described have proved to be efficient in practice because most of the patents are quite recent innovations. The Author does not comment in this respect, either. However, in our days, when the transfer of technological know-how and scientific-technical information is of paramount importance, the usefulness of this book can hardly be overestimated, even if we have to consider that the majority of these processes are realizable in industrially well developed countries only.

P. FARKAS

Tibor KREMMER and LÁSZLÓ BOROSS: *Gel Chromatography — Theory, Methodology, Applications*

Akadémiai Kiadó, Budapest, 1979
299 pages, 133 figures, 47 tables

Gel chromatography was introduced only around 1960, but it is now a standard procedure in almost every biochemical laboratory and a known method in other chemical laboratories, too. The very rapid development of this liquid chromatographic technique shows the need for a separation method of this kind. Therefore, a critical review of the results in the field of gel chromatography is especially timely.

This book is the revised version of the original Hungarian "Gélkromatográfia" published by Műszaki Könyvkiadó, Budapest.

The book is divided into three main parts.

The topic of Part I is the fundamentals and theory of gel chromatography, including gel-forming substances and the structure of gels and the most recent kinetic and steric-volumetric theories, based on the analogy with the non-miscible polymer solutions and the osmotic properties of gels. According to famous works (ANDREW's investigations; SIEGEL and MONTY's investigations; the DETERMANN equations *etc.)* the correlation between molecular dimensions and the size of the gel pores as an important field of gel chromatography is demonstrated clearly and in detail by the authors. In sections of Part I the comparison of the empirical relationship between the volumetric parameters and the molecular weight of solutes in gel chromatography with theoretical aspects also has an important place. There is a logical connection between the sections in this part. It helps to understand the laws of this fundamentally simple procedure.

Part II deals with the methods and techniques of gel chromatography. The sections of this part discuss all the practical techniques, preparation and treatment of various gels, equipment, the normal and special devices used in the column, thin-layer chromatography or batch procedures. In the sections the reader finds pieces of advice to choose the best method for a given separation problem. The discussion of the methods and techniques follows the logical sequence of practice.

Part III summarizes the applicability of gel chromatography in the investigation of natural and synthetic compounds as well as inorganic ions by means of typical examples. The

laws and regularities of the gel chromatography of various proteins, nucleic acids, polysaccharides, oligosaccharides are surveyed shortly, illustrating with examples the different applications of the technique. The sections of Part III demonstrate that the success of the gel chromatographic separation of natural compounds acted as a powerful stimulant for analyses in synthetic organic chemistry. The sections of Part III illustrate convincingly that gel chromatography is suitable also for the fractionation of small organic molecules (*e.g.* aliphatic and aromatic hydrocarbons, organic acids, alcohols, ethers, phenols, organic bases, *etc.*). Therefore, gel chromatography becomes more and more known in various chemical laboratories.

The book is a very well written, outstanding work. It gives a full review of gel chromatography with good illustrations and sufficient methodological detail. Bibliography is carefully edited and contains all the substantial references to gel chromatography. A subject index at the end of the book, as well as the detailed table of contents at the beginning make possible a rapid orientation in a given gel chromatographic problem.

The book greatly helps orientation in the large subject and will serve as an excellent guide for chemists, biochemists, physicians and others interested in the theory and practice of gel chromatography.

E. TYIHÁK

MEL'NIKOV, V. N. and BLINICHEVA, J. B.: "*Theoreticheskie Osnovy Tekhnologii Krasheniya Voloknistykh Materialov*"

(Theoretical Principles of Dyeing Technology of Fibres) p. 303. (in Russian)
Izdat. Legkaya Industriya, Moscow, 1978

This volume offers a systematic review and evaluation of the results achieved in the fields of theory and practice of the dyeing of polar and of apolar fibre-forming polymers, with cellulose and polyethylene-terephthalate fibres as the models.

Kinetic and thermodynamic analyses of the dyeing processes in aqueous, non-aqueous solutions and in the solid phase serve as the foundation for the review of the roles of the most important factors in the dyeing process. Considering also dyeing processes carried out in organic solvents and at higher temperatures, conclusions are drawn in respect of the elaboration of better and more rational dyeing technloogies.

In this monograph its Authors have ordered the subject matter in chapters as follows

— *Fibres, as ones of the active participants in the dyeing process.* (Characteristics of fibre-forming polymers, due to their molecular and submicroscopic structure. Connexions between these characteristics and the dye-bonding qualities, and the affecting of these.)

— *Properties of dye solutions.* (Connexion between the chemical structure of colouring substances and the dyeing potency of these. The process of dissolution of dyes in water. Interactions of dyes and organic solvents. Advantageous modification of the state of dyes dissolved in water. The role of solubilization and hydrotropism in the aqueous dissolving of non-ionic dyestuffs.)

— *Physical and chemical basis of the dyeing of natural and of synthetic fibres in aqueous media.* (The normal affinity, enthalpy, and enthropy of dyeing. The role of the structure of the fibre and that of the dyestuff in the interactions as realized. The state and the distribution of the dyestuff within the fibrous materials.)

— *Kinetics of dyeing processes.* (The foundations of linear, non-equilibrium thermodynamics, and the application of it, in the study of dyeing processes. Kinetic models of dyeing processes.)

— *Perspectives of dyeing techniques in aqueous media.* (The role of liquid proportions in dyeing; the advantages of low liquid proportions. Activation of dyeing processes by higher temperatures. The effects of organic solvents and hydrotropic substances in the elaboration of dyeing processes.)

— *Theoretical basis of dyeing in the vapour and in the solid phases.* (Dyeing with vaporized dyestuffs: fixation mechanism in in the thermosol-dyeing and transfer-printing of fabrics from man-made fibres. Mechanism of thermal fixation for reactive dyestuffs on cellulose-based fibres. Progress of thermal fixation techniques for the colouring of textiles made from natural or synthesis fibres or from mixtures of these.)

— *Thermodynamic and kinetic aspects of dyeing synthetic fibres in organic solvents.* (Characterization of organic solvent applicable in textile dyeing. Distribution of dyestuff-concent-

rations in the fibre and in the bath when dyeing in an organic solvent is carried out The diffusion and the fixation processes in dyeing and in printing with organic solvents.)

This book deserves attention from theorists and practical experts alike in dyeing and printing of fibres and yarns. It is a useful aid in graduation and in post-graduate studies for the acquisition of knowledge of theories as well as of practical applications relative to dyeing.

I. RUSZNÁK

Chemistry Reviews, Vol. 1 (1979)
Soviet Scientific Reviews, Section B

Edited by M. E. VOLPIN

Published under licence and ditributed by Harwood academic publishers GmbH, Chur, Schweiz, pp. IX + 277

This series of volumes has been started with the aim of making recent scientific advances in the USSR accessible to scientists who do not read Russian. The review papers on selected fields of physics (Section *A*) and chemistry (Section *B*) are scheduled to appear on a yearly basis, to be followed by volumes on other branches of science. This effort is coordinated by the Academy of Sciences of the USSR. The speed of publication is strongly emphasized.

Volume 1 of Chemistry Reviews consists of the following articles:

1) Effect of magnetic field on radical reactions in solution (Yu. N. MOLIN, R. Z. SAGDEEV and K. M. SALIKHOV); p. 67, 98 references;

2) Molecular basis for heterogeneous catalysis by acids through the participation of Brönsted centers (V. KAZANSKII); p. 50, 21 references;

3) New developments in the reaction mechanisms of organometallic compounds (I. P. BELETSKAYA); p. 86, 70 references;

4) General principles of enzymatic catalysis (I. V. BEREZIN, A. A. KLYOSOV and K. MARTINEK); p. 72, 125 references.

The first paper is a survey on the effect of magnetic field on radical reactions. As noted by the authors, attempts at demonstrating this effect experimentally have mostly yielded negative results. The situation has changed with the discovery of magnetic effects involving triplet excitation in solids and the chemical polarization of nuclei. The experimental results over the past few years concerning free radical reactions are treated together with the underlying theory. Among other interesting features, the magnetic isotope effect is described and the likely future development of this new field is indicated.

The second paper is concerned with a field that has been extensively studied in connection with heterogeneous catalysis on surfaces featuring Brönsted acid centers. The main investigative tool is IR spectroscopy utilizing hydroxy group bands in the 5000—10,000 cm^{-1} region. The authors show how spectral data of this type may be used to obtain the height and shape of the potential barrier for proton transfer in heterogeneous acid catalysis.

The title of the third paper seems to be too general. Present-day organometallic chemistry is a very broad subject concerned with an unprecedented variety of compounds and reactions. The author concentrates on the substitution and redox reactions of organomercury and organotin compounds, revealing a number of interesting mechanistic patterns. A separate chapter is devoted to the reactivity of carbanions.

Enzymatic catalysis is the subject of the fourth paper. A factor determining enzymic activity is the sorption (binding) of the substrate to the enzyme so as to facilitate subsequent chemical reactions. Transition state theory is used to draw conclusions on enzyme-catalyzed reactions, altough the limitations of this approach are duly pointed out. Aspects of modelling natural enzymes are discussed.

This is a valuable book whose authors and editor have succeeded in demonstrating how the achievements of Soviet scientists are interconnected with the general advances in four selected fields of chemistry. The reviews are well written and translated, although the ever recurring problems of unified transliteration are still obvious: on p. 69 two names with the same ending are spelled differently. It is not desirable to translate journal names, as is done

on p. 117 (Kinetics and Catalysis for Kinet. Katal.) Printing is nice as are illustrations and figures.

The book, and further volumes in the series, will undoubtedly serve the purpose of surmounting the language barrier, as emphasized in the preface and foreword.

L. I. SIMÁNDI

Lecture Notes in Chemistry, Vol. 12
The Permutation Group in Physics and Chemistry

Springer-Verlag, Berlin—Heidelberg—New York 1979. p. 230

In July, 1978, a Symposium was organized at the Centre for Interdisciplinary Studies of the University of Bielefeld upon the subject of permutation symmetry groups. This volume contains thirteen contributions of the meeting. Permutation symmetry considerations are rapidly becoming important, in particular in molecular spectroscopy, due to new interest in large amplitude motions in molecules. The boost behind is the rapid advance of high resolution spectroscopic techniques. The present book contains a set of previously uncorrelated ideas and mathematical techniques. In the following, short resumés of each chapter are given.

A. KERBER: *Counting isomers and such.* On the basis of PÓLYA's paper in combinatorics, various developments in enumeration theory are described for defining and counting isomeric molecular structures. The author uses multigraphs appropriate for various bond orders. Chemists will need graph theoretical education to appreciate the work.

J. G. NOURSE: *Application of the permutation group to stereoisomer generation for computer assisted structure elucidation.* The paper defines the configuration symmetry group based on graph theory for generating, classifying and enumerating stereoisomers of organic molecules of a given empirical formula. The example of tetramethyl-cyclobutane is used for illustration purposes. A limitation is that the method is not capable of taking conformational problems (*se.g.* internal rotation) into account. Again, for understanding, a thorough group theoretical knowledge is indispensable.

J. G. NOURSE: *Applications of the permutation group in dynamic stereochemistry.* Various intramolecular rearrangements, such as the Berry pseudorotation, can be described by permutation group concepts. The paper investigates the relationships among chemical concepts (isomerization modes, combined experiments with different effective symmetry groups, *etc.)* and group theoretical categories (cosets, subgroups, *etc.)*. Without group theoretical know-how, the average chemist is going to profit but little from this work.

P. R. BUNKER: *The spin doulbe groups of molecular symmetry groups.* A theoretical classification paper for the electron-vibrational-rotational energy levels of molecules, for which electron spin double groups are required. The paper is clearly written, plentifully illustrated by energy level diagrams, and is explicit enough to give a glimpse into the spectra of ionic species, *e.g.*: $CH_3BF_2^+$. Highly recommended paper for molecular spectroscopists on advanced levels.

J. D. LOUCK: *Relationship between the feasible group and the point group of a rigid molecule.* An interesting work to elucidate the role of conventional point group symmetries for rigid molecules, and their relations to feasible permutation-inversion symmetry operations. Eckart conditions and the rovibrational Hamiltonian function are specifically dealt with. The conclusion is that for rigid molecules there appears to be no need for the introduction of symmetries higher than geometrical.

A. W. M. DRESS: *Some suggestions concerning a geometric definition of the symmetry group of non-rigid molecules.* The paper indicates that geometrical symmetry approaches may exist for non-rigid molecules. This contribution is characterized by heavy mathematical presentation. The chemist who is able to absorb these concepts is lucky.

R. S. BERRY: *Symmetry and thermodynamics from structured molecules to liquid drops.* This is a beautiful and original paper whose main feature is correlations among rigid and non-rigid structures, illustrated copiously on simple three- and four-body problems. Non-rigid molecules are treated on equal footing to clusters of atoms, albeit they are found to lie fairly close to the rigid limit. This work is likely to be important for spectroscopists dealing with large-amplitude problems.

The following three papers are: L. C. BIEDERHARN and J. D. LOUCK: *Representations*

of the symmetric group as special cases of the boson polynomials in U(n); J. D. LOUCK and L. C. BIEDERHARN: *The permutation group and the coupling of n spin — 1/2 angular momenta*; B. R. JUDD: *The permutation group in atomic structure.* These three contributions are rather specially aimed at the problems of spin and angular momentum couplings in molecules and atoms. The treatments are based on the classification of electronic wave functions using the symmetric group. All three papers use a rather advanced formalism for angular momentum algebra.

In the next two papers: T. H. SELIGMAN: *Double cosets and the evaluation of matrix elements*; J. S. FRAME: *Properties of double cosets with applications to theoretical chemistry*, the authors deal with the applications of the symmetric group irreducible representations in calculations of the quantum mechanical matrix elements *(e.g.* configurational mixing matrix elements) for molecular spectroscopic problems. In FRAME's paper the infrared and Raman spectra of complexes are treated in particular; noteworthy for chemical spectroscopists interested in ligand and skeletal motions.

Finally A. W. M. DRESS in his paper: *The chirality algebra* describes the Ruch—Schönhofer chirality theory for rigid and nonrigid molecules. This is a presentation for popularizing chirality algebra among mathematicians, and so it is not directly intended for the physicochemist. DRESS points out that the Ruch—Schönhofer theory is applicable for phase transitions in molecules as well.

As a conclusion we can state that Volume **12** of the Series helps research workers in the theoretical fields of chemistry and physics in their efforts to update their symmetry apparatus to meet modern structural and spectroscopic demands. The book contains many references, is nicely printed with few typographic errors.

L. NEMES

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SULFENYL CHLORIDES, XIV*

THE REACTION OF ARYLTHIOLSULFONATES WITH ARYLSULFENYL HALIDES

J. LÁZÁR and E. VINKLER

(*Institute of Pharmaceutical Chemistry, Medical University, Szeged*)

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Utilizing partial results published earlier [8], the sulfenylation reaction of aromatic thiolsulfonates was investigated. Aromatic thiolsulfonates rapidly react with sulfenyl bromide in acetonitrile solution, whereas with sulfenyl chloride the splitting of the thiolsulfonate bond proceeds only in dimethylformamide and under forceful conditions.

Sulfenyl halides, acting as sulfenyl cations, are known in the literature as electrophilic reagents [1—3]. They have been used so far, only in a new cases for the splitting of the sulfur-sulfur bond. In the case of disulfides, MOORE and PORTER [4] described the splitting of the sulfur-sulfur bond and the exchange of aryl groups. DOUGLASS [5], DOUGLASS and KOOP [6] examined the reaction of methane- and ethanesulfenyl chlorides with aliphatic thiolsulfonates, and PINTYE, STÁJER and VINKLER [7] reported on the conversion of trichloromethanesulfenyl chloride with aromatic thiolsulfonates. The reaction of methanesulfenyl chloride with methane- and methane-ethane--thiolsulfonates was first described by DOUGLASS [5].

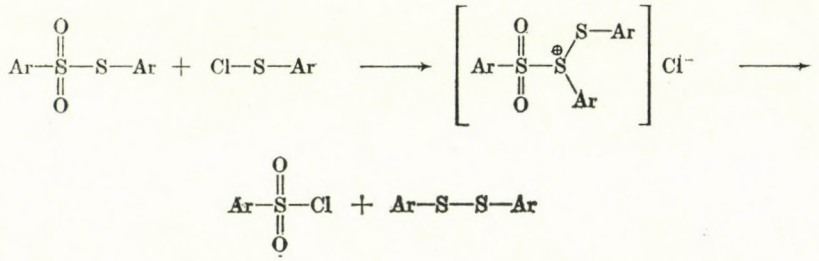
In our earlier communication [8], dealing with the reaction of thiolsulfonates with sodium halides in dimethylformamide, several parallel and consecutive reactions have been assumed leading to the end-product obtained. Of these, a decisive role was attributed to the reaction of *p*-toluenesulfenyl chloride with *p*-toluenethiolsulfonate (1).

$$Ar-S-Cl + Ar-SO_2-S-Ar = Ar-S-S-Ar + Ar-SO_2-Cl \qquad (1)$$

In spite of the fact that according to PINTYE *et al.* this reaction did not occur either in a polar glacial acetic acid [7], or in an apolar benzene [9] solvent, in our model experiments performed in dimethylformamide the as-

* Part XIII: PINTYE, J., STÁJER, G.: Acta Chim. Acad. Sci. Hung., **105,** 155 (1980)

sumed reaction pathway, the splitting of the sulfur-sulfur bond could be effected also in the case of aromatic thiolsulfonates. The course of the reaction is depicted by the following scheme (2).



(2)

Since this reaction has been described so far only for aliphatic compounds [5], it seemed interesting to study the case of a few aromatic compounds, and to investigate the effect of the halogen of the sulfenyl halides on the course of the reaction. It was found that the substituents of the aromatic, ring did not affect the course of the reaction in a perceptible measure but suddes difference was observed if sulfenyl bromide was used instead of the chloride. With sulfenyl chloride the reaction proceeded very slowly and gave a somewhat poorer yield, whereas in the case of sulfenyl bromide it was very rapid. With sulfenyl chloride, the reaction could be effected only in dimethylformamide, while sulfenyl bromide readily reacted also in acetonitrile. The sulfonyl chloride, presumably formed during the sulfenylation in dimethylformamide, could not be isolated because it decomposed in the reaction mixture; therefore, the sulfonic acid formed from it was characterized in the form of its *S*-benzylisothiuronium salt. In the reaction mixture obtained in acetonitrile, the sulfonyl bromide was characterized as sulfonamide. The disulfide formed as the end-product could be continuously detected in increasing quantities by thin-layer chromatography in both reaction mixtures.

Experimental

Reaction of arysulfenyl chlorides with arylthiolsulfonates in dimethylformamide solution

The arylthiolsulfonate 0.025 mole was dissolved in anhydrous dimethylformamide 50 cm³, and on an oil bath at 115 °C ±5°, under magnetic stirring, arylsulfenyl chloride, prepared from 0.0125 mole + 10% of aryl disulfide with gaseous chlorine in 30 cm³ of carbon tetrachloride, was added to it dropwise during 16 h. The reaction mixture was heated for further 8 h, the dimethylformamide was evaporated in vacuum water pump, 100 cm³ of water was added and the mixture extracted with benzene. To the aqueous phase 10 g 0.05 mole of *S*-benzylisothiuronium hydrochloride dissolved in 50 cm³ of water was added, the solution was placed into a refrigerater, and the *S*-benzylisothiuronium arylsulfo acid salt which separated was filtered off, dried and weighed. The benzene phase was dried over sodium sulfate

Table I

Sulfenyl chloride	Thiolsulfonate	*S*-benzylisothiuronium salt	Disulfide	Thiolsulfonate
Phenyl	Phenyl	6.6 g 81.5% M.p. 147—148 °C	4.83 g 88.7% M.p. 61—62 °C	0.51 g 8.2% M.p. 38—40 °C
p-Tolyl	*p*-Tolyl	7.14 g 84.8% M.p. 180—182 °C	5.7 g 92.6% M.p. 44—45 °C	0.45 g 6.4% M.p. 76 °C
p-Chloro-phenyl	*p*-Chloro-phenyl	7.46 g 83.2% M.p. 174—175 °C	6.48 g 91.3% M.p. 71—72 °C	0.59 g 6.5% M.p. 133 °C

and, after evaporation of the solvent the aryl disulfide and unchanged thiolsulfonate were separated on a silica gel column by elution with petroleum ether and benzene, and weighed. The experimental results are summarized in Table I.

Reaction of arylsulfenyl bromides with arylthiolsulfonates in acetonitrile solution

The arylthiolsulfonate 0.025 moles was dissolved in 50 cm^3 of acetonitrile, and on an oil bath at 75 °C ±5°, under magnetic stirring, arylsulfenyl bromide, prepared from 0.025 mole + 10% of aryl dilsulfide with 2.2 g 0.0125 mole + 10% of bromide in 30 cm^3 of carbon tetrachloride, was added to it dropwise during 1 h. The reaction mixture was heated for further 2 hrs, the solvent was evaporated in vacuum, the redisue dissolved in dry benzene and saturated with gaseous ammonia. The benzene was evaporated, petroleum ether was added, and the precipitate which separated was filtered off, washed thoroughly with petroleum ether, and dried on the filter. From the dry precipitate ammonium bromide was extracted with water, and the arylsulfonamide, remaining on the filter, was dried and weighed. The solution in petroleum ether was chromatographed on silica gel with petroleum ether and benzene, in order to separate the aryl disulfide and unchanged thiolsulfonate, which were weighed. The experimental results are summarized in Table II.

The compounds obtained in the experiments were identified after repeated recrystallizations, by determination of the m.p., m.m.p., by thin-layer chromatography (adsorbent: Kieselgel 60 G, Merck; solvent mixture; benzene-petroleum ether (5 : 5); detection with alkaline potassium permanganate) and by elementary analysis.

Table II

Sulfenyl bromide	Thiol sulfonate	Sulfonamide	Disulfide	Thiolsulfonate
Phenyl	Phenyl	2.94 g 74.8% M.p. 153 °C	5.10 g 93.6% M.p. 61—62 °C	0.37 g 6% M.p. 38—40 °C
p-Tolyl	*p*-Tolyl	3.26 g 76.9% M.p. 139 °C	5.8 g 94.3% M.p. 44—45 °C	0.35 g 5% M.p. 76 °C
p-Chloro-phenyl	*p*-Chloro-phenyl	3.66 g 78% M.p. 144 °C	6.75 g 95.15% M.p. 71—72 °C	0.44 g 5.6% M.p. 133 °C

The disulfide-thiolsulfonate mixtures were separated either by fractional crystallization from petroleum ether, or by column chromatography on silica gel (Kieselgel 40 for column chromatography; 0.062—0.20 mm; Merck), using petroleum ether and benzene as eluents.

M.p.'s were determined on a Boetius' (Franz Küstner, Dredsen) micro melting point determining apparatus, and are uncorrected.

REFERENCES

[1] KHARASCH, N., BUESS, C. M., KING, W.: J. Am. Chem. Soc., **75,** 6035 (1953)
[2] ROBINSON, E. A., ZAIDI, S. A. A.: Canad. J. Chem., **46,** 3927 (1968)
[3] MALHOTRA, C. G., PURI, J. K.: Indian J. Chem., **9,** 1409 (1971)
[4] MOORE, C. G., PORTER, M.: J. Chem. Soc. (London), **1958,** 2890
[5] DOUGLASS, I. B.: J. Org. Chem., **24,** 2004 (1959)
[6] DOUGLASS, I. B., KOOP, D. A.: J. Org. Chem., **27,** 1308 (1962)
[7] PINTYE, J., STÁJER, G., VINKLER, E.: Acta Chim. Acad. Sci. Hung., **95,** 307 (1977)
[8] LÁZÁR, J., VINKLER, E.: Acta Chim. Acad. Sci. Hung., **101,** 175 (1979)
[9] PINTYE, J.: To be published

János LÁZÁR
Elemér VINKLER } H-6701 Szeged P.O.B. 121

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AMINOPHTHALAZINONE DERIVATIVES, VI*

SYNTHESIS OF 4-(HYDROXYALKYLAMINO)-BENZO[*g*]-1(2*H*)-PHTHALAZINONES

K. KÖRMENDY and F. RUFF

(*Department of Organic Chemistry, Eötvös L. University, Budapest*)

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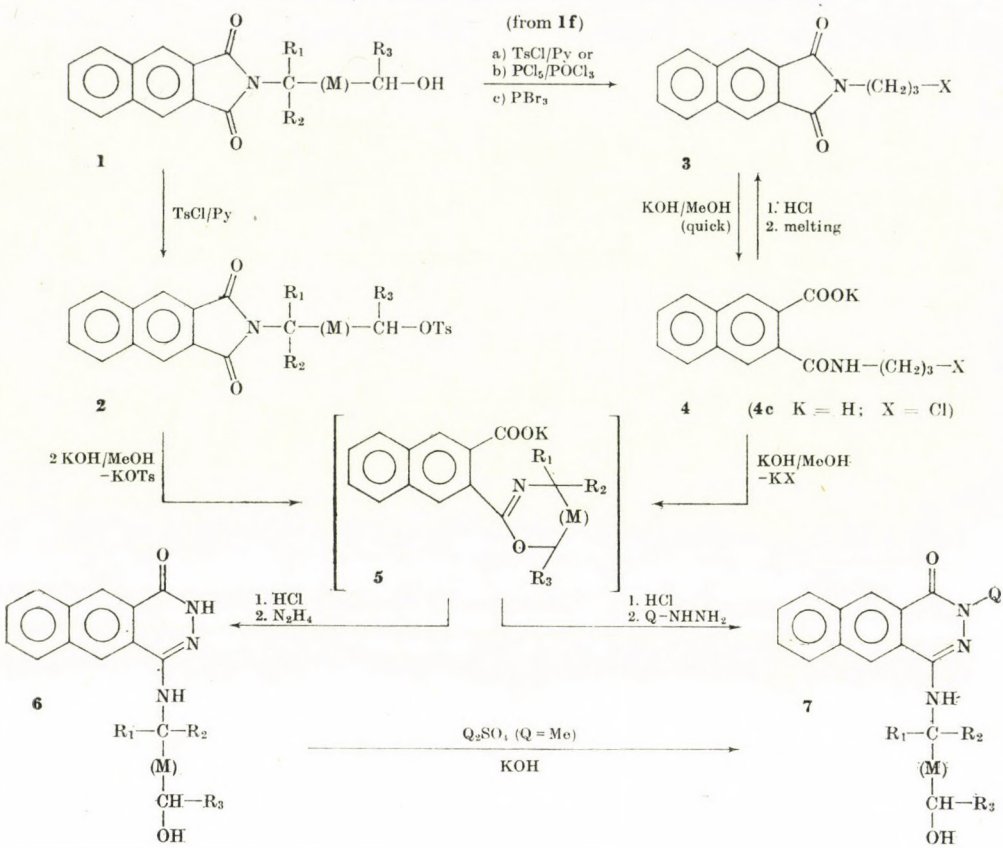
The methods developed from procedures published earlier [1—3] make possible the synthesis of various 4-(alkylamino)-benzo[*g*]-1(2*H*)-phthalazinones. *Method A* (**1** → **6**, **7**) is suitable for the incorporation of 1,2- or 1,3-aminoalcohols. When starting from *N*-β-tosyloxyalkylnaphthalene-2,3-dicarboxylic imides (**2**; M: —) and 3-bromopropylimides (**3b**), parent compounds **6** and the compounds containing methyl, 2-hydroxyethyl and 2-dietilaminoethyl substituents at the N(2) position (**7**) are formed in excellent and medium yield, respectively. A greater variety of derivatives can be synthesized by *Method B*, since coupling of 4-chlorobenzo[*g*]-1(2*H*)-phthalazinone (**9**) with aminoalcohols (**9** → **6a, 6f, 11, 12**) is independent of the relative distance between the amino and hydroxy terminals, and the N-substitution (**9** → **13, 14**) of hydroxy-free primary and secondary amines can also be achieved in ethylene glycol solutions.

In the present series, tautomerization studies have also been made, in parallel to synthetic work. The results required the extension of models, therefore, benzene homologues have been prepared starting from naphthalene-2,3-dicarboxylic anhydride according to the synthesis procedure elaborated previously [1—3].

Method A [1] (Fig. 1; **1** → **6**, **1** → **7**).

The 2- and 3-hydroxyalkylimide derivatives (**1**) obtainable by fusion of naphthalene-2,3-dicarboxylic anhydride and aminoalcohols, usually in 80—90% yield (Table I), are all new compounds. The tosylation reaction **1a—e** → → **2a—e** can be realized in 90—100% yield in pyridine medium (Table II). The 2-tosyl ester can easily be converted into the oxazoline derivative **5** (M: —) with methanolic potassium hydroxide, the product affords **6** with hydrazine in excellent yield (Table III), while it is converted into **7** with *N*-monosubstituted hydrazines (Table IV) in satisfactory yield. (The oxazoline intermediates **5** were not isolated owing to the well-known instability of analogous compounds, but their formation was definitely verified through formation of **6** and **7** as end-products [4, 5]).

* Part V: Acta Chim. Acad. Sci. Hung. **102**, 39 (1979)



(1, 2, 5, 6)	R_1	R_2	R_3	M	(7)	Q	(7)	Q	(7)	Q	(3, 4)	X
a	H	H	H	—	a	Me	g	$(CH_2)_2$—OH	m	$(CH_2)_2$—NEt_2	a	Cl
b	H	H	Me	—	b		h		n		b	Br
c	Et	H	H	—	c		i		o			
d	Me	Me	H	—	d		j		p			
e	Me	H	Ph	—	e		k		q			
f*	H	H	H	CH_2	f		l		r			

*2f is unknown

Fig. 1

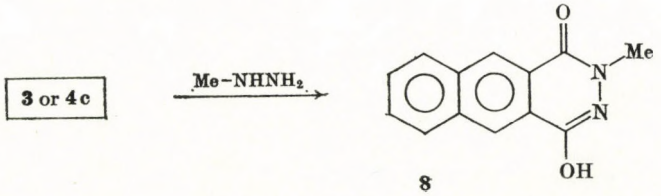
The 2-methyl derivatives **7a—c** and **7e** are identical in structure, irrespective of the fact whether they were prepared from the oxazoline intermediates **5** with methylhydrazine (**5** → **7**) or by methylation of compounds **6** (**6** → **7**). Derivative **7d** was an exception; it was obtained in two forms (**A** and **B**),

depending on the way of preparation. Compounds **7dA** and **7dB** melt at the same temperature, but the IR spectra recorded in KBr pellets show significant differences (Table IVb). Since compound **A** and **B** do not transform into each other on repeated crystallization from aqueous ethanol, the possibility of crystalline dimorphism can be regarded as excluded, the substances differ in their molecular structure. It can be established from the IR spectra that in the metastable compound 7**dB**, H-bridgeing of the NH group is stronger, while in the stable **7dA** the association of OH predominates.

In the metastable **7dB** obtained by methylation in alkaline medium, the conversion **B** → **A** could be achieved on fusing or in chloroform solution at room temperature. The unstable form **B** is well soluble in chloroform; stable **A** of lower solubility precipitates from the clear solution on standing. Studies on the structure of the two substances will be reported later.

The procedure described above in less suitable for the preparation of 3-hydroxypropylamino compounds (**6f**, **7f**, **7l** and **7r**), since, similarly to other 3-hydroxypropylimides [1, 6], the 3-hydroxypropylnaphthalene-2,3-dicarboxylic imide (**1f**) also behaves anomalously in the tosylation reaction, and not the tosyl ester (**2f**) is formed, but 3-chloropropylimide (**3a**) is obtained in medium yield (47%). The latter substance is preferably prepared in the reaction of hydroxypropylimide with phosphorus pentachloride. Under the effect of bases, imide **3a** rapidly opens, but cyclization **4a** → **5f** of 3-chloropropylamide is, on one hand, a very slow process (refluxing for 15 hrs is required for optimum formation of intermediate **5f** and to obtain maximum yield in the rapid final reaction (**5f** → **6f**, **7f**, **7l** and **7r**), on the other hand, during the preparation of **6f**, naphthalene-2,3-dicarboxylic hydrazide is formed in significant amounts in unidentified side-reactions. In the synthesis of **7f** and **7l**, the by-product is 3-chloropropylimide (**3a**). The appearance of the latter substance indicates the presence of an unknown precursor stable toward monosubstituted hydrazines in the course of hydrazinolysis, since both imide **3a** and amide acid **4c** readily yield *N*(2) methylated hydrazides (**8**) with methylhydrazine.

The procedure starting from 3-bromopropylimide (**3b**) is significantly faster and better, since the development of the dihydro-1,3-oxazine intermediate (**3b** → **5f**) can be regarded as complete already on boiling for 1 hr, and the side-reactions are negligible, the yields of derivatives **6f**, **7f**, **7l** and **7r** being 84%, 73.1%, 73.6% and 83%, respectively.



8

Fig. 2

Method B [2, 3] (Fig. 3).

While *Method A* described above can be employed to a limited extent only, owing to the presence of cyclic intermediates (**5**) (it is suitable only for the preparation of ethanolamine and 3-aminopropanol derivatives), chloro compound **9** obtainable from naphthalene-2,3-dicarboxylic hydrazide makes possible the preparation of a greater variety of derivatives. Owing to its vinylhalide structure, **9** is resistant to bases and amines, similarly to chlorophthalazinone, but it reacts readily with aminoalcohols. It seems probable that in the case mentioned the substitution reaction occurs through a reactive alcohol adduct of α-chloroether type (**10a** [2]), as was already assumed for analogous reactions of chlorophthalazinone.

The conversion is effected in 95% and 82% yield with ethanolamine and 3-aminopropanol, respectively; coupling was quantitative with 6-aminohexanol and *N*-2-hydroxyethylpiperazine.

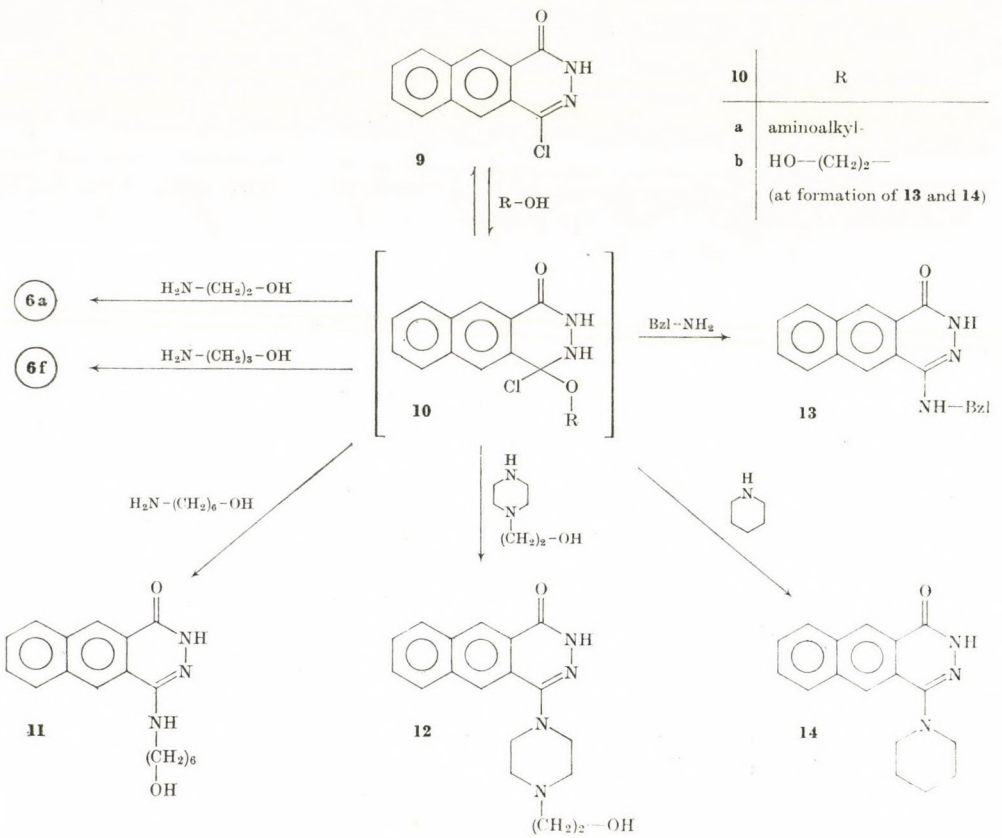


Fig. 3

N-substitution of hydroxy-free amines can be effected in ethylene glycol solutions; here the analogous reactive glycol adduct (**10b** [3]) makes possible the completion of the reaction. In the absence of glycol, *N*-substitution does not take place. There are hardly any differences in yield of coupling as compared to analogous reactions of chlorophthalazinone.

Experimental

The melting points were determined with a Boetius type micro melting point device. The IR spectra were recorded in KBr pellets with UR-10 and an IR-75 (Zeiss, Jena) spectrophotometers.

Method A

Naphthalene-2,3-dicarboxylic anhydride (M. w. 198.2)

Naphthalene-2,3-dicarboxylic acid (21.6 g) prepared as suggested by FREUND and FLEISCHER [7] was fused at 250—260 °C (30 min). After recrystallization from glacial acetic acid (350 ml), 19.2 g of product (97%) was obtained. In vacuum the substance undergoes sublimation without melting, between 230 and 240 °C. (Lit. m.p. 246 °C).

IR (KBr): νCO 1835, 1772, 1759 cm^{-1}.

2-Diethylaminoethylhydrazine

Diethylaminoethyl chloride hydrochloride (43 g, 0.25 mol) dissolved in water (50 ml) was added dropwise to hydrazine hydrate (57 g of 98% hydrazine hydrate in 13 ml of water) under vigorous stirring in a flask equipped with a stirrer. First an emulsion was formed, which became clear on warming (1—1.5 hrs). The solution obtained was concentrated to half volume in vacuum, then the residue was mixed with sodium hydroxyde solution (9.8 g in 10 ml water) and ethanol (100 ml). The salt precipitated was filtered off, the filtrate was distilled in a rotary evaporator at 60 °C in vacuum (20 Torr). The mixture of two phases was separated, the upper layer was fractionated in vacuum. After repeated fractional separation diethylaminoethylhydrazine (14.2 g, 43.4%) was obtained. $B.p._{12}$ 82—85 °C (*lit.* $b.p._9$ 76—77 °C [8]; $b.p._{50}$ 111—113 °C [9]).

$C_6H_{17}N_3$ (131.1). Calcd. N 32.0. Found N 32.4%.

Synthesis of hydroxyalkylimides (1) (Tables Ia, b)

An equimolar mixture of naphthalene-2,3-dicarboxylic anhydride and the aminoalcohol was fused in an open flask until cessation of water liberation. The cold, solidified melt was crystallized from the solvent given in Table Ia. The products are colourless crystalline substances.

Tosylation reaction (1 → 2) (Tables IIa, IIb)

The appropriate hydroxyalkylimide (**1**; 0.02 mol) was stirred with tosyl chloride (5.32 g, 0.028 mol) in anhydrous pyridine (20 ml). A solution was rapidly formed; when dissolution was slow, the mixture was slightly heated. It was allowed to stand overnight in a sealed flask, then diluted with water to 800 ml. The raw tosyl ester separated as a solid or in the form of a rapidly solidifying oil. The crystalline product was filtered off, washed with water then recrystallized from the solvent given in Table IIa. Colourless crystalline substances.

Table Ia

Preparation of hydroxyalkyl-naphthalene-2,3-dicarboxylic imides* (**1**)

Product	Yield (%)	Crystallization		M.p. (°C)	Molecular		Analysis	
		solvent	crystal form		formula	weight	Calcd. N(%)	Found N(%)
1a	92.5	EtOH	needles	193—194	$C_{14}H_{11}NO_3$	241.3	5.8	5.9
1b	84.9	EtOH—H_2O	needles	163—164	$C_{15}H_{13}NO_3$	255.3	5.5	5.5
1c	82.5	EtOH—H_2O	needles	116—118	$C_{16}H_{15}NO_3$	269.3	5.2	5.3
1d	59.5	EtOH	prisms	167—169	$C_{16}H_{15}NO_3$	269.3	5.2	5.2
1e	80.0	EtOH—H_2O	plates	140—142	$C_{21}H_{17}NO_3$	331.4	4.2	4.1
1f	90.2	EtOH—H_2O	plates	148—149	$C_{15}H_{13}NO_3$	255.3	5.5	5.6

* Hydroxyalkyl groups:
1a 2-hydroxyethyl-
1b 2-hydroxy-2-methylethyl-
1c 1-ethyl-2-hydroxyethyl-
1d 1,1-dimethyl-2-hydroxyethyl-
1e 1-methyl-2-hydroxyphenethyl- (*erythro*)
1f 3-hydroxypropyl-

Table Ib

Main IR bands of hydroxyalkyl-naphthalene-2,3-dicarboxylic imides (**1**) *in KBr*

	νOH	νCO_{Imide}	νC—O	1,2 disubst. Ar ring	Monosubst. Ar ring
1a	3450	1751 1690	1005	772	—
1b	3422	1756 1705 1692	1036	767	—
1c	3438 3358	1751 1705 1691	1050	768	—
1d	3518	1757 1689	1071	769	—
1e	3515	1755 1691	1021	768	709 768
1f	3539	1753 1702	1051	770	—

Table IIa

Preparation of tosyloxyalkyl-naphthalene-2,3-dicarboxylic imides* (**2**)

Product	Yield (%)	Crystallization		M.p. (°C)	Molecular		Analysis	
		solvent	crystal form		formula	weight	Calcd. S(%)	Found S(%)
2a	98.2	EtOH	needles	199—200	$C_{21}H_{17}NO_5S$	395.5	8.1	8.0
2b	100.0	EtOH	plates	206—207	$C_{22}N_{19}NO_5S$	409.5	7.8	7.9
2c	92.8	EtOAc-ligroine	prisms	129—130	$C_{23}H_{21}NO_5S$	423.5	7.6	7.6
2d	90.4	EtOH	powder	156—157	$C_{23}H_{21}NO_5S$	423.5	7.6	7.7
2e	90.7	benzene	powder	164—165	$C_{28}H_{23}NO_5S$	485.6	6.6	6.5

* Tosyloxyalkyl groups:
2a 2-tosyloxyethyl-
2b 2-tosyloxy-2-methylethyl-
2c 1-ethyl-2-tosyloxyethyl-
2d 1,1-dimethyl-2-tosyloxyethyl-
2e 1-methyl-2-tosyloxyphenethyl- (*erythro*)

Table IIb

Main IR bands of tosyloxyalkyl-naphthalene-2,3-dicarboxylic imides (**2**) *in KBr*

Product	νCO_{imide}	νSO_2	δSO_2	1,4 disubst. Ar ring	1,2 disubst. Ar ring
2a	1764	1362 as	574	818	770
	1711	1179 sym	551		
2b	1769	1365 as	555	816	771
	1710	1178 sym	578		
2c	1761	1361 as	553	811	770
	1708	1179 sym	578		
2d	1764	1333 as	553	810	769
	1713	1175 sym	582		
2e	1761	1368 as	550	810	768
	1713	1171 sym	562		
	1704				

Synthesis of 4-(2-hydroxyalkylamino)-benzo[*g*]-1(2*H*)-phthalazinones (6)
(Tables IIIa and IIIb)

The tosyl ester (**2**; 0.01 mol) was refluxed with a methanolic (100 ml) solution of potassium hydroxyde (1.4 g, 0.025 mol) for 30 min. The solution was cooled in ice-water, then it was slightly acidified with concentrated hydrochloric acid in the presence of some drops of methyl orange indicator (overacidification is disadvantageous). After the addition of hydrazine

Table IIIa

Synthesis of 4-(hydroxyalkylamino)-benzo[g]-1(2H)-phthalazinones* (**6a—e**)

Method		Yield (%)	Crystallization		M.p. (°C)	Molecular formula (weight)	Analysis					
			solvent	crystal form			Calcd.			Found		
							C(%)	H(%)	N(%)	C(%)	H(%)	N(%)
6a	*A*	96.7	EtOH	needles	282—284	$C_{14}H_{13}N_3O_2$ (255.3)	65.9	5.1	16.5	65.8	5.1	16.6
	B	94.5										
6b	*A*	89.2	EtOH	needles	250—252	$C_{15}H_{15}N_3O_2$ (269.3)	66.9	5.6	15.6	66.8	5.5	15.8
6c	*A*	93.6	EtOH	powder	260—262	$C_{16}H_{17}N_3O_2$ (283.3)	67.8	6.0	14.8	67.9	6.1	14.8
6d	*A*	93.6	EtOH	powder	267—268	$C_{16}H_{17}N_3O_2$ (283.3)	67.8	6.0	14.8	67.8	6.2	15.0
6e	*A*	63.8	EtOH	needles	264—266	$C_{21}H_{19}N_3O_2$ (345.4)	73.0	5.5	12.2	73.2	5.6	12.3

* 4-(hydroxyalkylamino) groups:
6a 4-(2-hydroxyethylamino)-
6b 4-(2-hydroxy-2-methylethylamino)-
6c 4-(1-ethyl-2-hydroxyethylamino)-
6d 4-(1,1-dimethyl-2-hydroxyethylamino)-
6e 4-(1-methyl-2-hydroxyphenethylamino)- *(erythro)*

Table IIIb

Main IR bands of 4-(hydroxyalkylamino)-benzo[g]-1(2H)-phthalazinones (**6a—e**) *in KBr*

	νNH (exocyclic)* νNH_{amide}, νOH	νCO_{amide}	δNH	νC—O	1,2 disubst. Ar ring	Monosubst. Ar ring
6a	3392* 3500—2500	1640	1545	1071	756	—
6b	3250* 3450—2600	1640	1544	1086	745	—
6c	3340* 3500—2700	1642	1536	1039	742	—
6d	3395* 3450—2400	1662	1528	1054	741	
6e	3300* 3600—2600	1646	1520	1033	748	698 755 sh

hydrate (3 ml, 72% solution) the mixture was refluxed for 1 hr. The solution, which turned yellow, was diluted with water and concentrated in a rotary evaporator. The solid residue was suspended in water, neutralized with hydrochloric acid and filtered after standing. Purification of the product was effected by crystallization from the solvent given in Table IIIa. Bright yellow crystals, whose hydrochloric acid solutions are colourless.

Preparation of 2-methyl-4-(2-hydroxyalkylamino)-benzo[*g*]-1(2*H*)-phthalazinones (7a—e) (Tables IVa and IVb)

a) (Cyclization with methylhydrazine)

As given above, the tosyl ester (**2**; 0.01 mol) was allowed to react with methanolic potassium hydroxide. The ice-cold solution was first acidified with hydrochloric acid, then mixed with methylhydrazine (0.92 g, 0.02 mol) and refluxed for 3 hrs. The intensely yellow solution was evaporated to dryness and powders of **7a** and **7b** were isolated by filtration, sticky substances **7c** and **7d** were recrystallized from aqueous ethanol, while compound **7e** was washed with cold ethanol. For further purification, the individual substances were crystallized from the solvents given in Table IVa. Bright yellow crystals, whose solutions in hydrochloric acid are colourless.

b) (Methylation)

The parent compounds **6** (2 mmol) were dissolved in a mixture of Methyl Cellosolve (20 ml) and potassium hydroxide (1.12 g, 0.02 mol) under slight heating. Dimethyl sulfate (1.5 ml) was added dropwise to the cold solution under mechanical stirring. After standing for 2 hrs, the solution was diluted with water to 200 ml, the precipitate was filtered off and crystallized from the solvent given in Table IVa. The structure of the products obtained in the two ways is identical, except for **7d**.

Compound **7dB** obtained on methylation is metastable. It remains unchanged on crystallization from aqueous alcohol, is well soluble in cold chloroform, but the precipitation of the stable **7dA** from the solution starts soon. The IR spectrum of **7dA** of reduced solubility recorded in KBr pellet is identical with that of the substance obtained on cyclization with methylhydrazine. The conversion **7dB** → **7dA** takes place on fusing, too.

Preparation of 2-(2-hydroxyethyl)- and 2-(2-diethylaminoethyl)-4-(2-hydroxyalkylamino)--benzo[*g*]-1(2*H*)-phthalazinones (7g—k and 7m—q) (Tables IVa and IVb)

As given for the preparation of the parent compounds (**6**), the tosyl ester (**2**, 0.01 mol) was refluxed with methanolic potassium hydroxide solution (1.4 g KOH in 100 ml of methanol) for 1 hr. After acidification and mixing with 2-hydroxyethylhydrazine (1.52 g, 0.02 mol) or 2-diethylaminoethylhydrazine (1.96 g, 15 mmol), refluxing was continued for 3 hrs. The yellow solution obtained was evaporated to dryness in vacuum, the evaporation residue was mixed with water and made strongly alkaline with ammonium hydroxide. After standing, the solid product was filtered off (**7g—h** and **7m—p**), the sticky **7i—k** substances were crystallized from aqueous ethanol and compound **7q** from ethyl acetate, respectively. Further purification of the raw products was effected from the solvents given in Table IVa. These are compounds of bright yellow colour and give colourless solutions in acids. Aqueous solutions of diethylaminoethyl derivatives **7m—q** are alkaline.

