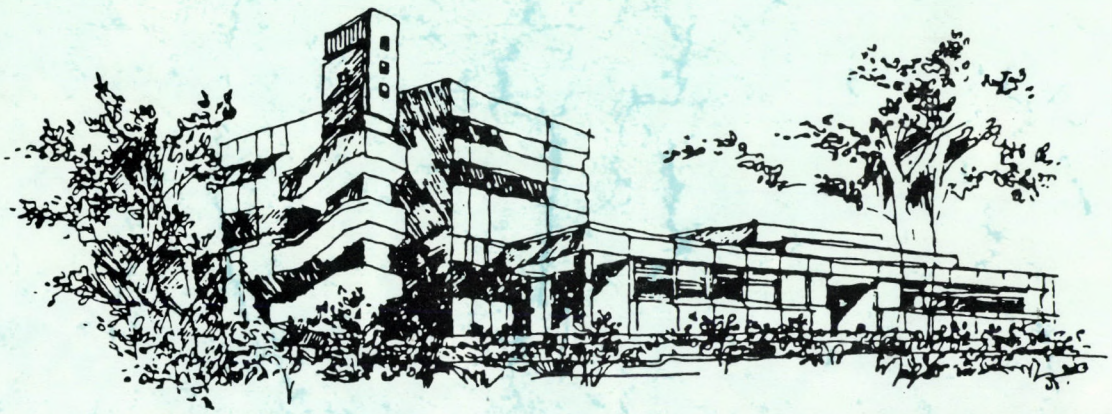
# ATOMKI
# ANNUAL REPORT
# 1995



INSTITUTE OF NUCLEAR RESEARCH
OF THE HUNGARIAN ACADEMY OF SCIENCES
DEBRECEN, HUNGARY

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# Preface

Despite tightening financial circumstances, the quest for revealing the "nature of Nature" was continued in the Institute of Nuclear Research in general physics, in particle, nuclear and atomic physics, and in a braod range of associated fields of science: from radioisotope production for medical purposes to the investigation of air pollution and natural water resources. This Annual Report gives a one-year account of this continuing endeavor.

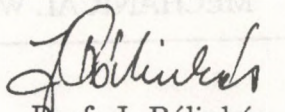
There has been no dramatic change in our activity during the last year. This relative calmness furnished a good opportunity to conduct devoted research, which is reflected in the great number of papers and contributions published in 1995. The details can be found on the subsequent pages and speak for themselves. The significance of teaching at both undergraduate and graduate level has further increased, and our more pronounced presence in CERN is bringing new results. In our ECR ion source we got the plasma at the end of the year and will get - hopefully highly charged - ions in 1996.

The calmness is, however, not exempt from foreboding. This report appears slightly later than in previous years, because very recently we have had to submit detailed reports for a thorough evaluation procedure. This evaluation of the research institutes of the Hungarian Academy of Sciences is aimed at measuring the scientific merits of their activity. This will help the Academy to set the budgets of its institutes and will help the government to set the budget of the Academy. The immediate positive effect of this "chore" is that our plans benefit from having been forced to have a "birds-eye-view" on our own activity, results and working conditions.

Although, there might be some uncertainty in the financial future of the research and educational institutions in Hungary, the impact of which on our Institute cannot be predicted yet, the dedication to pursuing high quality research, to solving unfathomable riddles of physics, and to a better understanding of the laws of Nature is stronger than ever.

More information on our Institute is available on the Internet at the address of **http://www.atomki.hu** .

April 15, 1996

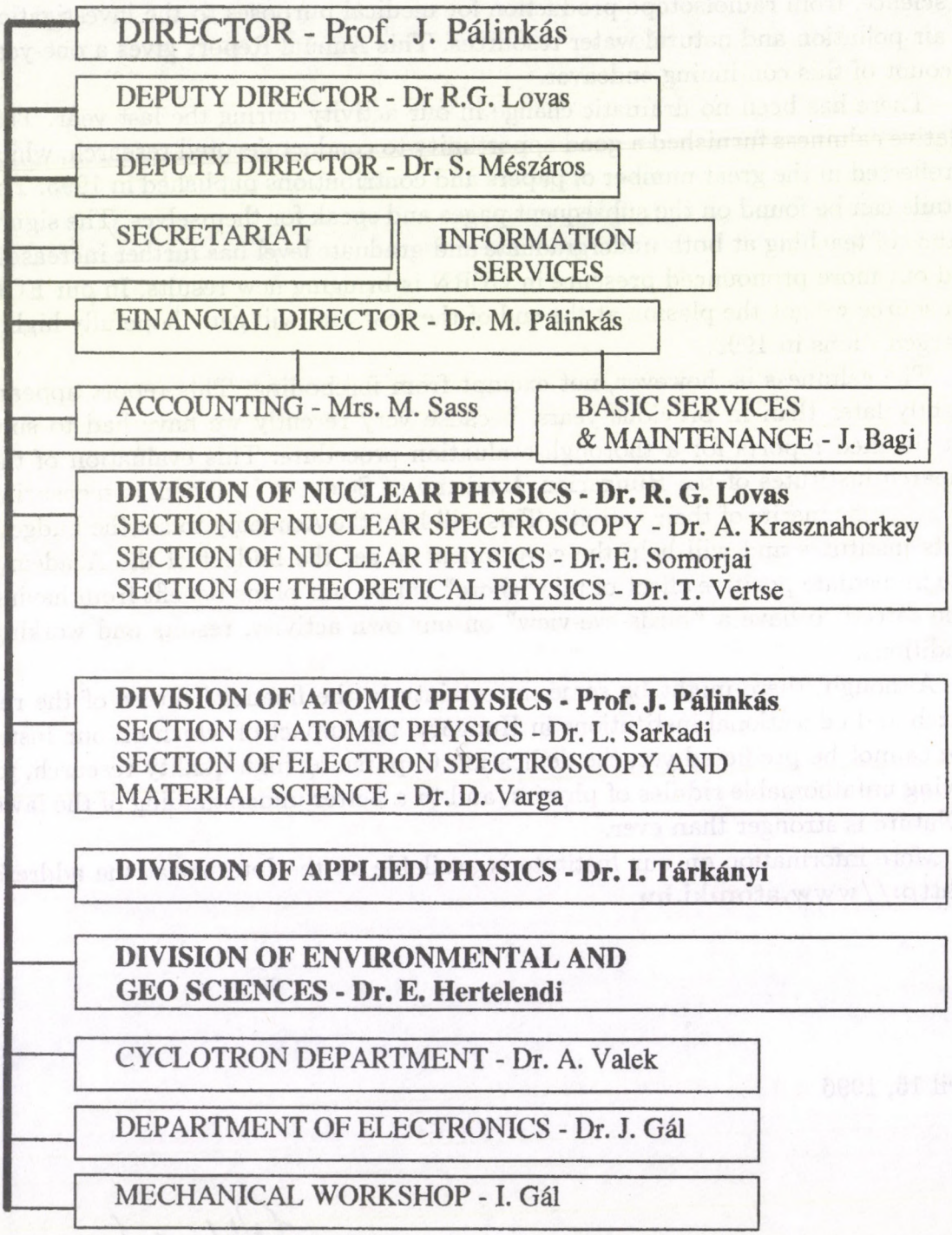


Prof. J. Pálinkás
director

The organisation structure of the

# Institute of Nuclear Research

of the Hungarian Academy of Sciences



# CONTENTS

## REPORTS:



## PUBLICATIONS AND SEMINARS:

# GENERAL PHYSICS

# The ground state of the $\pm J$ spin glass

K. F. Pál

The Edwards-Anderson $\pm J$ Ising spin glass is one of the simplest spin glass models with the more realistic short-range interactions. It is defined by the hamiltonian $H_J = -\sum_{ij} J_{ij} S_i S_j$, where the spins occupy lattice sites, spin $i$ may take one of the two values $S_i = +1$ or $S_i = -1$, the sum goes over nearest neighbours, each of the exchange interactions $J_{ij}$ has the fixed value of either $+1$ or $-1$, chosen randomly, independently and with equal probability. Despite its apparent simplicity, the behaviour of this system is complex and still not well understood. For more than two dimensional lattices even the determination of the ground state energy is exceedingly difficult, it is one of the most challenging optimization problems.

We determined ground state energies of three-dimensional systems of linear size $L$ between 3 and 14 with periodic boundary condition using a hybrid of genetic algorithm and local optimization[1]. The algorithm we developed was fast and reliable enough to allow us to consider much larger samples (i.e. more different sets of $J_{ij}$) for each $L$ than considered by others in earlier papers and to get better statistics. The size of the sample $N_L$, the average ground state energy per spin $e_L$, and the standard deviation $\sigma_L^E$, the third and the fourth moment of the ground state energy distributions are shown in the following table for each $L$:

| $L$ | $N_L$ | $e_L$ | $\sigma_L^E$ | skew. | kurt. |
|---|---|---|---|---|---|
| 3 | 1500000 | -1.67171(9) | 3.1174 | 0.306 | 0.273 |
| 4 | 500000 | -1.73749(8) | 3.7656 | 0.385 | 0.306 |
| 5 | 100000 | -1.76090(12) | 4.7693 | 0.324 | 0.251 |
| 6 | 50000 | -1.77130(12) | 5.9542 | 0.255 | 0.147 |
| 7 | 15000 | -1.77706(17) | 7.1765 | 0.202 | 0.095 |
| 8 | 6000 | -1.77991(22) | 8.8417 | 0.175 | 0.052 |
| 10 | 2000 | -1.78339(27) | 11.9770 | 0.117 | 0.159 |
| 12 | 50 | -1.78407(121) | 14.7256 | 0.269 | 0.153 |
| 14 | 25 | -1.78653(176) | 24.0854 | 0.007 | 0.128 |

A linear dependence on 1/volume approximates the data for $e_L$ very accurately in the whole range. We determined the ground state energy per spin of the infinite system with extrapolation. Our value $e = -1.7863 \pm 0.0004$ agrees very well with most previous estimates, but it is much more accurate. The main source of uncertainty is that the functional form of the very small but significant deviation from the linear 1/volume dependence is unknown.

1. K. F. Pál, Physica A223 (1996) 283.

# Phase-equivalent complex potentials

D. Baye†, G. Lévai and J.-M. Sparenberg†

Complex potentials play an important role in the analysis of collision processes where absorption can take place. They form a standard tool in the description of cross sections in heavy-ion scattering, for example. It is a well-known fact, however, that the same set of data can be fitted using potentials with a real component of "deep" or "shallow" nature. The same kind of discrete ambiguity is well-understood for pure *real* potentials. The deep and (singular) shallow potentials have been interrelated by supersymmetry transformations, for example [1]. The key element in this procedure is removing unphysical bound states of the deep potential while maintaining the same phase shifts. The same techniques have also been used to generate arbitrary modification of the bound-state energy spectrum of real potentials [2].

We extended the above procedures to complex potentials [3]. This required the determination of bound states, which, however, are not clearly defined in the complex case. There are, for example, square-integrable solutions corresponding to energy eigenvalues having *positive* real part. These developments raised the question whether these solutions can be removed by adapting the same supersymmetry manipulations as in the pure real case.

In order to explore this less well-known area we decided to analyze exactly solvable complex potentials, where the critical behaviour of the solutions could be studied by fine-tuning the potential parameters. We analyzed the solutions of complex Pöschl–Teller potentials and also used them to check the accuracy of numerical methods adapted for the complex situation. The two methods (complementary in their basic principles and their applicability) turned out to be stable and highly accurate in the applications to the Pöschl-Teller potentials. We then applied these numerical techniques to the physical problem of the $^{16}O + \alpha$ system. The supersymmetry transformations had a characteristic effect on the potentials: their real part changed similarly to the potentials in the pure real case, while their imaginary component developed a larger range and picked up $l$-dependence.

The generalization of the supersymmetry techniques to complex potentials opened the way to interesting new areas, which we plan to explore in the future.

This work was supported by the OTKA (No. T14321 and W15140).

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1. D. Baye: Phys. Rev. Lett. **58** (1987) 2738.
2. D. Baye and J.-M. Sparenberg: Phys. Rev. Lett. **73** (1994) 2789, and references.
3. D. Baye, G. Lévai and J.-M. Sparenberg: Nucl. Phys. A, in press.

# On some solutions of the Dirac equation

G. Lévai and A. Del Sol Mesa†

We have made a systematic search for exact solutions of the Dirac equation assuming minimal and non-minimal coupling terms that depend only on the coordinate $r$ [1]:

$$(\alpha \cdot (\mathbf{p} - \mathrm{i}\beta v(r)\mathbf{r} - u(r)\mathbf{r}) + m\beta - E)\Psi = 0,$$

where we have chosen the $c = \hbar = 1$ units. Separating the radial, angular and spin variables by writing the "large" component into the $\Psi_1 = f(r)\frac{1}{r}|(l\frac{1}{2})jm_j\rangle$ form we obtained a second-order differential equation for the unknown $f(r)$ function.

The exact analytical solutions of this Schrödinger-like equation can be searched for by choosing particular forms of $f(r)$. The problem thus becomes similar to the solution of the radial Schrödinger equation, where one can, for example, proceed further by trying to transform this equation into the differential equation of some special function of mathematical physics. Considering a particular expression in terms of the confluent hypergeometric function we obtained a general solution of the Dirac equation including not only the Dirac oscillator [2] as a special case, but also two of its extensions containing more general coupling terms with minimal [3] and non-minimal [4] substitution. We have also shown that functional forms based on hypergeometric and Bessel functions in $f(r)$ lead to exactly solvable problems for the trivial case of angular momentum $l = 0$ only.

Further solvable problems can be generated for arbitrary values of $l$ by substituting various polynomial expressions in $f(r)$. Then a finite number of solutions can be obtained by applying techniques known from the theory of quasi-exactly solvable (QES) problems of non-relativistic quantum mechanics [5]. A non-trivial extension of the Dirac oscillator emerges, for example, solving a Schrödinger-like equation with sextic oscillator terms. In this case the solutions for $j = l + 1/2$ and $E = m$ can be given in a straightforward way for arbitrary value of the angular momentum. Other solutions of this problem may require more general form of $f(r)$.

This work was supported by the OTKA (No. F4303) and the U.S.–Hungarian Science and Technology Joint Fund (JF345/93).

† Instituto de Física, UNAM, Apdo. Postal 20-264, 01000 México D. F., México

1. G. Lévai and A. Del Sol Mesa: submitted to J. Phys. A.
2. M. Moshinsky and A. Szczepaniak: J. Phys. A **22** (1989) L817.
3. O. Castaños, A. Frank, R. López and L. F. Urrutia: Phys. Rev. D **43** (1991) 544.
4. F. Domínguez-Adame and M. A. González: Europhys. Lett. **13** (1990) 193.
5. A. K. Ushveridze: "Quasi-exactly solvable models in Quantum Mechanics", IOP Publishing, Bristol, U. K., 1994.

# NUCLEAR PHYSICS

# Thermonuclear reaction rates of $^{9}Be(p,\gamma)^{10}B$

D. Zahnow *, C. Angulo **, M. Junker *, C. Rolfs *,

S. Schmidt * W.H. Schulte * and E. Somorjai

*Institut für Physik mit Ionenstrahlen, Ruhr-Universität Bochum, Germany

**CSNSM, Orsay, France

An excitation function of the $^{9}Be(p,\gamma)^{10}B$ capture reaction has been measured over the proton energy range $E_p$=75 to 1800 keV using a $4\pi$ summing crystal. The data are dominated by three broad resonances including interference effects with the direct–capture process. Near temperatures of $T_9$=0.8 the reaction rates are lower by a factor of 4 compared to values given in a compilation [1], while at other temperatures the rates are similar [2].

The astrophysical consequences of the lower reaction rates near $T_9$=0.8 have to await the results of stellar–model calculations.

This work was supported by Deutsche Forschungsgemeinschaft (Ro429/21-3 and 21-4), German–Hungarian Collaboration (B123) and OTKA (T016638).

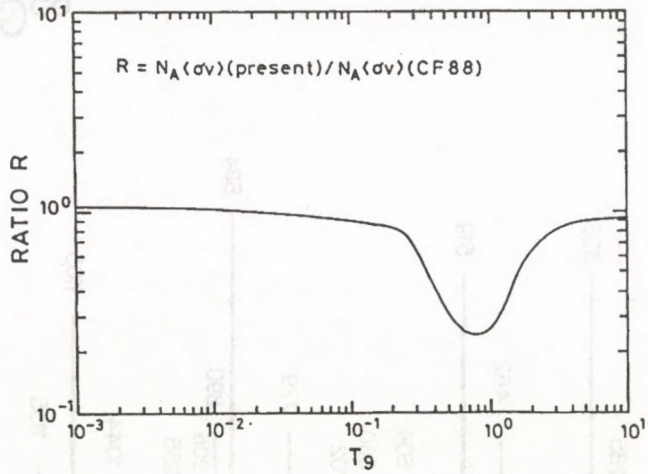


**Fig. 1.** Comparison of the $^{9}Be(p,\gamma)^{10}B$ reaction rates taken from the present data and those from the compilation [1] as a function of stellar temperature.