***N*-3-Chloropropylnaphthalene-2,3-dicarboxylic imide (3a)**

a) 3-Hydroxypropylnaphthalene-2,3-dicarboxylic imide (**1f**) (1.28 g, 5 mmol) was allowed to react with tosyl chloride (1.42 g) in anhydrous pyridine (5 ml) under shaking at room temperature. A yellow solution was rapidly formed. Next day it was diluted with water and the substance separated was crystallized from ethanol (0.64 g, 46.8%). Colourless needles. M.p. 163—165 °C.

b) In a flask equipped with a reflux condenser 3-hydroxypropylimide (**1f**) (2.55 g, 0.01 mol) was refluxed with a mixture of phosphorus oxychloride (10 ml) and phophorus pentachloride (2.08 g) for 10 min. After pouring it onto ice, the solid product was filtered off and washed with water until free from acid (2.74 g, 100%). The raw product melted at 165—167 °C, colourless needles were obtained from ethanol. The melting point remained unchanged.

c) Compound **3a** was formed during the preparation of **7f** and **7l** from 3-chloropropylnaphthalene-2.3-dicarboxylic imide (see later) in 18.3% and 13.7% yields, respectively. M.p. 165—167 °C from ethanol.

$C_{15}H_{12}ClNO_2$ (273.7) Calcd. Cl 13.0; Found Cl 13.1%.

IR (KBr): νCO_{imide} 1761, 1707; 1,2-disubstituted Ar ring 768 cm^{-1}.

Table IVa

Synthesis of 2-substituted-4-(hydroxyalkylamino)-benzo[g]-1(2H)-phthalazinones* (7)

Product	Yield (%)	Crystallization		M.p. (°C)	Molecular formula (weight)	Analysis					
		solvent	crystal form			Calcd.			Found		
						C(%)	H(%)	N(%)	C(%)	H(%)	N(%)
7a	91.1 100**	EtOH	needles	258—260	$C_{15}H_{15}N_3O_2$ (269.3)	66.9	5.6	15.6	66.8	5.7	15.7
7b	84.3 100**	EtOH—H_2O	needles	193—195	$C_{16}H_{17}N_3O_2$ (283.3)	67.8	6.0	14.8	67.6	6.1	14.8
7c	47.1 78.6**	EtOH—H_2O	needles	214—215	$C_{17}H_{19}N_3O_2$ (297.4)	68.7	6.4	14.1	68.9	6.5	14.2
7dA **7dB**	56.7 100**	EtOH—H_2O	needles	239—240	$C_{17}H_{19}N_3O_2$ (297.4)	68.7	6.4	14.1	68.8	6.5	14.1
7e	66.9 100**	EtOH	powder	289—290	$C_{22}H_{21}N_3O_2$ (359.4)	73.5	5.9	11.7	73.6	6.0	11.7
7g	93.6	EtOH—H_2O	needles	221—223	$C_{16}H_{17}N_3O_3$ (299.3)	64.2	5.7	14.0	64.2	5.8	14.2
7h	71.9	EtOH—H_2O	prisms	186—187	$C_{17}H_{19}N_3O_3$ (313.4)	65.2	6.1	13.4	65.4	6.2	13.3
7i	74.9	EtOH—H_2O	needles	169—171	$C_{18}H_{21}N_3O_3$ (327.4)	66.0	6.5	12.8	66.1	6.5	12.9
7j	52.0	EtOH—H_2O	plates	202—203	$C_{18}H_{21}N_3O_3$ (327.4)	66.0	6.5	12.8	66.2	6.4	12.8
7k	83.3	EtOAc	prisms	209—210	$C_{23}H_{23}N_3O_3$ (389.5)	70.9	6.0	10.8	71.0	6.1	10.9
7m	99.0	EtOH—H_2O	needles, prisms	165—166	$C_{20}N_{26}N_4O_2$ (354.5)	67.8	7.4	15.8	67.9	7.4	15.9
7n	76.0	EtOH—H_2O	prisms	187—189	$C_{21}H_{28}N_4O_2$ (368.5)	68.4	7.7	15.2	68.5	7.7	15.3
7o	90.2	EtOAc EtOH—H_2O	powder plates	137—139	$C_{22}H_{30}N_4O_2$ (382.5)	69.1	7.9	14.6	69.0	7.8	14.7
7p	84.4	EtOAc	plates	152—154	$C_{22}H_{30}N_4O_2$ (382.5)	69.1	7.9	14.6	69.2	7.9	14.7
7q	81.0	EtOAc	prisms	201—203	$C_{27}H_{32}N_4O_2$ (444.6)	72.9	7.3	12.6	73.1	7.4	12.9

* 2-substituted 4-(hydroxyalkylamino) groups:
7a 2-methyl-4-(2-hydroxyethylamino)-
7b 2-methyl-4-(2-hydroxy-2-methylethylamino)-
7c 2-methyl-4-(1-ethyl-2-hydroxyethylamino)-
7d 2-methyl-4-(1,1-dimethyl-2-hydroxyethylamino)-
7e 2-methyl-4-(1-methyl-2-hydroxyphenethylamino)- *(erythro)*
7g 2-(2-hydroxyethyl)-4-(2-hydroxyethylamino)-
7h 2-(2-hydroxyethyl)-4-(2-hydroxy-2-methylethylamino)-
7i 2-(2-hydroxyethyl)-4-(1-ethyl-2-hydroxyethylamino)-
7j 2-(2-hydroxyethyl)-4-(1,1-dimethyl-2-hydroxyethylamino)-
7k 2-(2-hydroxyethyl)-4-(1-methyl-2-hydroxyphenethylamino)- *(erythro)*
7m 2-(2-diethylaminoethyl)-4-(2-hydroxyethylamino)-
7n 2-(2-diethylaminoethyl)-4-(2-hydroxy-2-methylethylamino)-
7o 2-(2-diethylaminoethyl)-4-(1-ethyl-2-hydroxyethylamino)-
7p 2-(2-diethylaminoethyl)-4-(1,1-dimethyl-2-hydroxyethylamino)-
7q 2-(2-diethylaminoethyl)-4-(1-methyl-2-hydroxyphenethylamino)- *(erythro)*
** Yield of the product obtained on methylation

Table IVb

Main IR bands of 2-substituted-4-(hydroxyalkylamino)-benzo[g]-1(2H)-phthalazinones (**7**) *in KBr*

	νNH νOH	ν(CH_2N)	νCO_{amide}	δNH	νC—O	1,2 disubst. Ar ring	Monosubst. Ar ring
7a	3350 (NH, OH)	—	1622	1535	1061	752	—
7b	3360 (NH, OH)	—	1612	1548	1060	750	—
7c	3365 (NH, OH)	—	1617	1522	1041	753	—
7dA	3380 (NH) 3260 (OH)	—	1641	1534	1052	750	—
7dB	3365 (OH) 3340 (NH)	—	1630	1538	1060	750	—
7e	3427 (NH) 3296 (OH)	—	1622	1524	1017	758	696 758
7g	3320 (NH) 3264 (OH)	—	1619	1549	1053	750	—
7h	3380 (NH, OH)	—	1610	1538	1077	766	—
7i	3345 (NH) 3325 3225	—	1624	1550	1049	747	—
7j	3375 3265	—	1618	1535	1063 1052	742	—
7k	3440 (NH) 3400—3000 (OH)	—	1620	1530	1070	760	706 755 sh
7m	3320 (NH) 3275 (OH)	2820	1609	1542	1066	751	—
7n	3365 (NH, OH)	2802	1610	1545	1090	751	—
7o	3322 (NH) 3250 (OH)	2796	1621	1546	1058	746	—
7p	3385 (NH, OH)	2802	1622	1538	1052	750	—
7q	3447 (NH) 3270 (OH)	2792	1622	1529	1065	746	692 746

Naphthalene-2-(3-chloropropylcarbamoyl)-3-carboxylic acid (4c)

3-Chloropropylnaphthalene-2,3-dicarboxylic imide (0.546 g, 2 mmol) was refluxed in methanolic (20 ml) potassium hydroxide (0.14 g, 2.5 mmol) solution for 20 min. Methanol was distilled and the evaporation residue was dissolved in water. A colourless substance separated on acidifying (0.53 g, 90.9%); it was soluble in ethanol. Colourless plates were obtained from aqueous ethanol. M.p. 161—162 °C.

$C_{15}H_{14}ClNO_3$ (291.8). Calcd. Cl 12.2; Found Cl 12.1%.

IR (KBr): νNH 3292; $\nu OH_{carboxy}$ 3200—2200; $\nu CO_{carboxy}$ 1695; νCO_{amide} 1647; δNH 1548; 1,2-disubstituted Ar ring 754 cm^{-1}.

Cyclization (**4c** → **3a**): On fusing the amide acid, 3-chloropropylimide, poorly soluble in ethanol, was obtained. It was identified on the basis of the IR spectrum.

N-3-Bromopropylnaphthalene-2,3-dicarboxylic imide (3b)

In a flask equipped with a reflux condenser, 3-hydroxypropylimide (**1f**) (2.55 g, 0.01 mol) was kept with phosphorus tribromide (1 ml) at 140 °C for 1 hr. After decomposition with ice-water, the solid product was filtered off (3 g), then crystallized from a large amount of ethanol (about 350 ml). Colourless needles were obtained (2.73 g, 85.8%). M.p. 168—169 °C.

$C_{15}H_{12}BrNO_2$ (318.2). Calcd. Br 25.1; Found Br 25.2%.

IR (KBr): νCO_{imide} 1762, 1708; 1,2-disubstituted Ar ring 762 cm^{-1}.

4-(3-Hydroxypropylamino)-benzo[*g*]-1(2*H*)-phthalazinone (6f)

a) In a solution of methanolic (15 ml) potassium hydroxide (0.14 g), 3-bromopropylnaphthalene-2,3-dicarboxylic imide (**3b**) (0.318 g, 1 mmol) was refluxed for 1 hr. The solution was cooled to 0 °C and carefully acidified with hydrochloric acid in the presence of methyl orange indicator, then hydrazine hydrate (0.2 ml, 72% aqueous solution) was added to it and the solution was refluxed further 1 hr. On diluting with water, the raw product separated (0.226 g, 84%). M.p. 218—220 °C; it crystallized from ethanol in the form of a yellow powder. M.p. 223—224 °C.

b) After the reaction given under a) of 3-chloropropylimide (**3a**) (1.092 g, 4 mmol) in methanolic (40 ml) potassium hydroxide (0.56 g, 0.01 mol) requiring refluxing for 15 hrs, a maximum of 0.708 g (65.8%) of **6f** was obtained with hydrazine hydrate. After acidification, the hydrazine mother liquor yielded naphthalene-2,3-dicarboxylic hydrazide.

$C_{15}H_{15}N_3O_2$ (269.3). Calcd. 66.9, H 5.6, N 15.6; Found C 66.8, H 5.6, N 15.7%.

IR (KBr): νNH, νOH 3295; νNH_{amide} 3450—2700; νCO_{amide} 1628; δNH 1528; νC—O 1035; 1,2-disubstituted Ar ring. 743 cm^{-1}.

2-Methyl-4-(3-hydroxypropylamino)-benzo[*g*]-1(2*H*)-phthalazinone (7f)

a) In a methanolic (30 ml) potassium hydroxide (0.28 g, 5 mmol) solution, 3-bromopropylimide (**3b**) (0.636 g, 2 mmol) was refluxed for 1 hr, then the solution was cooled in ice-water and slightly acidified with concentrated hydrochloric acid. After the addition of methylhydrazine (0.184 g, 4 mmol), the mixture was again heated to boil (2 hrs). The substance separated on diluting with water (0.414 g, 73.1%, raw m.p. 197—199 °C) crystallized from ethanol in the form of yellow needles. M.p. 201—202 °C.

b) According to the above procedure a), 3-chloropropylimide (**3a**) (0.546 g, 2 mmol) was refluxed for 15 hrs and subsequently for 2 hrs, thus a mixture (0.304 g) was obtained, which consisted of **7f** (0.204 g, 36%) and 3-chloropropylimide (**3a**) (0.100 g, 18.3%). They were separated by crystallization from ethanol or by a short refluxing (15 min) with methanolic (10 ml) potassium hydroxide (0.3 g) solution. In the latter case the water-insoluble evaporation residue was chemically homogeneous **7f**. M.p. 201—202 °C.

c) In a flask equipped with a stirrer, 4-(3-hydroxipropylamino)-benzo[*g*]-1(2*H*)-phthalazinone (**6f**) (0.538 g, 2 mmol) was dissolved in a mixture of Methyl Cellosolve (20 ml) and potassium hydroxide (1.12 g) under slight heating. The solution was cooled and dimethyl sulfate (1.5 ml) was added to it under mechanical stirring. After standing for 2 hrs it was diluted with water and the solid product (0.462 g, 81.6%) was filtered off and crystallized from ethanol. M.p. 200—201.5 °C. According to the IR spectrum it was identical with the products of procedures *a)* and *b)*.

$C_{16}H_{17}N_3O_2$ (283.3). Calcd. C 67.8, H 6.0, N 14.8; Found C 67.9, H 6.1, N 14.7%.

IR (KBr): νOH 3392, 3346; νCO_{amide} 1624; δNH 1540; νC—O 1609; 1,2-disubstituted Ar ring 748 cm^{-1}.

2-(2-Hydroxyethyl)-4-(3-hydroxypropylamino)-benzo[*g*]-1(2*H*)-phthalazinone (7l)

a) According to procedure *a)*, given for the preparation of **7f**, starting from 3-bromopropylimide (**3b**) (0.636 g, 2 mmol) and using 2-hydroxyethylhydrazine (0.304 g, 4 mmol) reagent, 0.461 g of raw product (73.6%, m.p. 200—205 °C) can be prepared, which forms yellow needles from ethanol, melting at 204—205 °C.

b) According to procedure *b)*, suggested for the preparation of **7f**, starting from 3-chloropropylimide (**3a**) (0.546 g, 2 mmol), a mixture (0.329 g) was formed, which consisted of compound **7l** (0.254 g, 40.6%) and 3-chloropropylimide (**3a**) (0.075 g, 13.7%).

$C_{17}H_{19}N_3O_3$ (313.4). Calcd. C 65.2, H 6.1, N 13.4; Found C 65.3, H 6.2, N 13.5%.

IR (KBr): νNH 3320; νOH 3262; νCO_{amide} 1619; δNH 1548; νC—O 1052; 1,2-di-substituted Ar ring 750 cm^{-1}.

2-(2-Diethylaminoethyl)-4-(3-hydroxypropylamino)-benzo[*g*]-1(2*H*)-phthalazinone (7r)

The dihydro-1,3-oxazinecarboxylic acid derivative (**5f**) was prepared from 3-bromopropylimide (**3b**) (0.636 g, 2 mmol) according to the procedure given for the preparation of derivative **7f** (Procedure *a)*). The product was allowed to react with 2-diethylaminoethylhydra-

zine (0.393 g, 3 mmol) by refluxing for 3 hrs. The solvent was removed in vacuum, the distillation residue was mixed with some water and it was made strongly alkaline with ammonium hydroxide. A rapidly solidifying yellow oil separated (0.612 g, 83%). Yellow needles were obtained from ethyl acetate. M.p. 135—136.5 °C.

$C_{21}H_{28}N_4O_2$ (368.5). Calcd. C 68.4, H 7.7, N 15.2; Found C 68.5, H 7.7, N 15.4%.

IR (KBr): νNH, νOH 3310; $\nu(CH_2N)$ 2808; νCO_{amide} 1609; δNH 1538; νC—O 1032; 1,2-disubstituted Ar ring 748 cm^{-1}.

2-Methyl-benzo[*g*]-1(2*H*)-phthalazinone-4-ol (8)

Naphthalene-2,3-dicarboxylic anhydride (0.198 g, 1 mmol) or 3-chloropropylnaphthalene-2,3-dicarboxylic imide (**3a**, 0.273 g, 1 mmol) or the amide acid **4c** (0.292 g, 1 mmol) was refluxed with methylhydrazine (0.5 ml) in methanol (25 ml) for 1 hr. The yellow solution was evaporated to dryness in a rotary evaporator and the distillation residue was dissolved in water. A yellow powder separated on acidifying the solution (0.186 g, 82.3%, when starting from the anhydride), which crystallized in the form of yellow needles from ethanol. M.p.: sublimation at 300—310 °C.

$C_{13}H_{10}N_2O_2$ (226,2). Calcd. C 69.0, H 4.5, N 12.4; Found C 69.2, H 4.4, N 12.5%.

IR (KBr): νOH 3100—1800; νCO_{amide}, νC=N 1669, 1648, 1620; 1,2-disubstituted Ar ring 759 cm^{-1}.

Method B

4-Chloro-benzo[*g*]-1(2*H*)-phthalazinone (9)

Naphthalene-2,3-dicarboxylic hydrazide (10.6 g, 0.05 mol [10]) was chlorinated with phophorus pentachloride (25 g) in phosphorus oxychloride solution (100 ml) as suggested by HILL and EHRLICH [11]. The solution obtained on refluxing (3 hrs) was evaporated to dryness in vacuum and the distillation residue was decomposed with ice. The raw dichloro compound obtained was hydrolyzed with 2% potassium hydroxide solution (1.5 l) by refluxing for 5 hrs. The monochloro compound (8.5 g, 73.9%) separated on acidifying from the solution filtered. The substance sublimed in vacuum (12 Torr, 260 °C) was crystallized from glacial acetic acid; colourless crystals were obtained. M.p.: partial melting at about 280 °C, crystallization into needles and sublimation between 310 and 320 °C.

$C_{12}H_7ClN_2O$ (230.7). Calcd. Cl 15.4; Found Cl 15.4%.

IR (KBr): νNH_{amide} 3100—2700; νCO_{amide} 1680; νC=N 1621; 1,2-disubstituted Ar ring 771 cm^{-1}.

4-(2-Hydroxyethylamino)-benzo[*g*]-1(2*H*)-phthalazinone (6a)

A mixture of 4-chloro-benzo[*g*]-1(2*H*)-phthalazinone (**9**; 0.231 g, 1 mmol) and ethanolamine (3 ml) was refluxed (6 hrs). On dilution with water, halogen-free **6a** (0.241 g, 94.5%) separated (Table III).

4-(3-Hydroxypropylamino)-benzo[*g*]-1(2*H*)-phthalazinone (6f)

By analogy, with 3-amino-1-propanol as reagent, **6f** can be prepared (0.220 g, 81.8%)

4-(6-Hydroxyhexylamino)-benzo[*g*]-1(2*H*)-phthalazinone (11)

Sublimed 4-chloro-benzo[*g*]-1(2*H*)-phthalazinone (0.231 g, 1 mmol) was heated with 6-amino-1-hexanol (3 g) to 180 °C and kept at this temperature for 6 hrs. The excess aminohexanol was distilled in vacuum, the residue suspended in water and neutralized with hydrochloric acid (0.310 g, 100%). The halogen-free product crystallized from ethanol in the form of a yelow powder. M.p. 249—251 °C.

$C_{18}H_{21}N_3O_2$ (311.4). Calcd. C 69.4, H 6.8, N 13.5; Found C 69.5, H 6.8, N 13.6%.

IR (KBr): νOH 3358; νNH 3316; νNH_{amide} 3300—2600; νCO_{amide} 1624; δNH 1538; νC—O 1069; 1,2-disubstituted Ar ring 748 cm^{-1}.

4-(4[2-Hydroxyethyl]-piperazino)-benzo[*g*]-1(2*H*-)phthalazinone (12)

In a ground cone equipped with a reflux condenser, a mixture of *N*-(2-hydroxyethyl)-piperazine (1 g) and 4-chloro-benzo[*g*]-1(2*H*)-phthalazinone (**9**; 0.231 g, 1 mmol) was heated to 180 °C under a pressure of 80 Torr (6 hrs). The cold melt was diluted with water, the halogen-free product separated (0.322 g, 100%) crystallized from ethanol in the form of yellow prisms. M.p. 184—185 °C.

$C_{18}H_{20}N_4O_2$ (324.4). Calcd. 66.6, H 6.2, N 17.3; Found C 66.5, H 6.1, N 17.4%.

IR (KBr): νOH 3318; νNH_{amide} 3200—2400; νCO_{amide} 1647; νC—O 1010; 1,2-disubstituted Ar ring 752 cm^{-1}.

4-Benzylamino-benzo[*g*]-1(2*H*)-phthalazinone (13)

A mixture of **9** (0.231 g, 1 mmol) dissolved in ethylene glycol (2 ml) and benzylamine (0.214 g, 2 mmol) was refluxed for 20 hrs in a slow stream of nitrogen. The somewhat sticky substance (0.3 g) separating on dilution of water was boiled repeatedly with water, then crystallized from ethanol. Yellow plates were obtained. M.p. 255—256 °C (0.093 g, 30.9%).

$C_{19}H_{15}N_3O$ (301.4). Calcd. C 75.7, H 5.0, N 13.9; Found C 75,7, H 5.1, N 14.1%.

IR (KBr): νNH 3304; νNH_{amide} 3250—2800; νCO_{amide} 1627; δNH 1530; 1,2-disubstituted Ar ring 746; monosubstitution 695, 757 cm^{-1}.

4-Piperidino-benzo[*g*]-1(2*H*)-phthalazinone (14)

In nitrogen atmosphere, in a glycol (2 ml) solution, a mixture of **9** (0.231 g, 1 mmol) and piperidine (0.170 g, 2 mmol) was refluxed for 20 hrs. The raw product (0.28 g) separating on dilution with water was dissolved in hot ethanol; the by-product that separated on cooling was filtered off and the filtrate was evaporated to dryness in vacuum. The distillation residue crystallized from aqueous ethanol in the form of a yellow powder (0.196 g, 70%). M.p. 210—212 °C.

$C_{17}H_{17}N_3O$ (279.4). Calcd. C 73.1, H 6.1, N 15.0; Found C 73.0, H 6.3, N 15.1%.

IR (KBr): νNH_{amide} 3300—2600; νCO_{amide} 1653; 1,2-disubstituted Ar ring 751 cm^{-1}.

*

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REFERENCES

[1] KÖRMENDY, K.: Acta Chim. Acad. Sci. Hung., **94,** 373 (1977)
[2] KÖRMENDY, K.: Acta Chim. Acad. Sci. Hung., **88,** 129 (1976)
[3] KÖRMENDY, K.: Acta Chim. Acad. Sci. Hung., **98,** 303 (1978)
[4] KÖRMENDY, K., VOLFORD, J.: Acta Chim. Acad. Sci. Hung., **32,** 115 (1962)
[5] KÖRMENDY, K.: Thesis (in Hungarian) Budapest, 1965
[6] KÖRMENDY, K.: Acta Chim. Acad. Sci. Hung., **99,** 81 (1979)
[7] FREUND, M., FLEISCHER, K.: Ann. **402,** 68 (1914)
[8] EBNÖTHER, A., JUCKER, E., LINDENMANN, A., RISSI, E., STEINER, R., SÜESS, R., VOGEL, A.: Helv. Chim. Acta, **42,** 533 (1959)
[9] Farbenfabriken Bayer A. G. (KLOES, H., OFFE, H. A.): Ger. 1,095,841; C.A., **57,** P 11019i
[10] DREW, H. D. K., GARWOOD, R. F.: J. Chem. Soc., **1939,** 836
[11] HILL, J. H. M., EHRLICH, J. H.: J. Org. Chem., **36,** 3248 (1971)

Károly KÖRMENDY
Ferenc RUFF
H-1088 Budapest, Múzeum krt. 4/b.

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CONDENSED *as*-TRIAZINES, VIII*

DIRECT SYNTHESIS OF 1-SUBSTITUTED TRIAZOLES FUSED TO BENZO-*as*-TRIAZINE AND PYRIDO[2,3-*e*]-*as*-TRIAZINE RINGS

A. MESSMER,[1] GY. HAJÓS,[1] P. BENKÓ[2] and L. PALLOS[2]

([1] *Central Research Institute for Chemistry, Hungarian Academy of Sciences, Budapest, and* [2]*EGYT Pharmaceutical Works, Budapest*)

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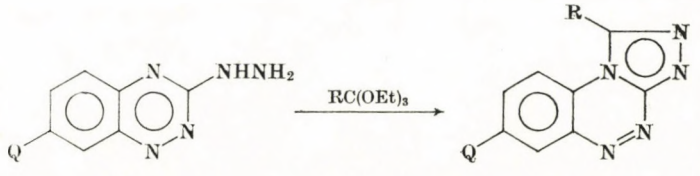
Ring closure reactions have been elaborated which allow the direct synthesis of *s*-triazolo[3,4-*c*]benzo-*as*-triazine and pyrido[2,3-*e*]-*s*-triazolo[3,4-*c*]-*as*-triazine ring system containing different substituents (alkyl, aryl, OH and SH groups) in position 1. Regarding ring closure and further reactions of substituted derivatives, a comparative study of the two systems has been made. Synthesis of approximately thirty compounds is described.

Triazoles fused to benzo-*as*-triazine and pyrido-*as*-triazine have been described in the literature only recently. The *s*-triazolo[3,4-*c*]-benzo-*as*--triazine (**2**) ring system and its 1-mercapto derivative were reported by SASAKI *et al.* [2] in 1970, whereas the first synthesis of the pyrido[2,3-*e*]-*s*-triazolo--[3,4-*c*]-*as*-triazine (**10**) system containing one more nitrogen atom was described by us [3].

The purpose of this study was to make comparative investigations on these two similar ring systems and to elaborate synthetic methods resulting in different 1-substituted derivatives.

A. Investigation of the *s*-triazolo[3,4-*c*]benzo-*as*-triazine ring system

SASAKI *et al.* [2] have reported that 3-hydrazinobenzo-*as*-triazine (**1**; Q=H) can be converted to *s*-triazolo-benzo-*as*-triazine (**2a**) by formic acid. No ring closure was found to take place, however, with any other acid applied. When 3-hydrazinobenzo-*as*-triazine (**1**) was treated with acetic acid, *e.g.*, only an acetyl derivative of the starting material was obtained [2]. In the



1 **2**

Chart 1

* For Part VII of this series, see Ref. [1].

course of our earlier studies, we found different ortho esters to be preferable to carboxylic acids as reagents for the general synthesis of 1-alkyl- and 1-aryl-substituted derivatives. Compounds **2** have been synthesized in fairly good (60 to 70%) yields.

The preparation of 1-mercapto-*s*-triazolo[3,4-*c*]-benzo-*as*-triazine (**4**) described by SASAKI *et al.* [2] has also been carried out by a novel method. 3-Hydrazinobenzo-*as*-triazine (**1**) was heated in the presence of phenyl isothiocyanate, and a red mercapto compound (**4**) was obtained in good yield. As is known from the literature [4], such ring closure reactions proceed through a thiosemicarbazide intermediate. Under appropriate experimental conditions, this intermediate could be isolated also in crystalline form (**3**).

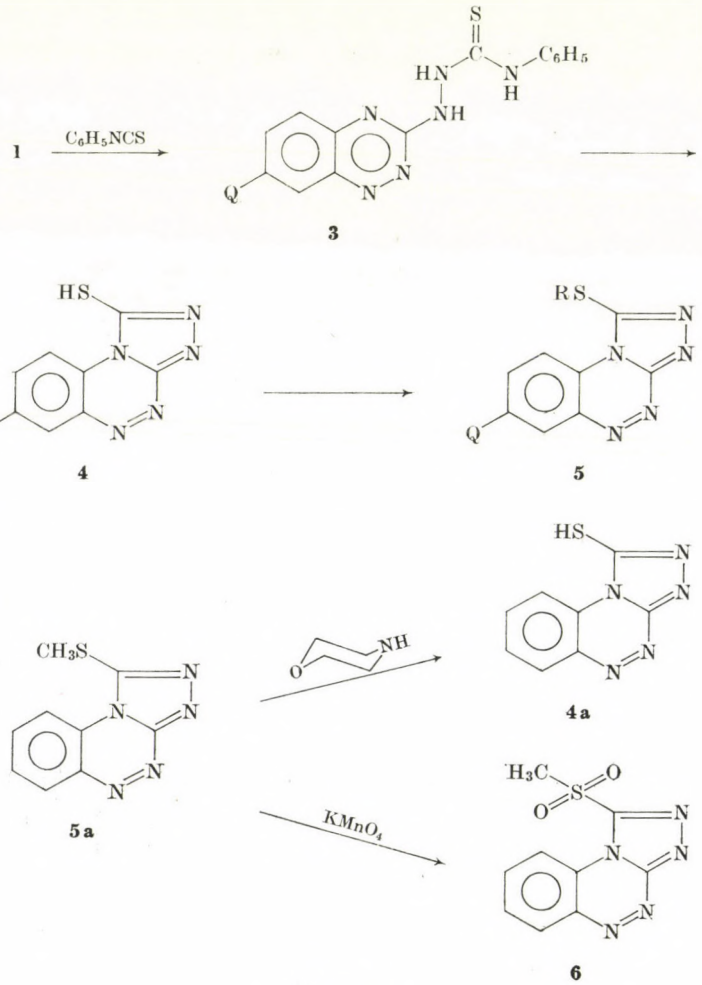
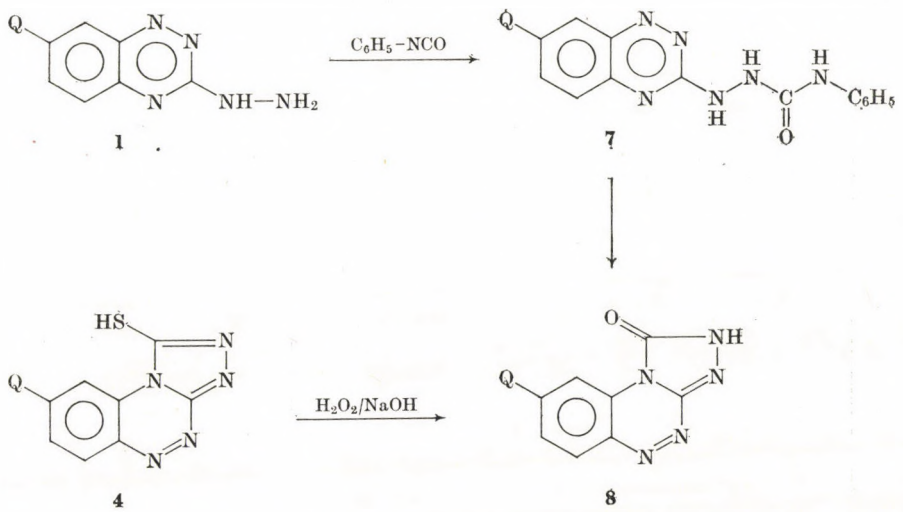


Chart 2

In comparison with 3-mercaptobenzo-*as*-triazine, mercapto compound **4** proved to be much more stable upon storage in air [5]. Its alkaline solution was found to react readily with alkylating agents, and, with disappearance of the red colour, 1-alkylthio, 1-arylthio and 1-thioglycolic acid derivatives were formed in good yield (**5a—5i**). The reaction of 1-methylthio-*s*-triazolo-[3,4-*c*]-benzo-*as*-triazine (**5a**) with potassium permanganate affords 1-methylsulfone compound (**6**).

Oxygen-containing compounds analogous to the above sulfur derivatives have also been synthesized. Thus, the reaction of 3-hydrazinobenzo-*as*-triazine (**1**) with phenyl isocyanate led to the potentially 1-hydroxy-substituted compound (**8**) which was shown by IR to exist in the triazolone form. This ring closure reaction, similarly to the sulfur analogue, proceeds through a semicarbazide intermediate which can be isolated in crystalline form (**7**). The reac-

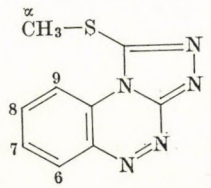


1 7 4 8

Chart 3

Table I

CMR chemical shifts of 1-methylthio-s-triazolo[3,4-]benzo-as-triazine (DMSO, 60 °C)

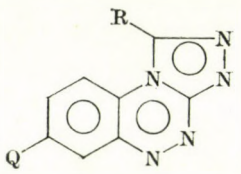


C	ppm
α	15.7
6	128.4
7	131.3
8	135.5
9	115.7

tion of 1-mercapto derivative (**4**) with an alkali peroxide solution also resulted in a 1-triazolone compound (**8**). This provided further evidence as to structure of the product.

Table II

Characteristic data of the s-triazolo[3,4-c]benzo-as-triazine derivatives



No.	Substituent		%	M.p. (°C) solvent of recryst.	Analysis (%)
	Q	R			
2a [2]	H	H	70	265—7 (EtOH)	
2b	H	CH_3	68	271—3 (MeOH—H_2O)	Calcd.: N 37.8 Found: N 37.5
2c	H	phenyl	62	240—1	Calcd.: N 28.3 Found: N 28.0
2d	Cl	H	70	253—4	Calcd.: N 34.1 Found: N 33.9
4a [2]	H	SH	75	270—80	
4b	Cl	SH	83	243—5	Calcd.: S 9.43 Found: S 9.04
5a	H	SCH_3	66	271—3 (benzene)	Calcd.: S 17.75, N 32.4 Found: S 14.48, N 32.6
5b	H	$SCH_2C_6H_5$	71	178—9 (benzene)	Calcd.: S 10.93 Found: S 11.01
5c	H	SCH_2COOH	68	251—3 (AcOH)	Calcd.: S 12.25, N 26.8 Found: S 11.95, N 26.5
5d	H	SCH_2CO-morph.	67	214—6 (NO_2CH_3)	Calcd.: S 9.70 Found: S 9.81
5e	H	SCH_2CO-piper.	75	211—3 (NO_2CH_3)	Calcd.: S 9.75 Found: S 9.45
5f	H	$SCH_2CO—N(iPr)_2$	75	236—7 (NO_3CH_3)	Calcd.: S 9.31, N 24.4 Found: S 9.25, N 24.0
5g	Cl	$SCH_2C_6H_5$	70	197—8 (benzene)	Calcd.: S 9.8 Found: S 9.4
5h	Cl	SCH_2COOEt	56	211—2 (BuOH)	Calcd.: S 9.9 Found: S 9.8
5i	Cl	$SCH_2CONHNH_2$	52	232—4 (DMF)	Calcd.: S 10.35, Cl 11.5 Found: S 10,58, Cl 12.0
8a	H	OH	75	253—5 (NO_2CH_3)	Calcd.: N 37.42 Found: N 36.99
8b	Cl	OH	70	316—8 (pyridine)	Calcd.: N 31.6, Cl 16.0 Found: N 31.3, Cl 15.6

In order to synthesize the 1-amino-substituted compound, we attempted to react 1-methylthio compound **5a** with secondary amines, *e.g.* with morpholine. Interestingly, however, formation of the unsubstituted mercapto compound (**4a**) was observed, whereas no detectable amount of either the amino compound or the presumed by-product, methylmercaptane, could be found. Therefore, an alternative possibility for the structure of compound **5a**, the existence of an *N*-methyl compound rather than *S*-methyl derivative, has also been taken into consideration, which would have been in agreement with the chemical behaviour. For structure elucidation, methylthio derivative **5a** was investigated by ^{13}C-NMR spectroscopy (Table I). The peak assigned unambiguously to the methyl group was found at 16 ppm, which value is characteristic for primary carbon atoms attached to sulfur [6]; this fact eliminates the possibility of the supposed *N*-methyl structure and the interesting consequence of the proven *S*-methyl structure is that the 1-methylthio group in ring system **2** is inert against nucleophilic attack.

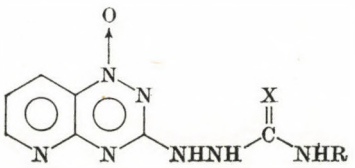
Characteristic data of the substituted new *s*-triazolo[3,4-*c*]benzo-*as*--triazines are summarized in Table II.

B. Investigation of the pyrido[2,3-*e*]-*s*-triazolo[3,4-*c*]-*as*-triazine system

Problems with the synthesis of 1-substituted derivatives of the pyrido--[2,3-*e*]-*s*-triazolo[3,4-*c*]-*as*-triazine (**10**) ring system were similar to the former case. An essential difference between systems **2** and **10** is that the only starting material for the latter case, described in the literature, was an *N*-oxide deriv-

Table III

Pyrido[2,3-e]-as-triazine-3-yl semicarbazide and thiosemicarbazide derivatives



No.	R	X	%	M.p. (°C) solvent of recryst.	Analysis (%)
11	C_6H_5	S	87	182—4 (nitromethane)	Calcd.: S 10.2, N 31.4 Found: S 10.4, N 31.2
14a	C_6H_5	O	72	235 (DMSO—MeOH)	Calcd.: N 32.98 Found: N 32.50
14b	*p*-F—C_6H_4	O	62	215 (DMSO—MeOH)	Calcd.: C 49.52, H 3.19 Found: C 49.20, H 3.47

ative: 3-hydrazinopyrido[2,3-*e*]-*as*-triazine-1-oxide (**9**) [7]. Therefore, product **10** also bears the *N*-oxide function. Further difference is caused by the plus one, electron withdrawing nitrogen atom. Differences in the chemical behaviour to **10** related to that of **2** can be generally explained by the effect of these two factors.

We reported in our earlier publication [3] that unsubstituted (**10a**) and 1-methyl-substituted (**10b**) triazoles can be prepared by ortho ester ring closure of 3-hydrazinopyrido[2,3-*e*]-*as*-triazine-1-oxide (**9**). Now we have found that 1-phenyl derivative (**10c**) can also be obtained by the same procedure. Thus, the ortho ester method proved to be a suitable way for direct preparation of different 1-alkyl and 1-aryl compounds. Characteristic data of the products are collected in Table IV.

The methods described by SASAKI [2] for the synthesis of the mercapto derivatives, however, were not applicable to synthesize mercapto compound **12**: the hydrazino group in compound **9**, probably due to the weak basicity of the ring nitrogen, did not react with carbon disulfide, and only the starting material was recovered from the reaction mixture.

Our method, however, leading to mercapto triazole *via* a thiosemicarbazide intermediate (**11**, Table III), followed by heating in dimethylformamide proved to be applicable to synthesize the mercapto derivative of ring system **10**: 1-mercaptopyrido[2,3-*e*]-*s*-triazolo[3,4-*c*]-*as*-triazine-5-oxide (**12**) has been

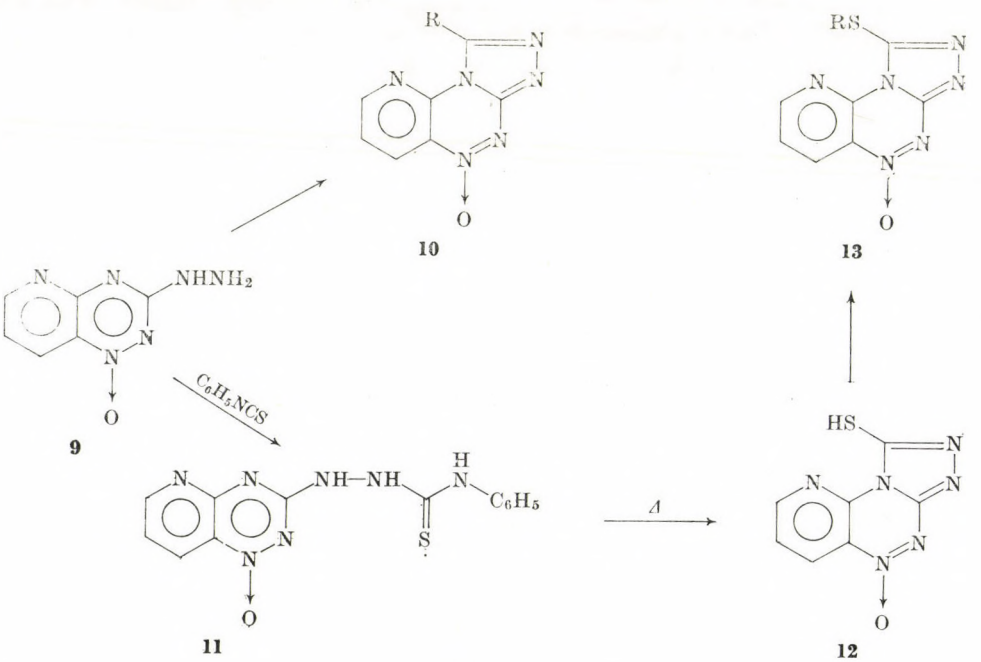
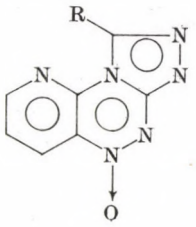


Chart 4

Table IV

Experimental data of pyrido[2,3-e]-s-triazole[3,4-c]-as-triazine-5-oxide derivatives



No.	R	%	M.p. (°C) solvent of recryst.	Analysis (%)
10a [3]	H	70	278 ($EtOH-H_2O$)	
10b [3]	CH_3	46	260—1 (Py)	
10c	C_6H_5	42	266—8 (CH_3NO_2)	Calcd.: N 31.81 Found: N 31.45
12	SH	72	255—7	Calcd.: S 14.6, N 38.2 Found: S 14.9, N 37.8
13a	$SCH_2C_6H_5$	54	265—6 (CH_3NO_2)	Calcd.: S 10.31 Found: S 10.56
13b	$2,4(NO_2)_2C_6H_4$	65	257—8 (DMF—MeOH)	Calcd.: S 8.30 Found: S 8.72
13c	SCH_2COOEt	50	196—7 (EtOH)	Calcd.: S 10.46 Found: S 10.42
13d	SCH_2CO-piper.	52	242—3 (CH_3NO_2)	Calcd.: S 9.28, N 28.4 Found: S 9.21, N 28.7
13e	SCH_2CO-morph.	49	254—6 (DMF)	Calcd.: S 9.28 Found: S 8.91
15	OH	38	above 310 (NaOH—AcOH)	Calcd.: C 41.18, H 1.97 Found: C 40.79, H 2.47

isolated in high yield in the form of dark red crystals. The product is soluble in alkali and upon reaction with alkyl chlorides, affords yellow alkylthio derivatives (**13**, Table IV).

Though crystalline semicarbazide **14a** can also be prepared from the hydrazino compound **9** with phenyl isocyanate, no formation of **15** was observed even after prolonged heating of this semicarbazide (**9**).

The lack of ring closure is probably due to the weak basicity of *N*-3 in the *as*-triazine ring, which is unable to attack the carbon atom in the semicarbazide moiety. In an attempt to promote the desired nucleophilic attack, efforts were made to prepare derivatives containing the semicarbazide chain with an electron attracting substituent.

In agreement with these considerations, we have found that semicarbazide **14b** (Table III) obtained with *p*-fluorophenyl isocyanate results in the desired triazolone derivative **15** in moderate yield. Similarly to the benzo-*as*-

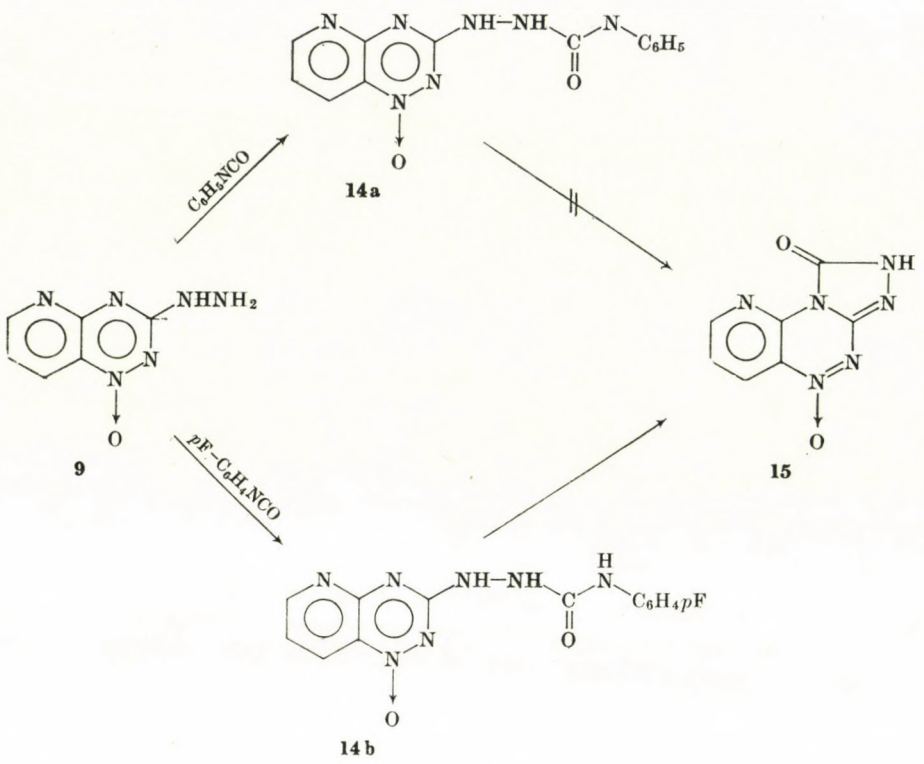


Chart 5

-triazine analogue **8**, this compound exists as a triazolone tautomer and forms a stable salt in alkali solution.

From studies in these two ring systems (**2** and **10**), the following conclusions can be drawn:

(*a*) 1-Alkyl and 1-aryl derivatives of both ring systems can be synthesized from the appropriate hydrazino compound (**1** and **9**) by treatment with ortho esters.

(b) Also 1-mercapto derivatives of both systems (**4** and **12**) can be obtained by the reaction of hydrazino compounds (**1** and **9**) with phenyl isothiocyanate. The product can be converted to *S*-alkyl and *S*-aralkyl compounds (**5** and **8**).

(c) Systems **2** and **10** react with phenyl isocyanate in different ways: the 1-oxo derivative of the *s*-triazolo[3,4-*c*]benzo-*as*-triazine system (**8**) can be obtained in the same way as thio compound **4**, however, the 1-oxo compound in the pyrido-*s*-triazolo-*as*-triazine series is not formed. This latter compound can be prepared by direct ring closure only from a starting material containing an activated reaction site

in the semicarbazide moiety, *e.g.* from compound **14b** containing the *p*-fluorophenyl group. The fact that oxo compound **15** is accessible, beside direct ring closure with a poor yield, also to transformation of the appropriate mercapto compound by alkali peroxide, is of preparative importance.

Experimental

3-Hydrazinobenzo-*as*-triazine (**1**) [1] and 3-hydrazinopyrido[2,3-*e*]-*s*-triazolo[3,4-*c*]-*as*-triazine-1-oxide (**9**) [7] were prepared according to the references. Infrared spectra were recorded with a Unicam SP 200 spectrophotometer, NMR spectra were obtained by a Varian XL-100 instrument. M.p.'s are uncorrected.

1-Alkyl- and aryl-substituted *s*-triazolo[3,4-*c*]benzo-*as*-triazines (2)

A mixture of 3-hydrazinobenzo-*as*-triazine (**1**) and a tenfold excess of ethyl orthoester was refluxed for 3 hrs, and the ethanol formed during the reaction was distilled off continuously. The product separated from the cold reaction mixture was filtered off.

1-Mercapto-*s*-triazolo[3,4-*c*]benzo-*as*-triazine (4)

A hot solution of 3-hydrazinobenzo-*as*-triazine (**1**) (15 mmol) in *o*-dichlorobenzene (20 ml) containing phenyl isothiocyanate (2.0 ml; 2.3 g; 19 mmol) was refluxed for 30 min. A dark red solution was obtained. After storage in a refrigerator for 12 hrs, the deposited crystalline substance was filtered off, washed with ether and recrystallized from the appropriate solvent.

1-Phenyl-4-(7′-chlorobenzo-*as*-triazine-3-yl)thiosemicarbazide (3b)

A mixture of 3-hydrazino-7-chlorobenzo-*as*-triazine [1] (0.5 g; 2.6 mmol), phenyl isothiocyanate (0.38 g; 0.33 ml; 2.8 mmol) and acetonitrile (5 ml) was refluxed for 30 min. Bright yellow crystals deposited from the cooled reaction mixture. M.p. 178—80 °C, yield 70%.
$C_{14}H_{11}ClN_6S$ (330.81). Calcd. S 9.70. Found S 9.82%.

1-Alkylthio-*s*-triazolo[3,4-*c*]benzo-*as*-triazines (5)

5a, **5b**, **5g**. A solution of alkyl halide (45 mmol) in ethanol (80 ml) was added to the red mixture of 1-mercapto-*s*-triazolo[3,4-*c*]benzo-*as*-triazine (41 mmol) and 4% sodium carbonate solution (250 ml). The reaction mixture was shaken until the red colour disappeared (approx. one hour). The precipitate was filtered off and recrystallized from the given solvent.

5c. The mixture of bromoacetic acid (0.5 g; 3.6 mmol) and water (5 ml) was neutralized with sodium carbonate. then added to a mixture of the 1-mercapto compound (**4**) (2.5 mmol) and 10% sodium carbonate solution (15 ml) and stirred for one hour. The resulting solution was purified by filtration and the filtrate was acidified by hydrochloric acid, whereupon the product precipitated.

5d, **5e**, **5f**. A mixture of 2.5 mmol of mercapto compound (**4**) (2.5 mmol), dimethylformamide (5 ml) and substituted chloroacetamide (2.7 mmol) was heated to 100 °C, then 1 ml of triethylamine was added. A rapid change in colour resulting in a deep brown solution took place, then the reaction mixture slowly turned yellow. At the end of the reaction, the product deposited in crystalline form.

1-Methylsulfonyl-*s*-triazolo[3,4-*c*]benzo-*as*-triazine (6)

A solution of potassium permanganate (1.5 g; 9.4 mmol) in water (12 ml) was added added to a mixture of 1-methylthio-*s*-triazolo[3,4-*c*]benzo-*as*-triazine (**5a**) (2.0 g; 9.2 mmol), acetic acid (80 ml) and acetone (20 ml) at room temperature. The reaction mixture was allowed to stand for 1/2 hour, then the excess of permanganate was decomposed by sodium hydrogen sulfite solution. The resulting yellow mixture containing crystalline precipitate was, after storage in a refrigerator for some hours, filtered off and crystallized from dioxane-petroleum ether. M.p. 211 °C.

***s*-Triazolo[3,4-*c*]benzo-*as*-triazine-1-one (8)**

A. A suspension of 3-hydrazinobenzo-*as*-triazine (**1**) (3.0 mmol) in *o*-dichlorobenzene (5 ml) was treated with phenyl isocyanate (0.4 g; 3.4 mmol). The mixture was refluxed, whereupon the starting material slowly dissolved. After a period of one hour, the resulting yellow solution was chilled and the crystalline precipitate was filtered off and recrystallized from nitromethane.

B. 1-Mercapto-*s*-triazolo[3,4-*c*]benzo-*as*-triazine (**4a**) was added to a 2% sodium hydroxide solution (10 ml). The resulting mixture was treated with 30% hydrogen peroxide solution (1 ml) at 30 °C and, after a period of 5 min, was acidified with acetic acid to pH 4 to give a pale yellow precipitate. On the basis of physical properties, the product proved to be identical with *s*-triazolo[3,4-*c*]benzo-*as*-triazine (**8a**).

1-Phenylpyrido[2,3-*e*]-*s*-triazolo[3,4-*c*]-*as*-triazine-5-oxide (10c)

A mixture of 3-hydrazinopyrido[2,3-*e*]-*as*-triazine-1-oxide (**9**) (0.5 g; 2.7 mmol), dimethyl formamide (6 ml) and ethyl orthobenzoate (2 ml) was refluxed for 15 min. The crystalline product precipitated from the cold reaction mixture upon the addition of ether.

1-Phenyl-4-(pyrido[2,3-*e*]-*as*-triazine-3′-yl)thiosemicarbazide-1′-oxide (11)

A mixture of 3-hydrazinopyrido[2,3-*e*]-*as*-triazine-1-oxide (**9**) (0.25 g; 1.4 mmol), *abs.* acetonitrile (10 ml) and phenyl isothiocyanate (0.19 g; 0.15 ml) was refluxed for 2.5 hrs. The resulting dark yellow solution was chilled, whereupon yellow needles separated, 0.38 g (87%), which were recrystallized from nitromethane; m.p. 182—184 °C.

1-Mercaptopyrido[2,3-*e*]-*s*-triazolo[3,4-*c*]-*as*-triazine-5-oxide (12)

A solution of thiosemicarbazide **11** (0.7 g; 2.24 mmol) in dimethylformamide (14 ml) was refluxed for 8 min. The chilled deep red reaction mixture was treated with ether. A red crystalline substance separated which was recrystallized from dimethylformamide, followed by drying at 170 °C for one hour. Yield: 0.35 g (72%) ; m.p.: 255—258 °C.

1-Alkylthiopyrido[2,3-*e*]-*s*-triozolo[3,4-*c*]-*as*-triazine-5-oxides (13)

Preparation of compound 13a: A mixture of mercapto compound **12** (0.4 g; 1.8 mmol) and pyridine (4 ml) was treated with ethyl bromoacetate (0.45 g; 0.3 ml; 2.7 mmol) and stirred for 15 min. After addition of water to the mixture, the product precipitated and was recrystalized from the given solvent.

Preparation of compound 13b: The mixture of mercapto compound **12** (0.4 g; 1.8 mmol), 4% sodium carbonate solution (12 ml), benzyl chloride (0.23 g; 2.0 mmol) and methylene chloride (10 ml) was shaken for 15 min. During this time the initial red colour turned yellow. The product was isolated by separation of the organic layer, followed by a threefold extraction of the water phase.

Preparation of compound 13c: A solution of mercapto compound **12** (0.7 g; 3.2 mmol) in dimethylformamide (7 ml) was added to a solution of dinitrochlorobenzene (0.64 g; 3.2 mmol) in dimethylformamide (3 ml). The mixture treated with triethylamine suddenly turned blue and a fine precipitate deposited with the mixture gradually becoming yellow. After addition of methanol to the reaction mixture, the precipitate was filtered off.

Preparation of compounds 13d, 13e: A mixture of mercapto compound **12** (0.5 g), dimethylformamide (5 ml) and chloroacetylpiperidide (0.4 g) was treated with triethylamine (1 ml) at 50 °C. The reaction was accompanied by a change in colour from red to yellow. The chilled solution was poured into water and the precipitate formed was recrystallized from the appropriate solvent.

1-Aryl-4-(pyrido[2,3-*e*]-*as*-triazine-3′-yl)semicarbazide-1′-oxide (14a, 14b)

To a suspension of 3-hydrazinopyrido[2,3-*e*]-*as*-triazine-1-oxide (**9**) (1.0 g; 5.6 mmol) in dimethylformamide (20 ml), the substituted phenyl isocyanate (8.4 mmol) was added. The mixture was stirred for 30 min at room temperature then treated with acetic acid (4 ml) and poured into a tenfold quantity of water. The product was separated as a crystalline yellow precipitate.

Pyrido[2,3-*e*]-*s*-triazolo[3,4-*c*]-*as*-triazine-5-oxide-1(2*H*)one (15)

A) A mixture of 1-*p*-fluorophenyl-4-(pyrido[2,3-*e*]-*as*-triazine-3′-yl)semicarbazide (**14b**) (0.4 g; 1.3 mmol) and dichlorobenzene (8 ml) was refluxed for 2.5 hrs. The precipitated product was filtered from the cold reaction mixture. It was dissolved in 2% sodium hydroxide solution, the solution was filtered and the filtrate was acidified with acetic acid to give a crystalline product.

B) 1-Mercaptopyrido[2,3-*e*]-*s*-triazolo[3,4-*c*]-*as*-triazine-5-oxide (**12**) was dissolved in 2% sodium hydroxide (10 ml) and the resulting red solution was treated with 30% hydrogen peroxide solution (1 ml) so that the temperature did not rise above 30 °C. The mixture was kept in a cold water bath to avoid overheating. Within 5 min, the starting deep blue colour turned red-yellow. The mixture was adjusted to a pH value of 4 with acetic acid and the precipitate obtained was filtered off. The product was purified by acidification of its alkaline solution with hydrochloric acid, and proved to be fully identical with the product obtained according to procedure *A* described above.

*

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REFERENCES

[1] MESSMER, A., HAJÓS, GY., BENKÓ, P., PALLOS, L.: Acta Chim. Acad. Sci. Hung. (In press)
[2] SASAKI, T., MURATA, M.: Chem. Ber., **102,** 3818 (1969)
[3] *a)* MESSMER, A., HAJÓS, GY., BENKÓ, P., PALLOS, L.: J. Heterocycl. Chem., **10,** 575 (1973)
b) MESSMER, A., HAJÓS, GY., BENKÓ, P., PALLOS, L.: Magy. Kém. Foly., **80,** 527 (1973)
[4] MOSBY, W. L.: Systems with Bridgehead Nitrogen, Part II, Heterocyclic Compounds ed. A. WEISSBERGER, Vol. **15,** pp. 749—752. Interscience, New York 1961
[5] ARNDT, F., ROSENAU, B.: Ber., **50,** 1248 (1917)
[6] PRETSCH, E.: Tabellen zur Strukturaufklärung Organischer Verbindungen, p. C30. Springer Verlag, Berlin 1976
[7] CARBON, A., TABATA, S. H.: J. Org. Chem., **27,** 2504 (1962)

András MESSMER
György HAJÓS
} H-1525 Budapest, P.O. Box 17.

Pál BENKÓ
László PALLOS
} H-1475 Budapest, P.O. Box 100.

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DETERMINATION OF THE CONFIGURATION OF DIASTEREOMERIC ETHANE DERIVATIVES BY ^{1}H NMR AND ^{13}C NMR SPECTROSCOPY

P. SOHÁR*, G. SCHNEIDER, G. ÁBRAHÁM, T. HORVÁTH and ZS. MÉHESFALVI

(Institute for Drug Research, Budapest)

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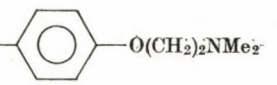
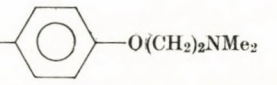
The diastereomers of substituted ethane derivatives were synthesized and their configuration determined by ^{1}H NMR and ^{13}C NMR spectroscopy.

Di- and triaryl-substituted ethane derivatives (**1**, **2**, and **3**) were synthesized and their diastereomers (**1a**, **1b**, **2a**, **2b**, **3a**, **3b**) separated. These intermediates were needed for obtaining analogues of a triarylethylene derivative (Tamoxifen) having antioestrogenic activity [1]. Depending on whether **1a** or **1b** and **3a** or **3b** was used as a starting material, mixtures containing different proportions of the geometric isomers of ethylene derivatives were obtained *via* elimination of HBr and H_2O, respectively [2]. As the geometric isomers of Tamoxifen and its analogues have usually the opposite biological activity, it was important to elucidate the configurations of the ethane derivatives obtained.

1: R = CF_3; R_1 = H; R_2 = Ph; R_3 = Br

2: R = COPh; R_1 = H; R_2 = Me; R_3 = 

3: R = Et; R_1 = OH; R_2 = Ph; R_3 = 

In this paper we report on the determination of the configurations of diastereomers of these three ethane derivatives. The diastereomeric mixture of **1a** and **1b** was obtained *via* bromination of 1,2-diphenyl-3,3,3-trifluoropropane with bromine. Addition of *p*-dimethylaminoethoxyphenylmagnesium bromide on the activated double bond of 1,2-diphenylbut-2-en-1-one afforded

* Author to whom correspondence should be addressed. Present address: "EGYT" Pharmacochemical Works, H-1475 Budapest, P.O. Box 100, HUNGARY

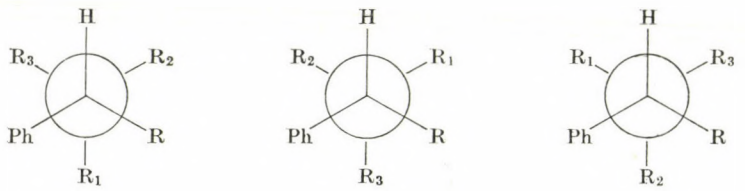
a mixture of diastereomers **2a** and **2b**. In both cases the pure diastereomers were separated. The Grignard reaction of 1,2-diphenylbutan-1-one with *p*-dimethylaminoethoxybromobenzene and the same reaction of 1-*p*-dimethylamino--ethoxyphenyl-2-phenylbutan-1-one with bromobenzene yielded **3a** and **3b**, respectively, in accordance with CRAM's rule [3].

It is a difficult task to determine the structure of diastereomers of substituted ethane derivatives. If at least one proton is attached to both carbon atoms of the ethane derivative, the vicinal coupling constants of these protons provide some information about the configuration. Of course the conformation must be taken into consideration, too, and the configuration can usually be determined only by comparing the spectra of both diastereomers.

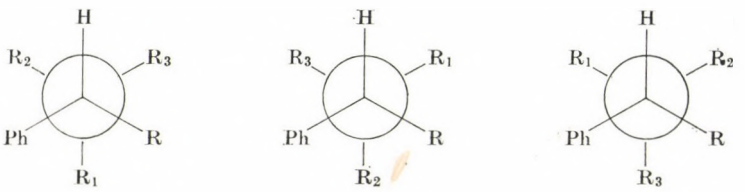
Combined configuration and conformation analysis constitutes a recognized method of NMR spectroscopy [4, 5, 6] and determination of configuration of some ethane derivatives can be found among the first papers of the NMR literature [7].

The ^{1}H NMR data of compounds investigated are listed in Table 1 according to the configuration determined as follows. The CH—CH dihedral angles of the diastereomeric pairs **1a**—**1b** and **2a**—**2b** are about 180°, deduced on the basis of the vicinal coupling constants (9 and 11 Hz, respectively). This means that in both isomers the methyne hydrogens are in *trans* position in the predominant rotamer **A**. Investigation of the molecular model leads to the same conclusion.

Among the rotamers of **1a** (1*R*, 2*S* + 1*S*, 2*R*), the predominance of **A** is reasonable as both the bulky trifluoromethyl group and the bromine atom,



a



b

as well as the two benzene rings are in *trans* position. Of the rotamers of **1b** (1*S*, 2*S* + 1*R*, 2*R*), **A** is preferred, too, for the 4 substituents are only pairwise in a *gauche* relation; in **B** and **C**, however, each substituent occupies a *gauche* position. As the bulky benzene rings are about parallel (propeller-like arrangement), their mutual anisotropic effect results in a diamagnetic shift of the signal of the aromatic protons in rotamer **A** of **1b** compared to rotamer **A** of **1a**. Therefore, structure **1b** can be assigned to the compound having a lower melting point as the chemical shift difference of the aromatic protons for **1a** and **1b** is 0.26 ppm, while those of all the other protons are smaller (0.12 and 0.02 ppm, respectively).

Rotamer **A** of **2a** (1*S*, 2*S* + 1*R*, 2*R*) is preferred as the bulky groups R and R_3 are in *trans* position. The reason of the predominance of rotamer **A** in the case of **2b** (1*S*, 2*R* + 1*R*, 2*S*) is the same as for compound **1b**. Therefore, comparing the spectral data of **2a** and **2b**, a diamagnetic shift for the methyl and benzoyl signals in **2b** and for the phenyl and R_3 signals in **2a** can be expected. The observed shift differences of all signals are in full agreement with these expectations, therefore, structure **2a** can be assigned to the higher melting diastereomer. It is to be noted that the protons of the phenyl ring give a singlet in the spectrum of **2a**, while in the case of diastereomer **2b** an *AA'BB'C* multiplet appears.

Utilizing the spectral data of the diastereomers (**1a**—**1b** and **2a**—**2b**), the configuration of **3a** and **3b** devoid of any vicinal protons can be elucidated, too. When choosing the preferred rotamer, it may be presumed that the mutual *gauche* position of the three benzene rings is improbable, consequently, in the conformational equilibrium the ratio of rotamer **B** is negligible. As regards benzene rings, the crowdedness of rotamers **A** and **C** is identical, having a *gauche* and a *trans* position each, therefore, the bulkier ethyl group (R) of the further two substituents plays a determining role. As R is in *gauche* position with two benzene rings in rotamer **C** but only with one ring in **A**, the latter is the most probable rotamer. Comparing the spectra of **3a** (1*R*, 2*S* + 1*S*, 2*R*) and **3b** (1*R*, 2*R* + 1*S*, 2*S*) a diamagnetic shift of the signal of the *p*-substituted benzene ring (R_3) in **3a** and of the phenyl group (R_2) in **3b** can be expected, therefore, structure **3a** can be assigned to the lower melting diastereomer.*

Structure **2a**—**2b**, **3a**—**3b**, supported by the ^{1}H NMR data have been confirmed by their ^{13}C NMR spectra, too (Table I).

From the ^{13}C NMR data, the diastereomers can be differentiated by the field effect [8] (steric compression shift), causing a diamagnetic shift for the sterically hindered carbon atoms. In the most probable conformation, **A** of **3b** is sterically more hindered than **3a** as the ethyl group is in *gauche* position with the bulkier *p*-substituted phenyl ring (R_3) instead of the phenyl

* Application of the CRAM's rule [3] leads to the same result.

Table I

^1H NMR data for compounds **1a, b, 2a, b,** *and* **3a, b** *in* $CDCl_3$

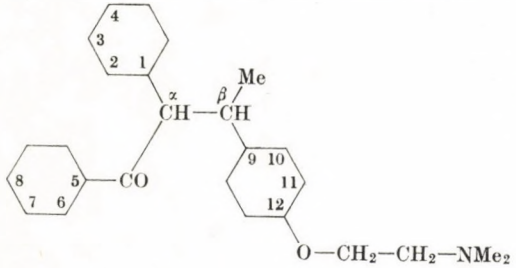
	Chemical shifts ($\delta_{TMS}=0$ ppm)					
Structure M.p. (°C)	**1a** (*R*, *S*+*S*, *R*) 162—163	**1b** (*R*, *R*+*S*, *S*) 93—96	**2a** (*R*, *R*+*S*, *S*) 154—156	**2b** (*R*, *S*+*S*, *R*) 98—99	**3a** (*R*, *S*+*S*,*R*) 120—121	**3b** (*R*, *R*+*S*,*S*) 135—137
δCH_3 (3H)	—	—	1.33 *d* (7)	1.07 *d* (7)	0.70 *t* (7)	0.75 *t* (7)
δCH_2 (2H)	—	—	—	—	1.75 *qi* (7)	1.83 *qi* (7)
δNCH_3 (6H)	—	—	2.26 *s*	2.30 *s*	2.20 *s*	2.30 *s*
δNCH_2 (2H)	—	—	2.60 *t* (6)	2.65 *t* (6)	2.55 *t* (6)	2.70 *t* (6)
δOH (1H)	—	—	—	—	~2.75 *s*	~2.5 *s*
δCH (1H)	4.00 *qi* (9)°	4.12 *qi* (9)°	3.63 2x*qa* (7,11)$^+$	3.68 2x*qa* (7,11)$^+$	3.50 *t*§ (7)	3.55 *t*§ (7)
δCH (1H)	5.38 *d* (9)•	5.40 *d* (9)•	4.63 *d* (11)^x	4.78 *d* (11)^x	—	—
δOCH_2 (2H)	—	—	3.90 *t* (6)	3.97 *t* (6)	3.80 *t* (6)	4.05 *t* (6)
δArH	7.38 ~ *s**	7.12 ~ *s**	7.05 ~ *s*#	425—450▼	7.00 ~ *s*▲⅄	7.08 ~ *s*▲⅄
νArH⌀	—	—	435—450▽		420—455≠⅄	415—435≠⅄
νArH⌀	—	—	470—490△	460—475△	—	—
δArH□	—	—	6.68	6.85	6.50	6.90⅄
δArH□	—	—	6.92	7.17	7.15⅄	7.48

° >CH—CF_3 group
\+ >CH—CH_3 group
§ Really a double doublet with about identical splittings
• >CHBr group
x >CH—C=O group
* Overlapping signals of the two phenyl rings, 10H
# Signal of the phenyl ring
▼ Overlapping multiplet of *meta* and *para* protons of the benzoyl group and the phenyl ring, 8H
▲ >CHPh group, 5H
⅄ Overlapping signals of 12H total intensity
⌀ Multiplets in Hz at 60 MHz
▽ Multiplet of *meta* nad *para* protons of the benzoyl group, 3H
≠ >C(OH)Ph group, 5H
△ Multiplet of *ortho* protons of the benzoyl group, 2H
□ Chemical shifts estimated from the *AA'BB'* multiplet of the *para*-disubstituted phenyl ring by *AB* approximation *(cf. e.g.* Ref. [6]), $J_{AB} = 9$ Hz

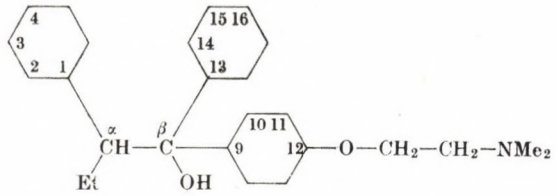
Table II

^{13}C NMR chemical shifts of compounds **2a**, **2b**, **3a** *and* **3b*** *in* $CDCl_3$ ($\delta_{TMS} = 0$ ppm)

Numbering of carbon atom:



2



3

Compound	δCH$_3$	δCCH$_2$	δCH	δNCH$_3$	δNCH$_2$	δCH$_\alpha$	δOCH$_2$	δC$_\beta$	δC=O
2a	20.4	—	42.1$^+$	45.9	58.3	61.0	66.0	—	198.6
2b	21.0	—	43.3$^+$	45.9	58.4	61.4	66.0	—	200.1
3a	12.6	23.5	56.6^x	45.8	58.2	—	65.8	80.7	—
3b	11.4	22.5	55.6^x	44.8	57.3	—	65.3	79.7	—

Compound	δC—1,9	δC—5 δC—13		δC—8 δC—15	δC—11	δC—12	δC—2,3	δC—6,7 δC—14,16		δC—4,10	
2a	137.6●	138.0●□		132.5	114.4	157.2	128.3□○	128.8○	129.0○	127.3∅	127.7∅
2b	136.5●	137.8●	137.9●	132.8	114.2	157.1	128.3□○	128.6○□	128.8○	126.7∅	128.3□∅
3a	139.0●	140.0●	146.4	130.3	113.6	157.0	127.7○	128.0○	126.3□∅	126.5∅	127.1∅
3b	137.5●	139.1●	145.9	129.2	113.1	156.6	126.4□○	126.5○	124.9□∅	125.2∅	126.4□∅

* The ^{13}C NMR data of compounds **1a** and **1b** are given in the footnote as follows, because, of the different character of the carbon atom involved. $\delta C_\beta \equiv \delta CBr$, *s*: 52.1 (**1a**) and 48.5 (**1b**) ppm, $\delta C_\alpha \equiv \delta C(CF_3)$, q*a* ($^2J_{CF} = 25$ Hz): 59.4 (**1a**) and 58.3 (**1b**) ppm, δCF_3, q*a* ($^1J_{CF} = 283$ Hz): 125.0 (**1a**) and 125.8 (**1b**) ppm, δC_{Ar} (substituted): 134.1 and 139.8 (**1a**) and 132.5 and 139.0 (**1b**) ppm, δC_{Ar} (unsubstituted): 128.1, 128.5, 128.6, 128.9, 129.5 and 129.9 (**1a**) and 128.0, 128.2, 128.4, 128.6, 128.9 and 129.5 (**1b**) ppm.

○, ●, ∅ An alternate assigment is also possible

□ Probably two overlapping signals

$^+$ C_β

^{x} C_α

ring (R_2). Therefore, smaller chemical shifts are expected for **3b** than **3a**. Similarly to the ^1H NMR data, the ^{13}C NMR results also assign structure **3b** to the higher melting diastereomer. Between the corresponding signals, a small but significant difference (about 1 ppm) can be found (Table II).

Similar differences were observed for diastereomeric pairs **1a**—**1b** and **2a**—**2b** in the shifts of C_α, and C_β; *e.g.* these signals were diamagnetically shifted in the more crowded **1b** and **2a**. The bulkier CF_3 group (R) and the bromine atom (R_3) in **1b** and the bulkier methyl (R_2) and benzoyl groups (R) in **2a** are in *gauche* position, therefore, smaller shifts can be expected and observed for these diastereomers, too.

Experimental

General methods. — All melting points are uncorrected. IR spectra were recorded on a Perkin-Elmer 577 grating spectrometer, and ^1H and ^{13}C NMR spectra on a Varian A-60D and a Varian XL-100 FT-spectrometer, respectively, at room temperature in $CDCl_3$ as solvent, using TMS as internal standard.

1,2-Diphenyl-3,3,3-trifluoroprop-1-ene

ω,ω,ω-trifluoroacetophenone (204 g) was reacted with benzyltriphenylphoshonium chloride (456 g) and sodium ethylate in ethanol, yielding **4** (271 g, 93.5%); b.p.$_{1.2}$: 117—120 °C.

$C_{15}H_{11}F_3$ (248.26). Calcd. C 72.57, H 4.47, F. 22.96; Found C 72.49, H 4.23, F 23.24%.

1,2-Diphenyl-3,3,3-trifluoropropane

4 (271 g) was hydrogenated on 10% Pd/C (27 g) in MeOH (4 l). The mixture was filtered, the solvent evaporated, and the residue distilled yielding **5** (252 g, 93.3%); b.p.$_{0.7}$: 96—108 °C.

$C_{15}H_{13}F_3$ (250.27). Calcd. C 71.98, H 5.26, F 22.75; Found C 72.12, H 5.36, F 22.51%.

1-Bromo-1,2-diphenyl-3,3,3-trifluoropropane (1a and 1b)

5 (91 g) in CCl_4 (1200 ml) was brominated with bromine (64 g) at reflux temperature for 10 hrs. The excess of bromine was removed with a solution of $Na_2S_2O_3$, the CCl_4 solution was washed with $NaHCO_3$ and water. The solvent was dried and evaporated, the residue recrystallized twice from ethanol yielding **1a** (48.2 g, 40.2%); m.p.: 162—163 °C. From the mother liquor **1b** was obtained (4.94 g, 4.12%); m.p.: 93—96 °C.

$C_{15}H_{12}BrF_3$ (329.18). Calcd. C 54.73, H 3.67, Br 24.28, F 17.32;
Found for **1a**: C 55.17, H 3.93, Br 23.98, F 17.28;
Found for **1b**: C 54.90, H 3.77, Br 24.01, F 17.36%.

1,2-Diphenylbut-2-en-1-one

1,2-Diphenyl-butan-1-one [9] (44.86 g) was treated in CCl_4 200 ml with bromine (10.5 ml) at 5 °C. The solvent was evaporated and the residue dissolved in fivefold AcOH. KOAc (60 g) was added and the mixture boiled for 30 min, yielding **6** (22%); m.p.: 62.5—63.5 °C (Et_2O).

$C_{16}H_{14}O$ (222.29). Calcd. C 86.44, H 6.36; Found C 84.65, H 6.32%.

3-*p*-Dimethylaminoethoxyphenyl-1,2-diphenylbutan-1-one (2a and 2b)

Compound **6** (8.96 g) was reacted with 1.5 M *p*-dimethylaminoethoxyphenylmagnesium bromide in THF (100 ml) at reflux temperature yielding **2a** (39%); m.p.: 154—156 °C (*i*-PrOH) and **2b** (45%). M.p.: 97—99 °C (Et_2O).

$C_{26}H_{29}NO_2$ (387.54). Calcd. C 80.56, H 7.56, N 3.62;
Found for **2a** C 80.75, H 7.74, N 3.51;
Found for **2b** C 80.53, H 7.68, N 3.63%.

1-*p*-Dimethylaminoethoxyphenyl-1,2-diphenylbutan-1-ol (3a and 3b)

1,2-Diphenylbutan-1-one [9] (44.86 g) was reacted with 1.25 *M* *p*-dimethylaminoethoxyphenylmagnesium bromide in THF (200 ml) at 55 °C yielding **3b** (82.3%). M.p.: 135—137 °C (*i*-PrOH).

$C_{26}H_{31}NO_2$ (389.56). Calcd. C 80.16, H 8.02, N 3.60; Found C 80.21, H. 7.99, N 3.53%.

3a was prepared by Grignard reaction of 1-*p*-dimethylaminoethoxyphenyl-2-phenylbutan-1-one with phenylmagnesium bromide accroding to the literature [10]; m.p.: 120—121 °C.

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REFERENCES

[1] HARPER, M. J. K., WALPOLE, A. L.: Nature, **212,** 87 (1966)
[2] SOHÁR, P., ÁBRAHÁM, G., SCHNEIDER, G., HORVÁTH, T., FUGGERT, E.: Acta Chim. (Budapest), **100,** 69 (1979)
[3] CRAM, D. J., WILSON, D. R.: J. Am. Chem. Soc., **85,** 1245 (1963)
[4] BOOTH, H.: Applications of ^1H NMR Spectroscopy to the Conformational Analysis of Cyclic Compounds (In Progress in Nuclear Magnetic Resonance Spectroscopy, Eds EMSLEY, J. W., FEENEY, J., SUTCLIFFE, L. H.), Vol. **5,** pp. 149—382, Pergamon Press, London, New York 1969
[5] TOMAS, W. A.: NMR Spectroscopy in Conformational Analysis (In Annual Review of NMR Spectroscopy, Ed. MOONEY, E. F.), Vol. **1,** pp. 44—90. Academic Press, London New York 1968
[6] SOHÁR, P.: Nuclear Magnetic Spectroscopy (in Hungarian). Akadémiai Kiadó, Budapest 1976
[7] BOTHNER-BY, A. A., NAAR-COLIN, C.: J. Am. Chem. Soc., **84,** 743 (1962)
[8] GRANT, D. M., CHENEY, B. V.: J. Am. Chem. Soc., **89,** 5315 (1967)
[9] MEYER, V., OELKERS, L.: Chem. Ber., **21,** 1295 (1888)
[10] MICHAEL, M., KENNEDY, J., RICHARDSON, D. N.: Brit. 1,013,907 (1963)

Pál SOHÁR — H-1475 Budapest, P.O. Box 100

Géza SCHNEIDER
Gizella ÁBRAHÁM
Tibor HORVÁTH
Zsuzsanna MÉHESFALVI

H-1045 Budapest,
Szabadságharcosok útja 47—49.

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DEUTERIUM TRACER STUDY OF THE BEHAVIOUR OF CHEMISORBED HYDROGEN IN SOME METAL- AND SULPHIDE-CATALYSED HYDROGENATIONS AND HYDRODESULPHURISATIONS*

P. B. WELLS

(*Department of Chemistry, The University, Hull, England*)

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The behaviour of chemisorbed hydrogen in metal- and sulphide-catalysed hydrogenations is reviewed by collation of information mostly from the author's previous publications. The use of molecular deuterium as an isotopic tracer, and the evaluation of the results by the numerical procedures originally proposed by BURWELL and by KEMBALL, permits the effective ratio of adsorbed-H to adsorbed-D in hydrogen addition steps to be calculated. This paper assembles evidence to show that, whereas some reactions behave as though adsorbed hydrocarbon species react with a single source or pool of adsorbed hydrogen, others behave as though two or more such sources exist having different isotopic composition. Classification of the latter catagory reveals that reactions dependent on two pools of adsorbed hydrogen which exist without mixing arise because of the occurrence of (i) intramolecular hydrogen atom transfer, (ii) intramolecular hydrogen atom transfers, or (iii) the establishment of more than one phase in the solid catalyst. Two examples of bi-phase systems are presented involving (a) metal, and (b) metal sulphide catalysts.

This behaviour is demonstrated by reference to the hydrogenation of ethene, buta-1,3-diene, and but-2-yne, the geometrical isomerisation of *cis*-penta-1,3-diene, and the hydrodesulphurisation of thiophen and of tetrahydrothiophen.

Recognition of such behaviour of chemisorbed hydrogen improves our understanding of catalyst activity and selectivity.

Introduction

Studies of mechanisms of heterogeneously catalysed hydrogenations usually and naturally concentrate attention on the nature and reactivity of the hydrocarbon intermediates involved. However, the other reactant, hydrogen, is very versatile in the ways in which it can chemisorb at surface sites. The object of the paper is to review, by reference to a variety of the author's published and unpublished studies, some of the general classes of reactivity exhibited by chemisorbed hydrogen, in the hope that this will encourage other investigators to be inquisitive about the precise role played by hydrogen in their reactions.

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Experimental

All reactions were carried out in static glass reactors attached to standard high vacuum apparatus. Pressures of hydrocarbon and of deuterium were typically in the range 6.6—33.3 kPa. Deuterium was purified before use by diffusion through a heated palladium-silver thimble. Product analyses were achieved by g.l.c. and pure components eluted from the chromotograph were analysed by low-voltage mass spectrometry. Results quoted in the Tables refer to experiments analysed at low conversions (<10%). Calculations by KENBALL's method and by SMITH and BURWELL's method were carried out with the aid of a computer, the programmes having been checked against manual calculations. More detailed experimental information is given in the various quoted references.

Nomenclature

Throughout this paper the word "hydrogen" is used generically to mean either protium, or deuterium, or both, where the distinction is not important. Where greater precision is required the exact names (protium or deuterium) or the symbols (H or D) are employed.

Results and Discussion

1. *Single and Multiple Hydrogen Sources*

All metal-catalysed reactions of unsaturated hydrocarbons require the addition of two (or multiples of two) hydrogen atoms to the carbon framework, and without exception it is found, by deuterium tracer studies, that this addition occurs in a stepwise fashion. The molecularly simplest case is that of ethene hydrogenation in which the ethyl group is formed as an intermediate (Scheme 1)

$$C_2X_4\,(\text{ads}) \underset{-X}{\overset{+X}{\rightleftharpoons}} C_2X_5\,(\text{ads}) \xrightarrow{+X} C_2X_6\,(g) \quad [X = H \text{ or } D]$$

Scheme 1. Ethene hydrogenation

We therefore ask the simple question: is there a single source of X-atoms for this reaction, or do adsorbed-ethene and adsorbed-ethyl acquire X-atoms from different sources? This problem can be resolved when reactions of ethene with deuterium are investigated, because the added atom X may then be either H or D, and KEMBALL's method of circulation enables the isotopic composition of the chemisorbed hydrogen to be calculated [1]. We have used this technique to assess ethene hydrogenation catalysed by Ru [2], Rh [3], Pd [3, 1*b*], Re [4], Os [2], Ir [5], Pt [5, 6] and Au [7] and for each metal, except iridium, the isotopic composition of hydrogen involved in each elementary step is closely similar (Table I). Hence it is concluded that the interaction in each step is with a hydrogen atom, and that adsorbed-ethene and adsorbed-ethyl acquire these H- and D-atoms from the same soruce. For reaction over

Table I

Isotopic compositions of chemisorbed hydrogen involved in four representative ethene-deuterium reactions

Catalyst	Temp (K)	Composition of X in Ethene(ads) + + X → E Ethyl(ads)		Composition of X in Ethyl(ads) + X → Ethane		Ref.
		H	D	H	D	
17% Re-silica	298	0.10	0.90	0.10	0.90	[4]
0.1% Pt-magnesia	298	0.25	0.75	0.25	0.75	[6]
5% Pd-alumina	257	0.67	0.33	0.62	0.38	[1*b*]
5% Ir-alumina	257	0.67	0.33	0.10	0.90	[5]

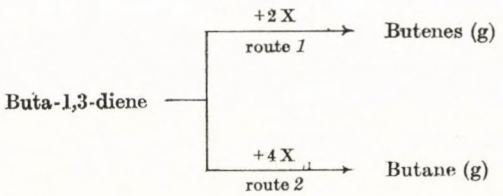
iridium the chance of adsorbed-ethyl acquiring deuterium was significantly greater than that for adsorbed-ethene (Table I). In this case, we must conclude either that there are two pools of chemisorbed hydrogen at the iridium surface of different composition or, more likely, that a proportion of the adsorbed-ethyls are converted to ethane by reaction with molecular deuterium, (Sheme 2).

$$C_2X_5\,(ads) + D_2\,(g) \longrightarrow C_2X_5D\,(g) + D\,(ads)$$

Scheme 2

Thus, from this simple reaction, we learn that careful numerical analysis must preceed statements concerning the source of hydrogen in elementary reaction steps.

The general question posed above may be re-expressed by reference to a two-step reaction such as alkyne or alkadiene hydrogenation, where alkene is formed by the addition of the first mole of hydrogen and alkane by the second. Scheme 3 represents a metal-catalysed reaction in which buta-1,3-



Scheme 3. Schematic representation of butadiene hydrogenation

-diene reacts with deuterium to give a mixture of butene and butane as initial products. Each product is observed to contain a wide distribution of deuterium indicating the formation on the surface of two adsorbed half-hydrogenated states, C_4X_7(ads) and C_4X_9(ads) in addition to adsorbed butadiene and butene, each half-hydrogenated state being in equilibrium with its precursor and adsorbed hydrogen. The operation of these equilibria render the deuterium

Table II

Isotopic compositions of chemisorbed hydrogen involved in three buta-1,3-diene-deuterium reactions

Catalyst	Temp. (K)	Composition of X in route *1* of Scheme 3		Composition of X in route *2* of Scheme 3		Ref.
		H	D	H	D	
17% Re-silica	373	0.22	0.78	0.10	0.90	[10]
5% Pt-alumina	293	0.28	0.72	0.24	0.76	[9]
5% Rh-alumina	293	0.28	0.72	0.18	0.82 (80%)	[9]
				0.86	0.14 (20%)	

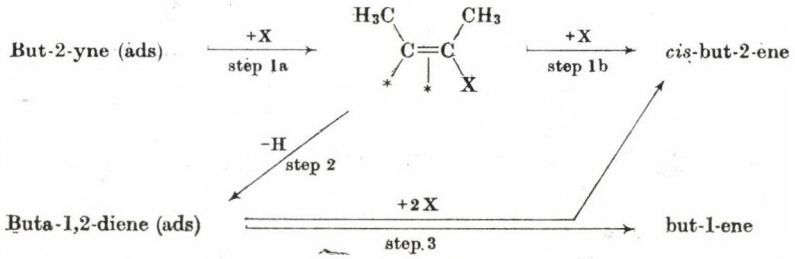
distributions in the products difficult to interpret; however, SMITH and BURWELL's method of calculation [8] permits the true exchange pattern (the N-profile to be determined, *together with the effective isotopic composition of the H : D pool for each route* represented in Scheme 3. (This method of calculation effectively assumes addition of hydrogen as atoms in the conversion of each intermediate). We can therefore address ourselves to the question: is the source of X-atoms for each route in Scheme 3 the same, or do the intermediates participating in each route require X-atoms from different sources? Some results for reactions of buta-1,3-diene with deuterium catalysed by Rh [9], Re [10] and Pt [9] are shown in Table II. Within the accuracy of the calculation it appears that both butene formation and butane formation over platinum involve the same pool of adsorbed-H and -D. However, the situation is clearly different at rhenium and rhodium surfaces, for which the results show that two or even three pools of adsorbed hydrogen, of different isotopic composition can co-exist at a catalytically active surface. In these cases it was concluded [9, 10] that butene and butane were formed at different regions of the surface. The physical significance of such "different regions of the surface" is discussed in Sections 3 and 4 below.

2. *Intramolecular and Intermolecular Hydrogen Atom Transfers without Mixing*

There are instances in which isotopic inhomogenity of adsorbed hydrogen is evident, but for which it is unreasonable to involve reaction at special site or at distinct regions of the surface. These reactions involve intremolecular or intermolecular hydrogen transfer; one or two examples of each will suffice.

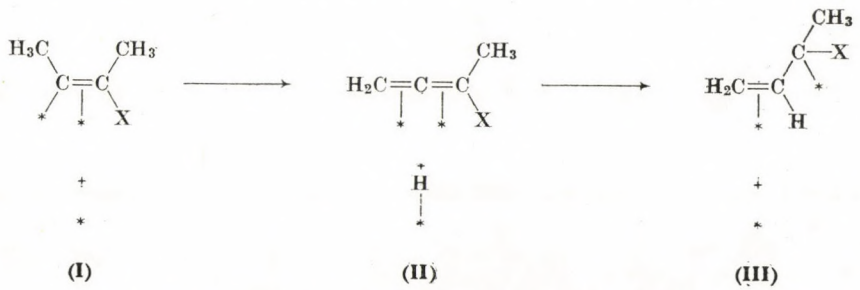
The hydrogenation of but-2-yne is well known to give *cis*-but-2-ene as the major product by simple *cis*-addition of two deuterium atoms to the adsorbed alkyne [11—13]. The yields of the other butenes are very small or zero over Ni, Pd, and Pt [11, 12], but they increase on passing to the left in Group VIII, and are substantial over Ru and Os at 358 K [13]. A deuterium tracer

study showed (i) that *cis*-but-2-ene was formed over Ru and Os by direct addition of two hydrogen atoms, the pool of hydrogen having approximately the composition H : D : : 1 : 9. But-1-ene was also formed as an initial product, ***via*** isomerisation of but-2-yne to adsorbed buta-1,2-diene and subsequent hydrogenation of the alkadiene (Scheme 4). The isotopic composition of the adsorbed hydrogen involved in step 3 was clearly not H : D : : 1 : 9 but was



Scheme 4. Formation of *cis*-but-2-ene and but-1-ene from but-2-yne over Ru and Os

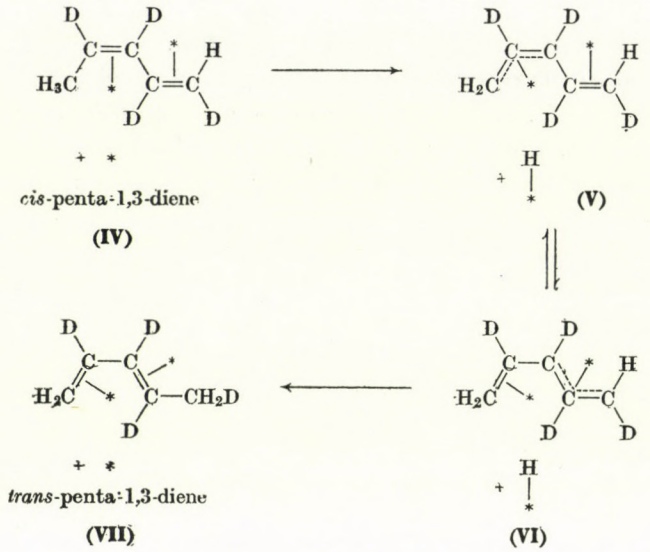
richer in protium, because the yield of but-1-ene-d_3 was less than expected and that of but-1-ene-d_2 was greater. The detailed distribution was consistent with steps 2 and 3 proceeding in part by an intramolecular hydrogen atoms transfer as shown in Scheme 5. It is curious that the adsorbed H in **(II)** does



Scheme. 5. Intremolecular H-transfer in but-2-yne hydrogenation

not mix rapidly with the general pool of adsorbed H and D atoms, but this work establishes experimentally that such mixing can be slow, and, that hydrogen atom migration over metal catalyst surfaces under working conditions is not always kinetically fast.

Another example of intramolecular hydrogen atom transfer without mixing has been observed [14] in the cobalt-alumina-catalysed geometrical isomerisation of *cis*-penta-1,3-diene-d_4 at 433 K. Although the labelling in the original material left something to be desired, the result showed clearly that isomerisation took place by the abstraction-addition process shown in Scheme 6. The adsorbed deuterium atoms present in **(V)** and **(VI)** did not mix



Scheme 6. Intramolecular H-transfer in *cis*-pentadiene isomerisation over Co

rapidly with adsorbed deuterium atom present on the cobalt by virtue of their spillover from the alumina support. This process is nominally a 1,5-transfer of the hydrogen atom; alternatively (and more likely) the process may be a succession of two 1,3-transfers with adsorbed-penta-1,4-diene being formed between (V) and (VI).

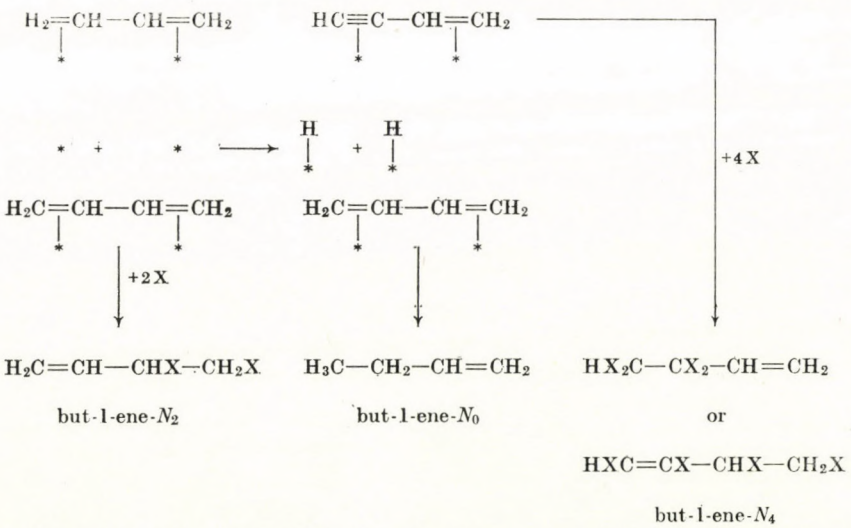
Since protium atoms can undergo *intra*molecular transfer without mixing with a general pool of adsorbed -H and -D, the next question to ask is whether *inter*molecular transfers can similarly occur. The author has not recognized such transfers in his own work, but believes that such processes are evident in the buta-1,3-diene-deuterium reaction catalysed by gold-alumina at 473 K, which has been reported by BUCHANAN and WEBB [15]. In their work, these authors observed that the butanes formed contained less than the expected amount of deuterium, and they proposed that "type B" protium was supplied to the reaction by the catalyst support. However, since easily exhangeable protium associated with the support had already been exchanged for deuterium before the execution of the experiments, the source of the type B protium remained obscure. I have taken their results and calculated N-profiles (exchange patterns) by BURWELL's method [16]. For example, a reaction [15] at 473 K gave but-1-ene having the deuterium distribution $C_4H_8 = 42\%$, $C_4H_7D = = 39.6\%$, $C_4H_6D_2 = 15.6\%$, $C_4H_5D_3 = 2.4\%$, $C_4H_4D_4 = 0.4;\%$ this distribution can be reproduced exactly by calculation, an acceptable* N-profile

* All other acceptable N-profiles contained larger values of N_0, so the argument does not change.

being:

$N_0 = C_4H_8 = 11.8\%$
$N_1 = C_4H_6X = 8.2\%$
$N_2 = C_4H_6X_2 = 64.4\%$
$N_3 = C_4H_5X_3 = 0.0\%$
$N_4 = C_4H_4X_4 = 15.6\%$ $\quad X = 60\%$ H, 40% D.

Now, it is normal chemical sense to expect of an N-profile (for butene formed from butadene) that $N_0 = N_1 = 0$; indeed, this is a criterion usually applied by the investigator in carrying out such calculations. But there the calculated information is clear. The product certainly contains a proportion of material (the N_0) in which none of the added hydrogen atoms has come from the H/D pool, and a further proportion (N_1) in which only one of the added hydrogen atoms has come from the H/D pool. The hydrogen not from the pool may either be BUCHNAN and WEBB's "type B" variety or, as I believe, may originate from the butadiene itself by intermolecular transfer as shown in Scheme 7. The adsorbed-hydrogen concentration on gold at 473 K is known to be low [15], and hence the proposed dehydrogenation of buta-1,3-diene to vinylacetylene as shown in Scheme 7 is reasonable. Scheme 7 predicts the formation of butene-N_4, with the yield of -N_4 being comparable with that of -N_0 which concurs with the calculated N-profile. Finally, the gold catalyst used in this work deactivated irreversibly with use, which may be attributed to the progressive accumulation of species more extensively dehydrogenated than the



Scheme 7. But-1-ene-N_0, -N_2, and -N_4 formation. The process of N_0 formation involves intermolecular H-transfer without mixing with the H/D pool. But-2-ene would be formed by analogous 1 : 4-addition

vinylacetylene. (My reinterpretation of this work is accepted by the original senior author as a valid alternative view). Thus, this reaction can be interpreted as providing evidence for intermolecular hydrogen transfer without mixing. It will be interresting to search in the future for other reactions, probably at IB-metal surfaces, in which the hydrogen atom coverage achieved by the chemisorption of molecular hydrogen is sufficiently low for a second source of hydrogen, generated by hydrocarbon dissociation, to play a distinctive role in the overall process.

3. *Co-existance of Two Hydrogen-Deuterium Pools without Mixing at Sulphide Surfaces*

Table II showed that two or three pools of hydrogen, each containing both H and D, can apparently co-exist at a metal surface. A similar situation has been observed for sulphide-catalysed reactions.