## References

1. G.R. Caughlan, W.A. Fowler, Atom. Data Nucl. Data Tables 40 (1988) 283.
2. D. Zahnow, C. Angulo, M. Junker, C. Rolfs, S. Schmidt, W.H. Schulte and E. Somorjai, Nucl.Phys. A589 (1995) 95.

# Study of structure of $^{65}$Ge nucleus

D. Sohler, Zs. Dombrádi and the NORDBALL collaboration

The neutron-deficient $^{65}$Ge nucleus was investigated via $^{12}$C($^{58}$Ni,1$\alpha$1n$\gamma$)$^{65}$Ge reaction. The experiment was performed at the Tandem Accelerator of the Niels Bohr Institute in Riso, Denmark. The emitted radiations following the decay of the compound nucleus $^{70}$Se were detected with the NORDBALL multi-detector array, which consisted of BGO shielded Ge detectors, a $4\pi$ charged-particle Si detector system and a $1\pi$ neutron-detector assembly to select different reaction channels [1,2]. The transitions belonging to the studied nucleus were identified. The cleaned spectrum of $^{65}$Ge is shown in Fig. 1.

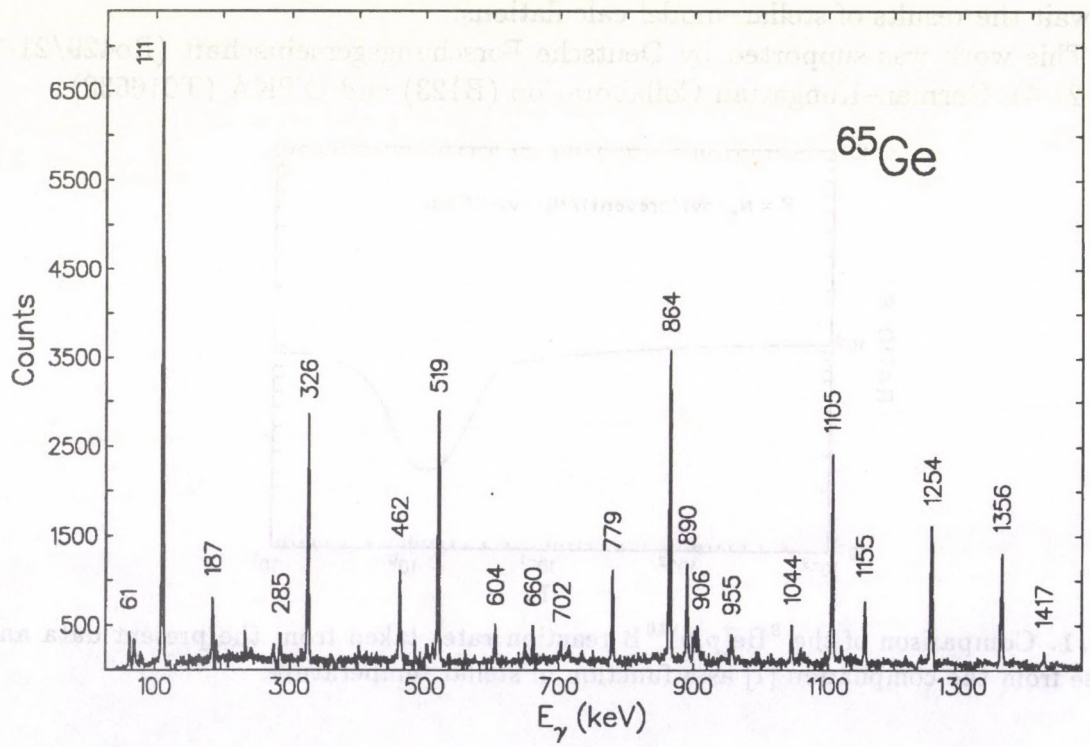


**Fig. 1.** The spectrum of $^{65}$Ge after subtracting contaminating transitions

[1] B. Herskind, Nucl. Phys. **A447** (1985) 395c.

[2] G. Sletten, Proc. Int. Seminar of The Frontier of Nuclear Spectroscopy, Kyoto 1992., Wolrd Scientific 1993.

# Spectroscopy of $^{67}$Ge nucleus

D. Sohler, Zs. Dombrádi and the NORDBALL collaboration

The $^{67}$Ge nucleus was investigated in heavy-ion reaction. A beam of $^{58}$Ni obtained from the tandem accelerator facilities of the Niels Bohr Institute in Denmark was used to bombard $^{12}$C target. The (2p1n) reaction channel was leading to the studied nucleus. The selection of the reaction channel was based on a technique of detection of $\gamma$ rays in coincidence with evaporated charged particles and neutrons observed using the NORDBALL detector array. The stronger transitions assigned to $^{67}$Ge can be seen in Fig. 1 in the spectrum obtained after subtracting contaminating transitions.

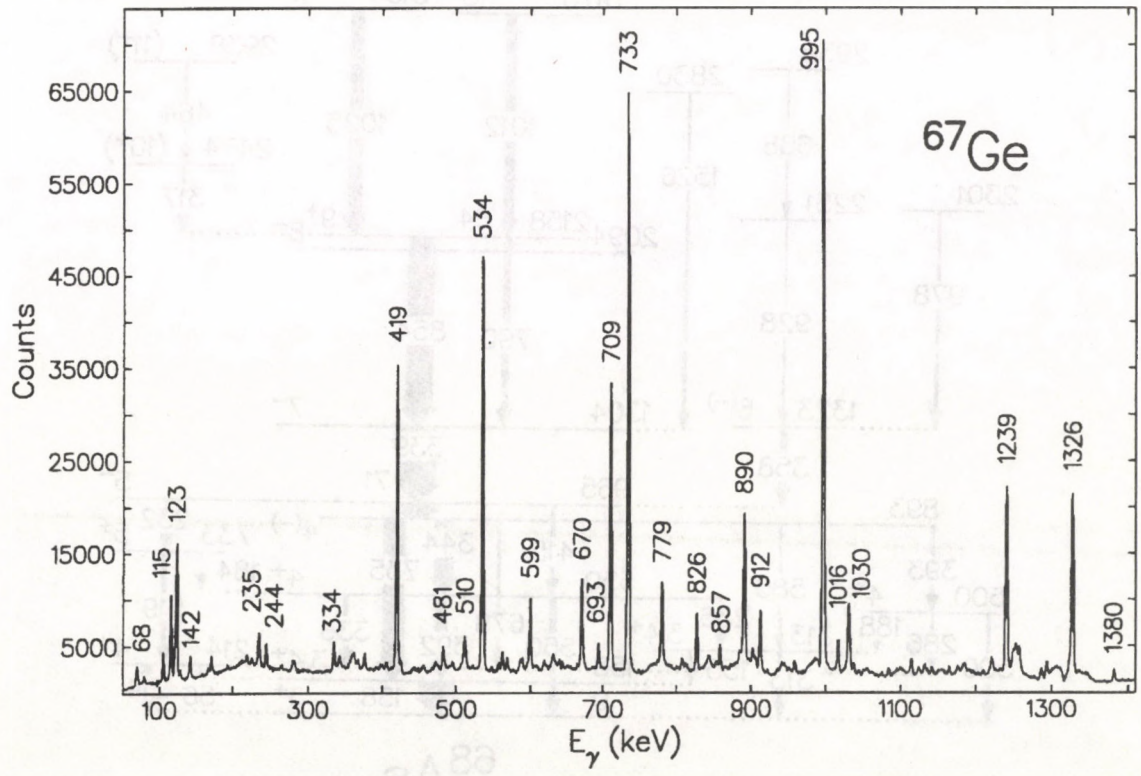


**Fig. 1.** The cleaned spectrum of $^{67}$Ge

# Structure of $^{68}$As nucleus

D. Sohler, Zs. Dombrádi and the NORDBALL collaboration

The structure of the odd-odd $^{68}$As nucleus which is lying far from the stability line was studied through $^{12}$C($^{58}$Ni,1p1n$\gamma$)$^{68}$As reaction with the NORDBALL detector array at the Tandem Accelerator of the Niels Bohr Institute in Risø, Denmark. The energies and the intensities of the transitions assigned to $^{68}$As were determined. The level scheme was built on the basis of the $\gamma\gamma$−coincidence relations. In order to obtaine the spin and parity values of the excited states the angular correlation ratios of the stronger transitions were analysed. The proposed level scheme of $^{68}$As is shown in Fig. 1. up to 3.2 MeV excitation energy.

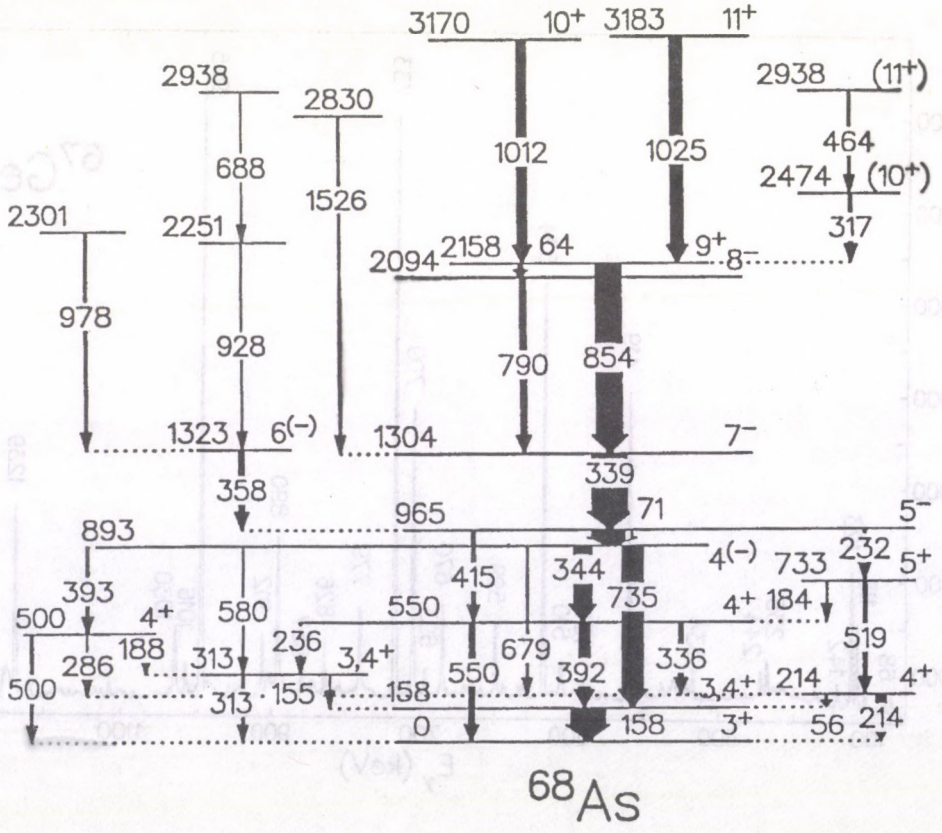


Fig. 1. The proposed level scheme of the $^{68}$As up to 3.2 MeV.

# Study of $^{69}Ga(\alpha,n\gamma)^{72}As$ reaction

D. Sohler, A. Algora, Zs. Podolyák and J. Gulyás

As a continuation of the study of the $^{72}As$ nucleus [1] $\gamma-$, internal conversion electron spectra (Fig. 1) and $\gamma\gamma-$coincidence matrix were measured at 14.2 MeV bombarding $\alpha$ energy. In the experiments Ge(HP) $\gamma-$ and superconducting magnetic lens plus Si(Li) electron spectrometers were used. The purpose of present investigation is to search for the levels with $J \geq 5$ spin value of the $^{72}As$ multiplets whose lower spin parts have already been observed from (p,n$\gamma$) reaction [1].

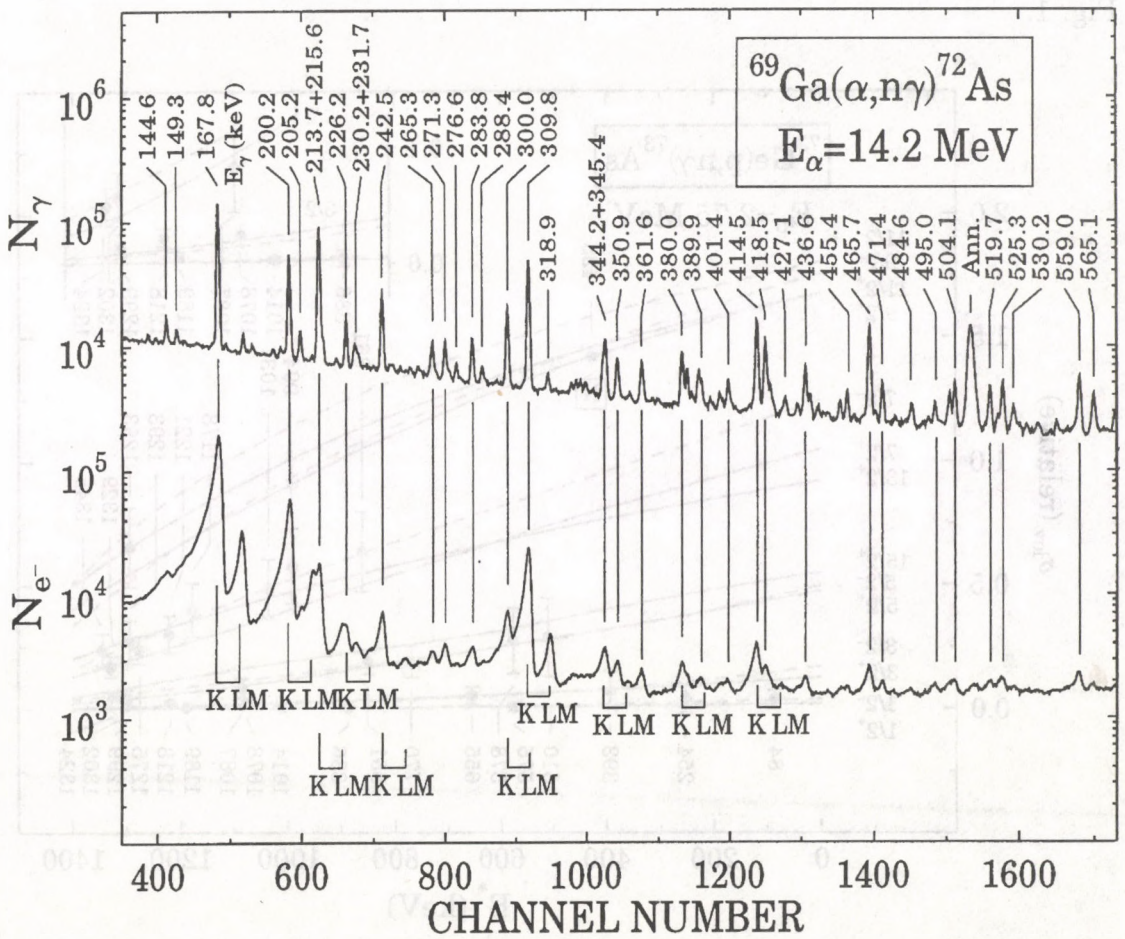


**Fig. 1.** Typical $\gamma-$ray and internal conversion electron spectra of the $^{69}Ga(\alpha,n\gamma)^{73}As$ reaction.

[1] D. Sohler, A. Algora, T. Fényes, J. Gulyás, S. Brant and V. Paar, Nucl Phys. A, submitted.

# Spectroscopy of the $^{73}$As nucleus

D. Sohler, Zs. Podolyák, J. Gulyás, T. Fényes, A. Algora and Zs. Dombrádi

As a continuation of our study of the $^{73}$As nucleus [1] the spin values of the levels have been determined from the Hauser–Feshbach analysis. The relative cross section measurements of the (p,n) reaction have been carried out at the proton beam of the 5 MeV Van de Graaff accelerator at 1.92, 2.27, 2.45 and 2.75 MeV bombarding energies. The results of the Hauser–Feshbach analysis are shown in Fig. 1.