Tetrahedrothiophen reacts with deuterium at the surface of MoS_2 powder at 693 K to give buta-1,3-diene and propadiene as the major initial products, and butenes as minor products [17]. Typical deuterium distributions are given in Table III; remarkably, the butadiene in mostly a mixture of C_4H_6 and C_4H_6. The most interesting step for our present purposes is the next stage of the reaction in which this butadiene is hydrogenated to butene. Clearly the butadiene-d_0 is converted to butene containing 0 to 6 deuterium atoms the distribution being contered at -d_2, whereas the butadiene -d_6 is converted cleanyl to butene-d_8. The conversion of the butadiene-d_0 to a range of deuteriated butenes is commonplace and has been observed over many metals; it occurs by the process shown in part (a) of Scheme 8 according to which the interconversion adsorbed-butadiene with half hydrogenated state causes the initial pool of adsorbed deuterium atoms to be isotopically diluted by protium atoms from the hydrocarbon. The very fact of isotope redistribution guarantees that both adsorbed-H and adsorbed-D are present at the sites where this C_4H_6 undergoes further reaction. The conversion of C_4H_6 to C_4D_8 proceeds by formally the same mechanism [part (b) of Scheme 8] except that, on this

Table III

Deuterium compositions in buta-1,3-diene and butene formed by reaction of tetrahydrothiopen with deuterium over powdered MoS_2 at 693 K
(Conversion = 5%)

Product	Deuterium distribution (%)								
	d_0	d_1	d_2	d_3	d_4	d_5	d_6	d_7	d_8
Buta-1,3-diene	49	11	8	6	4	2	20		
Butene	5	18	22	19	7	6	3	0	20

$$C_4H_6\ (ads) + D\ (ads) \longrightarrow C_4H_6D\ (ads) \xrightarrow{+D} C_4H_6D_2\ (g)$$

$$C_4H_6D\ (ads) \longrightarrow C_4H_6\ (ads) + D\ (ads)$$

$$C_4H_6D\ (ads) \longrightarrow C_4H_5D\ (ads) + H\ (ads)$$

$$C_4H_6\ (ads) + H\ (ads) \longrightarrow etc. \qquad (a)$$

$$C_4H_5D\ (ads) + H\ (ads) \longrightarrow etc.$$

$$C_4H_5D\ (ads) + D\ (ads) \longrightarrow etc.$$

$$etc.$$

$$C_4D_6\ (ads) \underset{-D}{\overset{+D}{\rightleftharpoons}} C_4D_7\ (ads) \xrightarrow{+D} C_4D_8\ (g) \qquad (b)$$

Scheme 8. Processes occurring in the hydrogenation of C_4H_6/C_4D_6 mixtures at the surface of molybdenum disulphide at 693 K

occasion, there can be no adsorbed protium present, otherwise butene-d_7 would have been formed. Thus the hydrogen pool in this process is 100% D. Since the products were formed in the same reaction two pools of hydrogen, one a mixture of adsorbed-H and -D, and the other purely adsorbed-D co-exist on the surface without mixing.

We similarly observed in the thiophen-deuterium reaction over the same powdered-MoS_2 that the pool of hydrogen involved in (D_2S + HDS + H_2S)--formation was very rich in deuterium (H : D $\sim$ 1 : 20) whereas that involved in simultaneous butene-formation was less rich in deuterium (H : D $\sim$ 1 : 3) [17].

The characteristics of butadiene-deuterium reactions catalysed by these sulphides [17, 18] vary depending on catalyst age and we infer, without direct analytical evidence, that this variation is due to changes in the surface Mo : S ratio. We speculate therefore, that the sulphide surface used in the experiment recorded in Table III was itself heterogeneous with respect to surface composition, and that each area of surface having a certain distinctive stoichiometry was associated with a pool of adsorbed hydrogen of distinctive isotopic composition. However, the nature of the barrier that prevented mixing is not clear.

4. *Interpretation of the Co-existance of Two Hydrogen-Deuterium Pools without Mixing at Metal Surfaces*

Table II, referred to in Section 1, shows that two or three H/D pools can co-exist without mixing at metal surfaces during buta-1,3-diene hydrogenation catalysed by rhenium and rhodium. It was concluded from these studies [9, 10] that butene and butane were formed at different regions of the surface, but the characteristics of these regions were unknown.

More recently, it became clear that one factor that influences the yield of butane *in the initial stages* of buta-1,3-diene hydrogenation is the extent of hydrogen occlusion in the metal [19]. The extent of hydrogen occlusion in a series of metal powders under standard conditions of catalyst preparation varied in the sequence Ir $>$ Os $>$ Ru $>$ Rh $>$ Pt $>$ Co $\sim$ Ni $\sim$ Cu $=$ Au $=$ $=0$, and the yield of butane in butadiene hydrogenation under standard conditions varied in the same sequence [19]. A cavity theory was advanced to account for the extent of hydrogen occlusion in the various metals and the regions of the surface active in butane formation were proposed to be either the surfaces of the cavitated zones or, more likely, the boundaries of such zones. According to this model, the cavities are formed because metal atoms at the moment of their formation (during chloride or oxide reduction) are restricted in their diffusion to proper lattice sites because of the low temperatures commonly employed ($\sim$500 K). There is thus a simple test of this theory. Catalysts which normally exhibit a low selectivity (*e.g.* Ir) should become highly selective if the metal is formed at a high temperature where metal atom diffusion is fast. Table IV shows some results [20] for a series of iridium powders prepared from chloride or oxide in the range 673—1273 K. Catalysts 1, 2, and 4 are powders prepared under normal conditions; they occlude hydrogen and exhibit low catalytic selectivities in buta-1,3-diene hydrogenation. They are similar to those reported previously in reference [19], except that catalyst 1 exhibited the highest extent of hydrogen occlusion that we have yet recorded. Catalysts 3 and 5 were prepared at temperatures of 1173 and 1273 K, well above the HUTTIG temperature for iridium, where metal atom mobility during reduction should have been considerable. Extents of hydrogen occlusion were low, which we attribute to a virtual absence of cavities, and the selectivities of these cata-

Table IV

Effect of catalyst preparation temperature upon the extent of hydrogen occlusion in iridium, and upon the selectivity of iridium in buta-1,3-diene hydrogenation

Sample	Precursor	Catalyst preparation[a] temp (K)	Catalyst[b]	Butadiene Hydrogenation[c]			
				Temp. (K)	Butene (%)	Butane (%)	Selectivity
1	$IrCl_3$	700	$IrH_{0.46}$	273	20	80	0.20
2	$IrCl_3$	673	$IrH_{0.12}$	298	60	40	0.60
3	$IrCl_3$	1173	$IrH_{0.03}$	298	95	5	0.95
4	IrO_2	673	$IrH_{0.20}$	385	70	30	0.70
5	$IrCl_3$	1273	$IrH_{0.02}$	385	99	1	0.99

[a] catalyst prepared in flowing hydrogen
[b] hydrogen content measured at 373 K by exchange with deuterium
[c] conversions = 10—30%. Butene composition: b-1, 45%; *c*-b-2, 30%; *t*-b-2, 25%

lysts were very high indeed, which follows if the butane-forming sites are indeed associated with the presence of the proposed cabitated zones.

Thus, the original observation of multiple H/D pools (Table II) has led, by a process of deductive logic, to a situation where the selectivity of a catalyst can be predictably improved by a change in preparation procedure.

Conclusions

These simple hydrocarbon reactions have revealed a considerable complexity in the manner in which chemisorbed hydrogen reacts at catalytically active metal and at sulphide surfaces. This fine detail concerning hydrogen atom reactivity can only be probed when deuterium is used as a tracer. The coexistance of two or more phases, either in metal-sulphur or in metal-hydrogen systems, may, in appropriate reactions, lead to distinctive behaviour on the part of adsorbed hydrogen which can have important effects on catalyst activity and selectivity. Even, however, where the catalyst does not posses this form of surface heterogeneity, its activity and selectivity can be influenced by the primary or secondary effects on intramolecular and intermolecular hydrogen atom transfer processes.

*

I warmly thank the organisers of the meeting for the invitation to me to present this paper, and I must acknowledge the very considerable contributions made by my many research colleagues whose names appear with mine in the listed references.

REFERENCES

[1] (*a*) KEMBALL, C.: J. Chem. Soc., **1956,** 735;
(*b*) KEMBALL, C., WELLS, P. B.: J. Chem. Soc. (A), **1968,** 444
[2] BOND, G. C., WEBB, G., WELLS, P. B.: Trans. Faraday Soc., **61,** 999 (1965)
[3] BOND, G. C., PHILLIPSON, J. J., WELLS, P. B., WINTERBOTTOM, J. M.: Trans. Faraday Soc., **62,** 433 (1966)
[4] GRANT J., MOYES, R. B., WELLS, P. B.: J. Chem. Soc. Faraday Trans. I, **69,** 1779 (1973)
[5] BOND, G. C., PHILLIPSON, J. J., WELLS, P. B., WINTERBOTTOM, J. M.: Trans. Faraday Soc., **60,** 1847 (1964)
[6] BRIGGS, D., DEWING, J., BURDEN, A. G., MOYES, R. B., WELLS, P. B.: J. Catalysis (submitted for publication)
[7] SERMON, P. A., BOND, G. C., WELLS, P. B.: J. Chem. Soc. Faraday Trans. I, **75,** 385 (1979)
[8] SMITH, G. V., BURWELL, R. L., jun.: J. Amer. Chem. Soc., **84,** 925 (1962)
[9] BATES, A. J., LESZCZYNSKI, Z. K., PHILLIPSON, J. J., WELLS, P. B.,WILSON, G. R.: J. Chem. Soc. (A), **1970,** 2435
[10] GRANT, J., MOYES, R. B., WELLS, P. B.: J. Catalysis, **51,** 355 (1978)
[11] MEYER, E. F.,BURWELL, R. L.: J. Amer. Chem. Soc., **85,** 2877 (1963)
[12] PHILLIPSON, J. J., WELLS, P. B., GRAY, D. W.: Proc. 3rd Intern. Congr. Catalysis (North-Holland, Amsterdam, 1965), **2,** 1250
[13] WEBB, G., WELLS, P. B.: Trans. Faraday Soc., **61,** 132 (1965)
[14] WELLS P. B., WILSON, G. R.: Discuss, Faraday Soc., **1966** (41), 237

[15] BUCHANAN, D. A., WEBB, G.: Trans. Faraday Soc., **71**, 134 (1975); BUCHANAN, D. A.: Ph. D. thesis, University of Glasgow, 1973
[16] WELLS, P. B.: unpublished work
[17] EYRE, M., MOYES, R. B., WELLS, P. B.: Paper submitted to Seventh International Congress on Caralysis
[18] BLAKE, M. R., MOYES, R. B., WELLS, P. B.: unpublished work
[19] WELLS, P. B.: J. Catalysis, **52**, 498 (1978)
[20] MARTOS, J., MOYES, R. B., WELLS, P. B.: unpublished work

Peter B. WELLS Department of Chemistry, The University, Hull, England. HUG 7RX

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SYNTHESIS OF VINCA ALKALOIDS AND RELATED COMPOUNDS, VII*

EPIMERIZATION STUDIES

Gy. KALAUS,[1] Zs. GYULAI,[1] M. KAJTÁR-PEREDY,[2] P. GYŐRY,[1] L. SZABÓ[1] and Cs. SZÁNTAY[1 2]

([1]*Institute of Organic Chemistry, Technical University, and* [2] *Central Research Institute for Chemistry, Hungarian Academy of Sciences, Budapest*)

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Oxidation, with sodium dichromate at room temperature, of the ethyl ester of vincaminic acid (**3a**) and of vincamine (**3b**) gave the corresponding anhydrocompounds **6a** and **7a** respectively. When this reaction was carried out at higher temperatures, further epimerization of the compounds ensued. The steric structures of the isolated products have been verified by chemical and by physical methods.

A few years ago in a preliminary communication we described the oxidation of vincamine, **3b**, with sodium dichromate, and reduction of the resulting iminium salt **6b** to 3-epivincamine, **8b** [2].

Subsequently, while reproducing this work, BOMBARDELLI *et al.* [3] obtained a mixture of two epimers **8b** and **9b** and on the basis of spectroscopic studies of the structures they stated that, in contrast to our communication, the epimer **9b** was the main product.

Here we intend to describe the details of the studies reported in our preliminary paper, furthermore to publish results of epimerization reactions of the ethyl esters **3a** and **4a** of vincaminic acid. The latter study seemed to be of interest because **3a** is genetically related to (+)-apovincaminic ethyl ester **5**, successfully applied in human medication as the cerebral vasodilator Cavinton®.

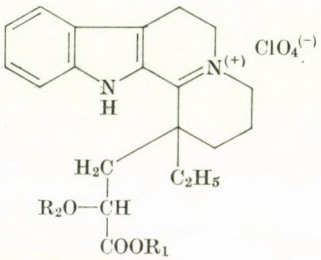
(A) Synthesis of the ethyl ester of vincaminic acid [4]

The ethyl esters of vincaminic acid and apovincaminic acid were synthesized by the same method as applied for the preparation of vincamine [5]. Accordingly, α-acetoxyacrylate was prepared in the same way as the methyl ester [6], and this was allowed to react with the known enamine [5] to obtain the adduct **1a**. Sodium borohydride reduction at low temperature gave the

* Part VI, see Ref. [1].

cis isomer **2a** with satisfactory stereoselectivity. Deacetylation of the latter led to the hydroxy derivative **2b**.

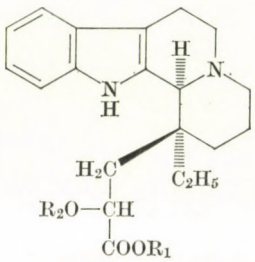
Oxidation of the hydroxy-ester **2b** was effected by means of the Fétizon reagent. When working at the boiling point of xylene, the isolated main product was the ethyl ester of vincaminic acid **3a**, whereas oxidation in benzene yielded mainly the ethyl ester of 14-epivincaminic acid **4a**. As also experienced with vincamine, the epi-compound **4a** in ethanol and in the presence of sodium ethoxide epimerizes to **3a**, which is more stable thermodynamically and crystallizes more easily.



1a $R_1 = C_2H_5$ $R_2 = CH_3CO$

1b $R_1 = C_2H_5$ $R_2 = H$

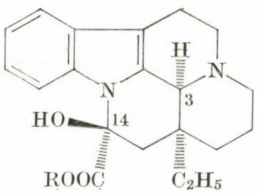
1c $R_1 = CH_3$ $R_2 = H$



2a $R_1 = C_2H_5$ $R_2 = CH_3CO$

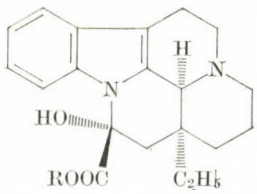
2b $R_1 = C_2H_5$ $R_2 = H$

2c $R_1 = CH_3$ $R_2 = H$



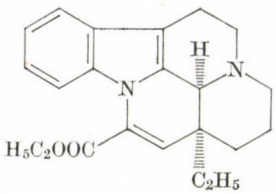
3a $R = C_2H_5$

3b $R = CH_3$

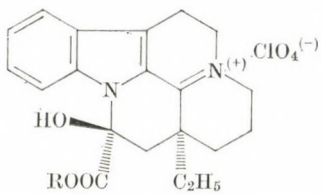


4a $R = C_2H_5$

4b $R = CH_3$



5



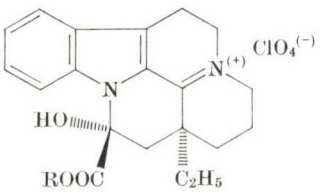
6a $R = C_2H_5$

6b $R = CH_3$

A simple way of proving that actually the C-14 epimers were present consisted in dehydration of **3a** and **4a** by means of acetic anhydride, which led, in both cases, to the same anhydro-compound **5**, the racemic counterpart of Cavinton.

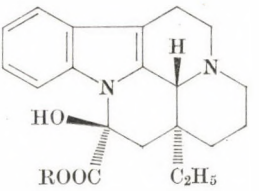
(B) Preparation of 3-epivincaminic acid esters

The esters **3a** and **4a** were oxidized with sodium dichromate in glacial acetic acid for four days at room temperature. This gave the derivatives **6a** and **7a**, respectively, in stereo-homogeneous reaction. Reduction by means of sodium borohydride in methanol at 0 °C uniformly produced the 3-epi products **8a** and **9a**.



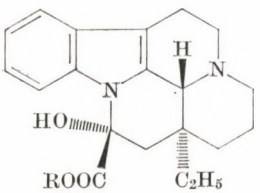
7a R = C_2H_5

7b R = CH_3



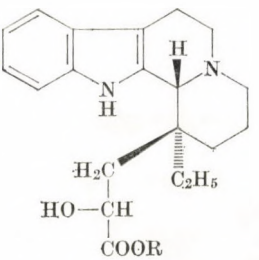
8a R = C_2H_5

8b R = CH_3



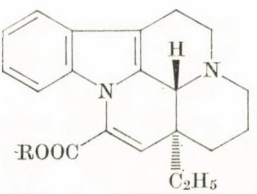
9a R = C_2H_5

9b R = CH_3



10a R = C_2H_5

10b R = CH_3



11a R = C_2H_5

11b R = CH_3

When the oxidation was accelerated by warming on a water bath, a mixture of **6a** and **7a** was obtained, either from pure **3a** or pure **4a**; *i.e.* under these conditions the reaction involved epimerization at the C-14 chiral centre. Reduction of the mixture as above gave **8a** and **9a**, isolable by TLC.

The stability of the epimers **8a** and **9a** during treatment with sodium ethoxide was studied. In contrast to the *cis*-type derivatives **3a** and **4a**, in the case of the *trans* epimeric pair **8a**, and **9a** it is the 14-epi-variant **9a** which has higher stability. Compound **8a** is completely converted in ethanol and in the presence of sodium ethoxide into **9a**.

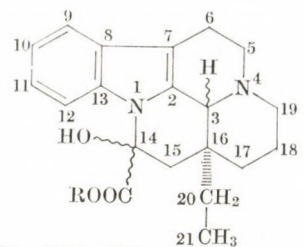
These epimers were also prepared from the adduct **1a**. In order to render the reduction of the carbon-nitogen double bond less stereoselective, the space requirement of the substituent at C-1 was diminished by deacetylation in ethanolic hydrochloric acid. Reduction of **1b** with sodium borohydride at room temperature, but especially in boiling ethanol, gave compound **10a** in considerable amounts, besides **2b**; oxidation of the former with the Fétizon reagent yielded a mixture of **8a** and **9a**. Epimerization induced by metal ions [5] also showed **9a** to be more stable than **8a**. Elimination of water, by means of acetic anhydride, from either of these compounds resulted in the apo-derivative with the structure **11a**.

Table I

^1H chemical shifts δ [ppm]

	3a	4a	8a	9a	3b	4b	8b	9b
C(3)—H	3.86	3.87	3.00	2.92	3.85	3.87	2.98	2.91
C(14)—OH	5.84	6.53	6.42	5.83	6.16	6.72	6.70	6.20
C(21)—H_3	0.90	0.90	0.63	0.82	0.89	0.89	0.61	0.82
$COOCH_2\mathbf{CH_3}$	1.20	1.18	1.18	1.19	—	—	—	—
$COO\mathbf{CH_2}CH_3$	4.26	4.16 4.18	4.17 4.18	4.24 4.26	—	—	—	—
$COOCH_3$	—	—	—	—	3.76	3.69	3.70	3.76

Solvent: a 3 : 1 mixture of $CDCl_3$—DMSO-d_6



R = C_2H_5, CH_3

Table II

^{13}C chemical shifts, δ [ppm]

	3a[a]	4a[a]	8a[a]	9a[a]	3b[b]	4b[b]	8b[b]	9b[b]
C-2	131.57	132.02	133.10	132.48	131.37	132.06	133.20	132.49
C-3	58.59	58.52	66.56	66.32	59.01	59.22	66.98	66.56
C-5	50.42	50.54	52.67	52.40	50.80	51.23	52.53	52.67
C-6	16.40	16.24	20.84	20.84	16.65	16.75	21.07	21.00
C-7	104.39	104.70	104.82	104.64	104.83	105.57	105.30	104.94
C-8		128.05	127.77	128.00	128.60	128.45	127.98	128.17
C-9	117.55	117.26	117.39	117.56	117.86	117.78	117.62	117.66
C-10	120.30	120.08	119.98	120.17	120.84	120.93	120.41	120.42
C-11	119.26	118.99	119.02	119.20	119.62	119.68	119.35	119.39
C-12	111.53	113.77	112.87	111.85	111.13	113.43	112.78	111.68
C-13		136	135.94	134.62	134.16	136	136.04	134.72
C-14	82.31	83.41	83.07	82.59	82.19	82.49	83.26	82.62
C-15	43.88	45.63	45.73	43.52	44.13	46.73	46.13	43.78
C-16	34.53	35.69	36.86	35.47	34.81	36.27	37.13	35.65
C-17	25.19	24.12	20.60	20.68	25.07	24.22	20.82	20.85
C-18	20.41	20.35	18.10	19.13	20.63	20.85	18.36	19.24
C-19	44.21	44.17	55.28	55.18	44.45	44.69	55.69	55.46
C-20	28.35	28.11	31.77	31.69	28.70	28.82	31.93	31.88
C-21	7.27	7.25	6.71	7.11	7.48	7.53	6.75	7.19
$COOCH_2CH_3$	61.75	61.16	61.42	61.79	—	—	—	—
$COOCH_2CH_3$	13.83	13.70	13.72	13.89	—	—	—	—
$COOCH_3$	—	—	—	—	53.12	52.79	53.09	52.95
CO	175.20	170.27	170.39	171.92	173.22	171.70	171.13	172.74

Solvents: [a] DMSO-d_6
[b] mixture of $CDCl_3$—DMSO-d_6

In the paper by BOMBARDELLI *et al.* [3] the chemical shifts of C-17 and C-18 in isomers **8b** and **9b** are in reverse order.

Vincamine itself showed an entirely similar behaviour. Compound **6b**, prepared by oxidation at room temperature with sodium dichromate, was readily epimerized when warmed in glacial acetic acid; as a result a mixture of **6b** and **7b** was obtained. In contrast to findings with the *cis*-type vincamine, of the products **8b** and **9b**, made by sodium borohydride reduction, the 14-epi compound **9b** proved to be the thermodynamically more stable one.

The saturation of **1c** [5] by means of sodium borohydride in methanol at the boiling point yielded **10b** besides very small amounts of **2c**. Oxidation with Fétizon reagent of **10b** in benzene, or xylene gave mainly the isomer **9b** and slight amounts of **8b**. Elimination of water by means of acetic anhydride equally afforded the same 3-epi-apovincamine **11b**.

(C) Spectroscopic study of the epimers

The ^{1}H-NMR spectra of the methyl and ethyl esters of vincaminic acid, epimeric at C-3 and C-14, were recorded at 100.10 MHz; their ^{13}C-NMR spectra were obtained at 25.16 MHz. Chemical shifts are listed in Tables I, and II. The results of NMR studies confirmed the steric structures of the epimers as shown in this paper. As reported by BOMBARDELLI *et al.* [3], the preferred conformations are such that in the cases of **3a**, **3b**, **4a**, and **4b** the C/D and D/E rings are *cis*-annellated, whereas in compounds **8a**, **8b**, **9a**, and **9b** they are *trans*-annellated.

(D) Conclusions

The thermodynamic stability, in the respect of the C-14 chiral centre, of the C-3 epimeric methyl and ethyl esters of vincaminic acid is just the opposite to what was observed earlier [4, 5] in the case of vincamine and the ethyl ester of vincaminic acid.

Consequently, when the oxidation of compounds **3a** and **3b** with sodium dichromate in acetic acid is not carried out at room temperature, then not **8a** or **8b** but **9a** or **9b**, *i.e.* the C-14 epimers, will be the main products of subsequent reduction. Though BOMBARDELLI *et al.* do not report in their paper the temperature of oxidation, the most probable reason why they were unable to reproduce our results [2] is that they effected the reaction at an elevated temperature.

Experimental

M.p.'s are uncorrected. IR spectra were recorded by means of a Spectromom 2000 spectrophotometer in KBr pellets.

3,4-Dehydro-14,15-dihydro-14-(ethoxycarbonyl)-14-hydroxyeburnamenin(14β, 16α) perchlorate (6a)

14,15-Dihydro-14-(ethoxycarbonyl)-14-hydroxyeburnamenin(3α, 14β, 16α) (**3a**) (1.0 g; 2.71 mmoles) was dissolved in glacial acetic acid (15 ml), and a solution of sodium dichromate dihydrate (0.3 g; 1.0 mmole) in glacial acetic acid (3 ml) was added. This mixture was allowed to stand 4 days at room temperature. To the resulting dark green solution an aqueous 70% solution (0.3 ml) of perchloric acid was added and the mixture was allowed to crystallize, to obtain yellow crystals (0.9 g; 71%), m.p. 204—207 °C.

$C_{22}H_{27}ClN_2O_7$ (466.92). Calcd. C 56.59; H 5.83; N 5.99. Found C 56.43; H 5.87; N 6.07%.

IR (ν_{max}): 1744 cm^{-1} (>C=O) 1645 cm^{-1} (>C=$\overset{(+)}{\underset{|}{N}}$—).

3,4-Dehydro-14,15-dihydro-14-(ethoxycarbonyl)-14-hydroxyeburnamenin(14α, 16α) (7a)

14,15-Dihydro-14-(ethoxycarbonyl)-14-hydroxyeburnamenin (3α, 14α, 16α) (**4a**) (3.0 g; 8.13 mmoles) was dissolved in glacial acetic acid (45 ml), and sodium dichromate dihydrate (1.0 g; 3.33 mmoles) in glacial acetic acid (10 ml) was added. This mixture was allowed to

stand 4 days at room temperature. The dark green solution was then mixed with a 70% aqueous solution (1 ml) of perchloric acid and allowed to crystallize, to obtain yellow crystals (2.0 g; 52.6%) m.p. 182—184 °C.

$C_{22}H_{27}ClN_2O_7$ (466.92). Clacd. C 56.59; H 5.83; N 5.99. Found C 56.80; H 6.03; N 5.74%.

IR (ν_{max}): 1764 cm^{-1} (>C=O), 1659 cm^{-1} (>C=$\overset{(+)}{N}$—).

(±)-3-Epivincaminic acid ethyl ester (8a)

The salt **6a** (1.3 g; 2.78 mmoles) was suspended in methanol (20 ml) and cooled to 0 °C, under vigorous stirring, then sodium borohydride (1.2 g; 31.88 mmoles) was added in small portions and the stirring was continued for 1 h. The mixture was acidified to pH 2—3 with 5 *N* HCl, and evaporated under reduced pressure; the residue was mixed with distilled water (120 ml) and made alkaline (pH 10) with 40% NaOH solution. The mixture was then extracted with dichloromethane (60, 50, 40 ml), the organic phase dried over $MgSO_4$ and the solvent evaporated under reduced pressure. The dry residue (1.0 g) was recrystallized from ethanol to yield white crystals (0.8 g; 78.2%) m.p. 182—183 °C.

$C_{22}H_{28}N_2O_3$ (368.48). Calcd. C 71.71; H 7.66; N 7.60. Found C 71.95; H 7.47; N 7.71%.

IR (ν_{max}): 1729 cm^{-1} (>C=O).

(±)-3-Epi-14-epivincaminic acid ethyl ester (9a)

The salt **7a** (1.3 g; 2.78 mmoles) was suspended in methanol (40 ml) and, under constant stirring, this suspension was cooled to 0 °C. Sodium borohydride (1.2 g; 31.88 mmoles) was added in small portions and the stirring was continued for 1 h. This reaction mixture was then acidified to pH 2—3 with 5*N* hydrochloric acid. Evaporation in vacuum left a residue, which was taken up in water (120 ml) and the solution was made alkaline (pH 10—11) with 40% NaOH solution. Extraction with dichloromethane (60, 50, 40 ml) gave an organic solution which was dried ($MgSO_4$) and evaporated under reduced pressure. The residue (1.0 g) was crystallized from ethanol to obtain a white, crystalline substance (0.75 g; 73.3%), m.p. 147—148 °C.

$C_{22}H_{28}N_2O_3$ (368.48). Calcd. C 71.71; H 7.66; N 7.60. Found C 72.11; H 8.26; N 7.34%.

IR (ν_{max}): 1720 cm^{-1} (>C=O).

Preparation of the mixture of isomers 6a and 7a

(*a*) Compound **3a** or **4a** (1.0 g; 2.71 mmoles) was dissolved in glacial acetic acid (15 ml) and treated with a solution of sodium dichromate dihydrate (0.3 g; 1.0 mmole) in glacial acetic acid (3 ml). The mixture was allowed to stand for 2 days at room temperature, then warmed on a water bath for 2 h. After cooling, the dark green liquid was mixed with 70% aqueous perchloric acid (0.3 ml), to obtain a yellow, crystalline substance (0.75 g; 59.3%), m.p. 189—195 °C.

IR (ν_{max}): 1751 cm^{-1} (>C=O), 1653 cm^{-1} (>C=$\overset{(+)}{N}$—).

(*b*) The perchlorate of 3,4-dehydro-14,15-dihydro-14-(ethoxycarbonyl)-14-hydroxy-eburnamenin-(14β, 16α) (**6a**) (1.0 g; 2.14 mmoles) was warmed on a water bath in glacial acetic acid (50 ml) for 20 hrs. The reaction mixture was then concentrated in vacuum to half its original volume, and allowed to crystallize, to obtain yellow crystals (0.65 g).

This substance was identical in all respects examined with the compound made according to (*a*).

Chemical reduction of the isomeric mixture 6a and 7a

The mixture of the isomeric salts **6a** and **7a** (0.65 g; 1.39 mmole) was suspended in methanol (20 ml) and cooled, with stirring, to 0 °C. Sodium borohydride (0.60 g; 15.94 mmoles) was added in small portions and stirring was continued for 1 h. After acidification with 5*N* HCl to pH 2—3, the solution was evaporated under reduced pressure, the residue was taken up in distilled water (60 ml) and adjusted to pH 10—11 with 40% NaOH solution. Extraction with dichloromethane (30, 25, 20 ml) followed, the organic phase was dried ($MgSO_4$) and evaporated under reduced pressure. The dry residue (0.35 g) was dissolved in dihloromethane and separated into its components by preparative TLC on a 20×20 cm, 1.5 mm thick layer

of Kieselgel $PF_{254+366}$, using a 7 : 1 solvent mixture of benzene and methanol. Elution was effected with dichloromethane and eluate was evaporated to dryness.

The substance with the lower R_f value was 0.224 g (43.7%) all its properties tested agreed with those of **8a**.

The substance with higher R_f (0.092 g; 17.9%) was in all respects identical with **9a**.

Stability studies

(*a*) (±)-3-Epivincaminic acid ethyl ester (**8a**) (0.15 g; 0.4 mmole) and sodium ethoxide in ethanol (20 ml; sodium ethoxide content 0.17 mmole) were refluxed, with the exclusion of moisture, for 3 hrs. After cooling, the reaction mixture was evaporated under reduced pressure and the residue rubbed with distilled water. The solid was collected, dried and recrystallized from ethanol, to obtain white crystals (0.12 g; 80.0%). This product was identical with compound **9a** in every respect.

(*b*) (±)-3-Epivincaminic acid ethyl ester (**8a**) (0.2 g; 0.54 mmole) was dissolved in dry benzene or xylene (10 ml) Fétizon reagent (1.0 g) was added and the suspension was refluxed, with stirring for 1 h. The solid was filtered off from the not mixture and the solution was evaporated under reduced pressure. The dry residue (0.18 g) was dissolved in dichloromethane and its components were separated by TLC on a 20 × 20 cm, 1.5 mm thick layer of Kieselgel $PF_{254+366}$, using a 7 : 1 solvent mixture of benzene and methanol. Elution was effected with dichloromethane, and the eluates were evaporated to dryness.

The substance with the lower R_f value was 0.03 g (15%) all its properties agreed with those of **8a**.

The substance with the higher R_f (0.12 g; 60%), was in all respect identical with **9a**.

(*c*) (±)-3-Epi-14-epivincaminic acid ethyl ester (**9a**) (0.15 g; 0.4 mmole) and sodium ethoxide in ethanol (20 ml; sodium ethoxide content 0.17 mmole) were refluxed with the exclusion of moisture. Chromatograms of samples taken from this mixture after protracted treatment did not reveal any sign of a conversion.

Chemical reduction of compound 1b [4]

1-Ethyl-1-(2-hydroxy-2-ethoxycarbonylethyl)-1,2,3,4,6,7-hexahydro-12*H*-indolo[2,3-*a*]-quinolizin-5-ium perchlorate (**1b**) (10.0 g; 21.3 mmoles) was suspended in ethanol (300 ml) and heated to the boiling point with stirring. Sodium borohydride (1.0g; 26.57 mmoles) was added and the mixture was refluxed for further 15 min. It was then cooled and adjusted to pH 2—3 with 10% HCl. The residue obtained on evaporation in vacuum was taken up in distilled water (300 ml) and made alkaline (pH 11) with 40% NaOH solution. Extraction with consecutive portions (150, 100, 80 ml) of dichloromethane, drying ($MgSO_4$) and evaporation of the solvent under reduced pressure gave dry a residue (7.22 g) which was subjected to fractional crystallization from ethanol to yield compound **2b** (0.77 g; 9.7%), m.p. 234—236 °C and compound **10a** (3.55 g; 44.9%), m.p. 140—142 °C.

Compound **10a**:

$C_{22}H_{30}N_2O_3$ (370.48). Calcd. C 71.32; H 8.16; N 7.56. Found C 71.36; H 8.36; N 7.86%.
IR(ν_{max}): 3240 cm^{-1} (indole-NH), 1718 cm^{-1} (>C=O).

Oxidation of compound 10a with Fétizon reagent

(*a*) 1α-Ethyl-1-(2-hydroxy-2-ethoxycarbonylethyl)-1,2,3,4,6,7,12,12bβ-octahydroindolo-[2,3-*a*]quinolizine (**10a**), (3.0 g; 8.1 mmoles) dissolved in dry xylene (50 ml) was mixed with Fétizon reagent (15.0 g), and the suspension was refluxed and stirred for 2 hrs. The solid was removed from the hot mixture by filtration and the xylene was evaporated in vacuum. The dry residue (2.8 g) was chromatographed on a column of aluminium oxide (110 g; activity grade 3) with benzene. The fractions containing homogeneous substances were combined and evaporated to dryness.

The substance with the lower R_f value was 0.20 g (6.6%). It was identical with compound **8a**.

The substance with the higher R_f (0.78 g; 25.9%) corresponded in every respect to **9a**.

(*b*) Compound **10a** (2.0 g; 5.4 mmoles) was dissolved in dry benzene (30 ml), Fétizon reagent (10.0 g) was added, and the mixture was stirred and refluxed for 20 hrs. The solid was removed from the hot suspension by filtration and the benzene was evaporated from the fil-

trate under reduced pressure. The dry residue (1.58 g) was chromatographed on a column of forty parts of aluminium oxide (63 g) (activity grade 3), with benzene. The fractions containing identical pure substances were combined and evaporated to dryness.

The substance with the lower R_f was 0.1 g (4.9%), identical with **8a**.

The substance with the higher R_f (0.41 g; 20.4%) had all the characteristics of **9a**.

(±)-3-Epi-apovincaminic acid ethyl ester 11a

Compound **8a** or **9a** (1.0 g; 2.7 mmoles) was dissolved in acetic anhydride (40 ml) and refluxed for 20 hrs. The residue obtained on evaporation in vacuum was dissolved in distilled water (80 ml) and adjusted to pH 11 with a 40% NaOH solution. Extraction with ether (30, 20, 10 ml), drying of the organic phase ($MgSO_4$) and evaporation under reduced pressure left a dry residue (0.9 g), which was crystallized from ethanol to yield white crystals (0.6 g; 63.1%), m.p.100—101 °C, and 102—103 °C after recrystallization from ethanol.

$C_{22}H_{26}N_2O_2$ (350.44). Calcd. C 75.40; H 7.48; N 7.99. Found C 75.02; H 7.57; N 7.97%.

IR (ν_{max}): 1749 cm^{-1} (>C=O), 1672, 1618 cm^{-1} (>C=C<).

^{1}H-NMR (60 MHz, in $CDCl_3$): δ 7.74—6.94 (m, 4H, arom. H); 6.24 (s, 1H, >C=CH—); 4.66—41.8 (q, 2H, $CH_3\mathbf{CH_2}O$); 1.36 (t, 3H, $\mathbf{CH_3}CH_2O$); 0.72 (t, 3H, $\mathbf{CH_3}CH_2$).

3,4-Dehydro-14,15-dihydro-14-(methoxycarbonyl)-14-hydroxyeburnamenin(14β, 16α) perchlorate 6b

14,15-Dihydro-14-(methoxycarbonyl)-14-hydroxyeburnamenin(3α, 14β, 16α) (**3b**) (3.0 g; 8.46 mmoles) was dissolved in glacial acetic acid (45 ml), and sodium dichromate dihydrate (0.95 g; 3.17 mmoles), also dissolved in glacial acetic acid (10 ml), was added. The mixture was let to stand at room temperature for 5 days. An aqueous solution (70%; 0.73 ml) of perchloric acid was added to the dark green solution and the mixture was allowed to crystallize, to yield a yellow, crystalline substance (1.7 g; 44.4%), m.p. 184—186 °C, and 195—196 °C after recrystallization from methanol.

$C_{21}H_{25}ClN_2O_7$ (452.88). Calcd. C 55.68; H 5.56; N 6.18; Found. C 55.47; H 5.71; N 6.14%.

IR(ν_{max}): 1745 cm^{-1} (>C=O), 1640 cm^{-1} (>C=$\overset{(+)}{N}$—).

Isomerization of compound 6b in warm glacial acetic acid

Compound **6b** (1.0 g; 2.2 mmoles), dissolved in glacial acetic acid (50 ml), was warmed on a water bath for 20 hrs. The reaction mixture was evaporated in vacuum, the residue suspended in methanol (30 ml) an cooled, with stirring, to 0 °C. Sodium borohydride (0.7 g; 18.6 mmoles) was then added in small portions. After stirring for 1 h more, the solution was adjusted to pH 2—3 with 5*N* HCl. The solvent was evaporated under reduced pressure, the residue was dissolved in distilled water (100 ml) and the pH was adjusted to 11 with 40% NaOH solution. Extraction with consecutive portions (50, 40, 30 ml) of dichloromethane, drying of the organic phase ($MgSO_4$), and evaporation under reduced pressure left a dry residue (0.75 g), which was separated into its components by preparative TLC on a 20×20 cm, 1.5 mm thick layer of aluminium oxide $PF_{254+366}$, using a 20 : 0.1 mixture of dichloromethane and methanol as the developing solvent. Elution was affected with dichloromethane the eluates were evaporated to dryness.

The substance with the lower R_f was 0.35 g (44.7%), identical in every respect with 3-epivincamine (**8b**).

The substance with the higher R_f (0.35 g; 44.7%), had all the properties of 3-epi-14-epivincamine (**9b**).

Chemical reduction of compound 1c [5]

1-Ethyl-1-(2-hydroxy-2-methoxycarbonylethyl)-1,2,3,4,5,7-hexahydro-12*H*-indolo[2,3-*a*]quinolizin-5-ium perchlorate (**1c**) (10.0 g; 21.98 mmoles) was suspended in methanol (300 ml) and heated to the boiling point, with stirring. Sodium borohydride (1.0 g; 26.57 mmoles) was added and refluxing was continued for 15 min more. The reaction mixture was allowed to cool and adjusted to pH 2—3 with 10% HCl. After evaporation under reduced pressure, the residue was taken up in distilled water (300 ml) and adjusted to pH 11 with a 40% NaOH solution. Extraction by means of shaking with dichloromethane (150, 100, 80 ml) gave a

combined organic phase which was dried ($MgSO_4$) and the solvent evaporated under reduced pressure. The dry residue (8.7 g) was fractionated by crystallization from methanol.

The products were compound **2c** (0.6 g; 7.6%), m.p. 231—233 °C and compound **10b** (3.6 g; 45.9%), m.p. 163—165 °C.

Oxidation of compound 10b with Fétizon reagent

(*a*) 1α-Ethyl-1-(2-hydroxy-2-methoxycarbonylethyl)-1,2,3,4,6,7,12,12bβ-octahydroindolo[2,3-*a*]quinolizine (**10b**) (1.0 g; 2.8 mmoles) was dissolved in dry xylene (30 ml) and Fétizon reagent (5.0 g) was added. The suspension was refluxed and stirred for 1 h. The solid was removed from the hot mixture by filtration, and the xylene was evaporated in vacuum. The dry residue (0.95 g) was chromatographed on forty parts of aluminium oxide (38 g) (activity grade 3), with benzene. The fractions containing identical, pure substances were combined and evaporated to dryness, then crystallized from methanol.

The substance with the lower R_f (0.09 g; 9.1%) had all the properties of 3-epivincamine (**8b**).

The substance with the highed R_f (0.35 g; 35.2%) was in every respect identical with 3-epi-14-epivincamine (**9b**).

(*b*) Compound **10b** (1.0 g; 2.8 mmoles) was dissolved in dry benzene (30 ml), Fétizon reagent (5.0 g) was added, and the suspension was stirred and refluxed for 20 hrs. The solid was removed from the hot solution by filtration and the benzene was evaporated in vacuum. The dry residue (0.9 g) was chromatographed in benzene on a column of forty parts of aluminium oxide (36 g) (activity grade 3). The fractions containing identical pure substances were combined and evaporated to dryness; the residues were crystallized from methanol.

The substance with the lower R_f (0.08 g; 8.05%) agreed in all its properties tested with 3-epivicamine (**8b**).

The substance with the higher R_f (0.32 g; 32.1%) was identical with 3-epi-14-epivincamine (**9b**).

(±)-3-Epi-apovincamine (11b)

Compound **8b** or **9b** (1.0 g; 2.82 mmoles) was refluxed in acetic anhydride (40 ml) for 20 hrs. The solvent was then evaporated under reduced pressure, the residue dissolved in distilled water (80 ml) and adjusted to pH 11 with 40% NaOH solution. Extraction with ether (30, 20, 10 ml), drying of the organic solution ($MgSO_4$) and evaporation of the solvent in vacuum left a residue which was crystallized from methanol to obtain white crystals (0.58 g; 61.1%), m.p. 152—154 °C.

$C_{21}H_{24}N_2O_2$ (336.42). Calcd. C 74.97; H 7.19; N 8.33. Found 74.77; 7.29; N 8.22%.

IR(ν_{max}): 1735 cm^{-1} (>C=O), 1620, 1610 cm^{-1} (>C=C<).

^{1}H-NMR (60 MHz; in $CDCl_3$): δ 7.68—7.00 (m 4H, arom. H); 6.14 (s, 1H, >C=CH—); 4.15 (s, 1H, annell. H); 3.28 (s, 3H, CH_3O).

REFERENCES

[1] Novák, L., Rohály, J., Szántay, Cs., Czibula, L.: Heterocycles, **6**, 1149 (1977)
[2] Szántay, Cs., Szabó, L., Kalaus, Gy.: Tetrahedron Lett., **1973**, 191
[3] Bombardelli, E., Bonati, A., Gabetta, B., Martinelli, E. M., Mustich, G., Danieli, B.: Fitoterapia, **2**, 51 (1975)
[4] Kalaus, Gy., Győry, P., Szabó, L., Szántay, Cs.: Acta Chim. Acad. Sci. Hung., **97**, 429 (1978)
[5] Szántay, Cs., Szabó, L., Kalaus, Gy.: Tetrahedron, **33**, 1803 (1977)
[6] Wolinsky, J., Novak, R.: J. Org. Chem., **29**, 3596 (1964)

György Kalaus
Zsuzsanna Gyulai
Péter Győry
Lajos Szabó
H-1521 Budapest, Gellért tér 4.

Mária Kajtár-Peredy
Csaba Szántay
H-1025 Budapest, Pusztaszeri út 59—67.

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^{1}H-NMR INVESTIGATION OF 4,6-*O*-BENZYLIDENE--2,3-DIDEOXY-2,3-EPIMINO-PYRANOSIDE DERIVATIVES

(SHORT COMMUNICATION)

G. TÓTH,[1] I. PINTÉR[2], J. KOVÁCS[2] and A. MESSMER[2]

([1] *N.M.R. Laboratory, and Institute for General and Analytical Chemistry, Technical University, Budapest,* [2]*Central Research Institute for Chemistry, Hungarian Academy of Sciences, Budapest*)

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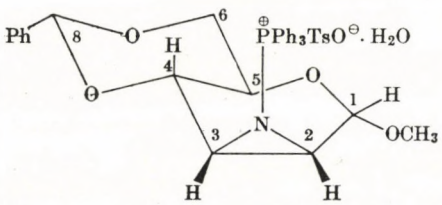
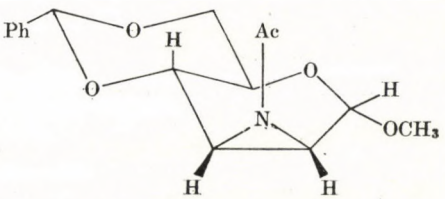
In the course of studying the stereochemistry of the formation of sugar phosphinimines [1, 2] we found a novel neighbouring group participation [3], which resulted in *N*-triphenylphosphonioepimino pyranoside derivatives (**1** and **2**). To corroborate their structures, we analyzed the ^{1}H-NMR spectra by comparing them with those of the known *N*-acetyl analogues (**3** and **4**) [4, 5], obtained from **1** and **2**, respectively, by treatment with potassium hydroxide and subsequent acetylation.



(1)



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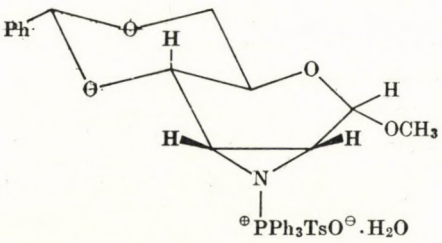

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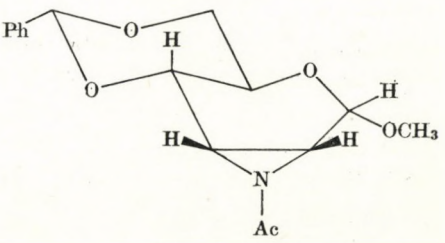

(4)

Scheme 1

BUSS *et al.* [6] earlier described the spectra of **3** and **4** together with those of the 2,3-epoxides, 2,3-episulfides and 2,3-epimino derivatives.

On the basis of the coupling constants, they suggested the half-chair conformation for the *allo* derivatives ($J_{1,2} = J_{3,4} = 0$ Hz; $J_{4,5} \sim 10$ Hz), and a significant conformational flattening for the *manno* compounds ($J_{1,2} = J_{3,4} = 2.5-4.5$ Hz; $J_{4,5} \sim 5-6$ Hz).

The assignment of ring protons in the *manno* series was later discussed by SWEET and BROWN [7], then by ALBANO, HORTON and LAUTERBACH [8]. Recently, X-ray analysis [9] proved the half-chair conformation also for epoxi-*manno* derivatives, and ACHMATOWICZ *et al.* [10] showed by means of the 260 MHz NMR spectrum that the assumption of conformational flattening was a consequence of the incorrect assignment of H-4.

Re-examining the ^{1}H-NMR spectra of the *N*-acetyl-2,3-epimino derivatives (**3** and **4**), we found that some assignments of the ring protons for the epimino-*manno* compounds must also be corrected.

When comparing the ^{1}H-NMR spectrum of **1** with that of **3** and the spectrum of **2** with that of **4**, a close similarity was found in these pairs (Table I). Substitution of *N*-acetyl with the *N*-triphenylphosphonio group resulted in a 0.10—0.65 ppm downfield shift of the ring proton signals. The absence of this effect on the signals of H-2 and H-3 in **1** is very probably due to the vicinity of the toluene-*p*-sulfonate anion. In the spectra of **1** and **2** singlets appear at 2.75 and 2.78, respectively, owing to the presence of a water molecule needed for crystallization [3], as also revealed by the X-ray study of the crystal structure of **2** [11].

In the *allo* series, the ^{1}H-NMR spectra of **2** and **4** exhibit doublets for H-1 at 5.13 and 4.91 with $J_{1,2} = 4.0$ Hz and 3.8 Hz, respectively, which are in good agreement with known [6] data. Irradiation at these values caused changes only in the signals at 3.56 and 3.20, thus these can be assigned to H-2, and the patterns at 3.22 and 3.05 to H-3. The large splitting (14 Hz) of the H-2 and H-3 signals in the spectrum of **2** is due to coupling with phosphorus.

When the nucleus at 4.20 or 3.92 was irradiated, the complex patterns of H-3 simplified, *i.e.*, the chemical shift of H-4 can be expected at these values.

Signals of H-5 and H-6*e* show a strongly coupled complex pattern overlapping with the signal of H-4 in both cases (**2** and **4**) in the 4.05—4.40 and 3.8—4.4 regions, respectively. Signals of H-6*a* appear as separate triplets at 3.78 and 3.69 and singlets of H-8 were observed also separately at 5.66 and 5.59. These results fit in well with the conformation established by X-ray [11] in the case of **2**.

^{1}H-NMR spectra of the *manno* derivatives **1** and **3** exhibit singlets of anomeric protons at 5.16 and 4.90, as expected. In the H-2, H-3 regions sharp signals appear at 2.70 and 2.81 ($W_{1/2} = 1.2$ Hz), while the signals at 2.86 and

Table I

Chemical shifts ($\delta_{TMS} = 0$ ppm) *and coupling constants* (Hz) *of compounds* **1—4** *in* $CDCl_3$, *from the 100-MHz spectra*

Compound	H-1	H-2	H-3	H-4	H-5	H_e-6	H_a-6	H-8	CH_2O	CH_2Ph	Ph	H_2O	CH_3CO
1	5.16	2.70	2.86	4.20	3.74	4.30	3.95	5.79	3.47	2.30	7.02 (2H) 7.20—7.50 (5H) 7.60—7.90 (17H)	2.75	
	$J_{1,2} \approx 0$; $J_{2,3} = 6.0$; $J_{3,4} \approx 0.5$; $J_{4,5} = 9.0$; $J_{5,6e} = 10{,}0$; $J_{6e,6a} = 10.0$; $^3J_{P,CH} = 14.0$												
2	5.13	3.56	3.22	4.20*	4.05—4.40		3.78	5.66	3.47	2.30	6.98 (2H) 7.38—8.00 (22H)	2.78	
	$J_{1,2} = 4.0$; $J_{2,3} = 6.3$; $J_{3,4} = 2.0$; $J_{5,6a} = 11.5$; $J_{6e,6a} = 11.5$; $^3J_{P,CH} = 14.0$												
3	4.90	2.81	3.09	3.55—3.90		4.25	3.55—3.90	5.42	3.47	—	7.30—7.60 (5H)	—	2.22
	$J_{1,2} \approx 0$; $J_{2,3} = 6.0$; $J_{3,4} \approx 0.5$												
3**	4.75	2.59	2.88	3.55*	3.40—3.80	4.14	3.40—3.80	5.34	3.18	—	7.25 (3H) 7.52 (2H)		1.84
4	4.91	3.20	3.05	3.92*	3.80—4.40		3.69	5.59	3.46	—	7.20—7.55 (5H)		2.22
	$J_{1,2} = 3{,}8$; $J_{2,3} = 6{,}1$; $J_{3,4} = 2.1$; $J_{5,6a} \approx J_{6e,6a} \approx 9$												

* Value based on double resonance experiment
** Measured in $CDCl_3$–C_6D_6 (1 : 9)

3.09 are broadened ($W_{1/2} = 3$ Hz), caused probably by a further small coupling ($J \approx 1$ Hz). Irradiation at 4.20 and 3.72 (H-4), caused sharpening of the signals at 2.86 and 3.09, consequently, these shifts are due to H-3, i.e., in the case of the *manno* compound, contrary to *allo* derivatives, the chemical shift of H-3 is higher than that of H-2.

While the signals of H-4, H-5 and H-6*a* in **1** are well separated, in the case of **3** the same signals give a nearly A_3 type pattern, and only the complex patterns of H-6*a* appears separately at 4.25, but its multiplicity makes the determination of coupling constants impossible. The accidental isochrony of the former three protons of **3** disappears in the mixture of benzene-d_6 and deuterochloroform (9 : 1) (Table I), but their patterns are still strongly coupled. The signal of H-6*e* was observed at 4.15 as a doublet of doublets with 10 Hz and 3 Hz spacing, indicating a geminal (H-6*a*) and a vicinal (H-5) gauche coupling. This is the signal which was assigned earlier, incorrectly, to H-4.

The H-8 singlet in the spectrum of **1** was observed at 5.79, and in the case of **3** at 5.42, *i.e.*, the downfield shift caused by the triphenylphosphonio substituent appears here again.

REFERENCES

[1] MESSMER, A., PINTÉR, I., SZEGŐ, F.: Angew. Chem., **76,** 228 (1964)
[2] PINTÉR, I., KOVÁCS, J., MESSMER, A.: Carbohydr. Res., **53,** 122 (1977)
[3] PINTÉR, I., KOVÁCS, J., MESSMER, A., TÓTH, G.; Carbohydr. Res., **72,** 289 (1979)
[4] GUTHRIE, R. D., MURPHY, D.: J. Chem. Soc., **1963,** 5294
[5] BUSS, D. H., HOUGH, L., RICHARDSON, A. C.: J. Chem. Soc., **1963,** 5301
[6] BUSS, D. H., HOUGH, L., HALL, L. D., MANVILLE, J. F.: Tetrahedron, **21,** 69 (1965)
[7] SWEET, F., BROWN, R. K.: Can. J. Chem., **46,** 1481 (1968)
[8] ALBANO, E. L., HORTON, D., LAUTERBACH, J. H.: Carbohydr. Res., **9,** 149 (1969)
[9] PILOTTI, A. M., STENLAND, B.: Acta Crystallogr. Sect. B, **28,** 2821 (1972)
[10] ACHMATOWICZ, O., Jr., SZECHNER, B.: Carbohydr. Res., **48,** 125 (1976)
[11] LINDBERG, K. B., KÁLMÁN, A., KOVÁCS, J., MESSMER, A., PINTÉR, I.: Cryst. Struct. Comm., **7,** 607 (1978)

Gábor TÓTH H-1521 Budapest, Gellért tér 4.

István PINTÉR
József KOVÁCS
András MESSMER
} H-1025 Budapest, Pusztaszeri út 59—67.

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REACTIONS OF ETHYLENEDIAMINE AND ETHANOLAMINE WITH ACETYLENIC ESTERS AND KETONES

M.N. BASYOUNI and F. A. FOULI

(Chemistry Department, Faculty of Science, Ain Shams University, Abbassia, Cairo, Egypt)

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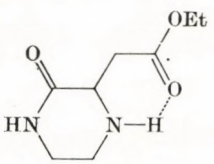
Ethylenediamine (**IIa**) reacts with methyl 3-aryl-propynoates (**IIIa—c**) and aryl-(2-phenylethynyl)ketones (**VIa, b**) to give the corresponding *N,N'*-ethylenebis-(3-arylpropynoic amides) (**IVa—c**) and (*Z,Z*)-*N,N'*-ethylenebis(3-amino-1-aryl-3-phenyl-2-propen-1-ones) (**VIIa, b**), respectively. However, excess **IIa** and **IIIa** gave *N*-(2-aminoethyl)-3-phenylpropynoic amide (**V**). Similarly, ethanolamine (**IIb**) gave with the ester (**IIIb**), *N*-(2-hydroxyethyl)-3-(*p*-chlorophenyl)propynoic amide (**VIII**) and with the ketones (**VIa, b**), the corresponding (*Z*)-3-amino-1-aryl-*N*-(2-hydroxyethyl)-3-phenyl-2-propen-1-ones (**IXa, b**).

The reaction of ethylenediamine with diethyl acetylenedicarboxylate has been reported [1] to give ethyl 3-oxo-2-piperazineacetate (**I**) as a result of reaction at both the acetylenic and ester groupings. The present investiga-

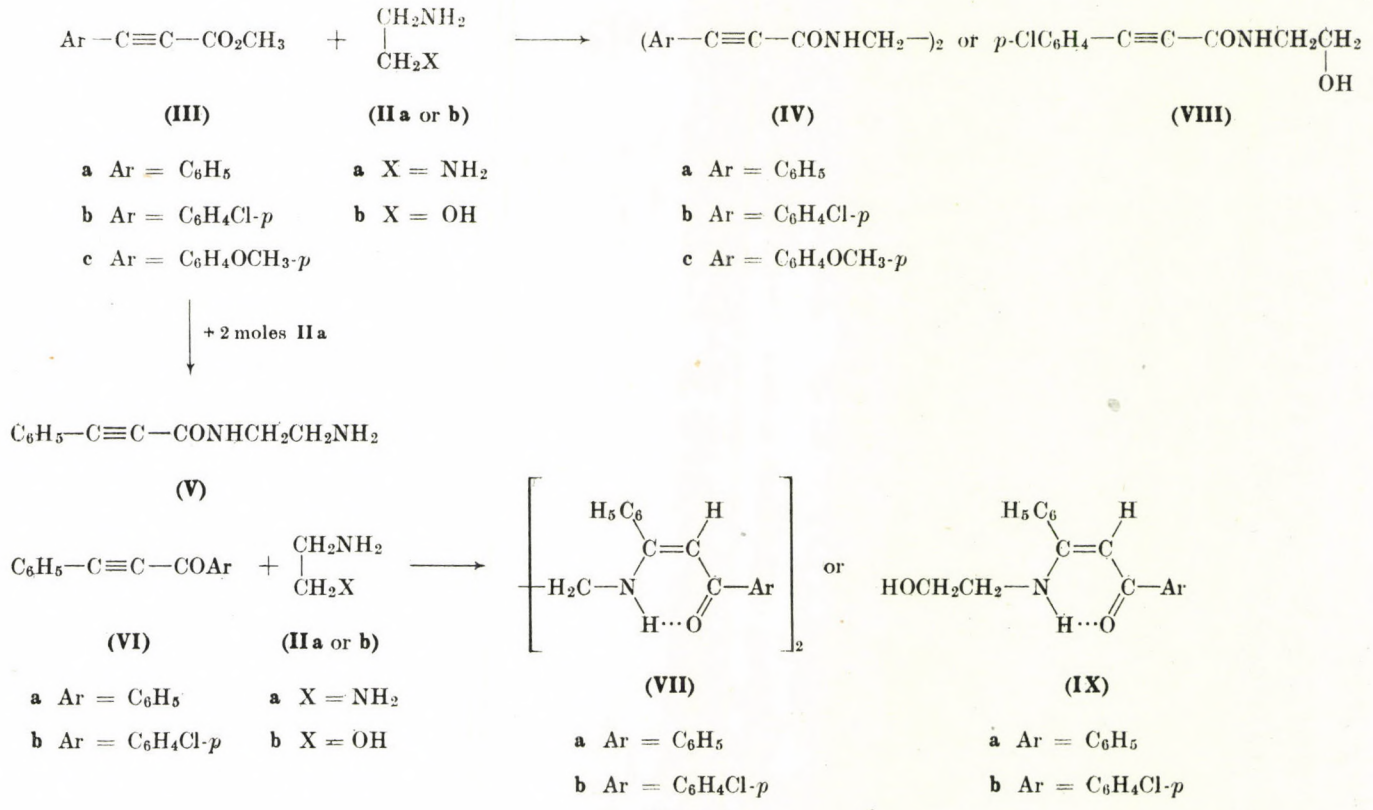


(I)

tion deals with the reaction of the same nucleophile (and of ethanolamine) with some other acetylenic esters (and acetylenic ketones) in order to establish both the structure and/or configuration of the products.

a) *Reaction of ethylenediamine* (IIa) *with methyl 3-arylpropynoates* (IIIa—c) *and aryl-(2-phenylethynyl)ketones* (VIa, b)

Equimolar amounts of ethylenediamine (**IIa**) and methyl 3-arylpropynoates (**IIIa—c**) react in methanol at room temperature to give the corresponding *N,N'*-ethylenebis(3-arylpropynoic amides) (**IVa—c**) (*cf.* Scheme 1). The structure of the products was established by infrared and electronic


Ar—C≡C—CO2CH3
CH2NH2
CH2X
(Ar—C≡C—CONHCH2—)2 or p-ClC6H4—C≡C—CONHCH2CH2
OH
(III)
(II a or b)
(IV)
(VIII)
a Ar = C6H5
b Ar = C6H4Cl-p
c Ar = C6H4OCH3-p
a X = NH2
b X = OH
a Ar = C6H5
b Ar = C6H4Cl-p
c Ar = C6H4OCH3-p
+ 2 moles II a
C6H5—C≡C—CONHCH2CH2NH2
(V)
C6H5—C≡C—COAr
(VI)
(II a or b)
a Ar = C6H5
b Ar = C6H4Cl-p
a X = NH2
b X = OH
H5C6
H
C=C
H2C—N
C—Ar
H···O
2
or
HOCH2CH2—N
(VII)
(IX)
a Ar = C6H5
b Ar = C6H4Cl-p
a Ar = C6H5
b Ar = C6H4Cl-p

Scheme 1

spectroscopy (Table I) and analytical data (Table II). However, the addition of 2 mol of ethylenediamine to 1 mol of methyl 3-phenylpropynoate (**IIIa**) gave *N*-(2-aminoethyl)-3-phenylpropynoic amide (**V**) (*cf.* Experimental). On the other hand, when equimolar amounts of ethylenediamine (**IIa**) and aryl--(2-phenylethynyl)ketones (**VIa, b**) were allowed to react in ethanolic solution, they afforded the corresponding (*Z,Z*)-*N,N'*-ethylenebis(3-amino-1-aryl-3--phenyl-2-propen-1-ones) (**VIIIa, b**) (*cf.* Scheme 1, Tables I and II).

Table I

Infrared (KBr discs) and electronic (ethanol) spectral data for compounds **IV, V, VII, VIII** *and* **IX**

Compound	Infrared spectra			Electronic spectra					
	νNH (cm^{-1})	$\nu C \equiv C$ (cm^{-1})	$\nu C{=}O$ (cm^{-1})	λ_{max} (nm)	log ε	λ_{max} (nm)	log ε	λ_{max} (nm)	log ε
IVa	3280	2210	1630	247.5	4.7	258	4.8	280	4.5
IVb	2360	2200	1625						
IVc	3280	2200	1630	277.5	4.9	291	4.85		
V	3280—3220*	2200	1640						
VIIa	3100—3000*	—	1600**	245	4.3	350	4.5		
VIIb	3100—3000*	—	1600**	250	4.4	350	4.6		
VIII	3380—3220	2210	1640						
IXa	3390—3250	—	1600**	250	4.0	350	4.2		
IXb	3400—3250	—	1600**	250	4.1	350	4.3		

* Chelated and/or bonded NH
** Chelated C=O

Table II

N,N'-ethylenebis(3-arylpropynoic amides) (**VIa—c**) *and (Z,Z)-N,N'-ethylenebis(3-amino-1-aryl-3-phenyl-2-propen-1-ones)* (**VIIIa, b**)

Compound	M.p. (°C)	Yield (%)	Formula	Analysis: Calcd. Found		
				C	H	N
IVa	220—1	60	$C_{20}H_{16}N_2O_2$	75.94 76.08	5.06 5.29	8.86 8.57
IVb	285—6	54	$C_{20}H_{15}Cl_2N_2O_2$	62.50 62.42	3.64 4.04	7.29 6.89
IVc	217—8	51	$C_{22}H_{20}N_2O_4$	70.21 69.78	5.31 5.38	7.44 7.38
VIIa	124—5	71	$C_{32}H_{28}N_2O_2$	81.35 81.80	5.93 6.12	5.93 6.06
VIIb*	208—9	75	$C_{32}H_{26}Cl_2N_2O_2$	71.11 71.08	4.80 4.88	5.20 5.30

*Cl Calcd. 12.96
Found 13.09

b) *Reaction of ethanolamine* (**IIb**) *with methyl 3-(p-chlorophenyl)propynoate* (**IIIb**) *and aryl-(2-phenylethynyl)ketones* (**IVa, b**)

When equimolar amounts of ethanolamine (**IIa**) and methyl 3-(*p*-chlorophenyl)propynoate (**IIIb**) or aryl-(2-phenylethynyl)-ketones (**VIa, b**) were allowed to react in ethanolic solution (*cf.* Experimental), they gave *N*-(2-hydroxyethyl)-3-(*p*-chlorophenyl)propynoic amide (**VIII**) and the corresponding (*Z*)-3-amino-1-aryl-*N*-(2-hydroxyethyl)-3-phenyl-2-propen-1-ones (**IXa, b**), respectively (*cf.* Scheme 1, Tables I and III).

Experimental

All melting points are uncorrected. Infrared spectra (KBr discs) were recorded on a Unicam SP 1200 spectrophotometer and electronic spectra (in ethanol) on Beckman DK-2 Ratio Recording and Unicam SP 800 spectrophotometer.

General procedure for the addition of equimolar amount of ethylenediamine to methyl 3-arylpropynoates (IIIa—c) [2] and aryl-(2-phenylethynyl)ketones]VIa, b) [3]

Aqueous ethylenediamine (50%, 1.2 g, 0.01 mol) in methanol (10 ml) was added to a solution of **III** or **VI** (0.01 mol) in methanol (20 ml) and the reaction mixture was allowed to stand at room temperature for one to two days until crystallization occurred. The precipitate was then filtered off and recrystallized from ethanol to give *N,N'*-ethylenebis(3-arylpropynoic amides) (**IV**) or (*Z,Z*)-*N,N'*-ethylenebis (3-amino-1-aryl-3-phenyl-2-propen-1-ones) (**VII**). The results are shown in Table II.

Refluxing the reaction mixture in the case of methyl 3-arylpropynoates (**III**) on a boiling water bath for 5—6 hrs resulted in the same products as above.

Addition of excess ethylenediamine to methyl 3-phenylpropynoate (IIIa)

Aqueous ethylenediamine (50%, 2.4 g, 0.02 mol) in methanol (20 ml) was added to a solution of **IIIa** (1.6 g, 0.01 mol) in methanol (20 ml) and the reaction mixture was allowed to stand at room temperature until crystallization occurred (2 days). The precipitate was filtered off and recrystallized from ethanol to give *N*-(2-aminoethyl)-3-phenylpropynoic amide (**V**), in 60% yield, m.p. 210 °C and mixed m.p. with **IVa** 170—175 °C.

$C_{11}H_{12}N_2O$ (188.22) Calcd. C 70.20, H. 6.38, N 14.89; Found C 69.83, H 6.29, N 14.54%.

Table III

N-(2-hydroxyethyl)-3-(p-chlorophenyl)propynoic amide (**VIII**) *and (Z)-3-amino-1-aryl-N-(2-hydroxyethyl)-3-phenyl-2-propen-1-ones* (**IXa, b**)

Compound	M.p. (°C)	Yield (%)	Formula	Analysis: Calcd. Found			
				C	H	N	Cl
VIII	121—122	62	$C_{11}H_{10}ClNO_2$	59.06 59.27	4.47 4.78	6.20 5.80	15.88 15.54
IXa	110	70	$C_{17}H_{17}NO_2$	76.40 76.57	6.37 6.58	5.24 5.00	
IXb	87	74	$C_{17}H_{16}ClNO_2$	67.66 67.30	5.30 5.12	4.60 4.56	11.77 11.54

General procedure for the addition of ethanolamine to methyl 3-(*p*-chlorophenyl)--propynoate (IIIb) and aryl-(2-phenylethynyl)-ketones (VI)

Ethanolamine (0.3 g, 0.005 mol) in methanol (10 ml) was added to a solution of methyl 3-(*p*-chlorophenyl)propynoate (**IIIb**) (1 g, 0.005 mol) or aryl-2-phenylethynyl)ketones (**VI**) (0.005 mol) in methanol (10 ml). The reaction mixture was allowed to stand overnight at room temperature. The precipitate obtained upon concentration was filtered off and recrystallized from ethanol to give *N*-(2-hydroxyethyl)-3-(*p*-chlorophenyl)-propynoic amide (**VIII**) or the corresponding (*Z*)-3-amino-1-aryl-*N*-(2-hydroxyethyl)-3-phenyl-2-propen-1-ones (**IX**). The results are shown in Table III.

REFERENCES

[1] IWANAMI, Y., KENJO, Y., NISHIBI, K., KAJIURA, M., ISOYAMA, S.: Bull. Chem. Soc. Japan, **37,** 1740 (1964); Chem. Abstr., **62,** 7755 (1964)
[2] BENGHAIT, I., BECKER, E. I.: J. Org. Chem., **23,** 885 (1958)
[3] FOULI, F. A.: Ph. D. Thesis, Ain Shams University, Cairo, Egypt, 1971

Mohamed Nahib BASYOUNI, F. Abdelrahiem FOULI
Chemistry Department, Faculty of Science, Ain Shams University, Abbassia, Cairo, Egypt.

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A NOVEL SYNTHESIS OF PYRIDINE-CARBOXYLIC ACID PIPERAZIDES

Z. BUDAI, T. MEZEI and A. LAY

(*EGYT Pharmacochemical Works, Budapest*)

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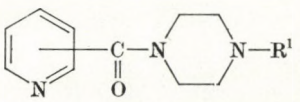
N-Substituted piperazides of pyridinecarboxylic acids were synthesized in the following way: the pyridinecarboxylic acids were converted into (alkoxy-formic acid—pyridinecarboxylic acid) mixed anhydrides by means of alkyl chloroformates, and these were then allowed to react with *N*-substituted piperazines. The compounds have considerable therapeutic interest.

In 1962 PASCARU *et al.* [1] reported the synthesis of two pyridinecarboxylic acid *N*-methyl-piperazides (**Id** and **If**) and their slight cardiovascular activity.

Later on, KŐRÖSI *et al.* [2] described the preparation of other *N*-substituted piperazides of 2-pyridinecarboxylic acid (**Ia** and **Ib**). Of these compunds, 1-benzyl-4-(2'-pyridinecarbonyl)-piperazine (**Ia**) had an antidepressant activity, also significant from the therapeutic point of view. The above authors prepared the compounds of general formula **I** by the reaction of the pyridinecarboxylic acid with the *N*-substituted piperazine in melt, maintaining temperatures higher than 160 °C for about 20–25 h [2]. According to another procedure suggested by them, the pyridinecarboxylic acid was converted first into an ester or amide, and this was allowed to react with the appropriate *N*-substituted piperazine, again in melt, at an elevated temperature [2].

The reaction of pyridinecarboxylic acid chloride hydrochloride and an *N*-substituted piperazine also yields the compounds with the general formula **I** [1, 2].

The compounds prepared by us can be characterized by the following general formula:



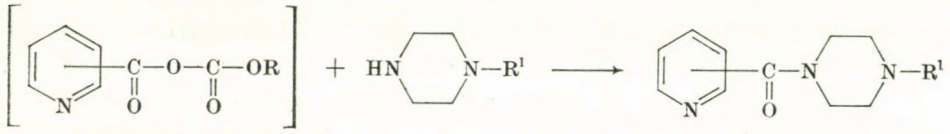
I

In the course of the experiments, the development of a procedure based on readily available raw materials was aimed at, which can be realized economically also on industrial scale.

In the first step of the synthesis developed by us, pyridinecarboxylic acid (**II**) was allowed to react with chloroformic acid ester (**III**) in the presence

Compound	Site of substitution in the pyridine ring	R^1	Ref.
Ia	2—	$CH_2—C_6H_5$	[2]
Ib	2—	CH_3	[2]
Ic	3—	$CH_2—C_6H_5$	—
Id	3—	CH_3	[1]
Ie	4—	$CH_2—C_6H_5$	—
If	4—	CH_3	[1]

of triethylamine in a homogeneous reaction; or potassium pyridinecarboxylate (**IIa**) was made to react with the chloroformic acid ester (**III**) in a heterogeneous reaction, to obtain (alkoxyformic acid—pyridinecarboxylic acid) anhydride (**IV**).



IV **V** **I**

R = CH_3, C_2H_5 R^1 = CH_3, $CH_2—C_6H_5$

The mixed anhydride **IV** was not isolated, but allowed to react with the appropriate *N*-substituted piperazine **V**; in this way the desired end-product **I** was obtained in satisfactory yields under properly chosen conditions. Under these circumstances the mixed anhydride **IV** behaved as a pyridinecarbonylating agent, and the *N*'-alkoxy-carbonylated derivative of the *N*-substituted piperazine formed only in very small amounts. These substituted piperazine derivatives were detected in the reaction mixture by means of urethanes prepared in an authentic manner.

One of the compounds prepared, 1-benzyl-4-(2'-pyridinecarbonyl)-piperazine, contained two moles of water of crystallization. According to thermogravimetric investigations, this dihydrate is stable up to 53 °C. Between 53 °C and 103 °C, a weight loss of about 11% is observed in the TG curve, which indicates the release of 2 moles of water from the molecule. Crystalline 1-benzyl-4-(2'-pyridinecarbonyl)-piperazine dihydrate releases the water of crystallization when dried at 105 °C. The anhydrous product is an oil. Anhydrous and water-containing **Ia** can be converted into each other in a reversible manner. The use of different chloroformic esters does not affect the yield. The preparation of 1-benzyl-4-(2'-pyridinecarbonyl)-piperazine dihydrate is favoured by lower reaction temperatures as can be seen from Table I. The effect of the solvent employed on the yield is shown in Table II.

Table I

Correlation between the yield and reaction temperature in the preparation of 1-benzyl-4-(2'--pyridinecarbonyl)-piperazine dihydrate by Method A

Temperature, °C	Yield, %
−15	84.5
−10	82.5
− 5	83.0
0	79.0
+10	68.5
+15	56.0

Table II

Effect of the solvent used on the yield of 1-benzyl-4-(2'-pyridinecarbonyl)-piperazine dihydrate

Method	Solvent	Yield
A	ethyl acetate	83.0
A	dichloromethane	74.9
B	DMF–THF	73.7
A	DMF–ethyl acetate	74.9
A	THF	66.6
B	dioxan	76.9
B	DMF	50.2

DMF: dimethylformamide (200 ml)
THF: tetrahydrofuran (200 ml)
DMF–THF: 20 ml + 180 ml
DMF–ethyl acetate: 20 ml + 180 ml

Results

A novel synthesis of *N*-substituted piperazides of pyridinecarboxylic acids has been developed, also following industrial production of these compounds. According to the procedure, the potassium salt or triethylamine salt of a pyridinecarboxylic acid is, allowed to react with alkyl chloroformate in a heterogeneous or homogeneous reaction; the resulting mixed anhydride is then treated with *N*-substituted piperazine to obtain the end-product. The mixed anhydride intermediate need not be isolated.

1-(Ethoxycarbonyl)-4-substituted piperazines, the expected by-products of the reaction, were also prepared and used for identifying of the products.

The effects on the yield of the nature of the chloroformate used, the temperature of the reaction and the solvents were also examined. One of the compounds prepared incorporates water of crystallization, greatly faciliting its isolation, purification and pharmaceutical utilization.

The procedure has several advantages over these described in the literature: reaction times are shorter (1–2 h, instead of 20–25 h), significantly lower reaction temperatures are used (–8°C–+20 °C, instead of temperatures higher than 160 °C), furthermore, yields are significantly higher.

Experimental

M.p.'s are uncorrected. The compositions of compounds were corroborated by elemental analyses. The purity of each compound was checked by TLC. For this, Kieselgel GF_{254} adsorbent was used; 5 μl of a 4% solution of the sample was dropped on it, and the chromatogram was developed over 15 cm length, in a mixture of *n*-butanol–glacial acetic acid–water (60 : : 15 : 25) (*v*/*v*). UV light (254 nm) was used for detection before, spraying with 0.1 *N* potassium permanganate and Dragendorff reagent.

The *R* values were calculated (Table IV).

Synthesis of the substituted N-(ethoxycarbonyl)-piperazines. General method

Triethylamine (0.1 mole) was dissolved in anhydrous ethyl acetate (200 ml) and a solution of ethyl chloroformate (0.1 mole) in anhydrous ethyl acetate (20 ml) was added to it dropwise at –8 °C. This was then mixed with a solution of the appropriate *N*-substituted piperazine (0.1 mole) in anhydrous ethyl acetate (20 ml), and allowed to react at –5 °C for 1 h. The triethylamine hydrochloride was filtered off and the filtrate evaporated. The residue was purified by fractional vacuum distillation. Physical data of the compounds prepared are shown in Table III.

Preparation of *N*-substituted piperazides of pyridinecarboxylic acids (Ia, Ib, Ic, Id, Ie, If). General method

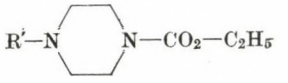
The appropriate pyridinecarboxylic acid (0.1 mole; 12.31 g) and triethylamine (0.1 mole) were suspended in anhydrous ethyl acetate (200 ml) at 20 °C. The suspension was cooled to –5 °C and chloroformic ester (0.1 mole) was added to it dropwise, followed 30 min later by the addition of the *N*-substituted piperazine (0.1 mole). After stirring for 2 h, the triethylamine hydrochloride was filtered off, the filtrate evaporated in vacuum, and the evaporation residue was either converted into a salt or purified by fractional vacuum distillation (Table IV).

Preparation of salts of the *N*-substituted piperazides of pyridinecarboxylic acids. General methods

Fumaric acid salts

The base (**Ia, Ib, Ic, Id, Ie,** or **If**) (0.1 mole) was dissolved in ethanol (50 ml) and added to a solution of fumaric acid (0.1 mole) in hot ethanol (110 ml). The hot solution was clarified

Table III



R'	Yield, %	B.p., °C/Pa	R_f	Ref.	Bp., °C/Pa
CH_3*	60	75/133.3 n_D^{20} 1.4655	0.247	[3]	96–97/800
$CH_2—C_6H_5$**	65	140/66.7 n_D^{20} 1.5240	0.460	[4]	130–135/20 n_D^{26} 1.5238

* m.p. of hydrogen fumarate 158–160 °C
** m.p. of hydrogen fumarate 173–175 °C

Table IV

Compound	Salt	Molecular formula	Molecular weight	Calculated			Found			R_f	M.p. °C	Yield,** %	Yield, %	Ref.
				C	H	N	C	H	N					
Ia	HFu	$C_{21}H_{23}N_3O_5$	397.439	63.46	5.83	10.57	63.51	5.91	10.50	0.367	164–166	83.0	65	[2]
	HCl*	$C_{17}H_{20}ClN_3O$	317.828	64.24	6.34	13.22	64.39	6.44	13.22		235–236		–	
	2HCl**	$C_{17}H_{21}Cl_2N_3O$	354.293	57.64	5.97	11.86	57.55	5.81	11.75		217			[2]
Ib	HFu	$C_{15}H_{19}N_3O_5$	321.341	56.07	5.96	13.08	55.87	5.87	13.02	0.126	161–162	63.0	45–50	[2]
Ic	HFu	$C_{21}H_{23}N_3O_5$	397.439	63.46	5.83	10.57	63.32	5.62	10.51	0.300	148–151*	79.4	–	
Id	HFu	$C_{15}H_{19}N_3O_5$	321.341	56.07	5.96	13.08	56.24	6.18	13.12	0.080	155–156	58.2	30	[1]
	2HCl*	$C_{11}H_{17}Cl_2N_3O$	278.195	47.49	6.16	15.11	47.68	15.19	15.19		130		–	
Ie	HFu	$C_{21}H_{23}N_3O_5$	397.439	63.46	5.83	10.57	63.21	5.49	10.55	0.313	182–185*	70.7	–	
If	HFu	$C_{15}H_{19}N_3O_5$	321.341	56.07	5.96	13.08	56.19	6.08	13.15	0.086	196–198	52.2	30	[1]
	2HCl*	$C_{11}H_{17}Cl_2N_3O$	278.195	47.49	6.16	15.11	47.57	6.28	15.20		272		–	[1]

* Point of decomposition; ** yields are given for the bases; HCl: monohydrochloride; 2HCl: dihydrochloride; HFu: hydrogen fumarate; *a**: calculated Cl 11.16; found Cl 11.2%; *a***: calculated Cl 11.86; found Cl 11.92%; *d**: calcd. Cl 25.49; found Cl 25.54%; f*: calcd. Cl 25.49; found Cl 25.41%.

and, after cooling, the crystals were filtered off. The yield varied between 90% and 95% (Table IV).

Hydrochlorides

The base (**Ia, Ib, Ic, Id, Ie** or **If**) (0.1 mole) was dissolved in anhydrous ethanol (50 ml) and ethyl acetate containing 1 or 2 equivalents of hydrogen chloride was added to it. After cooling, the crystals were filtered off and dried. In this way the stable monohydrochlorides or slightly hygroscopic dihydrochlorides were obtained in 73–83% yields (Table IV).

Preparation of potassium pyridinecarboxylate. General method

The pyridinecarboxylic acid (12.31 g; 0.1 mole) was dissolved in hot anhydrous ethanol (50 ml), and a solution of potassium hydroxide (5.6 g; 0.1 mole) in anhydrous methanol (10 ml) was added to it dropwise, under stirring, whereupon the precipitation of the potassium salt started. After completing the addition, the thick suspension was cooled to below 0 °C; the product was then filtered off and dried at 100 °C. The yields varied between 80% and 92%.

1-Benzyl-4-(2′-pyridinecarbonyl)-piperazine

Method A

2-Pyridinecarboxylic acid (12.3 g; 0.1 mole) and anhydrous triethylamine (10.1 g; 0.1 mole) were dissolved in dry ethyl acetate (200 ml), cooled to −5 °C, and at this temperature ethyl chloroformate (10.8 g; 0.1 mole) was added to the reaction mixture dropwise under stirring. The stirring was continued for 1 h at −5 °C, then a solution of *N*-benzyl-piperazine (17.6 g; 0.1 mole) in anhydrous ethyl acetate (20 ml) was added dropwise. Stirring was continued at 10 °C for 1 h, the triethylamine hydrochloride was then filtered off at room temperature, washed with a small amount of dry ethyl acetate and dried. Water (15 ml) was added o the filtrate under stirring, whereupon the separation of 1-benzyl-4-(2′-pyridinecarbonyl)-piperazine dihydrate started immediately (26.3 g; 83%).

The crude product (20 g) was dissolved in a mixture of ethyl acetate (100 ml) and distilled water (10 ml) at 70 °C, then cooled to below 0 °C under strirring. The crystals which separated were filtered off and dried (19 g; 95%), m.p. 81–82 °C.

$C_{17}H_{19}N_3O \cdot 2H_2O$ (317.4). Calcd. C 64.33; H 7.30; N 13.24. Found C 64.25; H 7.42; N 13.15%.

IR (KBr): $\nu C = O$ 1620 cm^{-1}

Water content (Karl-Fischer method): 11.35%. Calculated 11.3%. Weight loss on drying at 105 °C: 11.2%. B.p. of the anhydrous base: 218–220 °C/13.33 Pa.

Method B

Potassium 2-pyridinecarboxylate (m.p. 286–289 °C) (16.12 g; 0.1 mole) was suspended in a mixture of anhydrous tetrahydrofuran (100 ml) and dimethylformamide (16 ml) at 20 °C, and ethyl chloroformate (10.9 g; 0.1 mole) was added to the suspension. After stirring for 4 h, it was cooled to +10 °C and a solution of *N*-benzylpiperazine (17.6 g; 0.1 mole) in anhydrous tetrahydrofuran (40 ml) was added to the reaction mixture; it was stirred for 1 h, evaporated to dryness, and the residue was poured into water (50 ml) under stirring. The crystal mass was filtered off and dried at room temperature (22 g; 69.5%); m.p. 79–80 °C. Recrystallization of the crude product was effected as described in *Method A*.

REFERENCES

[1] Pascaru, E., Zotta, V., Popescu, M., Serper, A., Hociun, J., Gasmet, A., Ionescu, R.: Farmacia (Bucureşti), **10,** 81 (1962)
[2] EGYT Pharmacochemical Works: Hungarian Pat. 162, 396 (1971)
[3] Harfenist, M.: J. Am. Chem. Soc., **79,** 4356 (1957)
[4] Horrom, B. W., Frefelder, M., Stone, G. R.: J. Am. Chem. Soc., **77,** 753 (1955)

Zoltán Budai
Tibor Mezei
Aranka Lay
H–1475 Budapest, Keresztúri út 30–38

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UNIMOLECULAR DECOMPOSITION OF THE BENZENE MOLECULAR ION

M. PÁNCZÉL and J. BOROSSAY

(Department of General and Inorganic Chemistry, L. Eötvös University, Budapest)

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The mass spectrum of benzene was calculated with the use of a simplified form of the quasiequilibrium theory. Two assumptions were applied for describing the mechanisms of the four principal primary fragmentation processes ($C_6H_5^+$, $C_6H_4^+$, $C_4H_4^+$, $C_3H_3^+$).

1. All the reactions start from the ground state of the benzene ion.

2. The four reactions consist of two independent pairs of competing reactions. Hydrogen loss involves a vibrationally excited ground state; skeletal bond rupture takes place by the internal conversion of electronically excited benzene ion into the first excited state or to some isomer at the same energy.

Our calculations concerning the 70 eV mass spectrum of benzene have confirmed the latter assumption. A good agreement was found between the calculated and experimental data by presuming a 1 : 1 branching ratio of the two ionic states. The existence of two pairs of competing reactions is supported also by photo-ionization, electron monocromator, PIPECO and charge transfer measurements.

1. Introduction

The mass spectrum of polyatomic molecules is determined by the unimolecular decomposition processes of the molecular ion. On applying an adequate variant of the quasiequilibrium theory (QET) describing the unimolecular reactions, the theory of mass spectra gave a fair agreement between the experimental and calculated spectra.

In these calculations it was assumed that the excited molecular ion, prior to its dissociation, is converted by rapid internal corversions into an electronic ground state which is vibrationally and rotationally excited. All primary decompositions are starting then from this state.

Benzene entered the forefront of interest because, in connection with its decomposition, the possibility first energed that the primary processes do not start all from the same state. ROSENSTOCK [1] on investigating the mass spectrum of benzene, has concluded from certain experimental facts (too high differences between the measured appearance potentials of the various ions) that decompositions take place from two different states. VESTAL *et al.* have found in turn that on using more accurate initial data and on taking into account certain effects (kinetic shift) the assumption of isolated states is not needed.

Fortunately, owing to the enormous development of experimental methods in recent years, the problem can be approached at present also from the experimental side. ANDLAUER and OTTINGER [2], on measuring also directly the rate of formation of two fragments ($C_6H_5^+$ and $C_4H_4^+$) of the benzene molecular ion by the charge transfer method at two different levels of excitation energy, have found that these two processes are not competitive, they take place by starting from two different states of electronic excitation. ROSENSTOCK *et al.* [3] investigated the decomposition of benzene by photoionization. On calculating the yield curves by means of QET, they assumed two pairs of competitive reactions. They are of the opinion that the reactions combined with skeletal rupture start from electronically excited molecular ions or from isomeric ions possessing the same energy as the molecular ion. The agreement with the experimental data was very good in the threshold range. However, CHUPKA [4] has found in his measurements carried out similarly by photoionization that no isolated states exist in the case of $E < 8 \times \times 10^{-19}$ J. From this it obviously follows only that in the immediate neighbourhood of the ionization potential all the ions will return to the ground state due to the energy dissipation but this statistical distribution is absent at higher energy levels.

ELAND [5] first believed that the problem cannot be solved by measurements of photo-ion—photoelectron coincidence but later [6] he expressed the opinion that the existence of two states or isomers appears to be likely.

ROSENSTOCK *et al.* [7] assume on the basis of their latest measurements that decompositions start from the benzene ion in the ground state and from an isomer developed by skeletal isomerization.

On summarizing the results obtained thus far, the following assumptions appear to be possible for the primary decomposition processes of the benzene molecular ion:

1. All primary reactions take place in parallel to each other, from the ground state of the molecular ion.

2. The skeletal rupture reactions take place from the first excited state of the molecular ion, whereas both reactions were combined with hydrogen loss from the ground state.

3. The skeletal rupture reactions start from an isomer whose energy corresponds to the first electronically excited state, whereas the reactions were combined with hydrogen loss from the ground state.

In the present work we aimed at approaching the problem once more from the theoretical side. We shall deal with the case of electron impact ionization, and by means of the quasiequilibrium theory the spectrum of high energy (70 eV) will be calculated. This corresponds to the usual conditions of electron impact ionization. Choosing the initial data that appearing to be the best, we assume that the decomposition of the benzene molecular ion starts

from only one or two different states and the mass spectra calculated for each case are compared with that obtained experimentally. We wish to clarify in which case is a better accordance obtained and whether the approximation applied by us is sufficient for the detection of these effects.

2. Calculation of the mass spectrum of benzene

In our calculations we modelled the molecular ion by a sum of harmonic oscillators. The rate constant (k) depending on the energy has been calculated by means of the formula

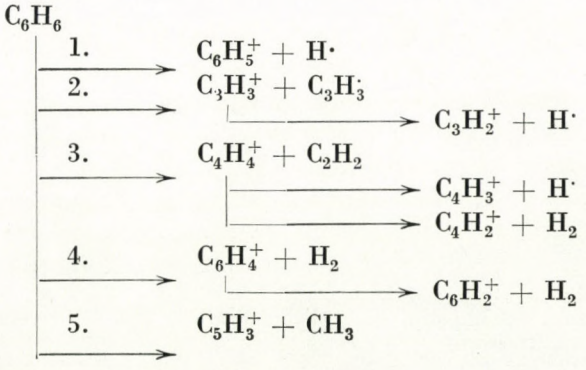
$$k(E) = \sigma \left(\frac{E - E_0}{E} \right)^{N-1} \frac{\prod_{i=1}^{3n-6} \nu_i}{\prod_{j=1}^{3n-7} \nu_j^*} \tag{1}$$

where σ denotes the number of identical reaction routes, $N = 3n-6$ (where n is the number of atoms forming the molecule), ν_i is the normal vibration of the molecular ion, ν_j^* the normal vibration of the transition state, E the internal energy of the reacting ion and E_0 the activation energy of the reaction.

Experimental data are required for the calculation. The knowledge of the mechanism of decomposition of the molecular ion, the activation energies of the individual reactions, the vibration frequencies of the molecular ion, the configuration and vibration frequencies of the transition state is needed.

3. Unimolecular decomposition of the benzene ion

The following scheme has been derived from the mass spectrum of benzene and from the metastable transitions:



The first column of the fragment ions indicates the products of primary reactions, whereas the second column those of the secondary reactions. The primary reactions are denoted by serial numbers. Reactions 2 and 3 take place with skeletal rupture, which does not occur in the other reactions. It appears from the mass spectrum that the intensity of the ion formed in reaction 5 is negligible, thus only processes 1 to 4 have been taken into account in our calculations.

4. Activation energies

On estimating the activation energies both the values of the thermochemical heat of formation and the IP and AP values of mass spectroscopy can be used. The prerequisite of accuracy is in the first case the knowledge of

Table I

Data available for the estimation of the activation energy

m	Molecule or ion	$\Delta H_{f\,\mathrm{neutr.}}$ (kJ/mol)	$\Delta H_{f\,\mathrm{ion}}$ (kJ/mol)	Thermochemical threshold (kJ/mol)	IP or AP (measured) (kJ/mol)	Method	Reference
78	Benzene	82.94±0.54	976.0	892.7	892.7		
	Benzene ion E_{2g}	82.94±0.54	1193	1109			
77	$C_6H_5^+$	331	1193±13		1330±8	PI	
			≥1193±13		1326±10	EM	[7]
				1249	1346	PI	[3]
				1269	1380—1409	EI	[9]
					1387	EI	[10]
39	$C_3H_3^+$	338	1076	1331	1375	PI	[3]
				1346	1563—1640	EI	[9]
					1544?	EI	[10]
52	$C_4H_4^+$		1223±8		1367±8	PI	[7]
			1202±8		1345±10	EM	
				1336*	1380	PI	[3]
				1336	1505—1534	EI	[9]
					1500	EI	[10]
76	$C_6H^+_4$			1249*	1341	PI	[3]
				1288	1457—1795	EI	[9]
					1408	EI	[10]

* = estimated value; EI = electron impact; PI = photoionization; EM = electron monochromator; PE = photoelectron spectroscopy

Table II

Values used in the calculations

Reaction	σ	Activation energy (kJ/mol)		Thermochemical threshold (kJ/mol)
		from the ground state	from the first excited state or from an isomer	
$C_6H_6^+ \rightarrow C_6H_5^+ + H$	6	356	139	1249
$C_6H_6^+ \rightarrow C_3C_3^+ + C_3H_3$	3	438	221	1331
$C_6C_6^+ \rightarrow C_4H_4^+ + C_2H_2$	6	444*	227*	1336*
$C_6H_6^+ \rightarrow C_6H_4^+ + H_2$	6	356*	139*	1249*

* — Estimated value

the geometry of the ion formed, whereas in the second case the negligibility of the kinetic shift.

Depending on whether reactions 2 and 3 are considered to take place from the ground state of from a state with an energy level higher by about 2.25 eV ($=3.6\times10^{-19}$ J) or from an isomer, obviously different activation energies are obtained. We assume that the reversed reaction has no activation energy, and thus the activation energies can be obtained directly from the thermochemical data.

The available values are summarized in Table I. It can be seen from the difference between the thermochemical and the measured thresholds that the kinetic shift is significant [8].

On subtracting the IP value of benzene measured by photoelectron spectroscopy from the thermochemical thresholds calculated from the heats of formation, the values of E_0 were obtained. These data, which have been used in our calculations, are given in Table II.

5. Configuration of the transition state

In the equation of $k(E)$ the quotient of the products of the normal vibrations of the molecular ion and the transition state is present. No experimental data on these values are known. Though the properties of the transition state are in principle calculable, it is in general impossible to carry out these calculations due to the lack of the knowledge of the potential energy surfaces. Therefore, we must rely on a number of empirical assumptions concerning the structure of the transition state.

At present, these assumptions can be built to a great extent on rational grounds and a number of directives are facilitating the estimations. In the

Table III

Vibration spectrum of benzene and configurations of the activated complex

Reaction	Normal vibration data					Configuration of the activated complex			
	Designation	Symmetry	Form of the vibration	Type	Frequency (cm^{-1})	DOC 1	DOC 2	DOC 3	DOC 4
1. $C_6H_6^+ \rightarrow C_6H_5^+ + H$	ν_{15}	E_{2g}	q(C—H)	C—H str.	3056	r.	r.	r.	r.
	ν_{17}	E_{2g}	β(CCH) Q(CC)	C—H bend.	1178	1178	589	300	100
	ν_{17}	E_{2g}	β(CCH) Q(CC)	C—H bend.	1178	1178	589	300	100
2. $C_6H_6^+ + C_3H_3^+ + C_3H_3$	ν_{16}	E_{2g}	β(CCH) Q(CC)	C—C str.	1599	r.	r.	r.	r.
	ν_{16}	E_{2g}	β(CCH) Q(CC)	C—C str.	1599	1599	800	400	100
	ν_{13}	E_{1u}	β(CCH) Q(CC)	C—C str.	1482	1482	741	371	100
	ν_8	B_{2g}	ϱ(C—H) $\varkappa$(CCC)	C—C—C puck.	707	707	353	177	100
	ν_{20}	E_{2u}	ϱ(C—H) $\varkappa$(CCC)	C—C—C bend.	404	404	202	100	100
	ν_{20}	E_{2u}	ϱ(C—H) $\varkappa$(CCC)	C—C—C bend.	404	404	202	100	100
3. $C_6H_6^+ \rightarrow C_4H_4^+ + C_2H_2$	ν_{13}	E_{1u}	β(CCH) Q(CC)	C—C str.	1482	r.	r.	r.	r.
	ν_{13}	E_{1u}	β(CCH) Q(CC)	C—C str.	1482	1482	741	371	100
	ν_{16}	E_{2g}	β(CCH) Q(CC)	C—C str.	1599	1599	800	400	100
	ν_8	B_{2g}	ϱ(C—H) $\varkappa$(CCC)	C—C—C puck.	707	707	353	177	100
	ν_{20}	E_{2u}	ϱ(C—H) $\varkappa$(CCC)	C—C—C bend.	404	404	202	100	100
	ν_{20}	E_{2u}	ϱ(C—H) $\varkappa$(CCC)	C—C—C bend.	404	404	202	100	100

Table III (continued)

						a	b			
4. $C_6H_6^+ \rightarrow C_6H_4^+ + H_2$	ν_{15}	E_{2g}	q(C—H)	C—H str.	3056	r.	r.	r.	r.	r.
	ν_7	B_{2g}	ϱ(C—H) $\varkappa$(CCC)	C—H bend.	990	1320	1155	1455	1800	1320
	ν_9	B_{2u}	β(CCH) Q(CC)	C—C str.	1309	1745	1527	1964	2518	1745
	ν_{17}	E_{2g}	β(CCH) Q(CC)	C—H bend.	1178	1570	1374	1767	1767	1570
	ν_{17}	E_{2g}	β(CCH) Q(CC)	C—H bend.	1178	1570	1374	1767	1800	1570
	ν_{10}	B_{2u}	β(CCH) Q(CC)	C—H bend.	1146	1528	1337	1719	2292	1528
	ν_{14}	E_{1u}	β(CCH) Q(CC)	C—H bend.	1037	1383	1210	1556	2074	1383
	ν_{14}	E_{1u}	β(CCH) Q(CC)	C—H bend.	1037	1383	1210	1556	2074	1383
	ν_{20}	E_{2u}	ϱ(C—H) $\varkappa$(CCC)	C—C—C bend.	404	404	404	404	404	808
	ν_{20}	E_{2u}	ϱ(C—H) $\varkappa$(CCC)	C—C—C bend.	404	404	404	404	404	808

r. = reaction coordinate; str. = stretching; puck. = puckering; bend = bending

majority of QET calculations the normal vibrations of the ions are considered to be identical with those of the molecules as an approximation. Vibrations of the transition state which do not participate directly in the conversion are considered to be similar to the corresponding vibrations of the molecular ion. As regards the degrees of freedom participating in the conversion, the activated complex is considered as one having a structure intermediate between those of the reactant and the products. Two types of transition states are usually distinguished *viz.* those with "close" and "loose" complexes, Loose complexes are present when vibrations of low frequency (so-called "softened" vibrations) occur.

In the case of benzene ROSENSTOCK [3] attempts to polish the approximation used for the transition state by the parametric variation of the properties of the activated complex. In this way it can be tested whether the "close" or the "loose" complex gives a better agreement with the experimental data. It is known from the investigation of the thermal decomposition of neutral organic molecules similar to benzene that the preexponential factor in the Arrhenius rate equations of these decompositions is between 10^{14} and 10^{17} sec^{-1}. This range of preexponential factors can be attained readily by the smaller or greater decrease of the frequency of some normal vibrations.