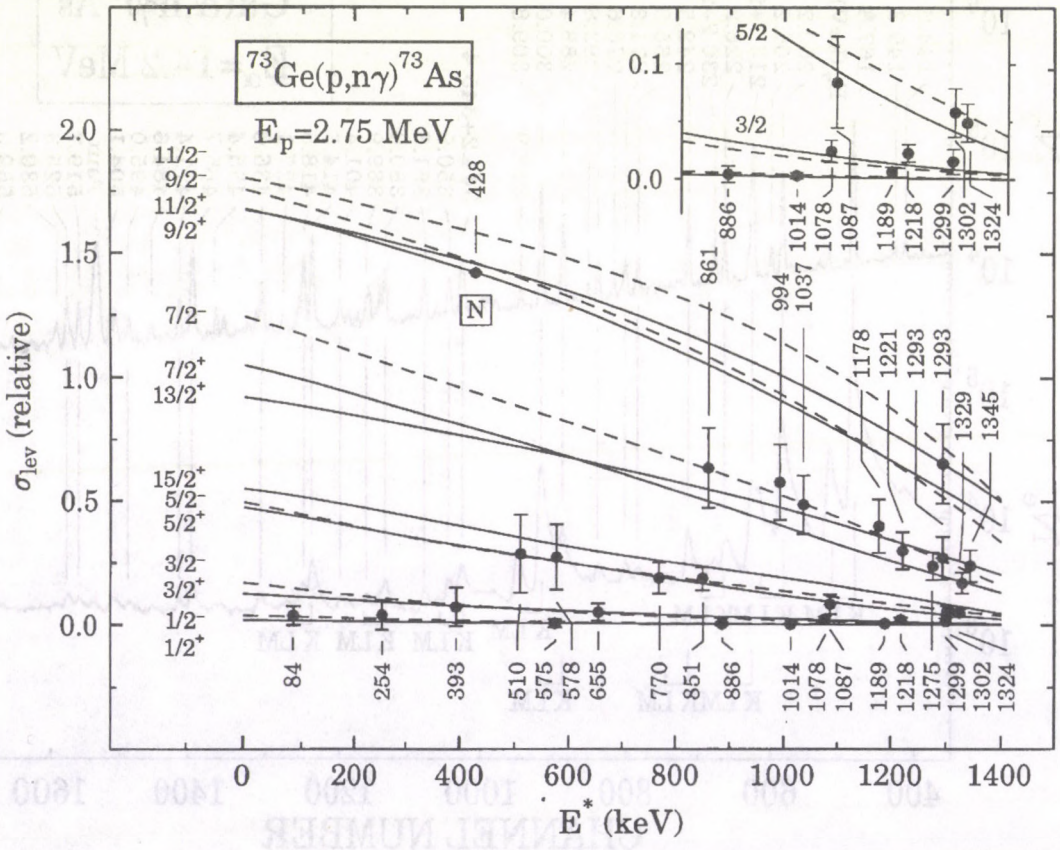


**Fig. 1.** Experimental relative cross sections ($\sigma_{lev}$) of the $^{73}$Ge(p,nγ)$^{73}$As reaction (dots with error bars) as a function of the $^{73}$As level energy ($E_{lev}$). The curves show Hauser–Feshbach theoretical results. *N* means normalization point.

[1] Zs. Podolyák and D. Sohler, ATOMKI Ann. Rep. 1994, p. 8.

# Spectroscopic Study of $^{74}$As from $^{71}$Ga($\alpha$,n$\gamma$)$^{74}$As Reaction

A.Algora, D.Sohler, Zs.Podolyák and Zs.Dombrádi

We have studied the low energy, medium spin (<8) states of $^{74}$As using the $^{71}$Ga($\alpha$,n$\gamma$)$^{74}$As reaction. $\gamma$-ray, internal conversion electron, and $\gamma\gamma$-coincidence spectra were measured with Ge(HP), $\gamma$-ray and superconducting magnetic lens plus Si(Li) electron spectrometers at a beam energy of 15 MeV. A new level scheme has been constructed on the basis of $\gamma\gamma$-coincidence measurement, which contains more than 20 new levels relative to refs. [1,2]. Internal conversion coefficients of 18 transitions (fig.1.) have been deduced for the first time resulting in many new $\gamma$-ray multipolarities and reliable parity assigments for levels below 700 keV.

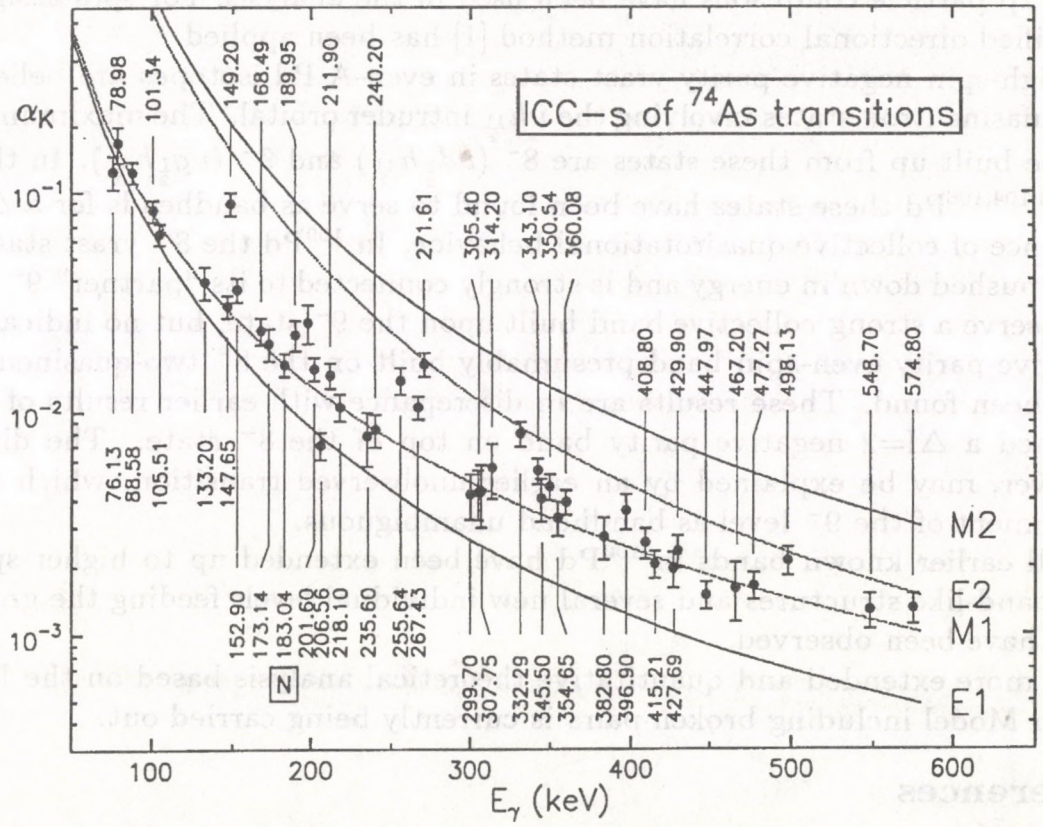


**Fig. 1.** Experimental internal conversion coefficients of $^{74}$As transitions (the curves show theoretical results)

1 A. Algora, D. Sohler, T. Fényes, Z. Gácsi, S. Brant and V. Paar, Nucl. Phys A **588** (1995) 399

2 B. Singh and D. A. Viggars, Nucl. Data Sheets **51** (1987) 225

# Structure of high spin states in $^{100}$Pd

G. E. Perez, B. M. Nyakó, Zs. Dombrádi
and
NORDBALL collaboration

New extensive experimental data on the excited states of $^{100}$Pd has been obtained with the NORDBALL detector array. In the experiment high spin states of $^{100}$Pd were populated through the $^{50}$Cr($^{58}$Ni,4p1$\alpha\gamma$)$^{100}$Pd reaction. The NORDBALL setup consisted of 15 BGO Compton supressed Ge detectors, a Silicon ball comprising 21 $\Delta$E-type Si detectors, 11 neutron scintillators and a 30-element $BaF_2$ calorimeter. Altogether, more than 60 $\gamma$ transitions belonging to $^{100}$Pd have been observed, among them about 30 $\gamma$ rays were identified for the first time. A preliminary level scheme of $^{100}$Pd has been constructed mainly from $\gamma$-$\gamma$ coincidence relations. Due to imperfect detection conditions events belonging to $^{100}$Pd were spread over several $E_\gamma$-$E_\gamma$ matrices gated with different combinations of detected protons, $\alpha$ particles and neutrons, for this reason matrices gated with 1$\alpha$0n and 4p, 3p or 2p particle conditions have been used in the analysis. For spin assignments a simplified directional correlation method [1] has been applied.

High-spin negative-parity yrast states in even-A Pd isotopes are believed to be two-quasineutron states involving the $\nu h_{\frac{11}{2}}$ intruder orbital. The maximum spin that can be built up from these states are $8^-$ $(\nu d_{\frac{5}{2}} h_{\frac{11}{2}})$ and $9^-$ $(\nu g_{\frac{7}{2}} h_{\frac{11}{2}})$. In the heavier [2] $^{102,104,106}$Pd these states have been found to serve as bandheads for a $\Delta$I=2 level sequence of collective quasirotational behavior. In $^{100}$Pd the $8^-$ yrast state appears to be pushed down in energy and is strongly connected to its "partner" $9^-$ state. We do observe a strong collective band built upon the $9^-$ state, but no indications for a negative-parity even-spin band presumably built on the $8^-$ two-quasineutron state have been found. These results are in discrepance with earlier results of [3], which assigned a $\Delta$I=2 negative parity band on top of the $8^-$ state. The discrepance, however, may be explained by an earlier unobserved transition, which makes the assignment of the $9^-$ level as bandhead unambiguous.

All earlier known bands in $^{100}$Pd have been extended up to higher spins. Also new band-like structures and several new individual levels feeding the ground state band have been observed.

A more extended and quantitative theoretical analysis based on the Interacting Boson Model including broken pairs is currently being carried out.

## References

[1] D. Seweryniak, *Doctoral Dissertation*, Uppsala University, 1994.

[2] W. F. Piel, G. Scharff-Goldhaber, A. H. Lumpkin, Y. K. Lee, and D. C. Stromswold, Phys. Rev. C **23**, 708 (1981).

[3] J. A. Grau, L. E. Samuelson, F. A. Rickey, P. C. Simms, and G. J. Smith, Phys. Rev. C **14**, 2297 (1976)

# Study of the $^{106}Cd(\alpha,n\gamma)^{109}Sn$ reaction

I. Dankó, Z. Gácsi, Zs. Dombrádi, J. Gulyás

and A. Krasznahorkay

Gamma-ray, internal conversion electron and $\gamma\gamma$-coincidence spectra of the $^{109}Sn$ from $^{106}Cd(\alpha,n\gamma)^{109}Sn$ reaction were measured with Ge(HP) $\gamma$-ray and superconducting magnetic lens (SMLS) plus Si(Li) electron spectrometers at different bombarding energies between $E_\alpha$=15-20 MeV (reaction Q-value is -10.15 MeV).

Approximately 38 million $\gamma\gamma$-coincidence events were recorded on magnetic tape in event-by-event mode with four Ge(HP) detectors. For analysis of the coincidence relations a 2-dimensional matrix was created from the list and a standard gating procedure was used. Several previously unobserved coincidence relations have been found as illustrated in Fig.1.

Preliminary experimental internal conversion coefficients were determined for ~20 $^{109}Sn$ transitions, about half of them were obtained for the first time.

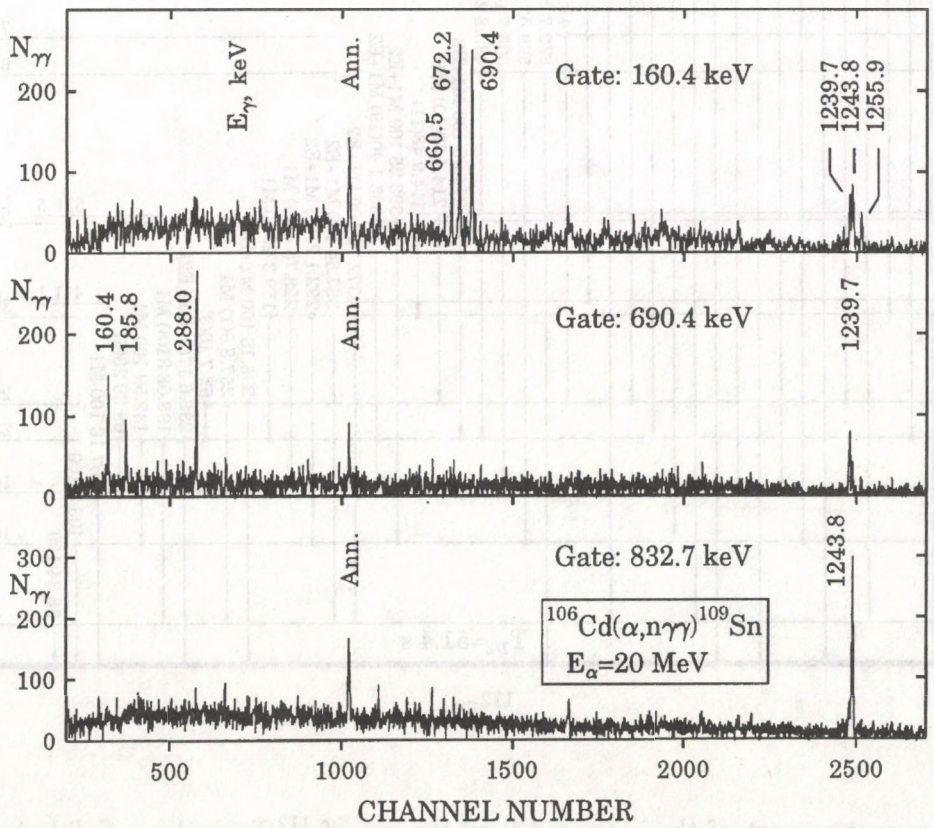


**Fig. 1.** Selected $\gamma\gamma$-coincidence gate spectra after background subtraction.

# The level scheme of $^{112}$Sb nucleus

M. Fayez Hassan, J. Gulyás and Zs. Dombrádi

We have measured the $\gamma$-ray, $\gamma\gamma$-coincidence, internal conversion electron and $\gamma$-ray angular distribution spectra of the $^{112}$Sn(p,n$\gamma$)$^{112}$Sb reaction. On the basis of our experimental results a new level scheme of $^{112}$Sb was proposed, which contains many new $\gamma$-ray transitions and several new levels. For spin determination the analysis of available $\gamma$-ray angular distribution data and the Hauser-Feshbach results is in progress.

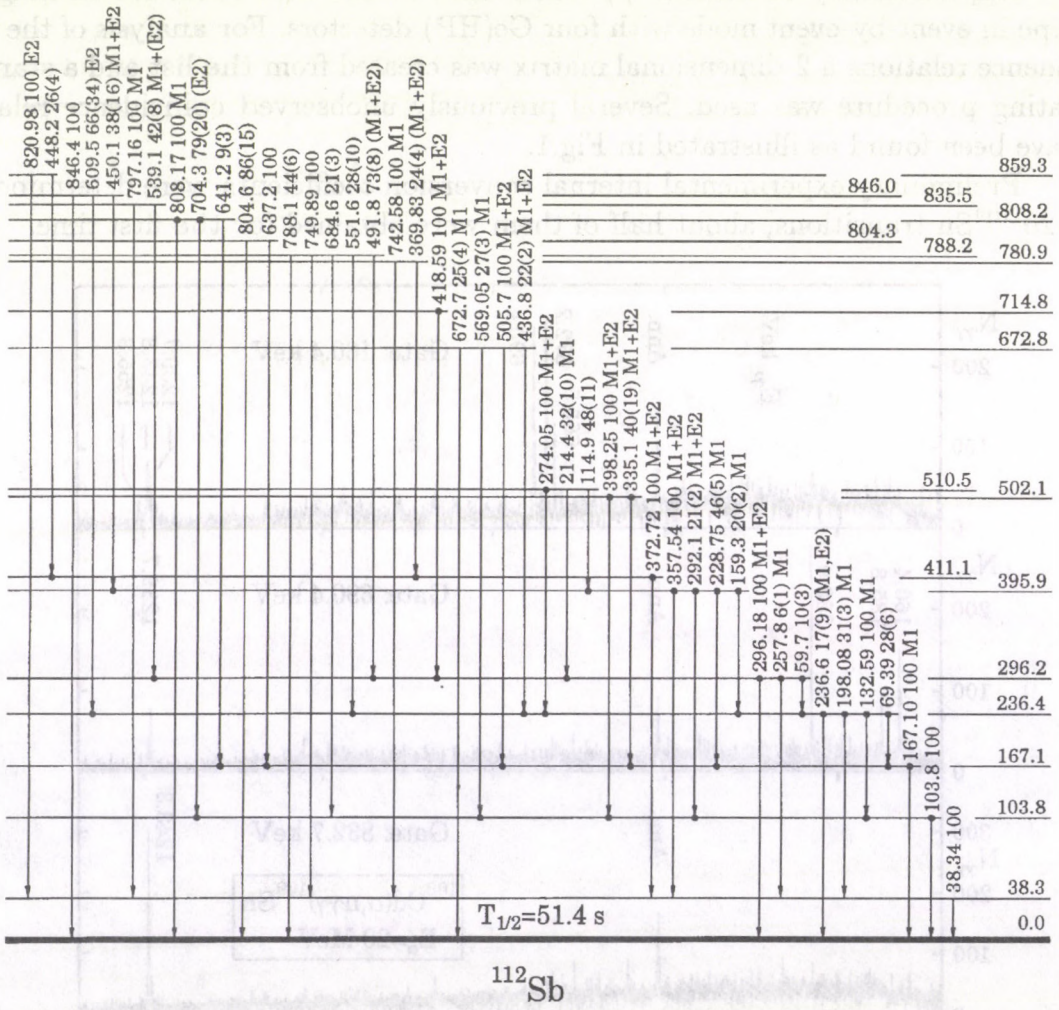


**Fig. 1.** Low-energy part of the proposed level scheme of $^{112}$Sb nucleus. Solid circles at the ends of arrows indicate $\gamma\gamma$-coincidence relations.