30 normal vibrations of benzene have been identified in IR, Raman and in combinations. Vibration frequencies assumed for primary reactions 1 to 4 are summarized in Table III. The estimations are based, with one exception, on comparison with the Arrhenius relationship of the thermal decomposition of similar neutral organic molecules [3].

In reaction 1 the ν_{15} (C—H stretching) vibration is the reaction coordinate, while in reaction 2 the ν_{16} (C—C stretching) vibration and in reaction 3 the ν_{16} (C—C stretching) vibration. In the three reactions, four types of estimates are given for the vibrations of the transition state: most of these are identical with the values measured in the molecule or they are as low as one half or one quarter or one tenth of the measured value.

In reaction 4 combined with hydrogen loss, the ν_{15} (C—C stretching) vibration is the reaction coordinate. In this case, besides the general change of 4/3, 3/2 or 2, assumed by ROSENSTOCK also an increase of 7/6 was estimated, on assuming a less stretched complex.

6. Internal energy distribution function

By means of Eq. (1) it is possible to calculate the rate of decomposition processes *vs.* the internal energy of the reactant ion. For the calculation of the mass spectrum, *i.e.* of the relative ion intensities, the knowledge of the internal energy distribution function of the molecular ion is needed $[P(E)]$.

In calculations carried out so far the function $[P(E)]$ is usually only estimated due to theoretical and experimental difficulties. Therefore, we also applied in our calculations three of them which had been used by various authors in calculating the spectrum of propane. These are denoted as $P(E)_1$, $P(E)_2$ and $P(E)_3$ [16, 17, 18]. Finally, the function denoted by us as $P(E)_4$ was the photoelectron spectrum of benzene recorded at 21.21 eV [11].

The specific rate constants were calculated at intervals of 0.5×10^{-12} erg/molecule, by an ODRA 1304 computer, using a program in Fortran language. As regards other details of the calculation procedure, the reader is refered to our earlier paper [12].

7. Results and Conclusions

The results of calculations, the average values of experimental spectra published in the literature and our own data measured by a Riber QML 51 type quadrupol mass spectrometer are presented in Table IV.

Of the calculated mass spectra, those obtained with the values DOC 1b $P(E)_1$ were the most favourable though the function $P(E)$ did not affect the values significantly. The first column indicates all the reactions calculated from the ground state. Then the intensity ratios were calculated for each two assumed independent pairs of reactions. Prior to determining the total fragment intensity, a novel problem emerged which did not appear in the QET calculations carried out so far, namely the question of the "concentration ratio" of the two different initial states, *i.e.* the probability of the formation of these states on ionization. Since no information of this type was available, we assumed at first the simplest ratio of 1 : 1 and we gave the values calculated by assuming the two types of states in column IV of Table IV. If, instead of this arbitrary ratio, the intensity ratio of reactions (1 + 4) and (2 + 3) of

Table IV

Results of calculations

m/e	Ion	Reaction	Experimental mass spectrum		Calculated mass spectrum (DOC 1 b, $P(E)_1$					$\frac{I_{experimental}}{I_{calculated}}$	
					I	II	III	IV	V		
			Average of literature data	This work	Ground state	1—4 ground	2—3 excited	Full spectrum (1 : 1)	Full spectrum (2 : 3)	(1 : 1)	(2 : 3)
77	$C_6H_5^+$	1	29.1±2.9	30±1	74.3	74.6		37.3	29.7	0.78	0.98
39	$C_3H_3^+$	2	24.0±2.1	27±1	0.17		44.4	22.2	26.7	1.08	0.90
52	$C_4H_4^+$	3	35.2±2.0	35±1	0.23		55.6	27.8	33.5	1.30	1.08
76	$C_6H_4^+$	4	10.7±1.0	8±1	25.3	25.4		12.7	10.1	0.84	1.06

the experimental spectrum (*i.e.* a ratio of 2 : 3) is taken into account, the spectrum values given in column V of Table IV are obtained.

It appears from the results that if all four reactions started from the ground state, the formation of $C_6H_5^+$ and $C_6H_4^+$ would predominate to a great extent, which contradicts the experimental spectrum.

The intensity ratio of pairs of reactions calculated from the ground and excited states is in fair accordance with the experimental values and finally, the full spectrum reflects, even in case of the rough approximation applied (1 : 1), satisfactorily the experimental spectrum of benzene in the energy range examined.

Thus, according to our calculations, the situation is actually as follows.

Decomposition occurs from two species which participate in reactions 1 and 4 on one hand, and in reactions 2 and 3, on the other hand. Reactions 2 and 3 take place with a species of an energy level higher by 3.6×10^{-19} J/molecule (= 2.2 eV = 216 kJ/mol). The initial "concentrations" are presumably not idential, their ratio estimated on the basis of the experimental spectrum is about 2 : 3 at 70 eV. Assuming this ratio in the calculation of the full spectrum, a very good agreement with the experimental values is obtained.

Thus it can be stated that the QET calculation carried out by the simplest formula confirms the assumed two types of initial state, furthermore, it is shown that the theory applied is suitable for modelling the decomposition processes of benzene.

Obviously, however, on the basis of our calculations we could not decide whether besides the ground state an excited state or an isomer of adequate energy takes part in the decomposition reactions.

In relation to this problem, it is wort comparing the energy-dependent spectrum of benzene measured by us [13] with the photoionization yield curves of 1,5-hexadiyne [7]. From the similar shape of the curves we can conclude on one hand that, also in the latter case, two pairs of competing reactions take place and, on the other hand, in case of benzene an isomeric state may be suspected. It can be expected that a more detailed experimental and theoretical study of the decomposition processes will eventually clarify a number of problems still unsolved in the case of benzene.

Recent statements by BEER [14, 15] based on photoelectron-photoion coincidence measurements (PIPECO) and QET calculations, can be considered as a remarkable advance in this field. His idea presented in the following gives some sort of synthesis of the contradictory views published thus far concerning the decomposition of benzene. At a low energy level in the vicinity of the threshold the molecularion formed in an excited electronic state is converted prior to dissociation into a vibrationally excited ground state by a radiationless transition (vibrational predissociation).

However, the situation in the case of ions having a high level of internal energy is still unknown. It is very likely that above a certain E value, the rate of direct dissociation from the excited state exceeds the rate of radiationless transition. Similarly, above a certain level of internal energy the rate of direct dissociation may exceed the rate of isomerization.

Our results are in accordance with these assumptions since we have calculated a mass spectrum of high energy level, and in fact the rate of direct dissociation from the isolated state proved to be higher than the rate of radiationless transition in the case of more complex reactions combined with skeletal rupture.

REFERENCES

[1] ROSENSTOCK, H. M., KRAUSS, M.: Advances is Mass Spectrometry, Vol. **2,** p. 251 (1963)
[2]ANDLAUER, B., OTTINGER, CH.: Z. Naturforsch., **27a,** 293 (1972)
[3] ROSENSTOCK, H. M., LARKINS, J. T., WALKER, J. A.: Int. J. Mass Spectr. Ion Phys., **11,** 309 (1973)
[4] CHUPKA, W. A.: Chemical Spectroscopy and Photochemistry in the Vacuum Ultraviolet, Ed. C. SÁNDORFY, P. J. AUSLOSS and M. B. ROBIN, D. REIDEL, Boston 1974
[5] ELAND J. H. D.: Int. J. Mass Spectr. Ion Phys., **13,** 457 (1974)
[6] ELAND, J. H., SCHULTE, H.: J. Chem. Phys., **62,** 3835 (1975)
[7] ROSENSTOCK, H. M., MCCULLOH, K. E., LOSSING, F. P.: Int. J. Mass Spectr. Ion Phys., **25,** 327 (1977)
[8] VESTAL, M. L.: Fundamental Processes in Radiation Chemistry, Ed. P. AUSLOOS, Interscience, New York 1968
[9] FIELD, F. H., FRANKLIN, J. L.: Electron Impact Phenomena. Academic Press, New York 1957
[10] MOMIGNY, J., BARKIER, L., d'OR, L.: Bull. Acad. Roy. Soc. Belg., **48,** 1002 (1962)
[11] MAY, D. P., TURNER, O. W.: Chem. Commun., **1966,** 199
[12] BOLYGÓ, E., BOROSSAY, J., SZEPES, L., INNORTA, G.: Magyar Kém. Foly., **82,** 593 (1976)
[13] PÁNCZÉL, M.: Thesis. L. Eötvös University, Budapest, 1978
[14] BAER, T.: J. Electron Spectr., **15,** 225 (1979)
[15] BAER, T., WILLETT, G. D., SMITH, D., PHILLIPS, J. S.: J. Chem. Phys., **70,** 4076 (1979)
[16] ROSENSTOCK, H. M.: Thesis, University of Utah, Salt Lake City, Utah, 1952; ROSENSTOCK, H. M., WALLENSTEIN, M. B., WAHRAFTIG, A. L., EYRING, M.: Proc. Natl. Acad. Sci. U.S.A., **38,** 667 (1952)
[17] EYRING, E. M., WAHRAFTIG, A. L.: J. Chem. Phys., **34,** 23 (1961)
[18] VESTAL, M., WAHRAFTIG, A. L., JOHNSTON, W. M.: J. Chem. Phys., **37,** 1276 (1962)

Mária PÁNCZÉL
József BOROSSAY } H-1088 Budapest, Múzeum krt. 6—8.

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OH/OD-VAPOUR PRESSURE ISOTOPE EFFECT OF TRIFLUOROETHANOL

Gy. JÁKLI,*[1] Gy. HOLCZER[2] and I. KISS[3]

([1]*Central Research Institute for Physics, Budapest,* [2]*Textile Research Institute, Budapest,* [3]*National Office of Measures, Budapest*)

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The vapour pressure differences between CF_3CH_2OH and CF_3CH_2OD were measured by differential mercury manometry between 0 and 120 °C. When combined with the absolute vapour pressures the results may be expressed as:

$$\ln (P_H/P_D) = 6.965 \times 10^{-2} - 70.4/T + 1.691 \times 10^4/T^2$$

A fit of the absolute vapour pressures of CF_3CH_2OH, measured by a "two-step" mercury manometer between −30 and 120 °C, resulted in the equation:

$$\log {}^{10}P(\text{Pascal}) = 9.933 - 1397/(209.3 + t)$$

Comparison is made with the corresponding values for the hydrocarbon alcohols.

1. Introduction

A comparison of the vapour pressure isotope effect (VPIE) of water, hydrocarbon alcohols and amines [1] shows that the magnitude and temperature dependence of VPIE are closely related with intermolecular hydrogen bonding. Self-association leads to hindered translation and rotation of the condensed phase molecules thereby giving a positive contribution to the VPIE [2], *i.e.* these effects make the lighter isotopic molecule more volatile than the heavy one. The stronger the hydrogen bonding interactions in the condensed phase, the greater the difference between the vapour pressures of isotopic molecules at a given temperature. Correspondingly, water has the highest VPIE, those of the alcohols are lower, and amines show the lowest among these compounds. If the temperature is raised the vapour pressure difference decreases rapidly due to the breakdown of the hydrogen bonded structure.

In order to obtain more information on the nature of the VPIE of associated compounds it seemed interesting to study the 2,2,2-trifluoroethanol (TFE) and deutero-TFE isotopic system because there is thermodynamic [3], infrared [4] and NMR [5] evidence that the hydrogen bonding ability of fluoroalcohols differs markedly from that of hydrocarbon alcohols.

* To whom correspondence should be addressed

2. Experimental

Materials: The sample of puriss. grade CF_3CH_2OH (Fluka), was dried over molecular sieves and then subjected to purification by preparative scale gas chromatography. The column was packed with celite supported diglycerol (30 wt%). A few grams of this sample were than deuterated *via* isotope exchange on a gas chromatographic column [6], containing in this case 30% deutero polyethylene glycol. The deuterium content of the labelled TFE, analysed by refractometry of the water produced upon combustion, was found to be at least 99 atomic per cent per hydroxyl group. Before measurement the protio and deutero compounds were dried in a vacuum apparatus over phosphorus pentoxide and distilled to the degassing bulb, where they were submitted to many freeze-pump-thaw cycles.

Vapour pressure measurements: Because we wished to determine the VPIE over a wide temperature range, we used mercury manometers instead of the high-accuracy capacitance type electronic manometers which can be used only up to 1 or at most 2 atm absolute pressure. The differences between the vapour pressures of the isotopic samples were measured using a U-type differential manometer, described previously [7], from 0 to 120 °C, where the absolute pressure is as high as 5 atm. The accuracy of the used PYE-type cathetometer was 7 Pa (0.05 torr), that of the thermometer was 0.1 °C.

For the measurement of the absolute pressure up to 4—5 atm we used a "two step" mercury manometer as shown in Fig. 1. A hole in a copper block (A) joined by metal to glass

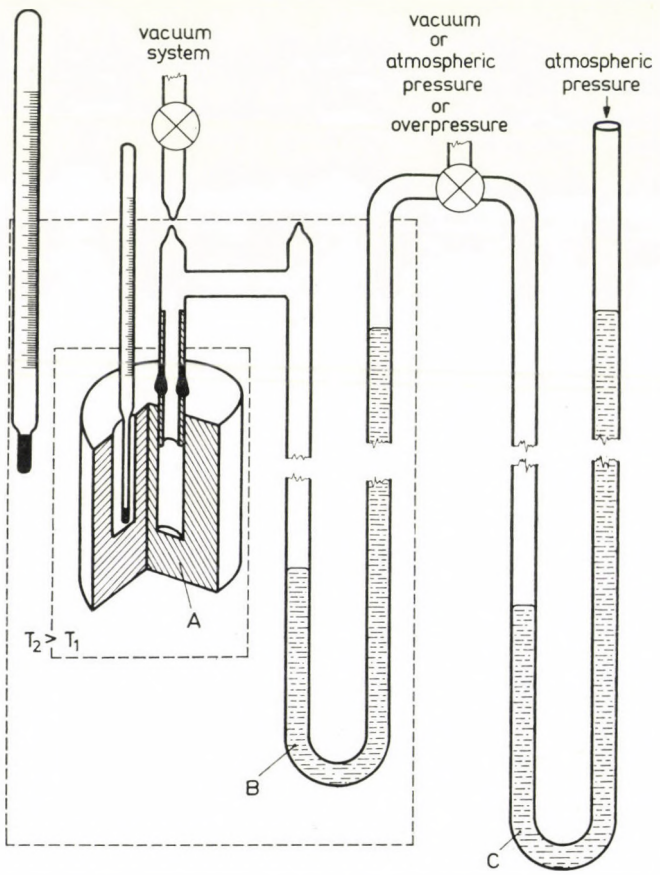

Fig. 1. Apparatus used for the measurement of P_{abs} up to 5 atm. (A: copper block, B: mercury manometer, C: mercury auxiliary manometer)

soldering to the glass tubing was used as the equilibrium vessel. To introduce the sample the manometer was joined to the vacuum system, evacuated to 0.1 Pa (10^{-3} torr), after which the 3—4 g sample was distilled from the degassing bulb into the equilibrium vessel. The vessel was then sealed by soldering its seal. The copper block together with the manometer (10 mm diameter, 100 cm length) was kept immersed in a liquid thermostat. The temperature of the equilibrium vessel was measured by a mercury thermometer with a scale calibrated to 0.1 °C accuracy. During the measurement, depending on the value of the absolute pressure, the reference side of the manometer (B) was kept under vacuum ($P_{abs} < 1$ atm), at atmospheric pressure ($1 < P_{abs} < 2$ atm), or at overpressure from a N_2-cylinder ($2 < P_{abs} < 5$ atm). Mercury level differences on the B-manometer were measured with a PYE-type cathetometer to 7 Pa (0.05 torr), that of the atmospheric pressure was measured with a mercury-type barometer to 13 Pa (0.1 torr), and that of the overpressure with an auxiliary manometer of 150 cm length (C) to 30—40 Pa (0.2—0.3 torr). The readings expressed by the differences of height of mercury levels have been corrected to 0 °C, the reduction of mercury height to latitude 45°; the sea-level- and capillary-depression corrections could be neglected.

3. Results and Discussion

The absolute vapour pressure and VPIE data are listed in Tables I and II, respectively. In the former case, within the temperature range from —35 to 120 °C, we have 176 data, in the latter case between 0 and 120 °C we have 97. The entries in Table I have been fitted by non-linear least squares to equations of the form $\ln P = A/T + B \ln T + C$ and $\log P = A + B/(C + t)$. The result of the first fit:

$$\ln P \text{ (Pascal)} = -7799/T - 8.608 \ln T + 84.34 \quad 243 < T < 393 \qquad (1)$$

that of the Antoine equation:

$$\log {}^{10}P(\text{Pa}) = 9.933 - 1397/(209.3 + t) \quad -30 < t < 120 \qquad (2)$$

The variance for equation (1) was 5.55×10^{-4}, that for equation (2) was 2.05×10^{-5}.

To calculate the VPIE values (Table II) from the isotopic pressure differences we used equation (1), the Antoine equation is given for convenience because usually the vapour pressure data in the literature are fitted to this form.

Our vapour pressure data are in reasonably good agreement with the earlier literature. Halocarbon Products Co. [8] gives a linear equation for $\ln P$ of TFE without giving the temperature range in which their equations is valid. The vapour pressure values calculated from their equation agree within 1% with our data in the temperature range from 25 to 65 °C. MEEKS and GOLDFARB [9] measured the vapour pressure of TFE from 0 to 25 °C, the agreement is again within 1%. Significantly deviating from these data are those of ROCHESTER and SYDMONDS [10] who measured the vapour pressure of TFE from 25 to 55 °C; the data of the last-named authors being 4—5%

Table I

Vapour Pressures of 2,2,2-Trifluoroethanol

t/°C	P_{abs}/kPa	t/°C	P_{abs}/kPa	t/°C	P_{abs}/kPa
−33.50	0.100	13.80	4.660	38.20	19.412
−27.30	0.180	14.50	4.840	38.40	19.558
−24.40	0.240	15.00	5.040	40.50	21.718
−18.30	0.413	15.30	5.093	40.50	21.851
−17.10	0.466	15.60	5.160	40.60	21.879
−14.20	0.600	15.95	5.346	40.65	21.958
−12.50	0.693	16.40	5.333	40.65	22.005
−11.20	0.747	16.70	5.653	44.60	26.871
− 8.15	0.967	16.95	5.746	44.60	26.978
− 7.10	1.047	17.10	5.800	44.70	27.111
− 5.10	1.260	18.10	6.226	45.50	28.218
− 4.10	1.367	18.30	6.253	45.60	28.231
− 2.85	1.486	18.50	6.466	45.60	28.351
− 1.85	1.593	18.60	6.393	46.90	30.177
− 0.60	1.753	19.00	6.606	47.20	30.577
0.60	1.950	20.40	7.166	47.40	30.824
1.20	2.020	21.20	7.513	50.10	35.484
3.50	2.293	21.35	7.553	50.15	35.617
4.25	2.426	23.70	8.733	50.15	35.650
5.10	2.586	25.90	9.966	50.20	35.617
6.20	2.786	28.40	11.272	50.20	35.750
6.60	2.860	28.70	11.586	50.25	35.777
6.90	2.913	29.00	11.499	52.20	39.370
7.30	3.040	29.30	11.988	52.50	39.910
8.20	3.173	30.00	12.399	52.50	40.176
8.50	3.293	31.00	13.086	53.10	41.277
9.30	3.546	31.10	13.246	53.30	41.597
9.70	3.606	31.50	13.479	53.60	42.090
10.10	3.626	31.50	13.566	54.30	43.436
10.50	3.706	31.60	13.572	55.90	46.789
10.90	3.886	33.80	15.332	57.40	50.686
11.20	3.893	34.10	15.577	57.90	51.322
11.60	3.993	34.15	15.585	59.95	56.349
12.00	4.174	36.30	17.605	60.45	57.602
12.40	4.206	36.40	17.652	61.05	59.229
12.90	4.393	36.50	17.692	61.35	59.635
13.30	4.566	38.10	19.212	63.35	65.481

Table I (continued)

t/°C	P_{abs}/kPa	t/°C	P_{abs}/kPa	t/°C	P_{abs}/kPa
63.45	65.401	83.20	146.528	95.00	219.382
66.35	74.274	83.20	144.261	96.55	231.641
66.35	74.087	83.50	145.801	96.75	233.494
66.35	73.927	83.90	149.614	96.75	231.568
69.75	85.346	84.10	148.228	96.90	230.401
70.05	86.360	86.30	161.287	99.10	253.466
70.35	87.126	86.50	161.607	99.35	254.666
72.05	93.966	87.00	164.366	99.35	255.506
73.15	98.219	87.20	165.456	100.75	268.398
73.35	98.945	88.60	175.612	100.75	268.465
73.45	98.919	88.70	175.865	100.75	268.725
77.80	117.097	89.50	180.552	100.75	268.718
78.00	117.770	89.75	180.632	105.15	304.182
78.00	118.664	89.80	182.459	105.55	309.037
78.40	118.757	90.85	189.658	105.85	312.088
78.70	121.403	90.95	191.338	106.15	315.454
78.90	122.142	94.25	214.042	107.60	331.959
79.00	122.783	94.40	215.876	107.70	333.499
79.00	123.090	94.55	216.722	107.80	334.413
81.60	135.156	94.75	214.396	107.90	335.196
82.80	141.735	94.90	206.823	113.70	399.201
				113.80	401.438

high. The apparent reason for this is that they measured their puriss. grade sample as received from Fluka without further purification and drying. From equation (1) for the boiling point of TFE we calculate 74.0 °C, reference [8] gives 73.6 °C, reference [4*a*] gives 73.8 °C.

The VPIE data of Table II have been fitted to the following equation:

$$\ln (P_H/P_D) = 6.965 \times 10^{-2} - 70.4/T + 1.691 \times 10^4/T^2 \quad 273 < T < 393 \quad (3)$$

The variance of the fit was 4.81×10^{-6}. Equation (3) can be used to evaluate the difference in the heats of vaporization (ΔH) of the isotopic varieties, according to the Clausius—Clapeyron relationship. At 25 °C $\Delta H(D) - \Delta H(H) = 362$ J/m, at the boiling point 220 J/m. The corresponding figures with ethanol are 658 J/m and 502 J/m. The boiling point of deutero-TFE lies 0.19 °C higher than that of the protio compound; the difference for the ethanols is

Table II

Vapour Pressure Isotope Effect of Trifluoroethanol ($\Delta P = P_H - P_D$)

t/°C	ΔP/Pa	$\ln(P_H/P_D)$	t/°C	ΔP/Pa	$\ln(P_H/P_D)$
0.0	80	0.0446	40.5	373	0.0171
5.0	93	0.0363	41.4	373	0.0163
5.7	93	0.0346	42.0	400	0.0170
6.5	93	0.0327	43.9	427	0.0164
7.2	93	0.0311	46.0	453	0.0157
7.7	107	0.0344	46.5	427	0.0144
8.1	100	0.0314	46.5	440	0.0149
9.0	100	0.0295	50.5	467	0.0130
10.1	113	0.0311	50.5	493	0.0137
10.6	120	0.0319	53.8	507	0.0121
10.7	133	0.0352	54.0	547	0.0129
11.1	133	0.0343	54.9	533	0.0121
12.2	147	0.0351	55.1	547	0.0122
12.4	113	0.0267	55.7	507	0.0110
13.1	140	0.0316	56.6	533	0.0111
13.9	140	0.0299	56.8	547	0.0113
15.5	133	0.0257	59.5	560	0.0103
16.5	160	0.0290	59.7	613	0.0112
17.7	160	0.0269	60.6	567	0.0099
19.0	180	0.0279	61.1	613	0.0105
19.0	186	0.0289	61.2	547	0.0093
19.9	173	0.0254	61.3	560	0.0095
20.5	180	0.0254	62.7	593	0.0094
20.5	173	0.0245	63.9	587	0.0089
22.0	213	0.0275	64.2	587	0.0088
24.0	227	0.0260	65.4	640	0.0091
28.2	267	0.0251	65.8	607	0.0085
28.8	280	0.0231	66.6	640	0.0086
30.4	280	0.0221	67.1	667	0.0088
31.5	293	0.0218	67.3	587	0.0077
33.3	307	0.0206	68.0	700	0.0088
35.4	340	0.0204	68.5	600	0.0075
35.6	333	0.0198	70.0	627	0.0073
37.4	360	0.0194	71.3	647	0.0072
37.8	360	0.0190	72.0	720	0.0078
38.3	360	0.0185	72.8	773	0.0081
38.3	387	0.0199	73.0	613	0.0063

Table II (continued)

t/°C	ΔP/Pa	$\ln(P_H/P_D)$	t/°C	ΔP/Pa	$\ln(P_H/P_D)$
74.3	800	0.0079	92.2	787	0.0040
78.1	773	0.0065	95.1	733	0.0033
79.5	613	0.0049	97.8	707	0.0029
81.2	733	0.0055	100.8	787	0.0030
81.5	627	0.0046	104.3	640	0.0021
83.2	673	0.0047	104.9	720	0.0023
84.2	720	0.0048	106.4	667	0.0021
85.3	800	0.0052	112.2	333	0.0009
86.2	667	0.0042	114.1	240	0.0006
87.2	667	0.0040	115.8	227	0.0005
87.2	747	0.0045	122.1	53	0.0001
90.1	733	0.0040			

0.55 °C. No earlier data for these isotope effects of TFE are available in the literature for purposes of comparison.

The logarithms of the isotopic pressure ratios together with the corresponding values for the CH_3CH_2OH/CH_3CH_2OD system [11] as a function of the reciprocal temperature are plotted in Fig. 2. For clarity only some of the representative data points are given. Similarly to the ethanol, the VPIE of

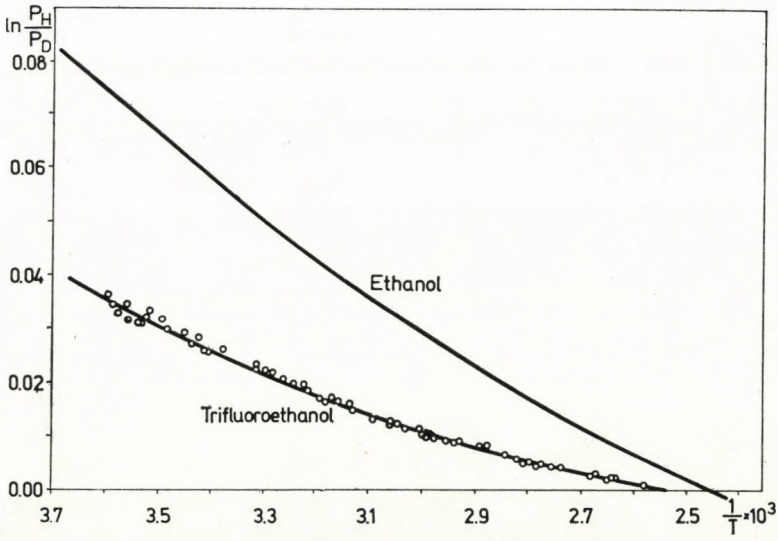

Fig. 2. The vapour pressure isotope effect of trifluoroethanol and ethanol

TFE is normal ($P_H > P_D$) and decreases smoothly in magnitude as the temperature increases. At the same temperature the VPIE of TFE is only half as much in magnitude as that of ethanol and its "crossover" temperature ($P_H = P_D$) is also much lower (119 °C, as opposed to the 135 °C of ethanol).

The fact that the VPIE of TFE amounts only to half of that of the ethanol together with its low lying cross-over temperature clearly indicates that in the liquid phase the extent and strength of self-association of TFE are much less than in the latter case. This result might be unexpected because it is well established that the electronegative inductive effect of the fluorine atoms in fluorocarbon alcohols makes the hydroxylic hydrogen atom considerably more acidic than the corresponding hydrogen atom in hydrocarbon alcohols [12—14]. This explains why hydrogen bonding interactions between fluoroalcohols and a particular base are more exothermic than the corresponding interactions for hydrocarbon alcohols and explains further the excellent solvent properties of TFE. TFE is capable of dissolving polymers (such as nylons [8, 13]) due to its strong hydrogen bonding ability in heteroassociated systems.

However, the presence of fluorocarbon groups in an alcohol also reduces the basicity of the hydroxyl group and therefore the oxygen atom becomes a weaker H-bond accepting site. The acid-strengthening and base-weakening effect of fluorine substitution will tend to make opposing contributions to the extent of self-association of TFE and the overall effect is that in the pure liquid TFE is less associated than ethanol. This conclusion is in accordance with the results of other thermodynamic [3], infrared [4] and NMR [5] investigations.

The difference between the results for the two kinds of alcohol may also arise in part because of the possibility of intramolecular H-bonding for TFE in the gas phase [15]. In the case of condensation (on transfer of molecules from the gas phase to pure liquid), the intramolecular H-bonds will be broken since intermolecular H-bonding will then predominate. This effect also leads to a decrease in both the IE of enthalpy of vaporization and the boiling point of TFE.

REFERENCES

[1] Kiss, I., Jákli, Gy., Illy, H.: Acta Chim. Acad. Sci. Hung., **71**, 59 (1972)
[2] Bigeleisen, J.: J. Chem. Phys., **34**, 1485 (1961)
[3] Rochester, C. H., Sydmonds, J. R.: J. Chem. Soc., Faraday Trans. I., **69**, 1267 (1973); **69**, 1274 (1973); **69**, 1577 (1973)
[4] *a)* Mukherjee, L. M., Grünwald, E.: J. Phys. Chem., **62**, 1311 (1958); *b)* Kivinen, A., Murto, J. A.: Suomen Kemistilehti, B, **40**, 6 (1967), *c)* Barnes, A. J., Hallam, H. E., Jones, D.: Proc. Roy. Soc. London, A **335**, 97 (1973)
[5] Rao, B. D. N., Venkateswarlu, P., Murthy, A. S. N., Rao, C. N. R.: Can. J. Chem., **40**, 387 (1962)
[6] Kiss, I., Jancsó, G., Jákli, Gy., Illy, H., Poros, K.: J. Lab. Comp. **3**, 411 (1967)
[7] Kiss, I., Jákli, Gy., Jancsó, G., Illy, H.: Acta Chim. Acad. Sci. Hung., **51**, 65 (1967)
[8] Booklet on trifluoroethanol, Halocarbon Products Corp., Hackensack, N. J. (1967)

[9] MEEKS, A. C., GOLDFARB, I. J.: J. Chem. Eng. Data, **12,** 196 (1967)
[10] ROCHESTER, C. H., SYDMONDS, J. R.: J. Chem. Soc., Faraday Trans. I., **69,** 1267 (1973)
[11] KISS, I., JÁKLI GY., JANCSÓ, G., ILLY, H.: J. Chem. Phys., **47,** 4851 (1967)
[12] ROCHESTER, C. H.: The Chemistry of the Hydroxyl Group, ed. S. PATAI (Interscience, London, 1971), p. 327
[13] MIDDLETON, W. J., LINDSEY, R. V.: J. Am. Chem. Soc., **86,** 4948 (1964); MIDDLETON, W. J.: U.S. Pat., 3,245,944 (1966)
[14] DYATKIN, B. L., MOCHALINA, E. P., KNUNYANTS, I. L.: Tetrahedron, **21,** 2991 (1965)
[15] BARNES, A. J., HALLAM, H. E., JONES, D.: Proc. Roy. Soc. London, *A*, **335,** 97 (1973)

György JÁKLI H-1525 Budapest, P.O. Box 49.
György HOLCZER H-1475 Budapest, P.O. Box 6.
István KISS H-1531 Budapest, P.O. Box 19.

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INVESTIGATION OF THE INTERACTION OF DIPEPTIDES WITH NUCLEIC ACIDS, III

COMPARISON OF MELTING TEMPERATURE, EQUILIBRIUM DIALYSIS AND SPECTROFLUORIMETRIC STUDIES

M. SZEKERKE and J. ÉRCHEGYI*

(Institute of Organic Chemistry, Eötvös Loránd University, Budapest)

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In order to achieve a more systematic investigation of peptide-DNA binding, the interaction specificity of a wider variety of model peptides and dipeptide esters with a number of double- and single-stranded nucleic acids of different base composition has been examined. The analysis of aromatic side chain contribution has been extended to phenylalanine derivatives. A number of glutamyl and aspartyl model peptides were synthesized. A combination was employed of different types of physical measurements — scanning of thermal denaturation, fluorescence quenching, analysis of UV and CD spectra, equilibrium dialysis — often with comparative studies of several methods, the advantages and limits of each method being compared.

The highest stabilizing effects were observed in the case of basic-aromatic amino acid combinations, although glutamyl- and aspartyl-phenylalanine methyl esters also excerted an unexpectedly high stabilizing effect on the DNA helix.

The insertion of D-amino acid residues resulted in a reduction of stabilization of the DNA helix in the series of basic-aromatic amino acid combinations, whereas in the series of glutamic acid-phenylalanine derivatives the presence of D-glutamic acid increased stabilization. The influence of the varying number of free carboxyl groups and the importance of the distance between the amino and carboxyl groups was also demonstrated.

Preliminary experiments suggest a tendency of slight C—G preference compared to A—T affinity of tryptophan-containing model peptides in the DNA and polynucleotide interaction.

Our results do not offer any experimental evidence for the previously postulated intercalation of tyrosine or phenylalanine derivatives. The existence of a strong binding site was obvious only in the case of tryptophan derivatives.

One of the essential relationships between nucleic acids and proteins is expressed in binding and recognition interactions.

It was postulated by several groups that the side chains of amino acids might play an important part in the recognition process. For the elucidation of the specific contribution caused by amino acid side chains, *in vitro* investigations were performed with various model systems [1—25].

Our laboratory followed one of the simplified approaches of studying protein-nucleic acid interactions, namely the investigation of the binding process between small peptides and nucleic acids. Two papers have been published in this field [26, 27].

* Present address: I. Institute of Biochemistry, Semmelweis University, Medical School, Budapest

In this communication we are concerned with an extension of previous studies to improve our understanding of the molecular mechanism involved in the binding process. In order to achieve a more systematic investigation, we have approached the problem by examining the interaction specificity of a wider variety of model peptides and peptide esters with a number of double- and single-stranded nucleic acids of different base composition. A combination was employed of different types of physical measurements, often with comparative studies of several methods, the advantages and limits of each method being compared. While scanning of thermal denaturation, fluorescent quenching, analysis of UV and CD spectra reflect peptide-DNA binding only indirectly, direct binding studies were carried out using equilibrium dialysis.

Experimental

Methods

The ultraviolet absorption spectra were obtained with Unicam SP 700 and Specord UV VIS recording spectrophotometers. Circular dichroism (CD) spectra were recorded with a J. Y. Dichrograph III in 1 mm quartz cells at ambient temperature.

Melting transitions were monitored with a Beckmann DU (G2400) spectrophotometer with a thermocouple inserted into the liquid [26].

Fluorescence spectra were taken with a Farrand spectrofluorometer, using 10 mm cells. Measurements were performed as described previously [27].

Equilibrium dialysis experiments were carried out using Visking casing. Cleaning of the casing and control experiments are described in detail elsewhere [28]. Peptide concentrations were determined based on UV absorption [29], using a Beckmann DU (G2400) spectrophotometer.

All measurements were carried out in 0.002*M* phosphate buffer solutions containing 0.001*M* NaCl, pH 6.35 (except when otherwise indicated). All buffer solutions were made up with doubly distilled water and filtered on Sartorius membrane filter SM 11306 (0.45 μm). pH was measured with a Universal OP 204 model pH-meter.

*Materials**

The following nucleic acid preparations were used: Chicken blood DNA (REANAL, Budapest) P 6.9%; N 10.9%; $\varepsilon(P)_{260\ nm}$ 7000 (pH 6.35).

Poly(A), potassium salt (Koch-Light) P 5.35%; MW 100 000.

Poly(C), potassium salt, A-grade (Calbiochem) P 8.76%, N 11.75%; MW $3.1 \cdot 10^4$.

Poly(C—G), potassium salt (Boehringer—Mannheim GmbH), base ratio 1 : 1; P 5.27%.

Poly(I)-poly(C), sodium salt (Calbiochem), A-grade, double stranded, $\varepsilon(P)_{248\ nm}$: 4600, (pH 7); P 7.25%.

Poly(dA)-poly(dT), potassium salt (Boehringer-Mannheim GmbH) 50 OD, E_{260}.

All dipeptides were prepared in our laboratory. During this work, it was necessary to synthesize — as starting materials — many derivatives of amino acids according to literature methods. Most dipeptides have been described previously in the literature, but in several cases we preferred the use of different methods, or some modification of the experimental conditions seemed to offer advantages. Peptide coupling was achieved by using the mixed anhydride or carbodiimide method. Benzyloxycarbonyl and benzyl ester were used as the temporary protecting groups in each case and were removed by catalytic hydrogenation; dipeptide esters were isolated as hydrochlorides. Experimental details were previously published [26]. The peptides used for the studies reported in the present paper were as follows (the amino

* Symbols and abbreviations are used according to the rules adopted by the IUPAC IUB Commission on Biochemical Nomenclature, J. Biol. Chem., **247,** 977 (1972). Further abbreviation: Z— = benzyloxycarbonyl.

acids were of L-configuration unless otherwise stated): Lys-TyrOMe [26], Lys-D-TyrOMe [26], Orn-TyrOMe [26], Orn-TrpOMe [26], Lys-TrpOMe [26], Ser-TyrOMe [30], Ser-TrpOMe [30], D-Ser-TrpOMe [30], Glu-PheOMe [31], Glu(PheOMe)OH [29], Glu(OMe)-PheOMe [29], Glu-TyrOMe [29], Glu(OMe)-TyrOMe [29], Glu-TrpOMe [27], Asp-PheOMe [32], Asp-TrpOMe [31], Glu-Ala [33], Glu-Val [34], Ala-Glu [33]. D-Lys-TrpOMe, D-Glu-PheOMe and D-Glu(PheOMe)-OH were prepared as described for the L-L diastereomers.

All peptides were checked for authenticity by elemental analysis and by TLC on silica gel.

IR spectra were recorded in KBr pellets with an IR spectrometer (Carl Zeiss, Jena) confirming the presumed structures.

Results

Melting temperature studies

The melting temperature of chicken blood DNA ($4.6 \cdot 10^{-5}$ $M(P)$) was monitored in the presence of the various peptides (concentration range $1 \cdot 10^{-4}$ $-1 \cdot 10^{-3}$ M) in 0.002 M phosphate buffer solution, pH 6.35, containing 0.001 M NaCl. As stated in Part I of this series [26,] a typical saturation behavior has been observed with T_m being proportional to the peptide concentration at low values of the latter, and reaching a limiting value of ΔT_m at higher concentrations. Results of these measurements are presented in Table I.

Previous observations with basic-aromatic amino acid combinations indicated that tryptophan peptides exerted a higher stabilizing effect on DNA than tyrosine-containing analogues [26]. A similar trend was observed in the

Table I

ΔT_m(°C $\pm$ 0.3 °C), the rise in the melting temperature of chicken blood DNA ($4.6 \cdot 10^{-5}$ *$M(P)$ solution in phosphate buffer*, pH 6.35, *I*: 0.0036) *due to the effect of various concentrations of mode peptides*

Peptide	Concentration of peptide (M)			
	$1 \cdot 10^{-4}$	$3 \cdot 10^{-4}$	$5 \cdot 10^{-4}$	$1 \cdot 10^{-3}$
Ala-Glu	3.6	4.0	4.5	6.8
Glu-Ala	2.1	4.5	5.3	8.7
Glu-Val		1.0	3.1	5.3
Glu-PheOMe	1.5	2.8	5.5	7.7
D-Glu-PheOMe	2.9	3.8	7.1	9.9
Glu(PheOMe)OH			2.1	2.2
D-Glu(PheOMe)OH	0.4	1.0	3.0	3.5
Glu-TyrOMe	0.5	1.0	1.9	4.1
Glu-TrpOMe	4.9	6.5	7.3	
Asp-PheOMe	4.7	8.9	12.0	13.4
Asp-TrpOMe	1.6	3.0	5.7	
D-Lys-TrpOMe	6.8	7.8	9.7	

series of acidic-aromatic amino acid combinations, the effect decreasing in the following order: Glu > Asp, Trp > Tyr. It has been reported by GABBAY *et al.* [12] that tyrosine-containing dipeptide amides stabilize the helix to a greater extent than the corresponding phenylalanine-containing systems do. In the case of our models this trend proved to be true only when phenylalanine was coupled with the γ-carboxyl group of glutamic acid. The results seem to be contradictory to the affinity scale reported for other peptides [6, 12], when phenylalanine was coupled to the α-carboxyl of either glutamic or aspartic acid. This anomalous behavior suggests that in addition to the assumed π-electron interaction of the aromatic ring [21], the γ-carboxyl group may give rise to an H-bond with the acceptor groups of DNA. As reported previously [27], no significant stabilizing effect was observed, when both carboxyl groups of these dipeptides were esterified.

The insertion of a D-amino acid resulted in a reduction of stabilization in the series of basic-aromatic amino acid combinations, while in the series of glutamic acid-phenylalanine combinations the presence of D-glutamic acid increased stabilization. We have no explanation for this observation for the time being.

The aliphatic-acidic amino acid combinations with free carboxyl groups had a rather low effect of stabilization. The effect decreased at higher ionic strength, *i.e.* in 0.02 *M* phosphate buffer solutions. No direct comparison has been made with the corresponding esters. The observation of GABBAY *et al.* [11] in respect of a sequence effect was confirmed in the case of Ala-Glu and Glu-Ala.

UV and CD spectral studies

The interaction of the model peptides with chicken blood DNA was also studied by UV absorption and the CD technique.

No significant difference was detected in the absorption spectrum of DNA in the presence of the dipeptide ester systems, *i.e.* the intensity at 260 nm varied by less than $\pm 3\%$. Similarly, no significant change was observed in the 240—330 nm wavelength interval of the CD spectrum of DNA and poly(A), respectively [6], in the presence of dipeptide esters. Ser-TyrOMe, Orn-TyrOMe and Orn-TrpOMe were used in these studies at a molar ratio DNA (P) — peptide 1 : 1 (pH 6.35; *I*: 0.0036). The results suggest that no gross alteration in DNA structure is occurring.

Equilibrium dialysis experiments

Equilibrium dialysis is the most direct way to obtain a measure of the amount of bound and free ligand. In determining DNA binding by equilibrium dialysis, 5 ml of a $1 \cdot 10^{-3}$ *M* DNA solution was put in the dialysis sac and 10 ml

peptide solutions of different concentrations ($5 \cdot 10^{-5} - 1 \cdot 10^{-3}$ *M*) were used as the dialysis bath. All solutions were made in 0.002 *M* phosphate buffer solution containing 0.001 *M* NaCl, pH 6.35. Dialysis was performed for 24 h at 4 °C. The external solution was then analysed spectrophotometrically [29], as previously reported for the protein binding of the same model peptides. Details of the experimental procedure including control experiments are described elsewhere [28]. Negligible amounts of the small molecules were found to be bound to the membrane.

The Donnan effect limits [35] the maximum DNA concentration which can be used at the low ionic strength that is necessary to obtain significant binding of the peptide, and lowering the peptide concentration significantly affects the accuracy of the quantitative assay determination employed in this work. To overcome the inherently poor experimental accuracy at low saturation, repeated measurements were carried out under identical conditions and the mean values were calculated.

Equilibrium data were plotted according to the SCATCHARD representation [36], correlating r, the mean number of moles peptide bound per mole phosphate, C_f, the molar concentration of unbound peptide, n, the theoretical number of binding sites, and K, the association constant. We are aware of the fact suggested by MCGHEE and von HIPPEL [37] that a considerable portion of the non-linearity of any SCATCHARD plot related to the binding to one-dimensional macromolecular lattices can be attributed to the "overlap" effect rather than the heterogeneity of binding sites. In consequence, the binding affinity constant of oligomers or polymers for DNA cannot be simply deduced from binding measurements using traditional SCATCHARD plots. Since our model peptides were relatively small molecules, we accepted, as a reasonable basis for comparison, the generally used approach of plotting data according to SCATCHARD and evaluating these plots in the usual way applied for the interaction of small molecules with DNA.

Similarly to previously reported spectrofluorometric studies with tryptophan peptides [28], the SCATCHARD plots derived from equilibrium dialysis data were also curved. In Fig. 1 the comparative DNA binding plots of four tryptophan-containing dipeptide esters are presented. The second amino acid influenced the binding affinity in the decreasing order Lys > Orn > Ser. An anomalous behavior can be observed in the case of the glutamyl peptide compared to our previous studies, since spectrofluorometric measurements indicated an almost identical binding affinity to DNA for the Ser-TrpOMe and Glu-TrpOMe dipeptide esters.

An explanation might be offered by the fact that in the equilibrium dialysis experiments higher concentrations of the peptides were applied, giving way to a more dominating influence of the electrostatic repulsion of the carboxyl groups on the binding process.

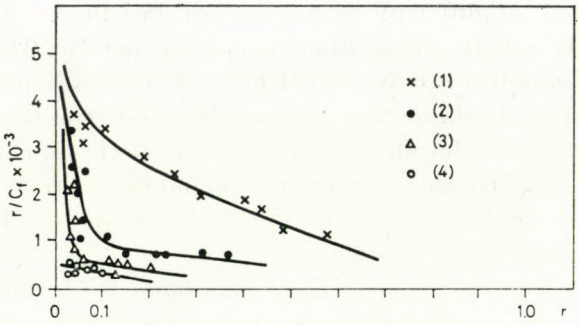

Fig. 1. Binding curves for Lys-TrpOMe (1); Orn-TrpOMe (2); Ser-TrpOMe (3); Glu-TrpOMe (4)

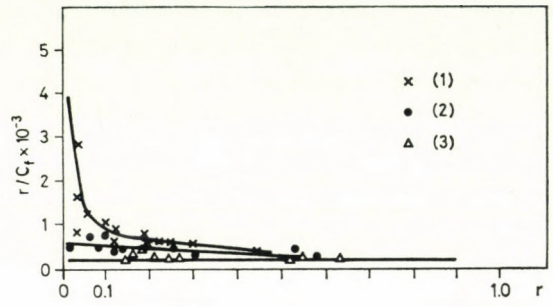

Fig. 2. Binding curves for TrpOMe (1); TyrOMe (2); PheOMe (3)

The theory of GAUGAIN *et al.* [38] can be regarded as an alternative explanation. In some cases, although the primary sites are occupied first and the secondary sites later, these secondary sites can yet be populated at the expense of the primary sites and they can even predominate at high free concentrations of the ligand. This effect is possible when the total gain in free energy becomes greater by saturation with the ligand at the secondary sites, because the lower binding free energy associated with the weaker secondary site binding constant is compensated by a greater density of secondary sites on DNA.

At present the information is insufficient for a decision between these two possible explanations and further work in this area will be required before such a choice can be made.

In Fig. 2 the strength of binding of the methyl esters of aromatic amino acids is compared; a decreasing order of affinity Trp > Tyr > Phe is found.

A similar trend, *i.e.* tryptophan affinity greater than tyrosine, could be observed when lysyl- (Fig. 3) and seryl- (Fig. 4) tryptophan and tyrosine dipeptide esters, respectively, were compared. A curved plot and the existence of a strong binding site was obvious only in the case of tryptophan derivatives;

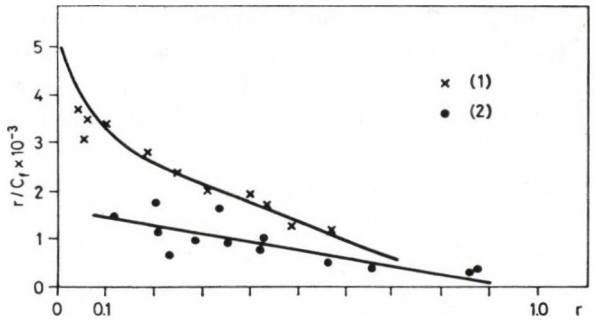

Fig. 3. Binding curves for Lys-TrpOMe (1); Lys-TyrOMe (2)

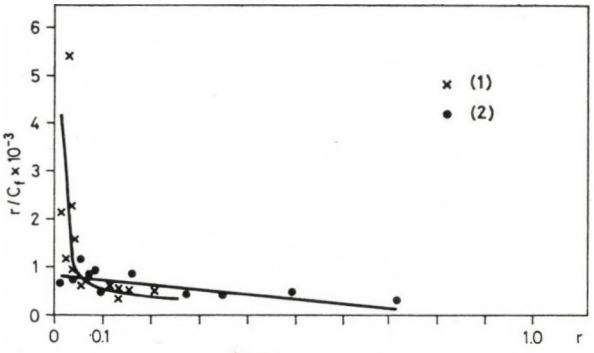

Fig. 4. Binding curves for Ser-TrpOMe (1); Ser-TyrOMe (2)

Figures 1—4. Scatchard display of data obtained by equilibrium dialysis for the binding of various dipeptide esters (concentration range investigated $5 \cdot 10^{-5} M - 1 \cdot 10^{-3} M$) to DNA ($1 \cdot 10^{-3} M$ (P) solution) at 4 °C, pH 6.35 phosphate buffer, I: 0.0036

in control experiments performed at higher ionic strength this strong binding site was not affected. While equilibrium studies could be extended to tyrosine peptides enabling a comparison of tryptophan and tyrosine peptide binding affinities, the interaction of phenylalanine peptides could not be evaluated reliably in this series. Glutamyl and aspartyl peptides, as mentioned before, did behave anomalously in the high concentration range applied in the equilibrium dialysis measurements. The phenylalanine peptides were all combinations of glutamic or aspartic acid, hence only partial evaluation in respect of the weak, secondary sites was possible. Also in the case of denatured DNA only the weak binding could be detected by equilibrium dialysis, corresponding to the secondary sites on native DNA. The models used in these experiments were Ser-TrpOMe and Orn-TrpOMe.