# Proton–neutron mutiplet states in $^{114}$Sb

Zs. Dombrádi, Z. Gácsi, B. E. Zimmerman+ and W. B. Walters+

+ University of Maryland, College Park, MD 20742, USA

The structure of $^{114}$Sb was investigated via (p,n) reaction in Debrecen [1], and from the $\beta^+$ decay of $^{114}$Te at the Oak Ridge National Laboratory [2]. A new, more complete level scheme was constructed on the basis of $\gamma\gamma$-coincidence relations. The structure of the nucleus is discussed in the framework of the particle vibration coupling model using the interacting boson-fermion formalism. On the basis of their electromagnetic properties the experimental states could be classified into proton–neutron multiplets.

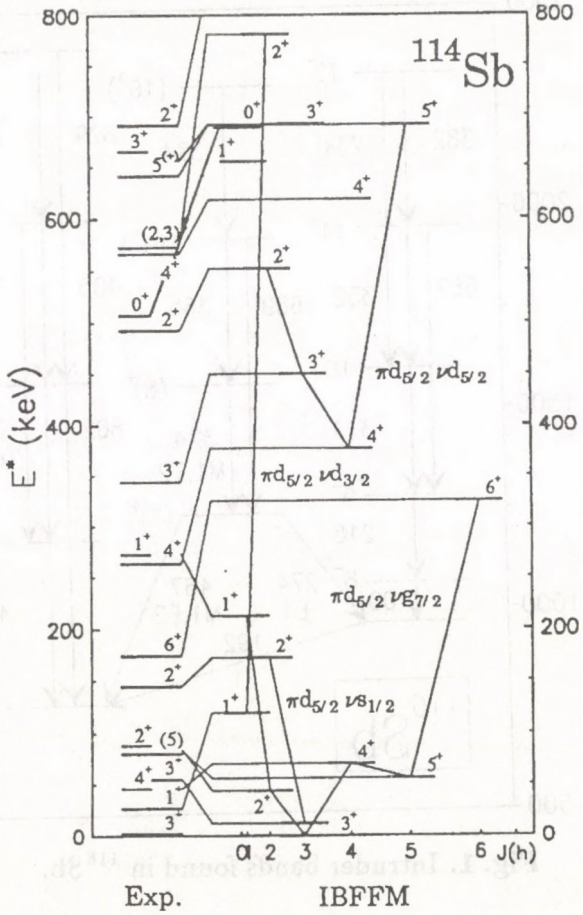


**Fig. 1.** Assignement of experimental states to the theoretical ones. States not grupped into proton–neutron multiplets have proton–neutron–phonon nature.

[1] Z. Gácsi, Zs. Dombrádi, Phys. Rev. C**50** (1994) 1833

[2] B. E. Zimmerman *et al.* , Phys. Rev. C in print

# Positive parity intruder states in $^{116,118}$Sb

Zs. Dombrádi, Z. Gácsi, J. Gulyás, and M. Fayez Hassan

The existence of intruder states in odd-odd Sb nuclei has been known for a long time [1]. Negative parity bands were found in $^{114-120}$Sb, and also in light antimony nuclei in heavy ion reactions. The interacting boson-fermion-fermion model analysis of the intruder structures predicted the existence of several low-lying positive parity bands, too. To search for these bands, our experimental data on $^{113,115}$In($\alpha$,n)$^{116,118}$Sb were reanalysed. In both nuclei start of two additional bands were found, with positive parity band heads. The structures found in $^{116}$Sb are shown in Fig. 1.

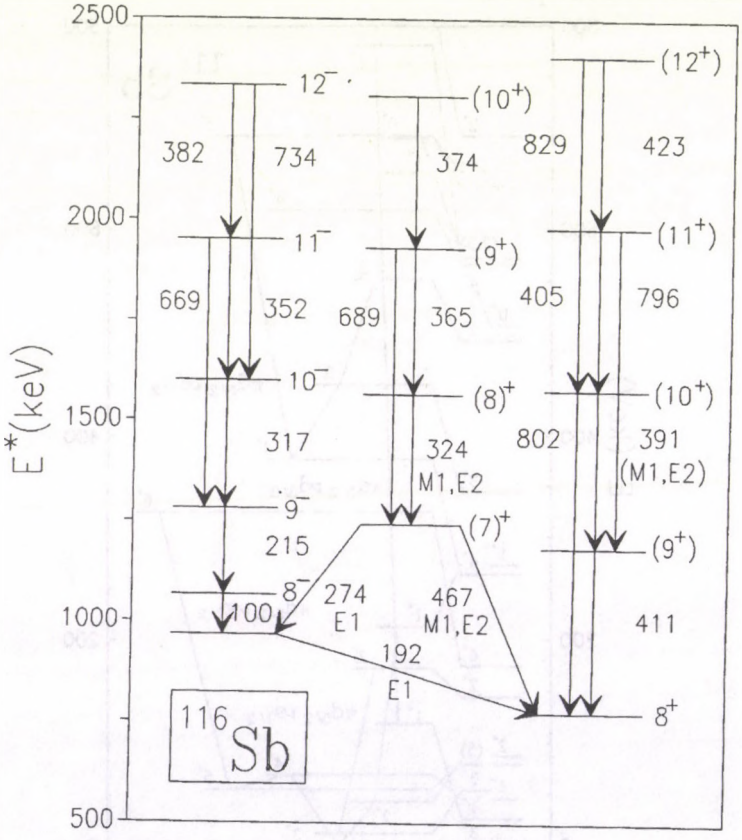


**Fig. 1.** Intruder bands found in $^{116}$Sb.

[1] P. van Nes *et al.* Nucl. Phys. **A379** (1982) 35, S. Vajda *et al.* Phys. Rev. C**27** (1983) 2995, R. Duffait *et al.* Z. Phys. A **307** (1982) 259.

# High spin structure of the $^{139}$Sm nucleus

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The excited states of the $^{139}$Sm nucleus has been populated through the $^{110}$Pd($^{34}$S,5n) reaction at beam energies of 150 and 165 MeV. The deexciting $\gamma$-rays have been detected using the GASP array. A total of 800 million triplets and higher fold events have been collected at each energy. The level scheme has been extended up to an excitation energy of 13.5 MeV and spin $(69/2^+)$. A band built on the $\nu i_{13/2}[660]1/2^+$ intruder orbital has been established and firmly linked to the known low-spin levels in the nucleus. A relatively strong $\Delta I = 1$ regular structure has been observed above spin $25/2^-$. A spectrum gated width the three strongest lines of the structure and width the transition collecting most of the intensity from the bandhead decay is shown in fig. 1.

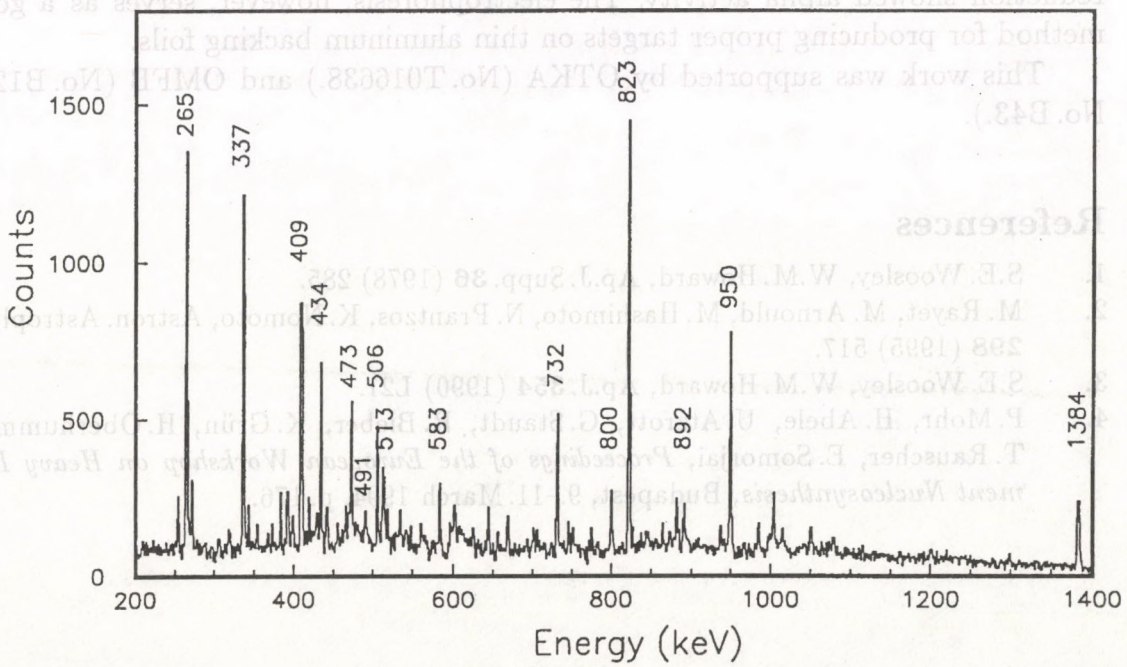


**Fig. 1.** Double gated spectrum for the $\Delta I = 1$ band observed above the 3325 keV $25/2^-$ state. The cube was first gated on the 265, 337 and 409 keV $\gamma$ rays and then on the 590 keV transition.

# Astrophysical p–process: $^{144}Sm(\alpha,\gamma)^{148}Gd$

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As a key nuclear reaction of the p–process we want to investigate the reaction $^{144}Sm(\alpha,\gamma)^{148}Gd$. This reaction determines the abundance ratio of $^{142}Nd/^{144}Nd$ in certain meteorites which in turn is of relevance for the cosmochronology and in general for the nucleosynthesis mechanism of the p–process [1,2]. The value for the cross section of this reaction is quite uncertain, showing differences up to a factor of 10 ([3,4]).

As the first step to the $^{144}Sm(\alpha,\gamma)^{148}Gd$ cross section measurements two methodes have been tested for preparing $^{144}Sm$ enriched targets.

Since the cross section will be determined via the detection of the alpha decay of the $^{148}Gd$ residual nucleus the alpha activity of the target material (as well as the backing) is not desirable. The well known reductive evaporation method proved to be unusable, because the small contamination of lanthanum used for the reduction showed alpha activity. The electrophoresis, however, serves as a good method for producing proper targets on thin aluminum backing foils.

This work was supported by OTKA (No. T016638.) and OMFB (No. B123., No. B43.).

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# Interpretation of structure of $^{156}$Tm

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The $^{142}$Nd + 120MeV $^{19}$F reaction was investigated at the Legnaro National Laboratory with help of the GaSP detector array. Excited states of $^{156}$Tm were identified for the first time. To interpret the experimental results the interacting boson-fermion-fermion model was used. In the model a transitonal between vibrational and rotational limits core was applied. The low-lying states, as well as the band structure and band crossings predicted by the model are shown in Fig. 1. The experimenal and theoretical states are connected on the basis of their decay properties.

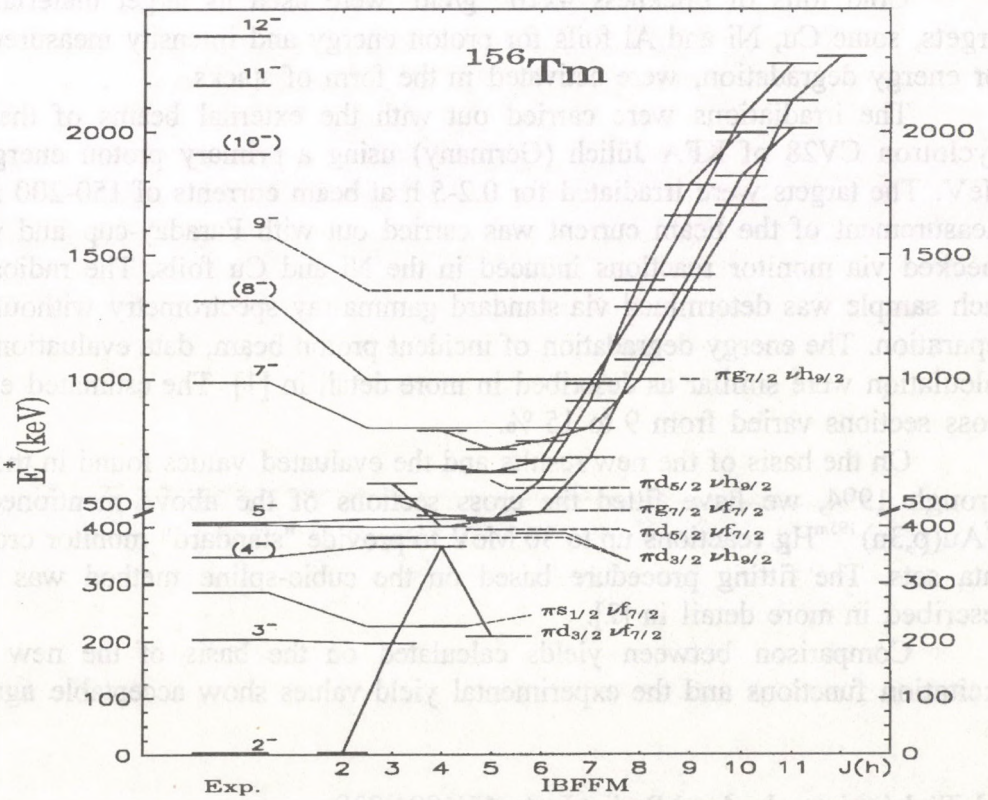


**Fig. 1.** Comparison of the experimental level scheme with the theoretical calculations based on the interacting boson–fermion–fermion model.

# (p,xn) and (p,pn) processes on $^{197}$Au: new proton monitor reactions up to 30 MeV

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Gold is frequently used as a target backing material in several nuclear cross section measurements due to its excellent chemical and mechanical properties. Only one attempt was, however, made in the past to use proton induced reactions on Au for monitoring proton beams. Since more reactions are induced simultaneously in Au up to 30 MeV, and some of their products ie. $^{196m}$Au, $^{196m,g}$Au, $^{197m}$Hg and $^{197m,g}$Hg can be easily evaluated from gamma spectra, Au can also be used for both beam energy and intensity measurements in the field of radioisotope production.

Unfortunately, till recently the available cross section data were either rather old and insufficient and/or contradictory and needed a critical comparison. Therefore, to extend the available reactions for low and middle energy proton beam monitoring, we have measured the cross sections of $^{197}$Au(p,n)$^{197m}$Hg, $^{197}$Au(p,n)$^{197m,g}$Hg and $^{197}$Au(p,pn)$^{197m}$Au, $^{197}$Au(p,pn)$^{197m,g}$Au processes over the mentioned energy region.

Gold foils of thickness $4\times10^{-2}$ g/cm$^2$ were used as target material. The Au targets, some Cu, Ni and Al foils for proton energy and intensity measurements and for energy degradation, were activated in the form of stacks.

The irradiations were carried out with the external beams of the Compact Cyclotron CV28 of KFA Jülich (Germany) using a primary proton energy of 18.7 MeV. The targets were irradiated for 0.2-5 h at beam currents of 150-200 nA. Direct measurement of the beam current was carried out with Faraday-cup and was cross-checked via monitor reactions induced in the Ni and Cu foils. The radioactivity of each sample was determined via standard gamma-ray spectrometry without chemical separation. The energy degradation of incident proton beam, data evaluation and error calculation were similar as described in more detail in [1]. The estimated error of the cross sections varied from 9 to 15 %.

On the basis of the new results and the evaluated values found in the literature through 1994, we have fitted the cross sections of the above mentioned and the $^{197}$Au(p,3n)$^{195m}$Hg reactions up to 30 MeV to provide "standard" monitor cross section data sets. The fitting procedure based on the cubic-spline method was similar as described in more detail in [2].

Comparison between yields calculated on the basis of the new evaluated excitation functions and the experimental yield values show acceptable agreement.

[1] Tárkányi *et al.*, Appl.Radiat.Isot. **45**(1994)239
[2] Takács *et al.*, NIM **B89**(1994)88

# Evidence for hyperdeformed nuclear shape in $^{236}$U

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In our recent work [1] the fission probability as a function of the excitation energy in $^{236}$U has been measured, with the method of Blons et al. [2] for the $^{235}$U(d,pf)$^{236}$U reaction slightly below the top of the fission barrier, with the aim of disclosing new resonant class III HD states in the third minimum of the fission barrier. A strong resonance at $E^* = 5.476$ MeV and also some weaker resonances around $E^* \approx 5.3$ MeV have been observed (see Fig. 1.a.).

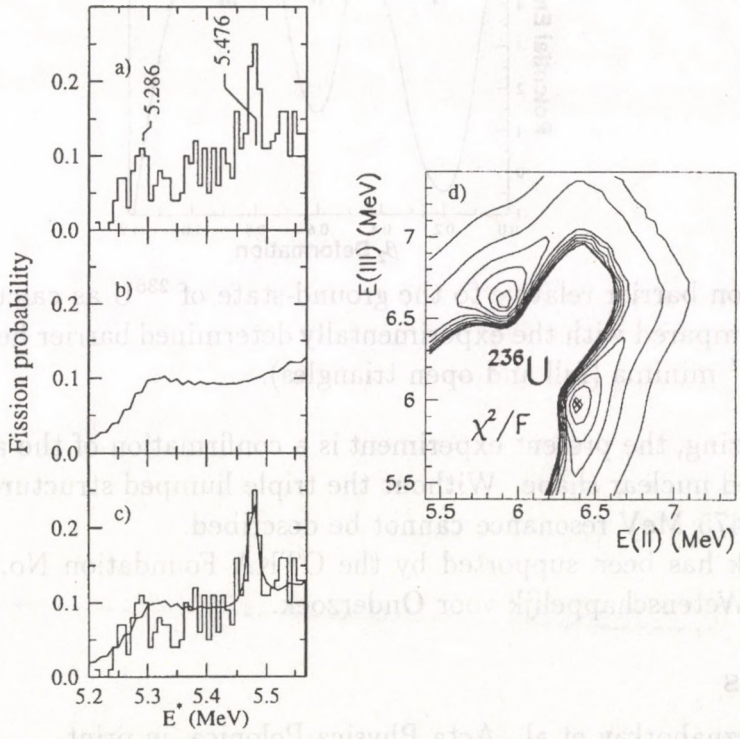


**Fig. 1.** Fission probabilities of $^{236}$U as a function of the excitation energy $E^*$. (a) experimental values, (b) calculated values with the program FISALL, (c) comparison of the measured fission probabilities (histogram) with the calculated ones using the result of FISALL [3] and the result obtained for a triple humped potential barrier (see in the text), (d) comparison of the measured and calculated fission probabilities of $^{236}$U using the $\chi^2$ method. The $\chi^2$ values were calculated as a function of the heights of the second and third potential barriers.

By supposing a double humped structure of the fission potential with the parameters given by Bhandary [4] and using the resonant version of the program FISALL of Back and Britt [3] the gross structure of the fission probability was calculated and shown in Fig. 1.b. Although the fission probability with the effect of the dumped superdeformed states at ≈5.3 MeV could be reproduced, the sharp resonance at $E^*$ = 5.476 MeV could not be described.

In order to understand the nature of the above strong resonance a triple humped potential barrier of Howard and Möller [5] (see Fig. 2.) was taken into account. The place of the resonance could be reproduced exactly by changing slightly the depth of the third well. The strength and width of the resonance was obtained from a least square fitting procedure by varying the height of the second and third barriers (see Fig. 1.d.). The results of the $\chi^2$-analysis are shown in Fig. 1.c. and in Fig. 2.

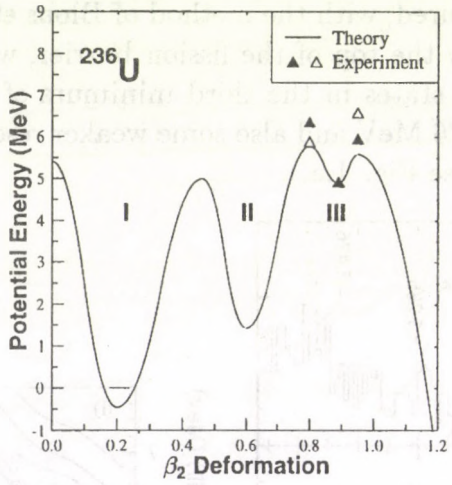


**Fig. 2.** Fission barrier relative to the ground-state of $^{236}$U as calculated by Howard and Möller compared with the experimentally determined barrier heights corresponding to both $\chi^2$ minima (full and open triangles).

Summarizing, the present experiment is a confirmation of the appearance of the hyperdeformed nuclear shape. Without the triple humped structure of the potential barrier the 5.475 MeV resonance cannot be described.

This work has been supported by the OTKA Foundation No.:7486 and by the Nederlandse Wetenschappelijk voor Onderzoek.

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# Microscopic theory of cluster radioactivity

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A comprehensive review paper is being prepared on this subject. Recent developments in the dynamical microscopic theories of cluster decay are reviewed with special emphasis on the nuclear structure aspects and on the understanding of the physics and performance of the models. What we call dynamical microscopic theories are those in which the decay width is derived from the nucleonic structures, of the participating nuclei, which are deduced through the solution of their equations of motion. After a brief review of the various expressions for the decay width, we turn to the nuclear-structure aspects of the problem. We thoroughly discuss the treatment of the Pauli effects in models involving macroscopic elements. We settle the long-standing controversy over the cluster–core norm operator that relates microscopic and macroscopic functions in the transition amplitude by proving that the way it was originally introduced in the mid-seventies is in principle correct. The main part of the paper is a detailed review, in which the approaches considered are grouped according to the structure models they use for the parent nucleus. The approaches discussed are the ordinary shell models, the cluster-like shell models and the Bardeen–Cooper–Schrieffer (BCS) approach. By discussing these diverse calculations, it is concluded that the most essential prerequisite for a realistic model of the mother nucleus is that it should correctly describe the cluster correlation in the surface region. This implies that the proton–neutron interaction is indispensable, and the moderate success of ordinary shell models is accounted for by their failure to include both proton–neutron interaction and large enough bases. Cluster-like models are able to cope with this problem, for the special case of a doubly-closed shell residual state, because their bases are more economical, and, for these cases, they provide a fully satisfactory decay theory. The BCS approach, on the other hand, is widely applicable, and is the only one that has been applied to heavy-cluster decay with reasonable success. We point out, however, that the formation amplitude calculated in this model still contains rough approximations. We explain the success of the BCS theory by showing that, in spite of appearance, it does include proton–neutron interaction, in an effective manner. In discussing the results for the widths, we address the problem of the preformation probability of a cluster–core pair in the parent nucleus. One can be fairly confident that in the ground state of $^{212}$Po the amount of core–$\alpha$-clustering is as high as 20–30%, but, in respect of other cluster-decaying nuclei, the theory is not yet conclusive. We conclude that a satisfactory understanding of heavy-cluster radioactivity requires the application of both more sophisticated cluster models and improved BCS approaches.

# Criticism on bound-state-like models of light nuclei

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In most nuclear structure calculations, most notably in the shell model, unbound states are treated as if they were bound: their wave functions are expanded in terms of square-integrable bases of finite sizes. This may cause serious errors, especially for light nuclei, where the actual boundary conditions are often of few-body nature, and a bound-state-like expansion is critical even for weakly bound states. These pitfalls can be well illustrated by the cases of $^6$Li and $^5$He. In a recent publication Zheng, Vary, and Barrett [1] have reproduced the negative quadrupole moment of $^6$Li, which many apparently reliable models fail to achieve, and produced low-lying positive-parity states of $^5$He by using a no-core shell model. We show [2], however, that these results hinge on the inadequate treatment of the asymptotic few-body dynamics. This shortcoming of the (non-continuum) shell-model approach is not self-evident, and most nuclear-structure experts fail to appreciate it. We demonstrate it by viewing it from the perspective of the complementary cluster-model approach, which treats the few-body dynamics properly.

As for $^6$Li, (i) we point out that the model $^6$Li is, incorrectly, $\alpha$+d unstable, and (ii) we demonstrate by cluster-model calculations that the calculated quadrupole moment is strongly correlated with the calculated value of the lowest threshold energy. From these premises it follows that this shell-model result cannot be accepted as a solution to the long-standing problem of the $^6$Li quadrupole moment.

The evidence for the existence of low-lying positive-parity states in $^5$He is not convincing, but, neglecting the $\alpha$+n continuum, shell-model calculations insistently yield such states. Now we argue as follows: (i) with realistic large-scale continuum cluster model we get no such states; (ii) to produce these states in cluster models, either the parameters have to be unphysical or the continuum should be switched off. In the shell-model calculations the parameters are realistic, thus the states found must result from the neglect of the continuum, i.e. they must be spurious.

## References

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2. A. Csótó and R. G. Lovas: Comment on "Large-space shell-model calculations for light nuclei", Phys. Rev. C, in press

# Gaussian bases in variational calculations

K. Varga

Gaussian bases have been widely used in wave-function expansion methods for solution of few-body problems. The aim of this work is to test various versions of the Gaussian representation in the variational approach. The angular momentum projected Gaussians $\varphi_l^\nu(\mathbf{r}) \sim r^l Y_{lm}(\hat{\mathbf{r}})\exp\{-\nu r^2\}$ has proved to be a precious tool in solving $N$=3-7 body problems [1]. The solution of the $N$-nucleon Schrödinger-equation for more than $N$=6-7 particles, however, is very difficult as both the partial wave expansion and the calculation of the matrix elements of the Hamiltonian become too complicated. The shifted Gaussian $\varphi_{\mathbf{s}}^\gamma(\mathbf{r}) \sim \exp\{-\gamma(\mathbf{r}-\mathbf{s})^2\}$ functions are also often used in few-body and few-cluster calculations. States of good angular momenta can be obtained by letting an angular momentum projection operator act on the full wave function. The calculation of the matrix elements in this case much more simple and no partial waves appear.

The wave functions of the relative motions in this variational approach is expanded in terms of angular momentum projected or shifted Gaussians, and the nonlinear parameters are selected by the stochastic variational method (SVM) [1] or by an appropriate direct optimatization.

The solutions for different few-body systems using angular momentum projected Gaussians agree very well with those of other methods [1]. High accuracy can be reached by using only a moderate number of basis functions. On the other hand, in the case of the shifted Gaussian basis, the energy quite slowly converge and for few-body systems it fails to reach the same value as on the angular momentum projected Gaussian (see Table I). For heavier systems, where the angular momentum projected Gaussian basis is not feasible, the results on shifted Gaussian basis is quite close to those of other methods such as the Integrodifferential Equation Approach (IDEA) or the Hartree-Fock-Bogoljubov (HFB) method.

The Antisymmetrized Molecular Dynamics (AMD) and Fermionic Molecular Dynamics (FMD) methods use the shifted Gaussian basis functions and often approximate the wave function of a multinucleon system by only one Slater-determinant ($K = 1$ in Table I.). Table I. shows that this approximation can be insufficient, and the linear combination of Slater determinants considerably lowers the ground state energy.

1. K. Varga and Y. Suzuki, Phys. Rev C52 (1995) 2885, and Phys. Rev. A in press.

Table 1: The binding energies (in MeV) of different A-nucleon systems interacting via the Volkov potential ($m = 0.6$)

| | $K=1$ | $K=100$ | method | result |
|---|---|---|---|---|
| $^3$He | −6.66 | −8.31 | SVM | −8.46 |
| $^4$He | −27.92 | −29.75 | SVM | −30.42 |
| $^6$He | −23.59 | −29.38 | SVM | −31.82 |
| $^8$Be | −52.60 | −57.09 | | |
| $^{16}$O | −1100.1 | − − − | IDEA | −1101. |

# Structure of the mirror nuclei $^9$Be and $^9$B in a microscopic cluster model

K. Arai[1], Y. Ogawa[2], Y. Suzuki[3] and K. Varga

The microscopic multicluster model was applied to study the mirror nuclei $^9$Be and $^9$B. These nuclei was described in a three-cluster model comprising two $\alpha$-particles and a single nucleon. The two-nucleon interaction consists of central and spin-orbit and Coulomb potential. The ground state of $^9$Be, the only particle-bound state in the spectra of these nuclei, was calculated using the stochastic variational method, while the other particle-unbound states were studied by the complex scaling method. The three-body dynamics of the clusters was taken into account by including both of the possible arrangements, $(\alpha\alpha)N$ and $(N\alpha)\alpha$, and by using all the relevant partial waves of the relative motion of the clusters. The calculated spectrum of $^9$Be below the excitation energy 8 MeV was in fair agreement with the experiments. We obtained two broad overlapping resonances with $J^\pi = 7/2^-$ and $9/2^+$ around 6.5 MeV, in agreement with the conclusion of the recent experiments. A previously unknown $5/2^-$ state was predicted at about 8MeV. The spectrum of $^9$B was found to be similar to that of $^9$Be. The first excited $1/2^+$ state was not localized in the present study and thus no definite argument was possible on a Thomas-Ehrman shift in this case.

The theory reproduced very well the electromagnetic properties of the $^9$Be ground state such as the charge radius, the magnetic moment, the quadrupole moment, and the elastic electron scattering form factors. The calculated ground state density was consistent with the total reaction cross section data. The $1/2^+ \to 3/2^-$ $E1$ transition and the $5/2^- \to 3/2^-$ $E2/M1$ transitions were studied by treating the excited states as quasibound states. The calculated transition rates were in good agreement with the experiment.

The fact that the present calculation reproduced all the data very well strongly supports that the three-cluster model is quite appropriate for describing the structure of $^9$Be and $^9$B, provided that the three-body dynamics is treated properly in the calculation. We were also able to explain the $\beta$ decay of $^9$Li to $^9$Be by admixing a small components into the wave function which induced by the distortion of the $\alpha$-particle into $t+p$ and $h+n$ configurations. A unique advantage of the microscopic multicluster model was exemplified by being able to accommodate such distortion into the model consistently.

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# Precise solution of few-body problems with the stochastic variational method

K. Varga and Y. Suzuki[1]

We have formulated a variational calculation for few-body systems using the stochastic variational method (SVM) on the correlated Gaussian basis [2]. We have demonstrated the versatility of the correlated Gaussians and the efficiency of the stochastic variation by various numerical examples for $N = 2 - 7$-particle systems.

The comparison with other calculations has corroborated the accuracy and efficiency of the method. In none of the test cases has the present method proved to be inferior to any of the alternative methods, and yet the method does not require excessive computational effort.

The correlation between the particles plays an important role in describing the few-body system realistically. It has been taken into account in the framework of the correlated Gaussian functions. The correlated Gaussians are constructed from products of the Gaussian wave-packet single-particle functions through an integral transformation, which has enabled us to evaluate the center-of-mass motion free matrix elements analytically starting from the single-particle level. The nonlinear parameters of the correlated Gaussians have been selected by the stochastic variational method with a trial and error procedure. The success of the method using the correlated Gaussian basis is probably due to the fact that none of the Gaussians is indispensable, that is, there are different sets of the Gaussian parameters that represent the wave function equally well.

As an example we compare our results to those of other methods in Table I.

The method presented in this report can be useful to solve few-body problems in diverse fields of physics such as description of microclusters, non-relativistic quark model, and halo nuclei. Among others, the most important application is the solution of the nuclear few-body problem, that is, the description of light nuclei by using *realistic* nucleon-nucleon potentials.

1. Department of Physics, Niigata University, Niigata 950-21, Japan

2. K. Varga and Y. Suzuki, Phys. Rev C52 (1995) 2885, and Phys. Rev. A in press.

Table 1: Energies and rms radii of $N$-nucleon systems interacting via the Malfliet-Tjon potential V

| $N$ | $(L,S)J^\pi$ | Method | $E$ (MeV) | $\langle r^2\rangle^{1/2}$ (fm) | $K$ |
|---|---|---|---|---|---|
| 3 | $(0,1/2)1/2^+$ | Faddeev | −8.25273 | | |
| | | SVM | −8.2527 | 1.682 | 80 |
| 4 | $(0,0)0^+$ | CRCG | −31.357 | | 1000 |
| | | SVM | −31.360 | 1.4087 | 150 |
| 5 | $(1,1/2)3/2^-$ | VMC | −42.98 | 1.51 | |
| | | SVM | −43.48 | 1.51 | 500 |
| 6 ($^6$He) | $(0,0)0^+$ | VMC | −66.34 | 1.50 | |
| | | SVM | −66.30 | 1.52 | 800 |
| 7 ($^7$Li) | $(1,1/2)3/2^-$ | SVM | −83.4 | 1.68 | 1300 |

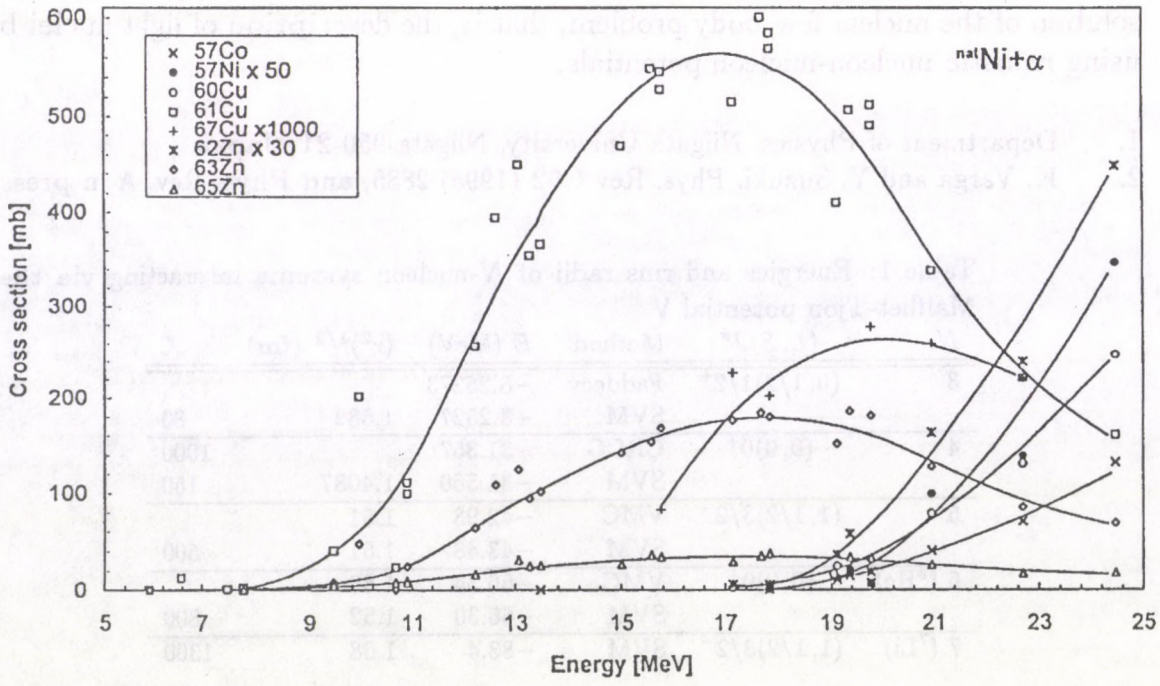
# Excitation Function of $\alpha$-Particle Induced Nuclear Reactions on Natural Nickel

S. Takács, F. Tárkányi and Z. Kovács

Cross section data of charged particle induced nuclear reactions are needed in a number of fields of applications and basic sciences. However, the status of the charged particle reaction data is in many cases not satisfactory. The evaluated and recommended data are available only for a few reactions. In the frame of re-measurement and critical comparison of the most important charged particle induced nuclear reactions on technological materials, we have measured the excitation functions of alpha-particle induced nuclear reactions on natural nickel leading to the formation of $^{62,63,65}$Zn, $^{60,61,67}$Cu, $^{57}$Ni and $^{57}$Co up to 25 MeV.