WEBER [39] called attention to the fact that a good way of comparison for data obtained by spectrofluorometric titration and by equilibrium dialysis

is offered by the BJERRUM "formation function" [40], in which the logarithm (or — log) of the free ligand concentration C_f, is plotted against r, the degree of saturation of the average number bound. The resulting graph may be termed a titration curve of DNA with the ligand. Several aspects make this plot greatly preferably to others; these include that a complete titration curve is characterized by the presence of a saturation region at which an increment of free ligand does not result in any appreciable change in saturation, thus giving rise to a "vertical" segment in the titration curve. An incomplete titration curve is shown by the absence of a saturation region.

The comparison of the titration curves of DNA with two tryptophan containing dipeptide esters using fluorescence quenching and equilibrium dialysis is presented in Figs 5—6 in the form of BJERRUM plots. The plots

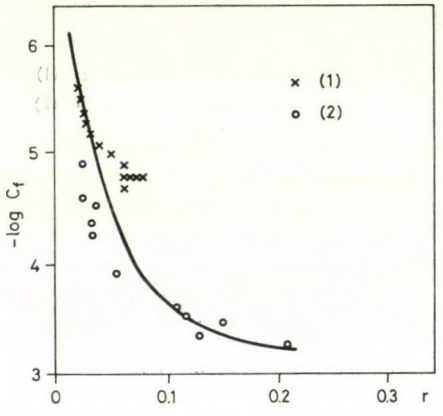

Fig. 5. Titration curves for DNA with Ser-TrpOMe

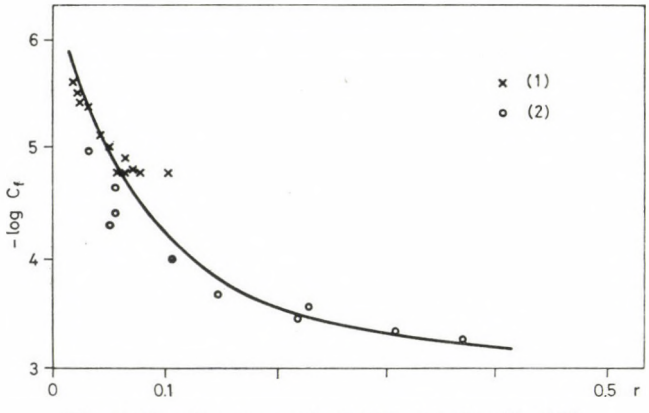

Fig. 6. Titration curves for DNA with Orn-TrpOMe

Figures 5—6. Titration curves for DNA with dipeptide esters: (1) fluorescence quenching measurements, (2) equilibrium dialysis; C_f: the molar concentration of unbound peptide, r: the mean number of moles peptide bound per mole phosphate

based on the spectrofluorometric measurements were constructed from data obtained by the titration of the peptides in a $2 \cdot 10^{-5}$ *M* solution (pH 6.35) with varying concentrations ($2 \cdot 10^{-5}$—$4 \cdot 10^{-4}$ *M* (*P*)) of the DNA solution. Experimental details were previously reported [27]. Some differences in the values of binding parameters might be related to a temperature effect, since spectrofluorometric measurements were performed at ambient temperature, while equilibrium dialysis experiments were carried out at 4 °C [41]. The existence of two classes of sites, *i.e.* strong binding and a high number of weaker binding sites is evident from these figures.

In our experiments a more complete titration curve was obtained by fluorescence quenching, while equilibrium dialysis experiments yielded an incomplete curve.

Fluorescence experiments; nucleotide specificity

In order to learn more about the specificity of the peptides for a particular base or a particular nucleic acid structure, we studied the interaction of three dipeptide esters, Orn-TrpOMe (Fig. 7), Glu-TrpOMe (Fig. 8) and Ser--TrpOMe (Fig. 9), with a number of double- and single-stranded polynucleotides.

Fluorescence spectral studies were carried out by titrating a $2 \cdot 10^{-5}$ *M* peptide solution with varying concentrations ($2 \cdot 10^{-5}$—$4 \cdot 10^{-4}$ *M*(P)) of the polynucleotide solutions (pH 6.35). The percentage decrease in fluorescence intensity as plotted against the molar ratio of DNA(*P*)/peptide are depicted in Figs 7—9. Although the data were insufficient to construct reliable SCATCHARD plots, some conclusion can be drawn about the relative ability of the three peptides to be bound to polynucleotides.

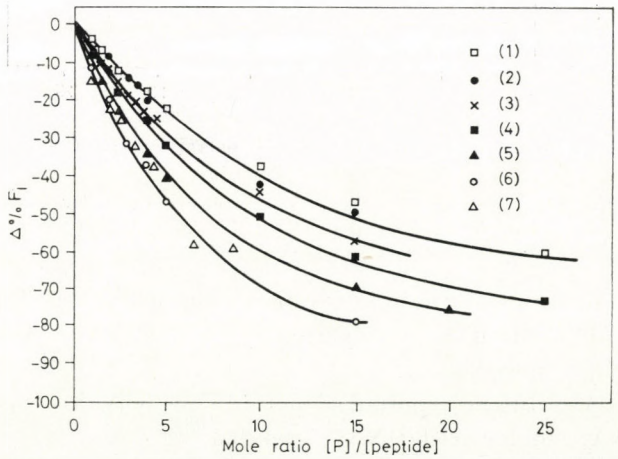

Fig. 7. Interaction of Orn-TrpOMe with poly(dA)-poly(dT) (1); poly(A) (2); poly(I)-poly(C) (3); DNA (4); denatured DNA (5); poly(C) (6); poly(C—G) (7)

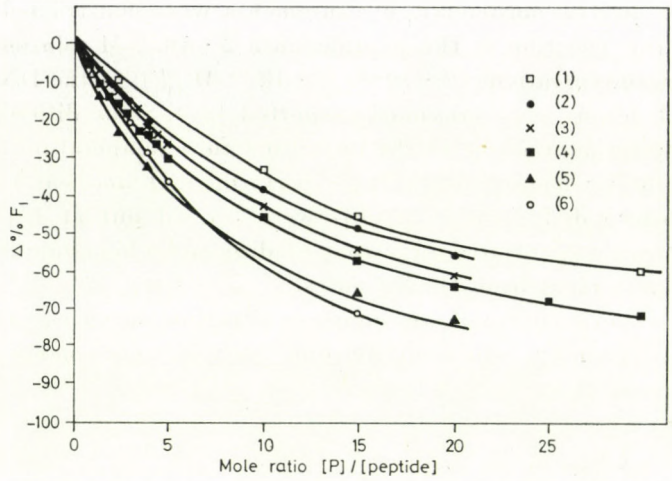

Fig 8. Interaction of Glu-TrpOMe with poly(dA)-poly(dT) (1); poly(A) (2); poly(I)-poly(C) (3); DNA (4); denatured DNA (5)

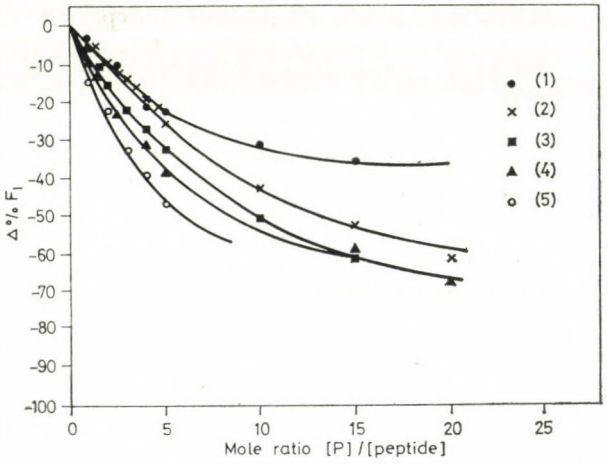

Fig. 9. Interaction of Ser-TrpOMe with poly(A) (1); poly(I)-poly(C) (2); DNA (3); denatured DNA (4); poly(C) (5)

Figures 7—9. Percentage decrease in fluorescence intensity plotted against the molar ratio nucleic acid [P]/[peptide]; pH 6.35, *I:* 0.0036

Binding affinities increase in the following order: Orn-TrpOMe (Fig. 7): poly(A)=poly(dA)-poly(dT) < poly(I)–poly(C) < DNA < denatured DNA < poly(C) = poly(G—C);

Glu-TrpOMe (Fig. 8): poly(dA)–poly(dT) < poly(A) < poly(I)–poly(C) < DNA < denatured DNA < poly(C);

Ser-TrpOMe (Fig. 9): poly(A) < poly(I)–poly(C) < DNA < denatured DNA < poly(C).

These results suggest the tendency of C—G preference in binding affinity, consistent with our previous spectrofluorometric measurements performed with *Micrococcus lysodeikticus* DNA (G—C content 72%) and the same dipeptide esters.

A similar trend, *i.e.* slight C—G affinity has been observed by WEHLING *et al.* [21] for lysine-tryptophan copolymers, and also by NOVAK *et al.* [15] for a tyrosyl-glycine pentapeptide. SAXINGER *et al.* [22] measured the highest selectivity coefficient with immobilized tryptophan binding for 5'-Gp and 5'-Ip. On the other hand, GABBAY *et al.* [12] reported A—T specificity from equilibrium dialysis studies with a series of lysyl-aromatic amino acid amides.

The data presented in the Figs 7—9 clearly indicate that significant binding is possible to both single-stranded homopolymers and helical copolymers, provided the base composition is also adequate. This observation supports the postulation about the importance of H-bonding in the binding and recognition process — as discussed by SEEMAN *et al.* [23].

These studies must be regarded only as preliminary experiments, since the series of polynucleotides is incomplete. At the same time it seems justified to regard our present data as relative indices suitable to reflect differences in binding affinity.

Discussion

The choice of peptides for the present experiments was planned by keeping in mind the several conceptions that have emerged up to now, trying to explain recognition specificity. The increased interest in acidic nuclear proteins also seemed to justify the choice of a number of glutamyl and aspartyl model peptides. These models are suitable to evaluate the influence of the varying number of free carboxyl groups.

The role of the distance between the amino and carboxyl groups could be studied by moving the peptide bond to the γ-carboxyl group of glutamic acid, or by replacing glutamic acid by aspartic acid. By the insertion of D-amino acids the "stereospecificity" of complex formation of diastereomeric peptides was investigated, and attention was also paid, to some extent to evaluation of the sequence effect. The analysis of aromatic side chain contribution to binding specificity has been restricted in the two previous papers to tryptophan and tyrosine peptides, but in the present series phenylalanine derivatives have also been included. Experiments were carried out to examine any possible base specificity.

Binding affinities were studied by three independent methods, the scanning of thermal denaturation of DNA, equilibrium dialysis and fluorescence measurements.

Tryptophan-containing peptides were investigated by all three methods, while tyrosine and phenylalanine peptides only by two. The reason for this

was that application of the fluorescence technique for tyrosine and phenylalanine is less reliable and more complicated. Both the quantum yield and the molar absorbancy are much lower than those of tryptophan [42], and the calculation of a number of correction factors would be necessary due to the extensive overlap of the absorption and emission spectra [43].

As has been pointed out earlier [26], the interpretation of T_m-data is complicated by at least two competing process. It should be regarded therefore as a qualitative indication of the existence of an interaction, but no quantitative estimation or detailed analysis of the binding process is possible on this basis.

Equilibrium dialysis is regarded as the best way of investigating the strength of binding. The advantages and limits of the two methods, equilibrium dialysis and fluorescence spectroscopy, was analysed by a comparison of the experimental results in the form of BJERRUM plots, which revealed the highest sensitivity intervals.

The picture which emerged so far in connection with our model peptides may be summarized as follows.

Binding studies with lysyl and ornithyl peptides clearly show that the addition of an extra positive charge to the peptide system enhances the binding affinity to DNA. The analysis of glutamyl — including α- and γ-peptides — and aspartyl peptides indicates that the sequence and stereochemistry of the amino acid residues is important with respect to the magnitude of the stabilizing effect. These findings are in line with the results obtained by GABBAY *et al.* [11, 12] with various dipeptide amides.

The increase in the binding affinity of the peptides with aromatic amino acids relative to aliphatic amino acid-containing variations (Glu-Ala, Glu-Val, *etc.*) is obviously a specific contribution of the aromatic ring system involved. Whether in the case of native DNA the affinity gain superimposed over the contribution of the partner amino acid results from intercalation or merely from interaction with the DNA surface or grooves is still under controversial discussion [4, 9, 14, 21] and may depend on the aromatic residue involved.

Preliminary experiments with tryptophan-containing model peptides and a number of double- and single-stranded polynucleotides were carried out by the spectrofluorometric technique. A slight C—G preference compared to A—T affinity has been observed. This observation is consistent with the results of WEHLING [21], but controversial to other reports [6, 12].

Nuclear protein-DNA interactions were analysed so far mainly with the aid of basic — and to some extent with apolar — amino acid-containing model peptides, but little attention [15, 44, 45] has been paid to model peptides containing acidic residues. Our experiments indicate that the two types of peptides might affect DNA in a very different way, and acidic amino acids of proteins could also play an important part in protein-nucleic acid recognition.

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REFERENCES

[1] Leng, M., Felsenfeld, G.: Proc. Nat. Acad. Sci. USA, **56,** 1325 (1966)
[2] Gabbay, E. J., Kleinman, R.: J. Am. Chem. Soc., **89,** 7123 (1967)
[3] Gabbay, E. J., Kleinman, R., Shimshak, R. S.: J. Am. Chem. Soc., **90,** 1927 (1968)
[4] Heléne, C., Dimicoli, J. L.: FEBS Letters, **26,** 6—10 (1972)
[5] Brown, P. E.: Biochim. Biophys. Acta, **213,** 282 (1970)
[6] Durand, M., Maurizot, J. C., Borazan, H. N., Heléne, C.: Biochemistry, **14,** 563 (1975)
[7] Brun, F., Toulmé, J. J., Heléne, C.: Biochemistry, **14,** 558 (1975)
[8] Toulmé, J. J., Heléne, C.: J. Biol. Chem., **252,** 244 (1977)
[9] Quadrifoglio, F., Giancotti, V., Crescenzi, V.: FEBS Letters, **65,** 345 (1976)
[10] Maurizot, J. C., Boubault, G., Heléne, C.: FEBS Letters, **88,** 33 (1978)
[11] Gabbay, E. J., Sanford, K., Baxter, C. S.: Biochemistry, **11,** 4329 (1972)
[12] Gabbay, E. J., Sanford, K., Baxter, C. S., Kapicak, L.: Biochemistry, **12,** 4021 (1973)
[13] Eckstein, H., Schott, H., Bayer, E.: Biochim. Biophys. Acta, **432,** 1 (1976)
[14] Gabbay, E. J., Adawadkar, P. D., Wilson, W. D.: Biochemistry, **15,** 146 (1976)
[15] Novak, R. L., Dohnal, J.: Nucleic Acid Res., **1,** 753 (1974)
[16] Olins, D. E., Olins, A. E., von Hippel, P. A.: J. Mol. Biol., **33,** 265 (1968)
[17] Shapiro, J. T., Leng, M., Felsenfeld, G.: Biochemistry, **8,** 3219 (1969)
[18] Zama, M., Ichimura, S.: Biochim. Biophys. Acta, **294,** 214 (1973)
[19] Williams, R. E., Kielland, S. L.: Can. J. Chem., **53,** 542 (1975)
[10] Mandel, R., Fasman, G.: Biochem. Biophys. Res. Commun., **59,** 672 (1974)
[21] Wehling, K., Arfmann, H. A., Seipke, G., Wagner, K. G.: Nucleic Acids Res., **4,** 513 (1977)
[22] Saxinger, C., Ponnamperuma, C., Woese, C.: Nature New Biol., **234,** 172 (1971)
[23] Seeman, N. C., Rosenberg, J. M., Rich, A.: Proc. Nat. Acad. Sci. USA, **73,** 804 (1976)
[24] Rifkind, J. M., Eichorn, G. L.: Biochemistry, **9,** 1753 (1970)
[25] Arfmann, H. A., Lawaczek, R., Wagner, K. G.: Stud. Biophys., **40,** 161 (1973)
[26] Szekerke, M., Érchegyi, J., Sági, J.: Acta Chim. Acad. Sci. Hung., **80,** 183 (1974)
[27] Szekerke, M., Érchegyi, J.: Acta Chim. Acad. Sci. Hung., **87,** 293 (1975)
[28] Szekerke, M., Horváth, M.: Arzneim.-Forsch., **25,** 1016 (1975)
[29] Szekerke, M., Horváth, M., Érchegyi, J.: FEBS Letters, **44,** 160 (1974)
[30] Szekerke, M.: Ann. Univ. Sci. Budapestinensis, Sect. Chim., **13,** 47 (1972)
[31] Mazur, R. H., Schlatter, J. M., Goldkamp, A. H.: J. Am. Chem. Soc., **91,** 2684 (1969)
[32] Davey, J. M., Laird, A. H., Morley, J. S.: J. Chem. Soc. (C), **1966,** 555
[33] Sachs, H., Brand, E.: J. Am. Chem. Soc., **75,** 4608 (1953)
[34] Klieger, E., Schröder, E.: Ann. Chem., **661,** 193 (1963)
[35] Tanford, C.: "Physical Chemistry of Macromolecules", Wiley, New York, 1963
[36] Scatchard, G.: Ann. N.Y. Acad. Sci., **51,** 660 (1949)
[37] McGhee, J. D., von Hippel, P. H.: J. Mol. Biol., **86,** 469 (1974)
[38] Gaugain, B., Barbet, J., Capelle, N., Roques, B. P., Le Pecq, J. B.: Biochemistry, **17,** 5078 (1978)
[39] Weber, G.: "Advances in Protein Chemistry" Vol. **29,** p. 1 (Ed. Anfinsen, G. B., Edsall, J. T., Richards, F. M.) Academic Press, New York, 1975
[40] Bjerrum, N.: Z. Phys. Chem., **106,** 219 (1923)
[41] Dimicoli, J. L., Heléne, C.: Biochemistry, **13,** 724 (1974)
[42] Cowgill, R. W.: Arch. Biochim. Biophys., **100,** 36 (1963)
[43] Ketskeméty, I., Dombi, J., Horvai, R., Hevesi, J., Kozma, L.: Acta Phys. et Chem. Szeged, **7,** 17 (1961)
[44] Lancelot, G., Heléne, C.: Proc. Nat. Acad. Sci. USA, **74,** 4872 (1977)
[45] Lancelot, G., Mayer, R., Heléne, C.: J. Am. Chem. Soc., **101,** 1569 (1979)

Maria Szekerke H-1088 Budapest, Múzeum krt. 4/b.
Judit Érchegyi H-1088 Budapest, Puskin u. 9.

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SYNTHESIS OF ALKALOIDS USING REISSERT COMPOUNDS, III*

SYNTHESIS OF CORDRASTINE ISOMERS AND TWO FURTHER PHTHALIDEISOQUINOLINES

P. KEREKES[1], Gy. GAÁL[1], R. BOGNÁR[1], T. TÖRŐ[1] and B. COSTISELLA[2]

([1]Institute of Organic Chemistry, Kossuth Lajos University, Debrecen, and [2]Organic Chemical Institute, Academy of Sciences of the German Democratic Republic, Berlin—Adlershof, GDR)

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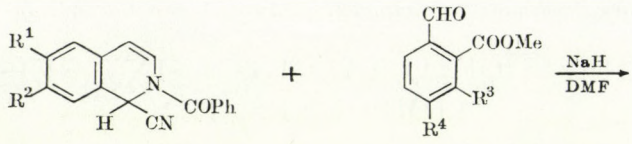
By the reaction of the Reissert compounds (**1a, b**) of unsubstituted and 6,7-dimethoxyisoquinoline with phthalaldehydic acid methyl ester (**2a**) or with opianic acid methyl ester (**2b**), the *erythro* and *threo* isomers of (±)-1-(1'-phthalidyl)-2-methyl-1,2,3,4-tetrahydroisoquinoline and (±)-1-[1'-(4', 5'-dimethoxyphthalidyl)]-2-methyl-1,2,3,4-tetrahydroisoquinoline (**6a, b**) and **7a, b**) were prepared; further on, new syntheses of (±)-cordrastine I (**7c**) and (±)-cordrastine II (**6c**) were achieved. The structures of the compounds were confirmed by ^{13}C-NMR and mass spectroscopic methods.

In an earlier paper [1] we described the use of Reissert compounds in the synthesis of phthalideisoquinoline alkaloids, and a new synthesis of hydrastine isomers (**6d** and **7d**) achieved in this way was reported. In the present paper further results obtained in this field will be discussed.

2-Benzoyl-1-cyano-1,2-dihydroisoquinoline (**1a**) (unsubstituted Reissert compound) or 2-benzoyl-1-cyano-1,2-dihydro-6,7-dimethoxyisoquinoline (**1b**) (6,7-dimethoxy-Reissert compound) were allowed to react with 2-formylbenzoic acid methyl ester (**2a**) (methyl ester of *o*-phthalaldehydic acid), or with 2,3-dimethoxy-6-formylbenzoic acid methyl ester (**2b**) (methyl opianate) in dimethylformamide, in the presence of sodium hydride. The respective diesters (**3a—c**) were isolated in 50—70% yields from the reaction mixtures; they were saponified with potassium hydroxide in aqueous alcoholic solution, and then subjected to lactonization by refluxing with acid. The aromatic phthalideisoquinolines (**4a—c**) prepared in this way were hydrogenated under a pressure of $3 \cdot 10^5$ Pa to obtain a mixture of (±)-*erythro*- and (±)-*threo*-norphthalideisoquinolines (**5a—c**). The ratio of the *erythro* and *threo* compounds was nearly 1:1 for **5a** and **5c**, and it was about 2:1 for **5b**.

In the case of compound **5a** and **5b**, separation of the isomers failed, therefore the isomer mixtures were methylated directly into the end-products (**6a**, **7a** and **6b**, **7b**).

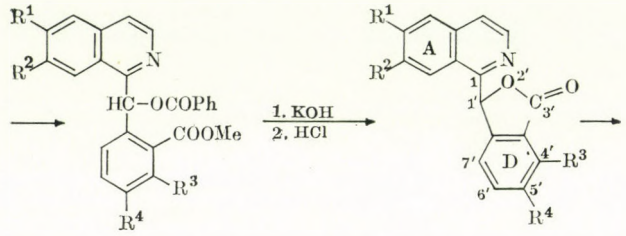
* Part II, see KEREKES, P., MAKLEIT, S., BOGNÁR, R.: Acta Chim. Acad. Sci. Hung., **98**, 491 (1978)



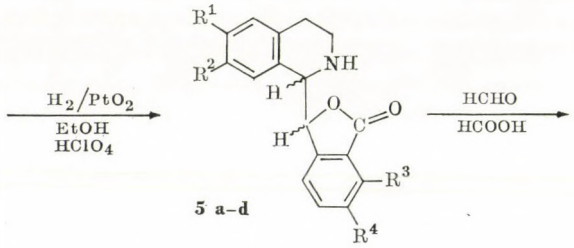
1 a–c **2 a,b**

1	R^1	R^2
a	–H	–H
b	–OMe	–OMe
c	$-OCH_2O-$	

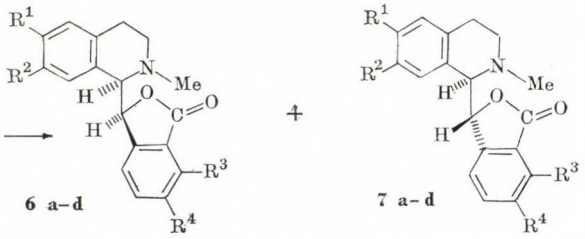
2	R^3	R^4
a	–H	–H
b	–OMe	–OMe



3 a–d **4 a–d**



5 a–d



6 a–d **7 a–d**

3–7	R^1	R^2	R^3	R^4
a	–H	–H	–H	–H
b	–H	–H	–OMe	–OMe
c	–OMe	–OMe	–OMe	–OMe
d	$-OCH_2O-$		–OMe	–OMe

Compounds **6a** and **7a** were then separated by preparative layer chromatgraphy; the *erythro* and *threo* isomers were distinguished in the ^{13}C-NMR spectra on the basis of the characteristic chemical shifts of C-3 and C-4 [2]. The (±)-*erythro*- (**6a**) and (±)-*threo*-1-(1'-phthalidyl)-2-methyl-1,2,3,4-tetrahydroisoquinolines (**7a**) are the parent compounds of the phthalideisoquinoline alkaloids, carrying no substituent in rings A and D. The above synthesis is the first one for these compounds.

The separation of **6b** and **7b** was achieved again by preparative layer chromatography and the analysis of the ^{1}H-NMR and ^{13}C-NMR spectra provided a possibility for differentiating between the *erythro* and *threo* isomers [2, 3]. The (±)-*erythro*- (**6b**) and (±)-*threo*-1-[1'-(4',5'-dimethoxyphthalidyl)]-2--methyl-1,2,3,4-tetrahydroisoquinoline (**7b**) are compounds which have not been isolated from natural sources. One optically active enantiomer of **6b** has been prepared from (−)-β-hydrastine [4]; our ^{1}H-NMR data are in good agreement with those the reported in the literature.

The mixture of the norcordrastine isomers (**5c**) was separated by fractional crystallization; the *erythro* isomer could only be crystallized as its hydrochloride. *N*-Methylation of (±)-*erythro*- and (±)-*threo*-norcordrastine yielded (±)-cordrastine II (**6c**) and (±)-cordrastine I (**7c**). The physical properties, IR and ^{1}H-NMR spectral data of the products are in good agreement with the respective data of compounds prepared in earlier syntheses [5—9].

^{13}C-NMR spectra

The structures of the phthalideisoquinoline alkaloids (**6**, **7**) and of the intermediates of their syntheses (**3—5**) were confirmed by ^{13}C-NMR spectroscopic analysis. Assignment of the signals was achieved by means of the off-resonance technique or on the basis of published spectra [2]. Table I lists the characteristic signals of the diesters (**3**) and lactones (**4**).

As established by MacLean *et al.* [2] for hydrastine isomers, the *erythro* and *threo* isomers (**6d** and **7d**) can readily be distinguished by ^{13}C-NMR spectroscopy.

Table I

Characteristic ^{13}C-NMR signals of the diesters **3a—d** *and lactones* **4a—d** *in $DMSO_{d6}$ solutions*

3	δ_{COOCH_3}	$\delta_{C-\alpha}$	δ^{1}_{CO}	δ^{2}_{CO}	**4**	$\delta_{C-1'}$	δ_{COO}
a	52.08	71.97	164.88	166.76	**a**	79.92	169.94
b	51.94	72.89	165.24	166.88	**b**	77.72	167.50
c	52.34	72.54	164.88	167.01	**c**	78.03	167.68
d	52.28	72.63	164.87	167.00	**d**	77.83	167.56

Table II

Characteristic ^{13}C-NMR signals of phthalideisoquinolines **6a—d** *and* **7a—d**

No.	Solvent	δ_{C-4}	δ_{N-CH_3}	δ_{C-3}	δ_{C-1}	$\delta_{C-1'}$	$\delta_{C-3'}$	*Lit.*
6a	$CDCl_3$	27.11	45.11	49.52	65.71	84.30	170.00	
7a	$CDCl_3$	29.25	44.91	51.27	66.23	82.28	170.30	
6b	$CDCl_3$	27.27	45.21	49.63	66.18	83.17	167.50	
	$DMSO_{d6}$	*26.24*	*44.21*	*48.49*	*65.03*	*81.93*	*166.89*	
7b	$CDCl_3$	29.41	44.96	51.42	66.48	80.87	167.90	
	$DMSO_{d6}$	*27.37*	*44.47*	*50.38*	*64.77*	*79.06*	*167.26*	
6c	*$DMSO_{d6}$*	*25.59*	*43.97*	*48.42*	*64.76*	*81.99*	*166.99*	
7c	*$DMSO_{d6}$*	*26.97*	*44.43*	*50.59*	*64.51*	*81.54*	*167.54*	
6d	$CDCl_3$	26.7	44.7	49.0	66.0	82.7	167.0	[2]
7d	$CDCl_3$	29.2	44.9	51.3	66.2	81.8	168.0	[2]

Table III

Characteristic ^{13}C-NMR signals of the nor-compounds **5**

5		Solvent	δ_{C-4}	δ_{C-3}	δ_{C-1}	$\delta_{C-1'}$	$\delta_{C-3'}$
c	*erythro*	$CDCl_3$	29.32	40.86	56.66	82.92	167.99
		$DMSO_{d6}$	*28.64*	*39.99*	*55.53*	*82.65*	*167.29*
c	*threo*	$CDCl_3$	29.56	41.64	57.70	82.55	167.89
		$DMSO_{d6}$	*29.06*	*41.34*	*56.05*	*83.09*	*167.50*
d	*erythro*	$CDCl_3$	29.87	40.68	56.97	82.84	168.01
		$DMSO_{d6}$	*29.22*	*39.73*	*55.92*	*82.22*	*167.30*
d	*threo*	$CDCl_3$	30.01	41.53	58.13	82.73	167.75
		$DMSO_{d6}$	*29.50*	*41.19*	*56.34*	*83.21*	*167.44*

This method of identification of the isomers has been tried on the com pounds synthesized by us (**6a—c**, **7a—c**). It has been found also in this case that the chemical shifts in the individual isomers for C-4, C-3 and C-1' differ significantly, and the differences are greater in $CDCl_3$ than in $DMSO_{d6}$. The chemical shift for C-3 and C-4 in the *erythro* isomers (**6a—c**) appears at higher field than in the *threo* isomers (**7a—c**), whereas a reverse effect can be observed for C-1'. The signals due to $N-CH_3$, C-1 and C-3' show only slight differences in the chemical shifts, yet they are characteristic enough for differentiating the isomers (see Table II).

The successful application of ^{13}C-NMR spectroscopy in the stereochemical investigation of phthalideisoquinolines (**6**, **7**) suggested an extension

of the method to the examination of the corresponding nor-compounds (**5**). In this case, only **5c** and **5d** were available as pure isomers. The signals suitable for distinguishing between the isomers are given in Table III.

There are characteristic differences in the chemical shifts also in the isomers of the nor-compounds **5**, which make possible an unambiguous differentiation between the isomers. Particularly high differences have been observed in the C-3 and C-1 signals; the signals of the *erythro* isomers appear at higher field than those of the *threo* isomers. The C-4 signals show a similar, but less emphasized effect. The C-1' signals in $DMSO_{d6}$ appear again at higher field in the *erythro* isomers; in $CDCl_3$, however, they are found at lower field and the differences are very small.

Mass spectra

Some of the compounds prepared were also examined by the mass spectrometric technique and the following information was obtained.

Diesters (**3a—c**): the molecular peak was found in each case; the base peak was $M-105$ (Ph—CO) when rings A and D were unsubstituted (**3a**), and $M-59$ (COOMe) if these rings were substituted (**3b, c**).

Lactones (**4a—c**): the respective molecular peak can well be observed in these compounds, too; in **4b** and **4c** this is also the base peak. In **4a** the base peak is $M-29$ (CHO).

Norphthalideisoquinolines (*erythro-* and *threo-***5c**): the molecular peak can only be observed at low excitation; spectra recorded at 70 eV indicate splitting of the molecules with fission of the C1—C1' bond; the base peak corresponds to the isoquinoline part.

Phthalideisoquinolines (**6b, 6c** and **7b, 7c**): no molecular peak is observed under normal recording conditions (70 eV). Splitting of the C1—C1' bond occurs in each case, and the base peak corresponds to the isoquinoline part. Similar results were published earlier for hydrastine by American authors [10] In strongly overexcited spectra the molecular peak can also be observed.

Experimental*

M.p.'s are uncorrected; the spectra were recorded with the following instruments: IR: Unicam SP 200 G (in KBr pellets); ^{1}H-NMR : Jeol Minimar 100 MHz, in $CDCl_3$ (internal standard: TMS, data given in δ ppm); ^{13}C-NMR: Varian CFT 20, in $CDCl_3$ (internal standard: TMS, in δ ppm) and in $DMSO_{d6}$ (internal standard HMDS, in δ ppm, referred to TMS); MS: Varian MAT CH6.

* For the preparation of **3d—7d**, see Ref. [1].

Preparation of diesters. General method

Sodium hydride (0.26 g) was added to a solution of the Reissert compound (**1a, b**) (10 mmoles) in anhydrous DMF (40 ml) in a stream of nitrogen at −20 °C, under stirring. After 15 min, a solution of the ester (**2a, b**) (11 mmoles) in anhdyrous DMF was added to it dropwise. The reaction mixture was stirred at −20 °C for 6 h, then poured into ice-water (200 ml). The product was filtered off and washed with water until neutral. The material was dissolved in $CHCl_3$ and the solution filtered to remove a small amount of insoluble solid.* The chloroform solution was washed with water (2×50 ml), dried (Na_2SO_4) and evaporated to dryness. The residue was crystallized from ethanol.

1-(α-Benzoyloxy-2-methoxycarbonylbenzyl)isoquinoline (3a)

The product (7.1 g) was obtained from **1a** (5.2 g; 20 mmoles) and **2a** (3.6 g; 22 mmoles) and it was twice recrystallized from ethanol. Yield: 3.88 g (49%); m.p. 138—141 °C. The m.p. of a sample purified for analysis was 141—142 °C.

$C_{25}H_{19}NO_4$ (397.41). Calcd. C 75.55; H 4.82; N 3.53. Found C 76.10; H 4.76; N 3.68%.

IR: $\nu C{=}O$ 1722 cm^{-1}.

MS(*m/e*): 397 (M^+), 388, 292, 260, 217.

1-(α-Benzoyloxy-2-methoxycarbonyl-3,4-dimethoxybenzyl)isoquinoline (3b)

The product obtained from **1a** (2.6 g; 10 mmoles) and **2b** (2.46 g; 11 mmoles) was twice recrystallized from ethanol to yield 3.22 g (70%) of **3b**, m.p. 163—165 °C.

$C_{27}H_{23}NO_6$ (457.46). Calcd. C 70.89; H 5.07; N 3.06. Found C 71.88; H 5.13; N 3.12%.

IR: $\nu C{=}O$ 1730 cm^{-1}.

MS (*m/e*): 457 (M^+), 389, 352, 320, 277.

1-(α-Benzoyloxy-2-methoxycarbonyl-3,4-dimethoxybenzyl)-6,7-dimethoxyisoquinoline (3c)

The product obtained from **1b** (3.2 g; 10 mmoles) and **2b** (2.46 g; 11 mmoles) was twice recrystallized from ethanol to yield 2.5 g (48%) of **3c**, m.p. 169—171 °C.

$C_{29}H_{27}NO_8$ (517.52). Calcd. C 67.30; H 5.26; N 2.71. Found C 67.47; H 5.33; N 2.62%.

IR: $\nu C{=}O$ 1723 cm^{-1}.

MS (*m/e*): 517 (M^+), 458, 412, 380, 337.

Hydrolysis. General method*

A mixture of the diester (**3a—c**) (1 mmole), ethanol (12.5 ml), KOH (0.17 g) and water (2.5 ml) was refluxed for 5 h. After the addition of 10% hydrochloric acid (5 ml), the mixture was refluxed for 1 h more. The solvent was evaporated in vacuum, the residue diluted with water, and made alkaline with NH_4OH. The product was filtered off, washed with water and dried.

1-(1′-Phthalidyl)-isoquinoline (4a)

The product prepared from **3a** (3.6 g; 9 mmoles) was twice recrystallized from ethanol to obtain 1.62 g (68%) of **4a**, m.p. 171—175 °C.

$C_{17}H_{11}NO_2$ (261.27). Calcd. C 78.15; H 4.24; N 5.36. Found C 78.33; H 4.23; N 5.39%.

IR: $\nu C{=}O$ 1770 cm^{-1}.

MS (*m/e*): 261 (M^+), 232, 217, 204, 133.

* All reactions gave a by-product, which was poorly soluble in chloroform or ethanol, and contained no nitrogen. This greatly hindered the purification of the main product. The structures of these compounds have not been investigated.

1-[1′-(4′,5′-Dimethoxyphthalidyl)]isoquinoline (4b)

The product prepared from **3b** (5.33 g; 11.65 mmoles) was twice recrystallized from ethanol to yield 2.64 g (71%) of **4b**, m.p. 157—159°C.

$C_{19}H_{15}NO_4$ (321.32). Calcd. C 71.02; H 4.71; N 4.36. Found C 71.20; H 4.73; N 4.38%.

IR: νC=O 1775 cm^{-1}.

MS (*m/e*): 321 (M^+), 306, 292, 276, 262, 193, 165.

1-[1′-(4′,5′-Dimethoxyphthalidyl)]-6,7-dimethoxyisoquinoline (4c)

The product prepared from **3c** (2.07 g; 4 mmoles) was crystallized from a mixture of dichloromethane and *n*-hexane to obtain 1.26 g (82%) of the product, m.p. 195—197 °C (d.); *(lit.* [6] m.p. 179—181 °C).

$C_{21}H_{19}NO_6$ (381.37). Calcd. C 66.13; H 5.02; N 3.67. Found C 66.51; H 5.04; N 3.74%.

IR: νC=O 1765 cm^{-1}.

MS (*m/e*): 381 (M^+) 366, 352, 336, 322, 193, 165.

Catalytic hydrogenation. General method

A solution of the phthalideisoquinoline (**4a—c**) (1 mmole) in a mixture of ethanol (60 ml) and 70% $HClO_4$ (0.25 ml) was hydrogenated in the presence of PtO_2 catalyst (0.1 g) at $3 \cdot 10^5$ Pa initial pressure at room temperature for 3 h. The catalyst was removed by filtration and the ethanol evaporated in vacuum. Water and dilute NH_4OH were added to the residue and it was extracted with chloroform. The chloroform solution was washed with water, dried and evaporated to dryness.

(±)-*Erythro*- and (±)-*threo*-1-(1′-phthalidyl)-1,2,3,4-tetrahydroisoquinoline (5a)

Compound **4a** (1.56 g; 6 mmoles) gave a brown oil (1.55 g), which was first converted into the hydrochloride, then again into the base. The product was 1.04 g (67%) of a yellow oil, which was used in the next step without further purification and separation of the isomers.

(±)-*Erythro*- and (±)-*threo*-1-[1′-(4′,5′-dimethoxyphthalidyl)]-1,2,3,4-tetrahydroisoquinoline (5b)

A yellow oil was obtained from **4b** (1.28 g; 4 mmoles); the product solidified on treatment with anhydrous ether. The substance was crystallized from ethanol, to obtain 0.8 g (62%) of **5b**, which was used in the next step without separating the isomers.

(±)-*Erythro*- and (±)-*threo*-1-[1′-(-4′,5′-dimethoxyphthalidyl)]-6,7-dimethoxy-1,2,3,4-tetrahydroisoquinoline, [(±)-norcordrastine II and (±)-norcordrastine I] (5c)

The product (1.07 g) obtained from **4c** (1.14 g; 3 mmoles) was crystallized from ethanol (15 ml). A crystalline substance (0.4 g) was obtained, which was twice recrystallized from ethanol to yield 0.33 g (28%) of **5c**, m.p. 185—187 °C, homogeneous by TLC ($CHCl_3$: MeOH = 9 : 1). This product was (±)-norcordrastine I *(threo* isomer), $R_f = 0.58$.

$C_{21}H_{23}NO_6$ (385.4). Calcd. C 65.44; H 6.01; N 3.63. Found C 65.72; H 6.14; N 3.41%.

IR: νC=O 1760 cm^{-1}.

^{1}H-NMR: 1.68 (1H, s, NH), 2.54—3.34 (4H, m, C3—H and C4—H), 3.80 (6H, s, $2 \times OCH_3$), 3.86 (3H, s, OCH_3), 4.04 (3H, s, OCH_3), 4.5 (1H, d, $J = 4$ Hz, C1—H), 5.65 (1H, d, $J = 4$ Hz, C1'—H) 6.53 (1H, s, C8—H), 6.70 (1H, s, C5—H), 7.16 (2H, s, C6'—H and C7'—H).

MS (*m/e*): 385 (M^+), 193, 192.

The alcoholic mother liquor of the first crystallization was evaporated to dryness, the residue was dissolved in ethanol (5 ml) then alcoholic hydrogen chloride was added to it. The hydrochloride was recrystallized from ethanol; yield 0.45 g, (33%), m.p. 202—204 °C. According to TLC, the substance was homogeneous (±)-norcordrastine II hydrochloride (the *erythro*-isomer) ($CHCl_3$: MeOH = 9 : 1); $R_f = 0.52$.

$C_{21}H_{23}NO_6 \cdot HCl \cdot 2\ H_2O$ (457.90). Calcd. C 55.08; H 6.16; N 3.06; Cl 7.74. Found C 55.43; H 6.29; N 2.98; Cl 8.03%.

IR: νC=O 1760 cm^{-1}.

^{1}H-NMR (base): 2.06 (1H, s, NH), 2.4—2.8 (4H, m, C3—H and C4—H), 3.82 (3H, s, OCH_3), 3.84 (3H, s, OCH_3), 3.88 (3H, s, OCH_3), 4.04 (3H, s, OCH_3), 4.65 (1H, d, $J = 4$ Hz, C1—H), 5.75 (1H, d, $J = 4$ Hz, C1'—H), 6.63 (1H, s, C5—H), 6.72 (1H, s, C8—H), 6.19 (1H, d, $J = 8$ Hz, C7'—H), 7.01 (1H, d, $J = 8$ Hz, C6'—H).

MS (base)(m/e): 385 (M^+), 193, 192.

N-Methylation. General method

A mixture of the nor-compound (**5a—c**) (1 mmole), formic acid (0.6 ml) and 37% formaldehyde (0.8 ml) was heated on a water bath for 4 h, then evaporated to dryness in vacuum. The residue was dissolved in dilute hydrochloric acid, clarified with carbon, filtered and made alkaline with dilute NH_4OH. The product was filtered off, or extracted with chloroform.

(±)-*Erythro*- and (±)-*threo*-1-(1'-phthalidyl)-2-methyl-1,2,3,4-tetrahydroisoquinoline (6a and 7a)

The nor-compound (**5a**) (1.04 g; 4 mmoles) was methylated, and the isomers were separated by preparative layer chromatography (chloroform : methanol = 9 : 1).

Erythro isomer (**6a**): 166 mg (from ether and *n*-hexane), m.p. 100—102 °C, $R_f = 0.58$.

$C_{18}H_{17}NO_2$ (279.33). Calcd. C 77.39; H 6.14; N 5.01. Found C 77.43; H 6.19; N 5.01%.

IR: νC=O 1752 cm^{-1}.

Threo isomer (**7a**): 172 mg(from ethanol), m.p. 130—131 °C, $R_f = 0.7$.

$C_{18}H_{17}NO_2$ (279.33). Calcd. C 77.39; H 6.14; N 5.01. Found C 77.36; H 6.20; N 5.01%.

IR: νC=O 1760 cm^{-1}.

(±)-*Erythro*- and (±)-*threo*-1-[1'-(4',5'-dimethoxyphthalidyl)]-2-methyl-1,2,3,4-tetrahydroisoquinoline (6b and 7b)

The nor-compound (**5b**) (0.32 g; 1 mmole) was methylated; the isomers were separated by preparative layer chromatography (chloroform : methanol = 9 : 1).

Erythro isomer (**6b**): 145 mg; recrystallized from ether, 112 mg, m.p. 125—127 °C, $R_f = 0.63$.

$C_{20}H_{21}NO_4$ (339.38). Calcd. C 70.78; H 6.25; N 4.13. Found C 71.04; H 6.37; N 4.00%.

IR: νC=O 1762 cm^{-1}.

^{1}H-NMR: 2.57 (3H, s, NCH_3), 2.1—3.0 (4H, m, C3—H and C4—H), 3.86 (3H, s, OCH_3), 4.03 (3H, s, OCH_3), 4.12 (1H, d, $J = 4$ Hz, C1—H), 5.54 (1H, d, $J = 4$ Hz, C1'—H), 6.29 (1H, d, $J = 8$ Hz, C7'—H), 7.02 (1H, d, $J = 8$ Hz, C6'—H), 6.8—7.2 (6H, m, ArH).

MS (m/e): 339 (M^+), 193, 146.

Threo isomer (**7b**): 73 mg; recrystallized from ether, 49 mg, m.p. 128—130 °C, $R_f = 0.78$.

$C_{20}H_{21}NO_4$ (339.38). Calcd. C 70.78; H 6.25; N 4.13. Found C 70.74; H 6.27; N 3.99%.

IR: νC=O 1760 cm^{-1}.

^{1}H-NMR: 2.58 (3H, s, NCH_3), 2.4—3.1 (4H, m, C3—H and C4—H), 3.8 (3H, s, OCH_3), 3.89 (3H, s, OCH_3), 4.11 (1H, d, $J = 4$ Hz, C1—H), 5.57 (1H, d, $J = 4$ Hz, C1'—H), 6.8—7.35 (6H, m, ArH).

MS (m/e): 339 (M^+), 193, 146.

(±)-*Erythro*-1-[1'-(4',5'-dimethoxyphthalidyl)]-2-methyl-6,7-dimethoxy-1,2,3,4-tetrahydroisoquinoline [(±)-cordrastine II] (6c)

A yellow oil (0.39 g) was obtained from (±)-norcordrastine II hydrochloride (0.45 g; 1 mmole), which was crystallized from a mixture of methanol and ether. The product was 217 mg (54%), m.p. 117—119 °C (lit. [6] m.p. 117—118 °C).

$C_{22}H_{25}NO_6$ (399.43). Calcd. C 66.15; H 6.31; N 3.51. Found C 65.59; H 6.43; N 3.40%.

IR: νC=O 1760 cm^{-1}.

^{1}H-NMR: 2.57 (3H, s, NCH_3), 2.2—3.0 (4H, m, C3—H and C4—H), 3.67 (3H s, OCH_3), 3.85 (3H, s, OCH_3), 3.88 (3H, s, OCH_3), 4.03 (3H, s, OCH_3), 5.57 (1H, d, $J = 4$ Hz, C1'—H),

6.58 (1H, d, $J = 8$ Hz, C7'—H), 7.12 (1H, d, $J = 8$ Hz, C6'—H), 6.32 (1H, s, C8—H), 6.61 (1H, s, C5—H); the signal of C1—H is overlapped by the singlet appearing at 4.03 ppm.
MS (*m/e*): 399 (M^+), 206, 193.

(±)-*Threo*-1-[1'-(4',5'-dimethoxyphthalidyl)]-2-methyl-6,7-dimethoxy-1,2,3,4-tetrahydroisoquinoline [(±)-cordrastine I] (7c)

A solid product (0.39 g) was obtained from (±)-norcordrastine I (0.39 g; 1 mmole); this was crystallized from methanol (10 ml) to yield 344 mg (86%) of **7c**, m.p. 154—155 °C (*lit.* [6] m.p. 156—157 °C).
$C_{22}H_{25}NO_6$ (399.43). Calcd. C 66.15; H 6.13; N 3.51. Found C 66.20; H 6.43; N 3.29%.
IR: νC=O 1750 cm^{-1}.
^{1}H-NMR: 2.63 (3H, s, NCH_3), 2.3—3.1 (4H, m, C3—H and C4—H), 3.70 (3H, s, OCH_3), 3.79 (6H, s, $2 \times OCH_3$), 3.88 (3H, s, OCH_3), 4.04 (1H, d, $J = 4$ Hz, C1—H), 6.70 (1H, s, C5—H), 7.0 (1H, d, $J = 8$ Hz, C6'—H), 5.58 (1H, d, $J = 4$ Hz, C1'—H), 6.36= (1H, s, C8—H),7.32 (1H, d, $J = 8$ Hz, C7'—H).
MS (*m/e*): 399 (M^+), 206, 193.