Cross sections were measured by activation method using the stacked-foil technique. The irradiations were carried out with the external beams of the Debrecen MGC 20-E ($E_{alpha}$= 16.0, 20.7 MeV) and the Jülich CV-28 ($E_{alpha}$=26.6 MeV) compact cyclotrons with 100-200 nA beam current. The duration of the irradiations varied between 0.5 hour and 2.0 hours. The beam current measured in the Faraday-cup was cross checked by performing separate irradiation of Cu and Ti monitor foils. All the cross sections were calculated for targets with natural isotopic composition. The overall error in the cross section measurements varies between 10% and 20%.

The reactions leading to the formation of $^{61}$Cu, $^{63}$Zn and $^{65}$Zn are very promising for monitoring alpha-particle beams because of the relatively high cross section values and low threshold energies. However, data published earlier completed with our results are still inconsistent both in maximum values and in energy scale and can serve as suitable data base only after critical evaluation. Therefore, further measurements are required to solve the discrepancies and to increase the number of potentially useful reactions by extending the bombarding energy towards higher energy regions that already have been started.



# Activation Cross Section Measurement of Deuteron Induced Nuclear Reactions on $^{nat}$Ni for Investigation of Production of $^{61}$Cu and for Monitoring the Beam Performance

S. Takács, F. Tárkányi, A. Azzam[1], M. Shonk[2], and A. Hermanne[2]

1 IAEA-Fellow from Nuclear Research Center, A.E.A., Cairo, Egypt
2 Free University of Brussels, VUB Cyclotron, 1090 Brussels, Belgium

For monitoring low energy deuteron beams only very few reactions were recommended and the quality of the existing data for the reactions are far from the requirement. After completing the study of excitation functions of p, $^{3}$He- and alpha induced reactions on natural nickel [1-3] we report the excitation functions of deuteron induced reactions on Ni target in this work. To investigate a new production route for the medically important ß$^{+}$ emitting $^{61}$Cu ($T_{1/2}$=3.4 h) isotope also motivated the work.

The excitation functions of the deuteron induced reactions on $^{nat}$Ni have been measured by using activation method and stacked foil technique at the MGC20E cyclotron in Debrecen ( up to 10 MeV) and at the CGR560 Cyclotron in Brussels (up to 20 MeV). Effective cross sections were determined for formation of $^{55,56,57,58}$Co, $^{57}$Ni and $^{60,61}$Cu isotopes of nickel target with natural isotopic composition.

The analysis of the measured experimental data and their comparison with the data from the literature [4-6] indicate that the $^{nat}$Ni(d,x)$^{56,58}$Co,$^{61}$Cu reactions could be very promising for monitoring. However, it has to be mentioned that the existing data are still inconsistent and additional measurements for intercomparison with other deuteron monitor reactions are required.

Production yield for 100% enriched $^{60}$Ni target were calculated to investigate and to optimize a new production route of positron emitter isotope $^{61}$Cu via $^{60}$Ni(d,n)$^{61}$Cu nuclear reaction. Contribution of (d,xn) reactions on $^{61}$Ni and $^{62}$Ni were neglected due to the low isotopic abundance and the relatively high Q-value of the reactions. For production $^{61}$Cu the optimum energy range was found to be beetwen 5-11 MeV and the thick target yield amounts 9.5 mCi/uAh. Yields of $^{61}$Cu from other investigated production routes are: 2.1 mCi/uAh for $^{nat}$Ni(α,x)$^{61}$Cu reactions at 21 MeV, 6 mCi/uAh using $^{59}$Co(α,2n)$^{61}$Cu at 40 MeV, 17.5mCi/uAh for $^{61}$Ni(p,n)$^{61}$Cu route at 9-12 MeV energy range [7] and 7 mCi/uAh for $^{62}$Ni(p,2n) reaction at 15-18 energy range [8]. The (d,n) process has lower yield than the investigated proton induced reactions, but has the advantages that low energy cyclotron can be used and due to the higher isotopic abundance of $^{60}$Ni in natural nickel ( $^{60}$Ni 26.1 %, $^{61}$Ni 1.13% and $^{62}$Ni 3.59%) the target material is significantly cheeper.

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# Status and Progress of Applied Nuclear Data Program

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## New experimental results

Measurements of excitation functions used in the field of thin layer activation technique and for monitoring of the performance of different charged particle beams were continued in collaboration with the Institute of Nuklearchemie (Forschungszentrum Jülich, Germany) and Cyclotron Department of Free University of Brussels (Belgium).

Excitation functions of the following charged particle reactions were measured:

- Alpha particle induced reactions on $^{nat}$Ti, $^{nat}$Ni and $^{nat}$Cu up to 40 MeV.
- Deuteron induced reactions on $^{nat}$Ti, $^{nat}$Ni, $^{nat}$Fe, $^{nat}$Cu, and $^{nat}$Mo up 20MeV.
- Reactions of medically important radioisotopes of $^{123,124}$I via $^{123}$Te(d,xn)$^{123,124}$I and $^{122}$(d,n)$^{123}$I also have been measured at 10 and 13 MeV deteron energies.
- Cross sections of $^{nat}$Ne($^{3}$He,x)$^{22,24}$Na, and $^{nat}$Ne($\alpha$,x)$^{22,24}$Na were measured from threshold up to 28 MeV $^{3}$He-, and 20 MeV of alpha particle energies for investigation of production possibilities of $^{22,24}$Na for ecological use.
- Measurement of cross sections of $^{197}$Au($^{3}$He,xn) reactions has been started to investigate the possible production of different Tl-isotopes for biological studies.

## Data compilation and data evaluation

Compilation of experimental cross section data of charged particle induced nuclear reactions in internationally accepted EXFOR format has been continued, several new entries have been compiled in 1995.

Compilation and critical evaluation of cross section data of proton induced nuclear reactions on natural nickel have been started.

A new project has been started for developing of recommended data sets of most important charged particle nuclear reactions used for medical isotope production (single photon and positron emitters) and for monitoring charged particle in collaboration with the International Atomic Energy Agency and with other four laboratories.

These works were partly supported by the International Atomic Energy (Project No. 6969/RB), by the German-Hungarian Collaboration in Science and Technology ( Project No. 231.7) and by the Scientific Collaboration Agreement between of the Belgian NFWO and the Hungarian Academy of Sciences.

# Consistent algebraic description of $\alpha$–cluster systems in the $A$=16 to 20 mass region

G. Lévai and J. Cseh

Based on earlier applications of the Semimicroscopic Algebraic Cluster Model (SACM) [1] we extended and reparametrized its Hamiltonian in order to enable it to describe several neighbouring cluster systems in a consistent way. One new element was the inclusion of spin–orbit terms, which are essential in the description of odd-mass nuclei. We also separated the Hamiltonian into a shell-model-like component and another one representing the coupling of the relative and internal degrees of freedom of the clusters. Considering core+$\alpha$ configurations the original and new form of the Hamiltonian (assuming $SU(3)$ dynamical symmetry) is

$$H = \epsilon + \gamma_R \hat{n}_\pi + \delta_R C^{(2)}_{SU_R(3)} + \delta_C C^{(2)}_{SU_C(3)} + \delta C^{(2)}_{SU(3)} + \theta K^2 + \beta \hat{L}^2 + \xi \hat{L} \cdot \hat{S}$$
$$= \epsilon' + \gamma_R \hat{n}_\pi + (\delta_R + \delta) C^{(2)}_{SU(3)} + \theta K^2 + \beta \hat{L}^2 - 4\delta_R \hat{Q}_R \cdot \hat{Q}_C - 3\delta_R \hat{L}_R \cdot \hat{L}_C + \xi \hat{L} \cdot \hat{S},$$

where the $R$ and $C$ indeces refer to "relative" and "core", respectively. In order to extract systematic mass-dependence of the parameters we chose $\gamma_R$ equal to the oscillator parameter for mass number $A$: $\gamma_R = \hbar\omega = 45\ A^{-1/3} - 25\ A^{-2/3}$.

We applied the above standardized Hamiltonian to the cluster systems $^{12}C+\alpha$, $^{14}C+\alpha$, $^{15}N+\alpha$ and $^{16}O+\alpha$ by fitting the remaining parameters to the experimental spectra of $^{16}O$, $^{18}O$, $^{19}F$ and $^{20}Ne$. The general trend of the parameters showed smooth behaviour with respect to the mass number. Based on this finding we determined the parameters for the missing $A$=17 case by interpolation from those obtained for the other $A$ values. The model spectrum of the $^{13}C+\alpha$ system was then constructed using these parameters and it was compared to the experimental spectrum of the $^{17}O$ nucleus. The agreement between the general features of the two spectra (e.g. the location and the density of states with given $J^\pi$ values, etc.) was remarkably good, although they had not been fitted to each other.

We plan to extend this parameter systematics to further mass regions and cluster configurations.

This work was supported by the OTKA (No. T14321) and the U.S.–Hungarian Science and Technology Joint Fund (JF345/93).

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# A geometrical relation of the semimicroscopic algebraic cluster model

P. O. Hess†, G. Lévai, J. Cseh

A geometrical mapping of the semimicroscopic algebraic cluster model is given. The method is an extension of that of refs. [1,2]. The geometrical variables are the relative radius vector and the quadrupole deformation parameters. In order to obtain the geometrical relation we calculate the expectation value of the Hamiltonian of the semimicroscopic algebraic cluster model [3] ($\mathbf{H}_{mic}$) with respect to the trial state $\mid \alpha >= \mathcal{N}_{N,n_o}(\alpha \cdot \pi^\dagger)^{n_o}\ [s^\dagger + (\alpha \cdot \pi^\dagger)]^N \mid 0 >$. Here, $\mathcal{N}_{N,n_o}$ is the normalization constant and $n_o$ is the minimal number of $\pi$-bosons, which is a consequence of the conservation of the Pauli-principle [3]. The potential is then defined by this expectation value, i.e., $V(\alpha) = < \alpha \mid \hat{H}_{mic} \mid \alpha >$. The variables $\alpha = (\alpha_m)$ are the collective parameter and can be related to the internuclear distance by the condition $< 0 \mid \mathbf{r}_m \mid 0 >= r_m$, with $\mathbf{r}_m = \sqrt{\frac{\hbar}{2m\omega}} \frac{(\pi_m^\dagger \sigma + \sigma^\dagger \pi_m)}{\sqrt{<0|\sigma^\dagger \sigma|0>}} + r_{o,m}$. Here $r_{o,m}$ defines the position of the nuclear molecular potential between the clusters and is given by $r_{o,m} \approx \sqrt{\frac{\hbar}{m\omega}} n_o$. The expression of the internuclear distance operator $r_{o,m}$ is determined by starting from the original expression and extending it such that the new operator conserves the total number $N + n_o$ of $\sigma$- plus $\pi$-bosons and that for $N = 0$ the mean square radius is conserved. As a potential one gets, up to a constant, a linear combination of terms like $(r - r_o)^n$ $(n = 2, 4)$.

The deformation variables of each cluster are defined as given in ref. [4]. This introduces a deformation and orientation dependence into the potential. The orientation dependence has its origin in the fact that the quadrupole deformation variables $\alpha_{2m}(k)$ $(k = 1, 2)$ of each cluster are independent.

The method was applied to the two cluster systems $^{16}O + \alpha$ and $^{12}C + \alpha$. The results are consistent to the ones obtained from geometrical models[5].

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# Cold binary fission and the pseudo SU(3) symmetry

A. Algora and J. Cseh

We investigate the cold binary fission processes of heavy nuclei from the microscopic viewpoint of nuclear structure, based on the pseudo SU(3) shell model scheme. As an example we consider the possible binary fission modes of the $^{252}$Cf nucleus, some of which have recently been observed experimentally [1]. These fission modes turned out to be forbidden in the approximation of the leading representation. The forbiddenness of different fission channels is analysed quantitatively.

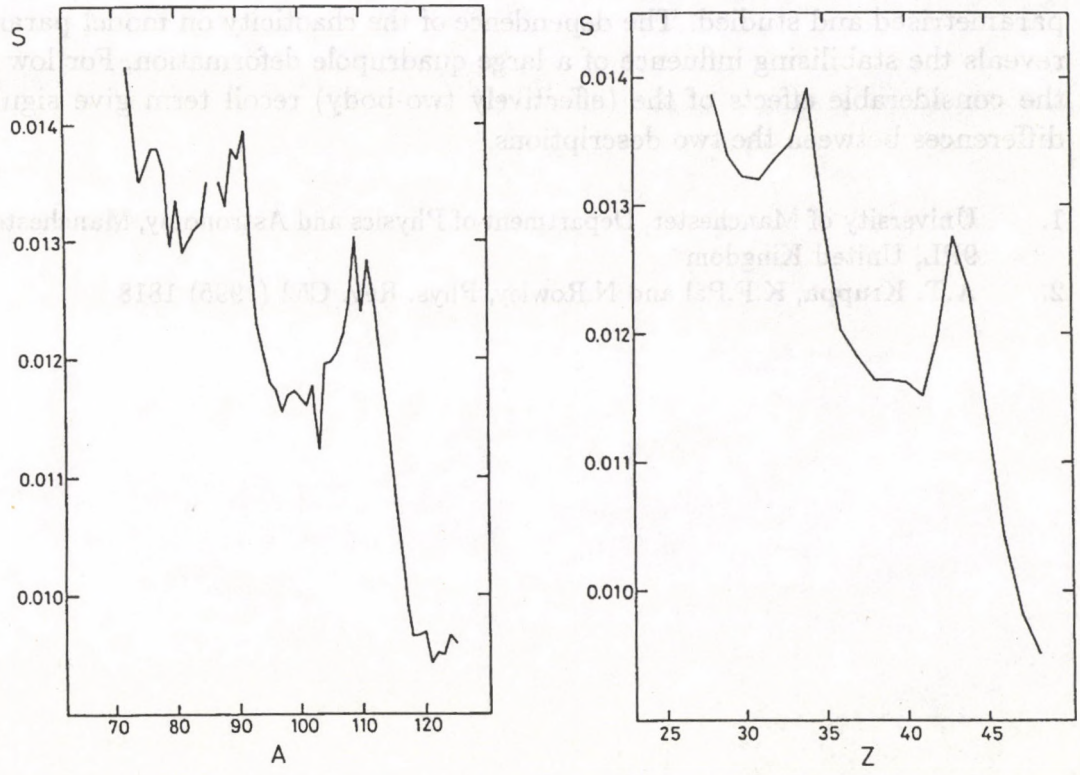


Fig. 1. The reciprocal forbiddenness $S$ versus mass number $A$ (charge number $Z$) of one of the clusters: $^{252}_{98}\mathrm{Cf}_{154} \rightarrow {}^{A}_{Z}\mathrm{X} + {}^{252-A}_{98-Z}\mathrm{Y}$. The results presented here for a value of $A$ ($Z$) were obtained by averaging over all possible binary channels with different charge numbers $Z$ (mass number $A$).

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# Chaotic behavior in the cranking and particles-rotor models

A. T. Kruppa, K.F. Pál and N. Rowley[1]

We investigate[2] the consequences on the order/chaos transition of replacing the scalar rotational energy of the particles-rotor model by a one-body cranking term.The nearest neighbor distribution of energy levels and the spectral rigidity are studied as a function of the spin or cranking frequency, respectively. Exact energies for our statistical analyses are obtained from a full diagonalisation of a many-body Hamiltonian with two-body forces for six particles in an $i_{13/2}$ shell coupled to a deformed core. In this model, the competing physical effects (two-body interaction strength, quadrupole deformation, and moment of inertia) are easily parametrised and studied. The dependence of the chaoticity on model parameters reveals the stabilising influence of a large quadrupole deformation. For low spins, the considerable effects of the (effectively two-body) recoil term give significant differences between the two descriptions.

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2. A.T. Kruppa, K.F.Pál and N.Rowley, Phys. Rev. C52 (1995) 1818

# Unified description of branching ratios and anisotropies for the $\alpha$−decay of deformed actinide nuclei

T. L. Stewart[1], M. W. Kermode[1], D. J. Beachey[1]

N. Rowley[2,3], I. S. Grant[2]

A. T. Kruppa

$\alpha$−decay through a deformed potential barrier produces significant mixing of the partial wave amplitudes when mapped from the nuclear interior to the outside. Using both WKB and coupled-channels transmission matrices, we have found[4] that *all* known branching ratios of even-even actinide nuclei can be fitted with essentially the same internal amplitudes. These same amplitudes also give good results for three known anisotropies of the favored decays of odd nuclei in the same mass region.

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# A representation for expanding resonances of realistic nuclear potentials

R. J. Liotta[1], E. Maglione[2], N. Sandulescu[3] and T. Vertse

In the completeness relation suggested by T. Berggren [Nucl. Phys. A109 (1968) 265.] a set of bound states, outgoing resonances and a limited number of scattering states calculated with energies from a complex path appear. These states form the basis of the Berggren representation. Since very little is known about the properties and the applicability of this representation an attempt has been done to explore this field. The basis vectors are taken to be the eigenvectors of a Hamiltonian having finite and spherically symmetric local potential. The potential used is a sum of the usual phenomenological Saxon-Woods and spin-orbit nuclear potential terms characterizing a more or less realistic neutron potential for $^{209}Pb$. Then we modify the parameters of the potential and calculate the matrix elements of this modified Hamiltonian using our basis. By diagonalizing the matrix we receive approximate eigenvalues of the modified Hamiltonian what we compare them to the "exact" eigenvalues calculated by solving the radial Schrödinger equation numerically using computer code GAMOW [T. Vertse, K.F. Pál and Z. Balogh, Comput. Phys. Commun. 27(1982)309].

Diagonalization of the Hamiltonian reproduce all the bound state and the resonant energies lying abow the complex path with reasonable accuracy and the rest of the eigenvalues still remain along the path. Convegence of the approximate bound and resonant energies to the "exact" values is reasonably fast when the number of basis (scattering) states increases. It is especially fast when a vector with the same number of internal nodes as the one to be expanded is present in the basis. Generalization of the method for wider class of Hamiltonians (e.g. including non-local or deformed potentials) is under way.

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# Calculation of shell corrections close to the drip line including the continuum part of the spectrum

T. Vertse, R. J. Liotta[1], W. Nazarewicz[2], N. Sandulescu[3] and

A. T. Kruppa

The Strutinsky shell correction method has been proved to be a reliable tool in calculating binding energies of nuclei along the beta-stability line. It is still an open question, how reliable the method is far from the stability region. Since the mean field felt by the nucleons can be approximated by a finite potential well, it is evident that the effect of the continuum should not be neglected especially in the vicinity of the drip lines.

A new approach has been developed for calculating the Strutinsky shell correction for finite potentials. The effect of the continuum is taken into account by using contour integration on the complex energy plane i.e. the integral along the real energy axis is replaced by an integral along a complex path and sum of discrete terms belonging to the resonances lying between the real axis and the path. Narrow resonances contribute to the level density in the same way as bound levels. The advantage of this transformation is that it is exact and we can chose the path going far from the resonant energies and the integrand along such a path is a smooth function. The integral of this function can be calculated faster and more accurately than the integral along the real axis. The long standing debate between Lin (W.-f. Lin, Phys. Rev. **C2**, 871 (1970)) and Ross-Bhaduri (C.K. Ross and R.K.Bhaduri, Nucl. Phys. **A188**, 566 (1972)) about the shell correction in the case of $^{208}Pb$ has been settled using the present method.

The power of the new method is illustrated by applying it to the case of the proton drip-line-nucleus $^{100}$Sn.

This work was partially supported by the Hungarian National Research Fund (OTKA) trough the contract T17298 and the financial support of the Swedish Royal Academy of Sciences is acknowledged.

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# ATOMIC PHYSICS

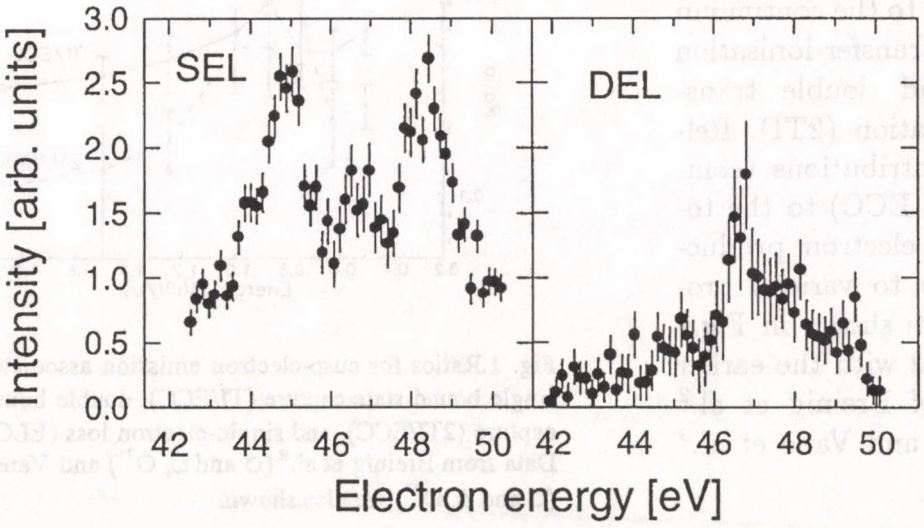
# Single and Double Electron Detachment from $H^-$ in Collisions with He

L. Víkor[$] , L. Sarkadi , F. Penent[1], A. Báder and J. Pálinkás

We studied the electron detachment in the collision of $H^-$ with gas target by the method of zero-degree electron spectroscopy performed with small electron acceptance angles [1,2,3]. In this way we could get information on the ejection of extremely low-energy electrons (due to the frame transformation).

For $H^-$ the electron detachment can proceed via *single electron loss* (SEL) and *double electron loss* (DEL). On the Figure results of our investigation of SEL and DEL processes in 85 keV $H^-$ on He collisions are presented. The $H^-$ ions were obtained by charge-changing collisions from $H^+$ ions produced with the 1.5 MV Van de Graaff accelerator of ATOMKI. SEL and DEL were identified detecting electrons in coincidence with the outgoing $H^0$ and $H^+$ particles, respectively. Regarding DEL, its contribution to the total electron yield is quite large (SEL: 73%, DEL: 27%). This means that the cusp seen in previous non-coincidence experiments for $H^-$ can be explained mainly by DEL. Similarly as in ref. 4, large asymmetry was observed for the DEL cusp.

The $(2s2p)^1P^\circ$ shape resonance of $H^-$ above the $H(n = 2)$ threshold giving rise to broad lines on each side of the cusp as can be seen in the SEL spectrum.

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# Cusp-Electron Emission from Intermediate-Energy $O^{7+,8+}$ + Ar Collisions

P.A. Závodszky[1] , E.Y. Kamber[1] , O. Woitke[1] , J.A. Tanis[1] , L. Sarkadi , L. Víkor[$] , J. Pálinkás , D. Berényi, M. Kuzel[2] and J. McDonald[3]

Our previous investigation[1] of cusp-electron production in $O^{7+}$ + Ar collisions was extended to lower energies and $O^{8+}$ projectiles. This work was done using the 6 MeV tandem Van de Graaff at Western Michigan University. The energy range of the present measurements is 0.3-1.5 MeV/u for $O^{7+}$ and 0.5-1.5 MeV/u for $O^{8+}$. Electrons emitted at 0° were detected in coincidence with the charge-state selected outgoing projectiles. The following processes were identified: electron capture to the continuum (ECC), electron loss to the continuum (ELC), transfer ionisation (TI), and double transfer ionisation (2TI). Relative contributions (compared to ECC) to the total cusp-electron production due to various processes are shown in Fig.1 compared with the earlier results of Breinig et al.[2] for $O^{7+}$ and Vane et al.[3] for $O^{8+}$.

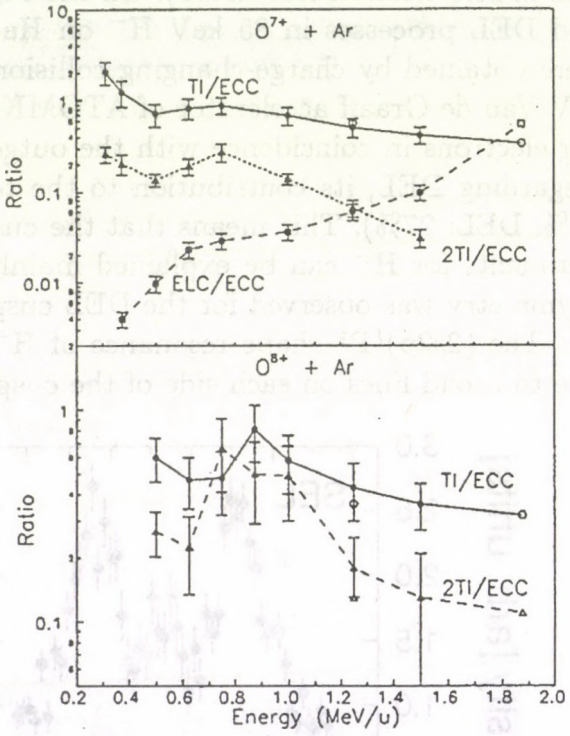


**Fig. 1.Ratios for cusp-electron emission associated with single bound-state capture (TI/ECC), double bound-state capture (2TI/ECC), and single-electron loss (ELC/ECC). Data from Breinig et al.[2] (○ and □, $O^{7+}$) and Vane et al.[3] (○ and △, $O^{8+}$) are also shown.**

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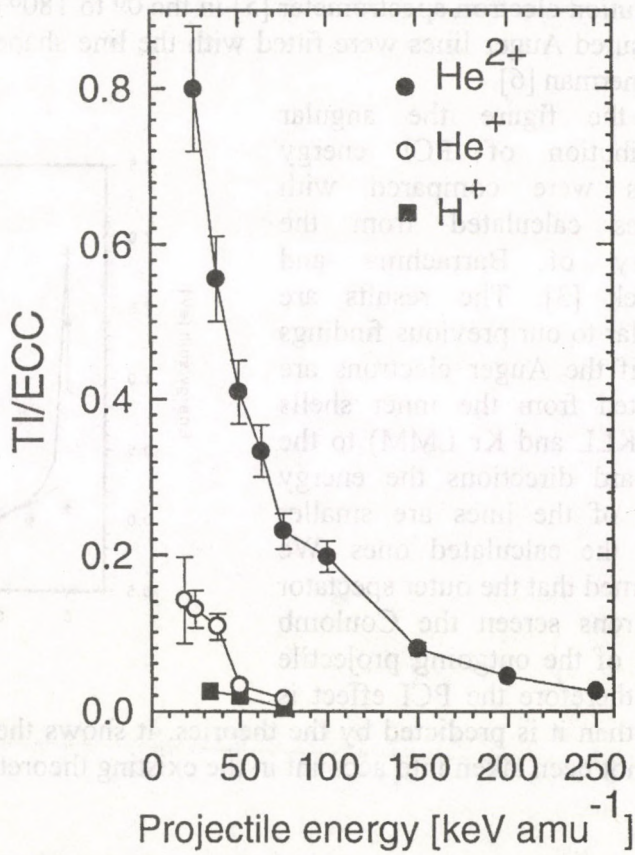
# Cusp-Electron-Production due to Transfer Ionization in 25-150 keV/u $He^{2+}$+Ar Collisions

L. Víkor[$] , L. Sarkadi, J.A. Tanis[1], A. Báder, P.A. Závodszky[1] , J. Pálinkás and D. Berényi

Cusp-electron production (i.e. continuum electrons emitted along the beam direction and traveling with the beam velocity), has been investigated for 25-150 keV/u $He^{2+}$ + Ar collisions. The ions were produced with the 1.5 MV Van de Graaff accelerator of ATOMKI. Here we focus on cusp-electron emission associated with bound-state capture, a process referred as transfer ionization (TI). This work represents an extension of our previos work[1-3] for $H^+$, $He^+$, and $O^{7,8+}$ + Ar collisions.

Cusp electrons were detected in coincidence with outgoing $He^{2+}$ and $He^+$ to identify the electron capture to the continuum (ECC) and TI contributions. In the Figure the contribution of TI relative to ECC. This ratio represents the probability for the two-electron TI process compared to the one-electron ECC process is shown. The present data are shown along with earlier results for $H^+$ (Ref.2) and $He^+$ (Ref.1). For the present data the ratio values are larger than the corresponding values for either $H^+$ or $He^+$ more than expected from a simple $Z^2$ scaling.

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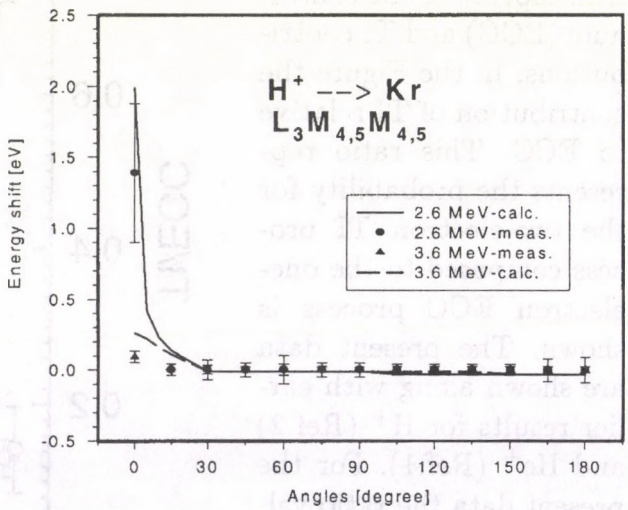
# The effect of Post-Collision Interaction on KR $L_{2,3}MM$ Auger Lines at 2.6 and 3.6 MeV $H^+$ impact

Gy. Víkor#, L. Tóth, S. Ricz, Á. Kövér,
B. Sulik and J. Végh

In our previous studies [1-2] we investigated the angular distribution of the energy shift of Auger lines caused by post collision interaction (PCI) at $H^+$ and $He^+$ impact. The results were in good agreement with the theoretical predictions [3]. In the last Annual Report [4], however, we showed that the energy shift is far more smaller than the expected value when the Auger electrons originated from core holes (Ar KLL). In order to verify this surprising results we extend our investigation to study the angular distribution of the energy shift of other core excited Auger electrons.
The Kr $L_{2,3}M_{4,5}M_{4,5}$ lines were studied at 2.6 and 3.6 MeV $H^+$ impact. The energy and angular distribution of Kr Auger lines were measured with the ESA-21 high resolution electron spectrometer [5] in the 0° to 180° angular region at every 15°. The measured Auger lines were fitted with the line shape recommended by Kuchiev and Sheinerman [6].

On the figure the angular distribution of PCI energy shifts were compared with values calculated from the theory of Barrachina and Macek [3]. The results are similar to our previous findings i.e. if the Auger electrons are emitted from the inner shells (Ar KLL and Kr LMM) to the forward directions the energy shift of the lines are smaller than the calculated ones. We assumed that the outer spectator electrons screen the Coulomb field of the outgoing projectile and therefore the PCI effect is less than it is predicted by the theories. It shows the importance of screening which has not been taken into account in the existing theoretical models.

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# Electron spectroscopy with very-highly-charged-ions

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A tandem parallel-plate electron spectrometer, which was designed and built at ATOMKI, was installed in the extraction beamline of the Electron Beam Ion Trap (EBIT) at the National Institute of Standards and Technology (NIST), U.S.A. The underlying purpose of the experiment was to investigate the feasibility of ion-surface intereaction studies with moderate high energy-resolution electron-spectroscopy using the highly-charged-ions of the EBIT.

There have been earlier experiments to measure the interaction of slow highly-charged-ions with surfaces at the EBIT source of the Lawrence Livermore National Laboratory [1]. These measurements concluded that EBIT sources offer a unique opprtunity to extend the slow ion-surface interaction studies into the very-high-charge-state regime.

In our present experiment we made an attempt to investigate the convoy electron production in the grazing incidence impact of slow highly-charged-ions ($Xe^{44+}$) on a gold surface. Convoy electrons are travelling with the speed and in the direction of the outgoing projectiles and were investigated in detail several times in the case of fast low charge ions [2-3]. In the present experiemet the $Xe^{44+}$ ions were created in the EBIT. The extraction, transport and charge state selection was performed by the newly operational extraction system of the NIST EBIT group. The impact energy of the ions was set to 8 keV*q. To overcome limitations of our electron spectrometer due to efficiency problems at low electron eneries we have designed and built a simple acceleration lens and placed it in front of the instrument. This lens accelerates the electrons into a convinient energy regime.

The most significant spectrum is shown on Fig. 1. We a have a strong indication for the presence of convoy electrons in the interaction process, but to confirm this, further measurements are needed. These should be performed at different ion impact energies and with different ion species which were not available at this time. In a further series of experiments we plan to perform a systematic study and detailed energy position and peak shape analysis to investigate the ongoing processes in detail (e.g. convoy electron production, the effect of image charge formation).