*

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REFERENCES

[1] Kerekes, P., Horváth, G., Gaál, Gy., Bognár, R.: Acta Chim. Acad. Sci. Hung., **97,** 353 (1978)
[2] Hughes, D. W., Holland, H. L., MacLean, D. B.: Can. J. Chem., **54,** 2252 (1976)
[3] Safe, S., Moir, R. Y.: Can. J. Chem. **42,** 160 (1964)
[4] Teitel, S., O'Brien, J. P.: J. Org. Chem., **41,** 1657 (1976)
[5] Haworth, R. D., Pinder, A. R.: J. Chem. Soc., **1950,** 1776
[6] Smula, V., Cundasawmy, N. E., Holland, H. L., MacLean, D. B.: Can. J. Chem., **51,** 3287 (1973)
[7] Kametani, T., Honda, T., Inoue, H., Fukumoto, K.: Heterocycles, **3,** 1091 (1975)
[8] Kametani, T., Honda, T., Inoue, H., Fukumoto, K.: J. Chem. Soc. Perkin I, **1976,** 1221
[9] (a) Ahmad, I.: Diss. Abstr. Int. B., **37,** 2848 (1976); C. A., **86,** 121 579 (1977)
(b) De Silva, S. O., Ahmad, I., Snieckus, V.: Tetrahedron Letters, **1978,** 5107
[10] Ohashi, M., Wilson, J. M., Budzikiewicz, H., Shamma, M., Slusarchyk, W. A., Djerassi, C.: J. Am. Chem. Soc., **85,** 2807 (1963)

Péter Kerekes
György Gaál
Rezső Bognár
Tibor Törő
H-4010 Debrecen, P.O. Box 20.

Burkhard Costisella 1199 Berlin-Adleshof (GDR)

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STEREOCHEMICAL STUDIES, XXXVIII* SATURATED HETEROCYCLES, XIV*

SYNTHESIS AND CONFORMATIONAL ANALYSIS OF STEREOISOMERIC *CIS*- AND *TRANS*-TETRAMETHYLENETETRAHYDRO-*N*-METHYL- AND -*N*-BENZYL-1,3-OXAZINES**

L. GERA[1], G. BERNÁTH[2] and P. SOHÁR[3]

([1]Institute of Organic Chemistry, A. József University, Szeged, [2]Institute of Pharmaceutical Chemistry, University Medical School, Szeged, and [3]EGYT Pharmacochemical Works, Budapest)

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Cis- and *trans*-2-methylaminomethyl- and -benzylaminomethyl-1-cyclohexanol (**1—4**), as well as *cis*- and *trans*-2-hydroxymethyl-1-methylamino- and -benzylaminocyclohexane (**5—8**) were allowed to react with *p*-nitrobenzaldehyde to yield 2-*p*-nitrophenyl-3-methyl- and 3-benzyl-*cis*- and *trans*-5,6-tetramethyleneperhydro-1,3-oxazines (**9—12**) and 2-*p*-nitrophenyl-3-methyl- and -3-benzyl-*cis*- and *trans*-4,5-tetramethyleneperhydro-1,3-oxazines (**13—16**).

On the basis of ^{1}H-NMR and ^{13}C-NMR spectroscopic investigations, the favoured conformation of compounds **9—16** was established. In contrast with the favoured conformation of the *cis* homologues containing an NH group in the hetero-ring examined earlier [5], where the NH-group attached to the cyclohexane ring was found to be in *axial* position, in the case of the *cis* compounds **13** and **15**, the *N*-methyl and *N*-benzyl groups attached to the cyclohexane ring were found to be in *equatorial* position. In the favoured conformation of the *cis* isomers **9** and **11**, the oxygen atom in the hetero-ring is again in *axial* position.

In the course of our studies on saturated heterocycles with condensed skeleton carrying two heteroatoms [1], the synthesis and conformational analysis was effected in the case of geometrical tetramethylene-1,3-oxazine-2-one isomers [3], the corresponding pentamethylene derivatives [3], and the dihydro- [4] and tetrahydro-1,3-oxazines with a condensed skeleton [5, 6]. The ^{1}H-NMR [1—6] and X-ray diffraction analysis [7] of these derivatives confirmed the *axial* position of the heteroatom (O, NH) attached to the cyclohexane ring and the *equatorial* position of the methyl or oxo group in the favoured conformation of the *cis*-tetramethylene derivatives.

The favoured conformation of *cis*-3-*p*-nitrophenyl-1-aza-3-oxadecaline and *cis*-3-*p*-nitrophenyl-2-aza-4-oxadecaline is also analogous to the above case

* Part XXXVII (and Part XIII): SOHÁR, P., GERA, L., BERNÁTH, G.: Organic Magnetic Resonance **14**, 204 (1980). For Part XXI of the series of "Saturated heterocycles" see Ref. [1].

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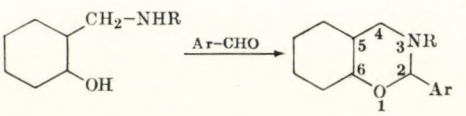
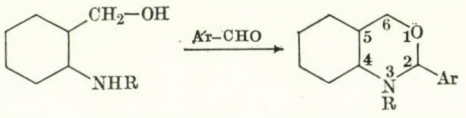


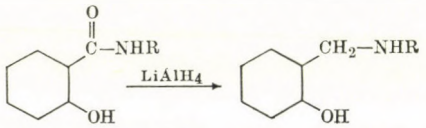
cis	*trans*	R	*cis*	*trans*
1	**2**	Me	**9**	**10**
3	**4**	Bzl	**11**	**12**
		H	**36**	



cis	*trans*	R	*cis*	*trans*
5	**6**	Me	**13**	**14**
7	**8**	Bzl	**15**	**16**
		H	**30**	

Ar = *p*-nitrophenyl; Bzl = $C_6H_5CH_2$

Fig. 1



cis	*trans*	R	*cis*	*trans*
17	**18**	Me	**1**	**2**
19	**20**	Bzl	**3**	**4**

Fig. 2

[5]. The effect of substituents attached to the nitrogen atom on the favoured conformation was investigated. Therefore, the following compounds were prepared: 2-*p*-nitrophenyl-3-methyl- and -3-benzyl-*cis*- and *trans*-5,6-tetramethyleneperhydro-1,3-oxazine (**9—12**), 2-*p*-nitrophenyl-3-methyl- and -3-benzyl-*cis*- and *trans*-4,5-tetramethyleneperhydro-1,3-oxazine (**13—15**) (Fig. 1).

Cis- and *trans*-2-methylaminomethyl- and -benzylaminomethyl-1-cyclohexanol (**1—4**) were prepared from the corresponding *cis*- and *trans*-2-hydroxy-1-cyclohexanecarboxamides (**17—20**) by reducing with $LiAlH_4$ (Fig. 2). The starting **17**, **18** *cis*- and *trans*-2-hydroxy-1-cyclohexanecarboxamides were prepared from ethyl-*cis*- and *trans*-2-hydroxy-1-cyclohexanecarboxylate with 30% ethanolic methylamine at 10—20 °C.

Synthesis of *cis*- and *trans*-2-hydroxymethyl-1-methylamino- and 1-benzylaminocyclohexane (**5**, **6** and **7**, **8**) was realized in several ways. *Cis*- and *trans*-2-benzoylamino-1-cyclohexanecarboxylic acid (**21**, **22**) can be converted into **7** and **8** with $LiAlH_4$.

The procedure suggested by DREFAHL and HÖRHOLD [8] for the preparation of *N*-alkyl-1,3-aminoalcohols has also proved to be suitable for the preparation of **7**. The $LiAlH_4$ reduction of the oxazine **24** obtained from *cis*-2-hydroxymethyl-1-cyclohexylamine (**23**) with benzaldehyde by the method described earlier [5] also yielded compound **7**. The best way of preparing **7** was, however, the reduction of *cis*-2-benzylamino-1-cyclohexanecarboxylic acid [9] obtained from the benzylidene derivative **25** reduced with $NaBH_4$. The second reduction step was effected with $LiAlH_4$ (Fig. 3).

Preparation of *cis*-2-hydroxymethyl-1-methylaminocyclohexane (**5**) was attempted from the *N*-formyl- (**28**) and *N*-alkoxycarbonyl- (**29a,b**) derivatives of *cis*-2-formylamino-1-cyclohexanecarboxylic acid (**28**) was obtained from **27** in the usual [10] formylation procedure, using formic acid and acetic anhydride, however, on reducing **28** with $LiAlH_4$ in contrast with the literature data [11], not the expected 2-methylamino-1-hydroxymethylcyclohexane [**5**] was obtained. The main product was *cis*-2-hydroxymethyl-1-aminocyclohexane (**23**) prepared earlier [12], that is, the formyl group was split during the reduction (Fig. 4).

The reduction of *cis*-2-alkoxycarbonylamino-1-cyclohexanecarboxylic acids (**29a, b**) [10] or their esters with $LiAlH_4$ yielded the aminoalcohol **5** only in 18—20%; compound **23** was again obtained in 20—25% yield, and the starting compound **29a,b** was also partly recovered (Fig. 4).

Eschweiler—Clarcke methylation of *cis*-4,5-tetramethylene-2-*p*-nitrophenylperhydro-1,3-oxazine (**30**) and reduction the expected *N*-methyloxazine derivative with $LiAlH_4$ failed in the preparation of **5**. Therefore, *cis*-2-hydroxymethyl-1-methylaminocyclohexane (**5**) was obtained from methyl-*cis*-2-methylaminocyclohexanecarboxylate (**34**) by reduction with $LiAlH_4$.

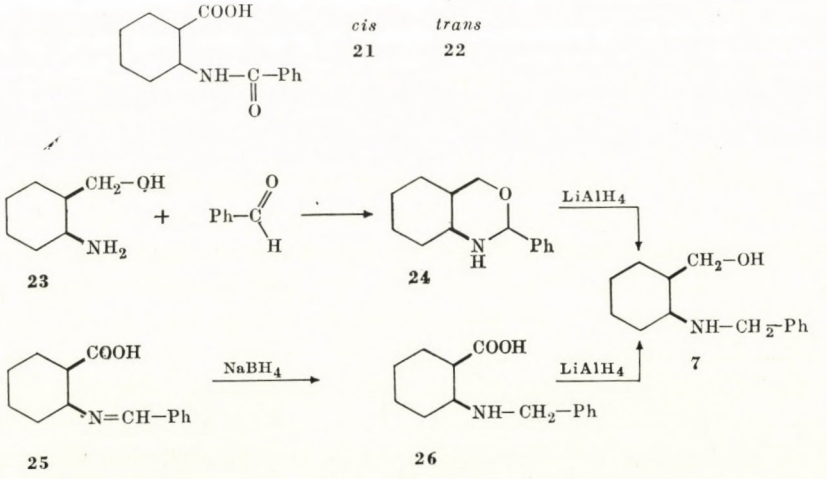


Fig. 3

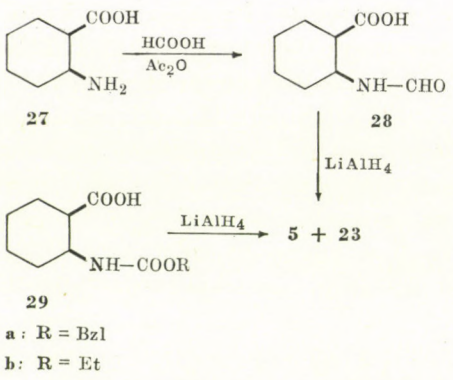


Fig. 4

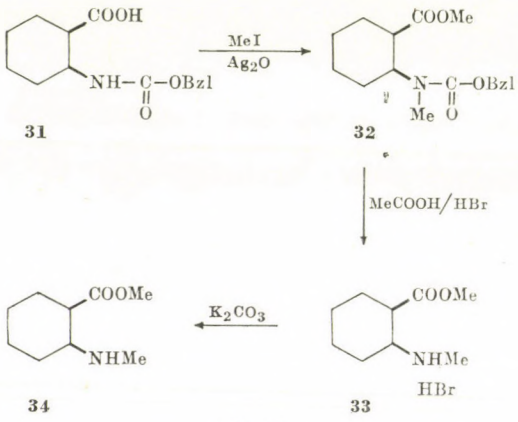


Fig. 5

Compound **34** was prepared from methyl-*cis*-*N*-methyl-2-benzyloxycarbonylamino-1-cyclohexanecarboxylate (**32**) obtained from *cis*-2-benzyloxycarbonylamino-1-cyclohexanecarboxylic acid (**31**) [13] (Fig. 5).

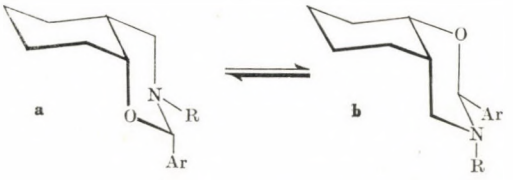
Trans-2-hydroxymethyl-1-methylaminocyclohexane (**6**) could be obtained by reducing *trans*-2-ethoxycarbonylamino-1-cyclohexanecarboxylic acid (**35a**) with $LiAlH_4$, *i.e.* no demethylation occurred, in contrast with the observations in the case of the *cis* isomer.

The aminoalcohols **1**—**8** were allowed to react with *p*-nitrobenzaldehyde in boiling benzene or chlorobenzene using a water separator to obtain 2-*p*-nitrophenyl-*cis*- and *trans*-5,6-tetramethyleneperhydro-1,3-oxazines (**9**—**12**) and 2-*p*-nitrophenyl-*cis*- and *trans*-4,5-tetramethyleneperhydro-1,3-oxazines (**13**—**16**). The 2-*p*-nitrophenyl-3-methyl-4,5-*cis*-tetramethyleneperhydrooxazine (**13**) was obtained only in 20—22% yield.

Conformational analysis of compounds **9—16** based on ^{1}H-NMR and ^{13}C-NMR spectroscopic methods has been reported in detail elsewhere [14]. Here only the results of the studies will be mentioned. Analysis of the ^{1}H-NMR data of the *cis* and *trans* isomers has shown that the favoured conformation of the *cis* derivatives **9** and **11** was **a**, where the attachment of the hetero-atom to the anellation point was *axial* and the methylene group of the hetero ring was in *equatorial* position (Fig. 6).

This favoured conformation is analogous to that found for 2-*p*-nitrophenyl--*cis*-tetramethylene-1,3-oxazines (**30**, **36**) [5], *cis*-tetramethylene-1,3-oxazine--2-ones (**37**, **38**) [2], *cis*-tetramethylene-1,3-oxazine-4-one (**39**) [1] and *cis*-5,6--tetramethylenetetrahydropirimidine-4(3*H*)-one (**40**) [15] (Fig. 7).

In the case of a representative of tetramethyleneperhydro-1,3-oxazines, carrying no substituent at the nitrogen atom (**30**), which can be derived from the *cis* isomers **5** and **7**, the conformer **a** with *axial* hetero atom predominates. In derivatives with methyl or benzyl groups at the nitrogen atom (**13**, **15**), however, in contrast to position isomers **9** and **11**, the other chair-chair conformation (**13b**, **15b**) is the favoured one, that is, where the substituted nitrogen atom is in *equatorial* and the methylene group in *axial* position (Fig. 8).



R		
Me: **9**	Bzl: **11**	H: **36**

Ar = *p*-nitrophenyl

Fig. 6

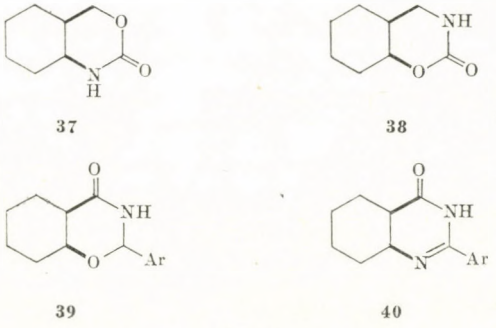


Fig. 7

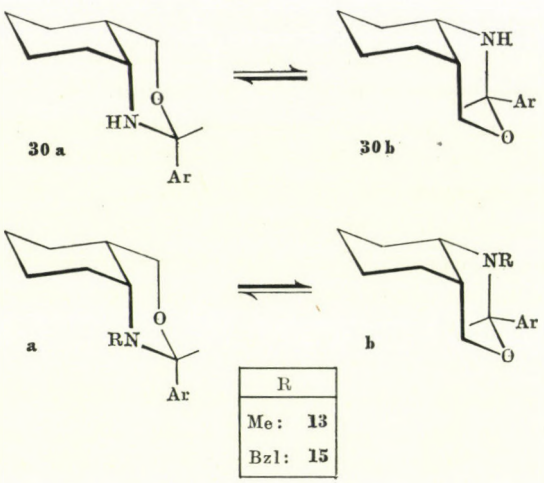


Fig. 8

This allows the conclusion that in this group of compounds the spatial requirement of the substituents attached to the bridgehead carbon atom can be arranged in the following order:

$$O < NH < CH_2 < N\text{-}CH_3 < N\text{-}CH_2\text{-}C_6H_5$$

Of course, the favoured conformation depends not only on the spatial requirement of the substituent attached to the nitrogen atom, but also on the interaction of lone electron pairs of the hetero atoms in positions 1 and 3. When the spatial requirement of the substituent at the nitrogen atom is small, in conformation **a** with the substituent in *axial* position the molecule can avoid the energy increase due to the repulsion of the 1,3-*axial* lone electron pairs of the hetero atoms.

3-Alkyltetrahydro-1,3-oxazines with a non-condensed skeleton structurally related to our compounds were studied by KATRITZKY *et al.* [16], while URBANSKI *et al.* [17] have examined several tetrahydro-1,3-oxazine derivatives.

The great difference in conformation energy (11.3 kJ mol^{-1}) [18], preferring the *equatorial* *N*-methyl group in *N*-methylpiperidine, falls nearly to zero in *N*-methyltetrahydro-1,3-oxazine, since in the case of an *axial* *N*-methyl group the unfavourable 1,3-*diaxial* interaction of the electron pairs of the nitrogen and oxygen atoms is reduced [19]. In the case of *N*,*N*'-dimethylhexahydropyridazine, the difference in free energy between the *diequatorial* and the *axial-equatorial* conformations is also small (1.67 kJ mol^{-1}) [20, 21].

In compound **30a** the hydrogen-hydrogen interaction is insignificant and no repulsion occurs between the 1,3-*diaxial* lone electron pairs of the hetero atoms. However, in the case of compounds with methyl or benzyl substituents at the nitrogen atom, in conformer **a** *diaxal* interactions would occur in *equato-*

rial position of the N–R group. Therefore, the conformations **13b** and **15b** seem to be more favourable than structures **13a** and **15a**.

The *p*-nitrophenyl substituent was assumed to be in *equatorial* position in all cases. According to the general fundamental principles of conformational analysis [2] this is evident, but this was also confirmed by detailed NMR investigations [14]. It should be noted that COOKE and FODOR prepared two epimeric μ-aryloxazine derivatives [23] from (—)-sediridine in a condensation reaction with *p*-nitrobenzaldehyde; also in these compounds, only the methyl group was in *equatorial* or *axial* position, the *p*-nitrophenyl group always retained its *equatorial* position.

Experimental

cis-2-Methylaminomethyl-1-cyclohexanol (1) prepared from 17

$LiAlH_4$ (3.8 g, 0.10 mol) was added to anhydrous tetrahydrofurane (600 cm^3) in small portions at 60 °C. After stirring for 1 hr, a solution of *N*-methyl-*cis*-2-hydroxy-1-cyclohexanecarboxamide (**17**) (7.86 g, 0.05 mol) in anhydrous tetrahydrofurane (100 cm^3) was added. After stirring for 50 hrs, the reaction mixture was decomposed in the usual manner [24]. The tetrahydrofurane solutions was dried over sodium sulfate and the residue was converted into the picrate (4.9 g, 26.5%). After crystallization from ethyl acetate, m.p. 144—145 °C.

$C_{14}H_{21}N_4O_8$ (373.35). Calcd. C 45.34; H 5.55; N 14.77. Found C 45.34; H 5.55; N 14.77%.

The picrate (3.73 g, 0.01 mol) was dissolved in anhydrous methanol (100 cm^3) under heating, then a solution of potassium hydroxide (0.56 g, 0.01 mol) in anhydrous methanol (40 cm^3) was added to it in small portions. After cooling, the potassium picrate separated was filtered off, the methanolic solution was evaporated to dryness and the residue was dissolved in anhydrous ether, evaporated to dryness the dissolved in *n*-hexane and clarified with carbon and concentrated for crystallization (0.75 g, 52.4%). M.p. 82—84 °C.

$C_8H_{17}NO$ (143.23). Calcd. C 67.09; H 11.96; N 9.78. Found C 67.27; H 12.26; N 9.32%.

trans-2-Methylaminomethyl-1-cyclohexanol (2)

It was prepared similarly to the *cis* derivative **1** from **18** by reduction with $LiAlH_4$. The picrate was crystallized from ethyl acetate (38.9%). M.p. 170—174 °C.

$C_{14}H_{21}N_4O_8$ (373.35). Calcd. C 45.03; H 5.67; N 15.01. Found C 44.72; H 5.44; N 14.60%.

The base was liberated with methanolic potassium hydroxide (62.5%). B.p. 88—94 °C at a pressure of 333 Pa.

cis-2-Benzylamino-1-hydroxymethylcyclohexane (7)

(*a*) The *cis*-2-benzoylamino-1-cyclohexanecarboxylic acid (**21**) was reduced with $LiAlH_4$ in anhydrous tetrahydrofurane solution (32.3%).

(*b*) *cis*-2-Amino-1-hydroxymethylcyclohexane (**23**) was allowed to react with benzaldehyde to obtain 2-phenyl-*cis*-4,5-tetramethyleneperhydro-1,3-oxazine (**24**) in the usual way [5] and the viscous product was reduced with $LiAlH_4$ yielding *cis*-2-benzylamino-1-hydroxymethylcyclohexane (**7**) (41.5%).

(*c*) *cis*-2-Benzylamino-1-cyclohexanecarboxylic acid (**26**) was reduced with $LiAlH_4$ and compound **7** was obtained in 52.5% yield. B.p. 124—128 °C at 333 Pa.

cis-2-Hydroxymethyl-1-methylaminocyclohexane (5) obtained by reducing *cis*-2-alkoxycarbonyl-1-cyclohexanecarboxylic acids (29a,b) with $LiAlH_4$

(*a*) $LiAlH_4$ (1.90 g, 0.05 mol) was added to anhydrous tetrahydrofurane (150 cm^3) in small portions in about 1 hr. After stirring for 2 hrs, a solution of *cis*-benzyloxycarbonylamino-1-cyclohexanecarboxylic acid (**29a**) (2.8 g, 0.01 mol) in anhydrous tetrahydrofurane (50 cm^3,

was added dropwise and the reaction mixture was stirred at 60 °C for 40 hrs. After decomposition of the reaction mixture [24] the filtered solution was dried over Na_2SO_4 and, after filtering, was evaporated to dryness. The residue was dissolved in anhydrous ether and converted into the picrate with an ethereal solution of picric acid. After crystallization from ethyl acetate, yellow crystals were obtained (1.2 g, 32.9%), M.p. 128—131 °C.

$C_{14}H_{21}N_4O_8$ (373.35). Calcd. C 45.03; H 5.67; N 15.01. Found C 45.18; H 5.28; N 14.49%.

The base liberated from the picrate (**5**) as given above was distilled at 333 Pa (B.p. 96—100 °C), the substance solidified at room temperature. M.p. 42—45 °C (0.45 g, 62.8%).

$C_8H_{17}NO$ (143.23). Calcd. C 67.09; H 11.96; N 9.78. Found C 67.23; H 12.08; N 9.82%.

(*b*) In a reaction of *cis*-2-amino-1-cyclohexanecarboxylic acid (**27**) (1.4 g, 0.01 mol) and ethylchloroformate (1.2 g, 0.011 mol), *cis*-2-ethyloxycarbonylamino-1-cyclohexanecarboxylic acid was obtained and the glassy, solidified oily product obtained was reduced with $LiAlH_4$ without further purification to yield compound **5**, this was converted into the picrate for purification purposes. After crystallization from ethyl acetate, yellow crystals were obtained (1.6 g, 42.8%). M.p. 129—131 °C.

Methyl-*cis*-2-*N*-methyl-*N*-benzyloxycarbonylamino-1-cyclohexanecarboxylate (32) prepared from *cis*-2-benzyloxycarbonylamino-1-cyclohexanecarboxylic acid (31)

cis-2-Benzyloxycarbonylamino-1-cyclohexanecarboxylic acid (**31**) (2.8 g, 0.01 mol) was dissolved in anhydrous dimethyl formamide (40 cm^3) under stirring, then methyl iodide (7.1 g, 0.05 mol) and silver oxide (11.1 g) were added, and the mixture was stirred for 8 hrs. The filtered solution was mixed with chloroform (160 cm^3) and washed with 5% aqueous potassium cyanide (3 × 50 cm^3) then with water (50 cm^3) and the organic phase separated was dried over Na_2SO_4. After filtering, the solvent was distilled at the pressure produced by the aspirator pump and the residue was distilled at 266 Pa. B.p. 180—185 °C, a thick oil (2.80 g, 91.6%).

$C_{17}H_{23}NO_4$ (305.37). Calcd. C 66.86; H 7.59; N 4.59. Found C 67.10; H 7.80; N 4.80%.

Preparation of methyl-(*cis*-2-methylamino-1-cyclohexanecarboxylate)-hydrobromide (33) from 32 by removal of the benzyloxycarbonyl group with hydrogen bromide in glacial acetic acid

Compound **32** (3.1 g, 0.01 mol) was allowed to stand with 33% hydrogen bromide in glacial acetic acid (15 cm^3) for 1 hr, then poured onto anhydrous ether (500 cm^3). The product separated was rubbed, when slightly yellow crystals were obtained; these were repeatedly washed with ether, then crystallized from a mixture of ethanol and ether (2.3 g, 91.2%). M.p. 169—172 °C.

$C_9H_{18}BrNO_2$ (252.16). Calcd. C 42.86; H 7.19; N 5.55. Found C 42.50; H 7.49; N 5.87%.

Base **34** liberated from **33** with 5% aqueous potassium carbonate was extracted with ether and dried over sodium sulfate. The solvent was distilled, the residue was distilled at 3730 Pa, b.p. 102—105 °C.

$C_9H_{17}NO_2$ (171.24). Calcd. C 63.13; H 10.00; N 8.18. Found C 62.83; H 10.30; N 8.18%.

cis-2-Hydroxymethyl-1-methylaminocyclohexane

The reduction of **34** with $LiAlH_4$ was effected in anhydrous ether, thus *cis*-2-hydroxymethyl-1-methylaminocyclohexane (5) was obtained in 63.2% yield. When crystallized from *n*-hexane, the m.p. was 42—45 °C.

trans-2-Ethoxycarbonylamino-1-cyclohexanecarboxylic acid (35a) prepared from *trans*-2-amino-1-cyclohexanecarboxylic acid

trans-2-Amino-1-cyclohexanecarboxylic acid was acylated with ethyl chloroformate in sodium hydroxide solution. After crystallization from ethyl acetate, the m.p. was 160—163 °C (yield: 76.2%).

$C_{10}H_{17}NO_4$ (215.25). Calcd. C 55.80; H 7.96; N 6.51. Found C 55.93; H 8.20; N 6.58%.

Methyl-(*cis*-2-ethoxycarbonylamino-1-cyclohexanecarboxylate) was obtained from **35a** esterified with diazomethane. After crystallization from hexane, m.p. 55—58 °C (61.2%).

$C_{11}H_{19}NO_4$ (229.28). Calcd. C 57.62; H 8.35; N 6.11. Found C 57.40; H 8.26; N 6.34%.

Ethyl-*trans*-2-ethoxycarbonylamino-1-cyclohexanecarboxylate (35c)

Ethyl-(*trans*-2-amino-1-cyclohexanecarboxylate) hydrochloride was acetylated with ethyl chloroformate in aqueous solution in the presence of calculated amounts of sodium hydrogen carbonate. Compound **35c** precipitated from the aqueous solution and crystallized rom cyclohexane. M.p. 57—59 °C, yield 85.7%.

$C_{12}H_{21}NO_4$ (243.31). Calcd. C 59.24; H 8.70; N 5.76. Found C 59.43; H 9.07; N 5.62%.

trans-2-Benzylamino-1-hydroxymethylcyclohexane (8)

It was prepared from *trans*-2-benzoylamino-1-cyclohexanecarboxylic acid (**22**) by reduction with $LiAlH_4$ (36.2%). After crystallization from petroleum ether, m.p. 80—83 °C.

$C_{14}H_{21}NO$ (219.33). Calcd. C 76.66; H 9.65; N 6.39. Found C 77.01; H 9.51; N 6.17%

General procedure for the preparation of 1,3-oxazines with *cis*- and *trans*-condensed skeletons

0.01 mol 1,3-Aminoalcohol (**1—8**) is dissolved in anhydrous benzene (or anhydrous chlorobenzene) (70 cm^3) and refluxed with *p*-nitrobenzaldehyde (0.11 mol) for 3—20 hrs using a water separator. After completion of the reaction, monitored by TLC, the solvent is distilled

Table I

Physical and analytical data for compounds **9—16**

Compound	Formula Molecular weight	M.p. °C	Analysis, % Calculated Found		
			C	H	N
9	$C_{15}H_{20}N_2O_3$ (276.33)	94— 96	65.19 64.99	7.30 7.10	10.14 9.95
10	$C_{15}H_{20}N_2O_3$ (276.33)	78— 81	65.19 64.89	7.30 7.41	10.14 9.79
11	$C_{20}H_{24}N_2O_3$ (340.41)	102—105	70.56 70.90	7.11 7.23	8.23 8.33
12	$C_{20}H_{24}N_2O_3$ (340.41)	113—115	70.56 70.96	7.11 6.95	8.23 8.42
13	$C_{15}H_{20}N_2O_3$ (276.33)	120—121	65.19 65.53	7.30 7.54	10.14 10.44
14	$C_{15}H_{20}N_2O_3$ (276.33)	102—103	65.19 65.50	7.30 7.33	10.14 10.58
15	$C_{20}H_{24}N_2O_3$ (340.41)	135—137	70.56 70.98	7.11 7.02	8.23 8.02
16	$C_{20}H_{24}N_2O_3$ (340.41)	132—135	70.56 70.34	7.11 7.13	8.23 8.31

and the residue subjected to chromatographic separation on an aluminium oxide column with hexane and petroleum ether. Melting point and analysis data of compounds **9—16** are summarized in Table I.

*

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REFERENCES

[1] Part XXI: FÜLÖP, F., BERNÁTH, G., HERMECZ, I., MÉSZÁROS, Z.: Acta Phys. et Chem. Szeged, **25,** 79 (1979)
[2] SOHÁR, P., BERNÁTH, G.: Organic Magnetic Resonance, **5,** 113 (1973)
[3] BERNÁTH, G., GÖNDÖS, GY., KOVÁCS, K., SOHÁR, P.: Tetrahedron, **29,** 981 (1973)
[4] BERNÁTH, G., FÜLÖP, F., GERA, L., HACKLER, L., KÁLMÁN, A., ARGAY, GY., SOHÁR. P.: Tetrahedron, **35,** 799 (1979)
[5] BERNÁTH, G., LÁNG, K. L., KOVÁCS, K., RADICS, L.: Acta Chim. Acad. Sci. Hung., **73,** 81 (1972)
[6] BERNÁTH, G., GÖNDÖS, GY., GERA, L., TÖRÖK, M., KOVÁCS, K., SOHÁR, P.: Acta Phys. et Chem. Szeged, **19,** 147 (1973)
[7] RIBÁR, B., LÁZÁR, D., KÁLMÁN, A., SASVÁRI, K., BERNÁTH, G., HACKLER, L.: Cryst. Struct. Comm., **6,** 671 (1977)
[8] DREFAHL, G., HÖRHOLD, H.: Chem. Ber., **94,** 1657 (1961)
[9] GERA, L., GÖNDÖS, GY., BERNÁTH, G.: Acta Chim. Acad. Sci. Hung., **99,** 175 (1978)
[10] BERNÁTH, G., GERA, L., GÖNDÖS, GY., PÁNOVICS, I., ECSERY, Z.: Acta Chim. Acad. Sci. Hung., **89,** 61 (1976)
[11] LEBEL, N. A., POST, M. E., WHANG, J. J.: J. Am. Chem. Soc., **86,** 3759 (1964)
[12] BERNÁTH, G., KOVÁCS, K., LÁNG, K. L.: Acta Chim. Acad. Sci. Hung., **64,** 183 (1970)
[13] OLSEN, R. K.: J. Org. Chem., **35,** 1912 (1970)
[14] SOHÁR, P., GERA, L., BERNÁTH, G.: Organic Magnetic Resonance, **14,** 204 (1980)
[15] GÖNDÖS, GY., GERA, L., TÓTH, G., DOMBI, GY., NAGY, K., BERNÁTH, G.: Lecture presented at the Meeting of the Hungarian Chemical Society, Debrecen, Hungary, August 23—26, 1977; Abstracts p. 72
[16] JONES, R. A. Y., KATRITZKY, A. R., TREPANIER, D. L.: J. Chem. Soc. (B), **1971,** 1300
[17] GÜRNE, D., URBANSKI, T., WITANOWSKI, M., KARNIEWSKA, B., STEFANIAK, L.: Tetrahedron, **20,** 1173 (1964)
[18] CROWLEY, P. J., ROBINSON, M. J. T., WARD, M. G.: J.C.S. Chem. Comm., **1974,** 825
[19] RIDELL, F. G., LEHN, M. J.: J. Chem. Soc. (B), **1968,** 1224
[20] NELSEN, S. F., BUSCHEK, J. M.: J. Am. Chem. Soc., **96,** 6987 (1974)
[21] NELSEN, S. F., WEISMAN, G. R.: J. Am. Chem. Soc., **96,** 7111 (1974)
[22] ELIEL, E. E., ALLINGER, N. L., ANGYAL, S. J., MORRISON, G. A.: Conformational Analysis, Interscience Publishers, New York, London, Sydney 1965
[23] COOKE, G. A., FODOR, G.: Can. J. Chem., **46,** 1105 (1968)
[24] MIČOVIĆ, V. M., MIHAILOVIĆ, M. L.: J. Org. Chem., **18,** 1190 (1953)

Lajos GERA H-6720 Szeged, Dóm tér 8.
Gábor BERNÁTH H-6720 Szeged, Eötvös u. 6.
Pál SOHÁR H-1475 Budapest, P.O.B. 100

RECENSIONES

W. W. ROBERTS and C. S. MCKEE: *Chemistry of the Metal-Gas Interface*

Clarendon Press, Oxford, 1978 (594 pages)

One of the central endeavours of theoretical chemistry has been, in the last decades, to establish a link between chemical and physical properties, among others to find relationships between structure and reactivity. This assumes a knowledge of the structures of reacting species (ions, atoms, molecules) and of the relationships between these structures and chemical interaction. Like all research efforts, this work is also subject to several hypotheses which become really confirmed only after comparison with experimental data. In the case of homogeneous reactions, the establishment of the relationships between structure and reactivity is essentially a matter of molecular structure studies and quantum chemistry. In the case of heterogeneous processes, such as metal catalysis, one of the reactants is a metal surface, and thus its electronic structure must also be known, for which special experimental methods should be elaborated and applied. Experimental techniques of such nature have rapidly been developed in the last decade. Although the main target — the establishment of a link between reactivity and structure — is quite far, several new results were obtained in the last years.

The book of M.W. ROBERTS and C. S. MCKEE reviews the principal physical processes and experimental techniques that pertain to the electronic structures of metal surfaces and arise, in part, from the research of the last decades. It also attempts to show how far these results contribute to the elucidation of relationships between structure and reactivity for relatively simple catalytic systems.

The main concern of the monograph is to give a review, without claiming to be a handbook for specialists dealing with certain experimental methods. It strives to explain basic concepts, and also gives the nomenclature used in the literature of this topic. At the end of each chapter a wealth of references is given to guide those who wish to acquire deeper insight into the special field discussed in the chapter. The volume is completed with very useful Author and Subject Indexes.

The reviews of various experimental methods clearly show the type of information obtainable by them. It would have been helpful to give the "price" of these pieces of information as well, *i.e.* the costs, difficulties and complexity of the methods in question, as a hint to catalysis experts wishing to support kinetic results by physical properties discussed in this book. For similar reasons, it would have been advantageous to relate the experimental conditions of these physical methods to those of kinetic measurements, which may be quite different in certain cases, requiring mutual extrapolation in the comparison of results, occasionally subjected to large uncertainties. This way of treatment would have truly compensated the overoptimistic or overpessimistic views concerning the basic idea.

The volume contains 13 chapters, guiding the reader didactically from the basic concepts of structure and interactions to the specific problems of catalysis.

Chapter *1* (49 pages) gives a brief account on the physical and chemical concepts discussed later in detail, such as the electronic and crystal structures of solids, the differences between surface and bulk phases, the concept of active sites, the adsorption as the simplest interaction, and basic concepts of kinetics.

Chapter *2* (44 pages), entitled Crystallography of Metals is concerned with the fundamentals of crystal structure, including the various crystallographic systems, the surface crystal structures of metals, dislocations, diffusion in the solid phase and on the surface.

Chapter *3* (76 pages) deals with the determination of surface crystal structures, discussing the physical background of LEED. The methods of interpretation are illustrated by several examples.

Chapter *4* (46 pages) discusses the fundamentals of electron spectroscopic methods in a similar manner. The principles of Auger (AES) and other methods (APS, INS) are illustrated by numerous examples.

The review of experimental methods is concluded by Chapter *5* (25 pages), in which a brief account is given on the application of infrared and Raman spectroscopy in the structure elucidation of adsorbed molecules.

Chapter *6* (47 pages) deals with the experimental aspects of surface kinetics, touching the problems of the direct determination, on the molecular level, of the collision number, accomodation coefficient, adsorption and desorption rate, combined with the kinetic and statistical interpretation of these parameters.

Chapter *7* (26 pages) is concerned with the problem of physical adsorption, discussing primarily the interactions occurring in the adsorption of noble gases on various metals.

Chapter *8* (42 pages) discusses the models of adsorption and desorption processes, including the detectability of the interactions between surface and adsorbed molecules and among the adsorbed molecules themselves, and their role in the derivation of kinetic equations.

Chapters *9*—*11* show the present state of art by reviewing the literature of some sumple catalytic systems, and the application of the data obtained by various physical methods to the interpretation of kinetic phenomena.

The investigations discussed in previous chapters and the interpretation of results obtained on the chemisorption of CO (Chapter *9*, 36 pages), H_2 and N_2 (Chapter *10*, 58 pages) and O_2 (Chapter *11*, 45 pages) on various metals (W, Pt, Ni, Cu) are reviewed exhaustively in these chapters, also mentioning the progress expected.

Chapter *12* (45 pages) deals with the adsorption of metals on metals. This topic has recently become very important in the interpretation of the catalytic effects of bimetallic catalysts and impurities. Therefore, the discussion of these problems is a proper choice even if both the nature and amount of experimental data presented here is much poorer than with the systems discussed in the preceding three chapters.

Chapters *13* (17 pages), to arouse interest, attempts to answer some actual and much debated problems of heterogeneous catalysis on the basis of the treatment presented in the book.

The Appendix of 7 pages summarizes the fundamentals of quantum mechanics.

The volume is very helpful for all of those dealing with heterogeneous catalysis, either from kinetic or from preparative aspects.

F. NAGY

Erwin RIEDER: *Allgemeine und anorganische Chemie*

Ein Lehrbuch für Studenten mit Nebenfach Chemie

Walter de Gruyter, Berlin—New York, 1979, 346 Seiten, 214 Abbildungen

Das Buch wurde für Studenten geschrieben, die sich im Laufe ihrer technischen Studie mit der Chemie nur als Hilfswissenschaft befassen. Demgemäß ist der die Grundlagen umfassende Teil Allgemeine Chemie etwa doppelt so umfangreich wie der Teil Anorganische Chemie. Der Verfasser hat sich bemüht auch in diesem Teil neben den in technischer Hinsicht wichtigen Kenntnissen, oder besser gesagt in Verbindung mit diesen die allgemeinen Beziehungen hervorzuheben und das chemische Denken der Studierenden zu fördern. Das Buch ist in fünf größere Kapitel unterteilt: *1.* Atombau; *2.* Die chemische Bindung; *3.* Die chemische Reaktion; *4.* Nichtmetalle; *5.* Metalle.

Die Behandlung der Thematik des Kapitel 1 basiert auf dem Stand unserer gegenwärtigen Kenntnisse aber auch die geschichtliche Entwicklung wird aufgezeigt; so wird auch das Daltonsche und Bohrsche Atommodell erwähnt. Der Verfasser hat jedoch bei der Behandlung der Unbestimmtheitsrelationen dafür Sorge getragen, daß die Grenzen des Bohrschen Modells deutlich werden. Das Unterkapitel über das Wellenmodell dient nur zur Vertiefung der Kenntnisse, ist für das Verständnis des weiteren Stoffes nicht notwendig. Zu Tabelle 1.6 dieses Unterkapitels soll jedoch bemerkt werden, daß die magnetische Quantenzahl $+1$ nicht dem Orbital $2p_x$, die magnetische Quantenzahl -1 nicht dem Orbital $2p_y$ zugeordnet werden kann, wie aus dieser Tabelle hervorzugehen scheint. Die weiteren Teile des Kapitels befassen sich mit dem Aufbau der Elektronenhüllen mehrelektronischer Atome, mit dem periodischen System und mit bestimmten Atomeigenschaften, die in Abhängigkeit von der Ordnungszahl charakteristische Änderungen aufweisen, wie z. B. die Ionisationsenergie und die Elektronenaffinität. Bei der Behandlung des Aufbaus und der Eigenschaften des Atomkerns werden u.a. die radioaktive Altersbestimmung, die Kernspaltung und die Kernfusion sowie die Häufigkeit der Elemente erörtert.

Das 2 Kapitel über die chemische Bindung beginnt mit der Erläuterung der Ionenbindung und vieler Kristalle mit Ionengittern. Darauf folgt die Behandlung der Atombindung, die mit der Lewisschen Theorie eingeleitet und mit der Elektronegativität abgeschlossen wird. Die Hybridisation ist recht ausführlich dargestellt, jedoch wird darauf aufmerksam gemacht, daß der Hybrid-Zustand kein realer Zustand des freien Atoms ist.

Als ergänzendes Unterkapitel behandelt das Buch auch die Grundlagen der Molekülorbital-Theorie, diese wird jedoch weder dem einfachen, durch die Lewissche Strukturformel und die Hybridisierung charakterisierten Bild des Moleküls gegenübergestellt, noch damit in Einklang gebracht. Daraus ergeben sich für den Leser Zweifel an der Richtigkeit der Theorien. Auch wäre es richtig gewesen, sich für eine der Elektronegativitätsskalen zu entscheiden, zumindest was deren Anwendung betrifft. Bei Betrachtung der Elektronegativitäts-Angaben in Abb. 2.25 und in der als Anhang angefügten Tabelle des periodischen Systems stellt sich heraus, daß in ersterer die Paulingschen Werte, in letzterer die Allred-Rochowschen Werte angegeben sind.

Im Kapitel über chemische Reaktionen werden zunächst die Begriffe von Mol und Konzentration sowie die Eigenschaften des idealen Gases behandelt. Darauf folgen Phasendiagramme und Phasenumwandlungen. Das Verstehen der Gesetze der chemischen Gleichgewichte wird durch zahlreiche wohlgelungene Abbildungen erleichtert. Dies ist besonders wichtig, da der Umfang des Buches eine gründliche Erläuterung der thermodynamischen Grundlagen keineswegs zuläßt. Darauf folgt die Behandlung der Begriffe und Zusammenhänge der Reaktionsgeschwindigkeit sowie die Anwendung der allgemeinen Gesetze der Gleichgewichte auf wässerige Lösungen. Der gegenwärtigen Auffassung entsprechend definiert der Verfasser die Begriffe von Säure und Base auf zweierlei Art und vertritt die Meinung, daß die Brönstedsche Theorie eine Erweiterung der Arrheniusschen Theorie sei.

Die beiden Kapitel über anorganische Chemie sind das Ergebnis einer zielbewußten Auswahl. Die Beschreibung der Eigenschaften der wichtigsten Elemente und Verbindungen ist auf glückliche Weise durch die Struktur klarmachende Abbildungen und durch praktische Angaben ergänzt, wie z. B. die Entwicklung der Weltproduktion der wichtigeren Metalle in den letzten Jahren. Hinsichtlich der metallischen Bindung und den intermetallischen Systemen bietet das Buch mehr und moderneres Material als die Lehrbücher gleicher Zielsetzung und ähnlichen Umfangs.

Der Verfasser hat eine eigentlich sehr schwere Aufgabe erfolgreich gelöst. Das verhältnismäßig wenig umfangreiche Buch scheint geeignet, die verschiedenartigsten Anforderungen zu befriedigen. Objektiv beurteilt kann es zur Ausbildung von Maschineningenieuren ebenso gut wie der von Wirtschaftsingenieuren und Umwelttechniker dienen.

Ein besonders hervorzuhebender Vorteil des Buches ist die klare und knappe Fassung, die nicht allein den hervorragenden Sinn für Stilistik, sondern auch die große pädagogische Erfahrung des Verfassers bezeugt. Ein weiterer Verdienst des Buches ist die konsequente Anwendung der SI-Einheiten.

Z. BOKSAY

Sludge Disposal by Landspreading Techniques Pollution Technology Review, No. 58

Edited by S. TORREY, Noyes Data Corporation, Park Ridge, New Jersey, U.S.A., 1979

The problem of sludge disposal is increasing in importance in parallel with the growth of human settlements, agricultural production, *etc.* Not only the highly industrialized and developed countries are confronted with this problem, but some developing countries, too, where the proper utilization of waste water is related to a number of sanitary, agronomic and other questions.

The book edited by S. TORREY and published by the Noyes Data Corporation, based fundamentally on the experience and new achievements in the United States, contains 372 pages, consists of fifteen parts and a list of sources utilized.

The introduction of the book is correct, emphasizing that in the course of sludge application numerous factors, such as pathogenic, hygienic, economic and nuisance have to be considered. Eventually municipal and other sludges often contain toxic or potentially toxic compounds (for instance heavy metal compounds) with either directly or potentially harmful effects through accumulations in the soils.

Apart from the hygienic and related factors, the disposal of sludge is associated with different other problems, which are broadly explained and discussed in the book.

When compiling a comprehensive book like this, it is inevitable to avoid publishing diverse, sometimes controversial opinions of different authors. In the Foreword the editor of the book calls attention to this fact, particularly when future potentional questions or monetary values are concerned.

In Part *1* a general overview of sludge disposal by landspreading is given. This part includes federal regulations in the United States concerning sludge, the characteristics of different sludge types as well as selection of the site and land, where the sludge could be spread. The reader finds here the different application and handling systems of sludge, furthermore, the public health and nuisance considerations. In the last section of this part, the control of odor, insect problems, runoff, pathogens, parasites and other problems are discussed. A chapter on monitoring and a summary close this part with indication of the most important references.

Part *2* deals with the problems of sludge characteristics and pretreatment. This part consists of only eight pages, however, succeeds to give a good overall picture of the problem.

Part *3* of the book gives an overview of site selection and land availability problems related to sludge disposal. Legal, economic, pedologic and other considerations, for instance climate, plant cover are included in the sixth chapter of this part, which is followed also by a list of references.

Part *4* describes the transportation and application of sludge, while in Part *5* the sludge-soil-plant interaction is discussed. This part is most valuable for soil scientists, agronomists and specialists of related subjects.

In Part *6* the reader meets with the problems of public health mostly caused by the pathogens in sludge. Certainly this part may arouse the interest of biologists and doctors.

Parts *7* and *8* deal with trace element sources and occurrences in municipal sludge as well as with the problems of further fate of trace element hazard from the point of view of agronomy and public health.

Monitoring is the subject of Part *9*, including the monitoring problems of sludge, soil, water and vegetation. The analytical problems and references are also comprised in this part.

Beginning with Part *10*, various aspects of the environmental effect of sludge application are described and discussed. In Part *10* the economics of landspreading, in Part *11*, sludge application in a northern hardwood forest, while in Part *12* the application of sludge for terrain stabilization in cold regions are the topics and subjects.

In Part *13* a very significant problem — the reclamation of anthracite coal refuse with sludge — is described as a practical method for appropriate sludge application. After introduction, a literature review describes the procedure of sludge application for reclamation of anthracite coal refuse as well as the results of the procedure including the effect in agricultural production.

In Part *14* a practical example, disposal of sludge by the city of Denver in a ten-year period is described and discussed. This part is one of the most valuable in the book, because it contains exact data and long-term experiences on efficient sludge disposal by a large and developed city.

In the final part of the book environmental assessment is discussed together with the methodology of site studies, program of sampling and descriptions of case study sites. The material in this part is taken from a report prepared by the office of solid waste.

The reader comes to the conclusion that in the technical literature there is hardly a a more up-to-date and comprehensive study on this subject. It will be very useful in the near future for a wide circle of specialists, including not only soil scientists, agronomists and industrial experts, but many of the representatives of other branches, who are engaged in public health, municipal, economic and other problems of modern sludge disposal.

I. SZABOLCS

INDEX

PHYSICAL AND INORGANIC CHEMISTRY

ORGANIC CHEMISTRY

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