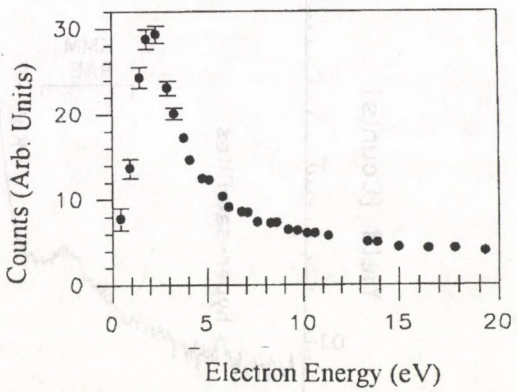


**Fig. 1.** *Spectrum of electrons in a grazing incidence $Xe^{44+}$-Au surface collission*

[1] F. Aumayr, H. Kurz, D. Schneider, M.A. Briere, J.W. McDonald, C.E. Kunningham and H.P. Winter, Phys. Rev. Lett. 71 (1993) 1943

[2] M. Breinig, S.B. Elston, S. Huldt, L. Liljeby, C.R. Vane, S.D. Berry, S.D. Glass, M. Schauer, I.A. Sellin, G.D. Alton, S. Datz, S. Overbury, R.Laubert and M. Suter, Phys. Rev. A **25**, 3015 (1982)

[3] A. Báder, U. Brinkman, L.Sarkadi, E. Takács, R. Hippler and J. Pálinkás: Observation of convoy electrons induced by Rutherfor-scattered protons, NIM B (1996) in press.

# The Kβ5 x-ray lines of Ca, Ti, Cr, and Fe

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We analised the Kβ spectra of Ca, Ti, Cr, and Fe. The measurements were performed in Ljubljana, using a Van de Graaff generator to excite the metallic samples by 1.2 MeV protons. A flat crystal spectrometer equipped with a PSD was improved (mainly the electronics) and used to get high resolution spectra. With this set up of improved resolution (5 eV at 3.7 keV), good quality spectra (Fig. 1.) have been obtained, despite the low intensity of the Kβ5 line. The evaluation of the high resolution spectra is in process. In a former paper [1] we showed the enhacement of the intensity of the Kβ5 line, where we used also our own spectra for the mentioned metals. Now we intend to get more accurate intensity values for the same targets.

This work was supported partly by the Slovenian-Hungarian Intergovernmental S&T Cooperation Programme, Project No. 9/95 and by the OTKA, grant No. T016636.

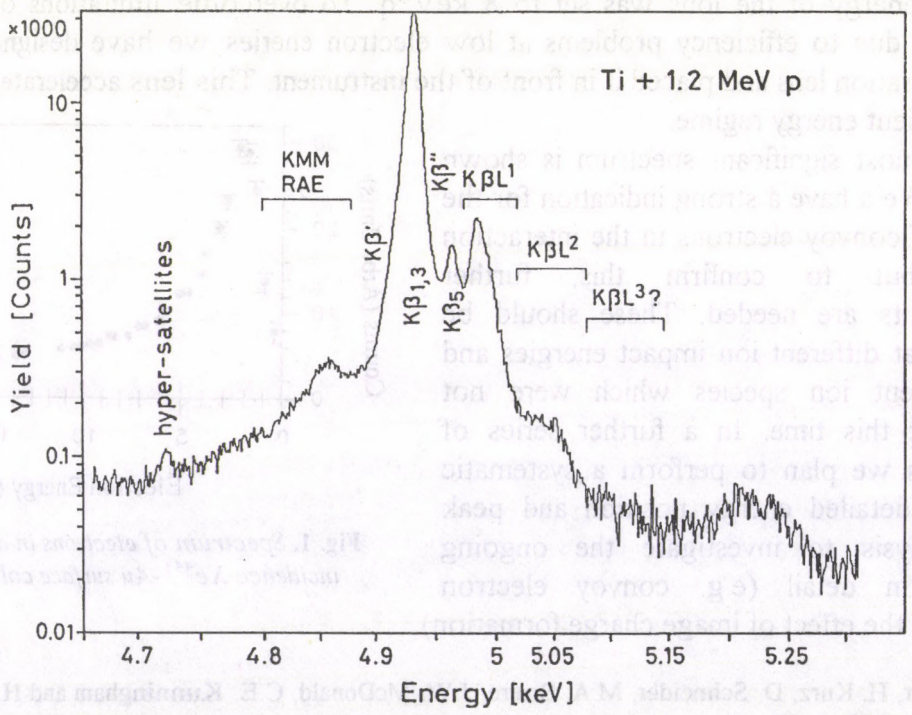


Fig. 1. The spectrum of the Ti Kβ x-ray lines.

[1] I. Török, T. Papp, J. Pálinkás, M. Budnar, A. Mühleisen, J. Kawai, J. L. Campbell, Relative intensity of the Kβ5 x-ray line. Submitted to Nucl. Instrum. Meth. B.

# The KβL$^n$ x-ray satellite lines of Ca, Ti, Cr, and Fe

M. Kavčič[1], I. Török, T. Papp, J. Pálinkás, M. Budnar[1], A. Mühleisen[1], J. Kawai[2], J. L. Campbell[3].

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We measured the Kβ spectra of Ca, Ti, Cr, and Fe. The measurements were performed in Ljubljana, using a Van de Graaff generator to excite the metallic samples by 0.7-1.5 MeV protons. An improved flat crystal spectrometer equipped with a PSD was used to get high resolution spectra. Because the intensities of the Kβ x-ray lines are much smaller than that of the Kα ones, it is not surprising, that only a few paper deals with them. To analyse the Kβ region is a difficult task: many weak and not well known transitions are there involved, like satellites, radiative Auger emissions, $K\beta_5$ line; and there is the K absorption edge of the elements. We made a systematics of the energy of the KβL$^n$ x-ray satellite lines (Fig. 1.), collecting data from the literature, and comparing our preliminary data to them. The measured energies and intensities are planned to be compared to theoretical predictions.

This work was supported partly by the Slovenian-Hungarian Intergovernmental S&T Cooperation Programme, Project No. 9/95 and by the OTKA, grant No. T016636.

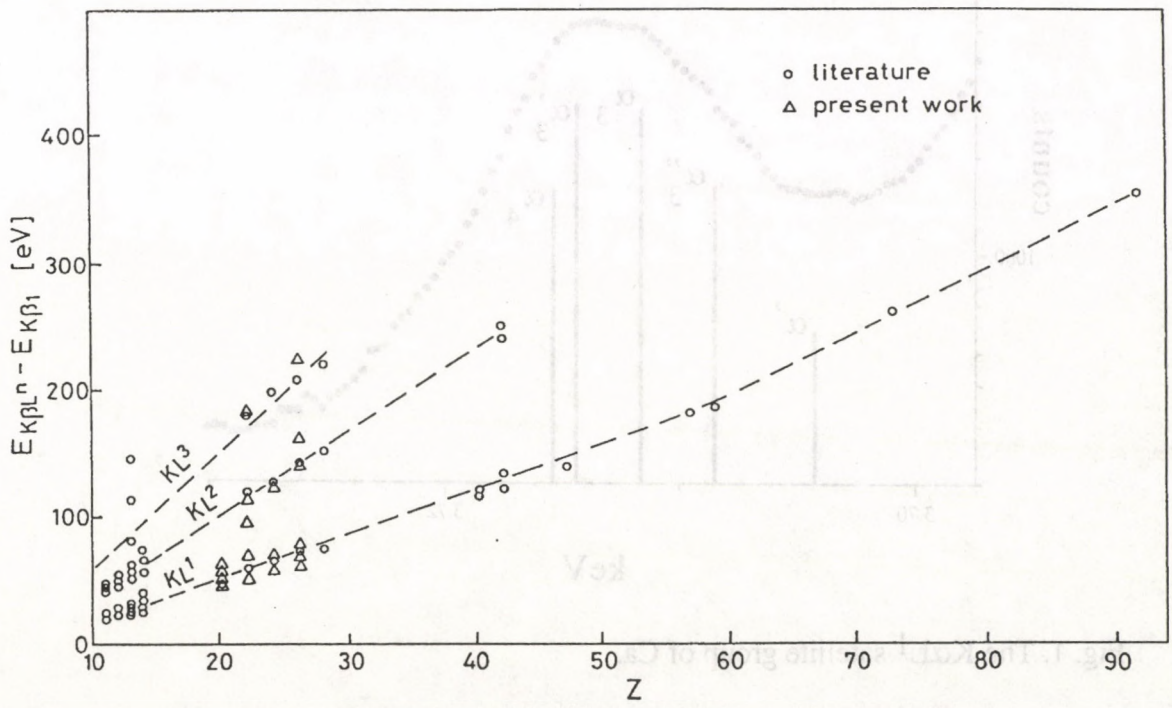


Fig. 1. Systematics of the KβL$^n$ x-ray satellite lines. Lines: guide to eye.

# Towards understanding of the Kα satellite structure at Z=20-26 elements

M. Budnar[1], M. Kavčič[1], I. Török.

[1] Jožef Štefan Institute, Ljubljana, Slovenia.

The measurements of the $K\alpha L^1$ satellites following the ionization of some Z=20-26 elements by 0.7-1.5 MeV protons have been performed to improve the data base necessary for the determination of $p_L(0)$ ionization probability below the ion-projectile matching velocity region. The precise study of the $K\alpha L^1$ satellite group revealed the structures similar to the one studied at Cu by Maskil & Deutsch [1]. The measured data are plannaed to be compared to theoretical predictions. The measurements have been done in Ljubljana, using a Van de Graaff generator to excite the metallic samples. A flat crystal spectrometer equipped with a PSD [2] was used to get high resolution spectra. The $K\alpha L^1$ satellite group of Ca is shown in Fig. 1.

This work was supported partly by the Slovenian-Hungarian Intergovernmental S&T Cooperation Programme, Project No. 9/95, and by the OTKA Grant No. T016636.

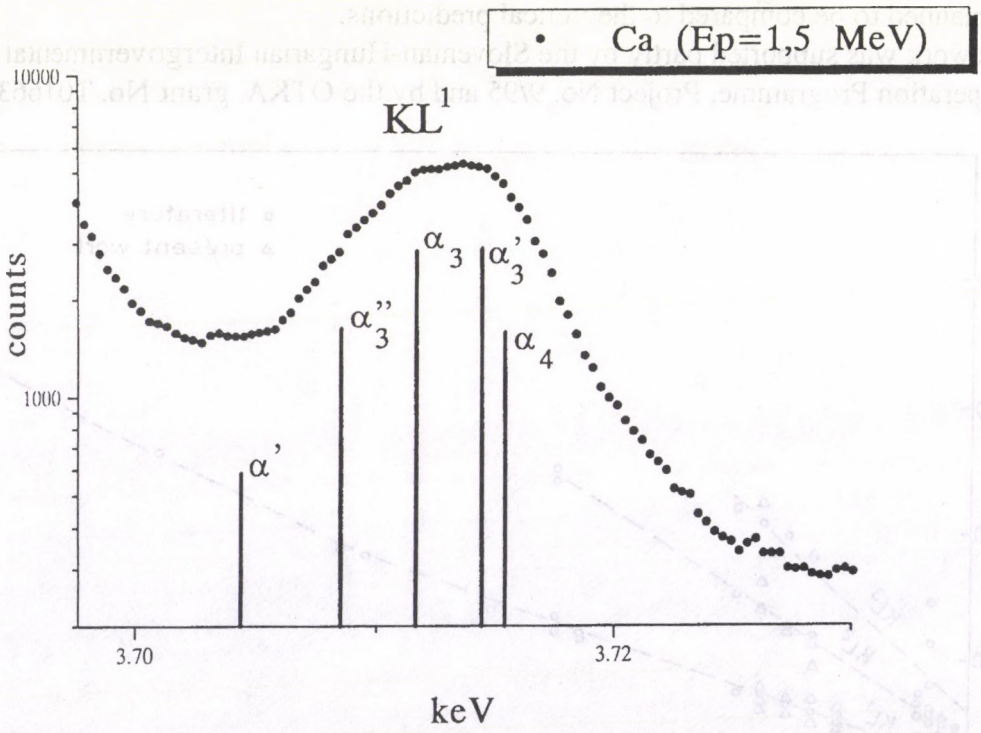


Fig. 1. The $K\alpha L^1$ satellite group of Ca.

[1] N. Maskil, M. Deutsch, Phys. Rev A38 (1988) 3467.
[2] V. Cindro, M. Budnar, M. Kregar, V. Ramsak, Ž. Šmit, J. Phys. B 22 (1989) 2161.

# Differential Elastic Cross-Section Measurements in Positron-Ar Collisions

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Recently there is a great interest in energy-resolved, elastic differential cross section (DCS) of positron scattering from Ar after Dou *et al* [1] found a marked structure in the energy range 55 - 60 eV. The structure is most pronounced at a scattering angle of 60°, where the DCS is observed to drop abruptly by a factor of two in this energy range. The origin of these features in not clear at present. The different theoretical approximations have not been able to describe this step [2]. Furthermore this structure cannot be found at electron impact

We investigated the differential elastic cross sections in order to check the data of Dou *et al* [1] and to aid the understanding the effect. The experimental set up was similar to that was used in our previous experiments [3].

Figure shows the elastic cross section data at 60° are plotted along with those of Dou *et al* [1] and the Truncated Couple-Static approximation (TCS) of McAlinden and Walters [2]. The three sets of data were normalized at 45 eV allowing the shape to be compared. Unlike the data of Dou *et al* [1] our values exhibit a shallow drop in the magnitude of the elastic cross section between 55 and 60 eV and show better agreement with the theory.

Very recently the Detroit group (Przybyla *et al* [4]) remeasured their elastic scattering data at 60° and 90° at different experimental conditions. Their results now display no convincing evidence of the structure reported previously [1].

[1]L.Dou, W.E.Kauppila, C.K.Kwan and T.S.Stein, Phys.Rev.Lett. **68**(1992)2913
[2]M.T.McAlinden and H.R.J.Walters, Hyperfine Interractions **89** (1994)407
[3] Á.Kövér, G.Laricchia, and M.Charlton, J.Phys.B: At.Mol.Opt.Phys. **27**(1994)2409
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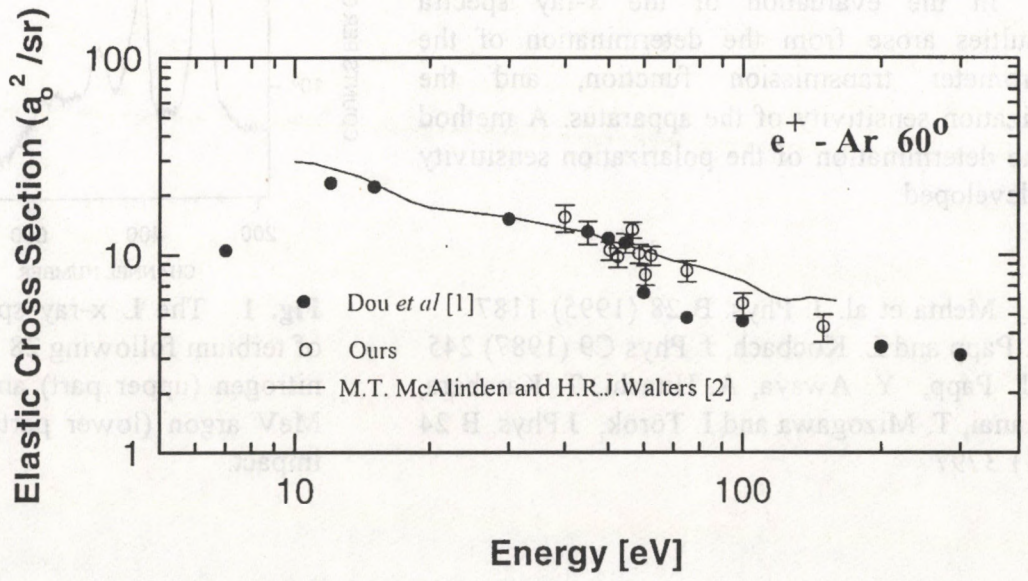

# Angular Distribution Measurements of X-rays from Multiply Ionized Atoms

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In heavy ion impact the dominant process is the multiple ionization of target atoms. However, in the determination of ionization cross sections the knowledge of decay parameters are necessary ingedients [1]. The available information on the decay parameters is very limited and strongly depends on the distributions of the vacancies on various shells. Generally, in the case of multiply ionized atoms the magnetic substate population of the initial state of the x-ray transition is nonstatistical. We have developed a formalism to describe the angular distribution and polarization of x-ray transitions between aligned initial and aligned final states [2].

To study this possibility, and to measure the L-shell x-ray yield ratios, an angular distribution measurement was carried out on terbium target using a broad range crystal spectrometer for the detection of x-rays. The experimental arrangement was similar to an earlier experiment reported in ref.[3]. The target atoms were ionized by nitrogen and argon ions of the RILAC accelerator. Reference spectra were also recorded following x-ray excitation from an x-ray tube. Typical spectra are presented for N and Ar projectile impact in figure 1. The Lγ complex was hardly discernible as an indication of the strong multiple outer shell ionization.

In the evaluation of the x-ray spectra difficulties arose from the determination of the spectrometer transmission function, and the polarization sensitivity of the apparatus. A method for the determination of the polarization sensitivity was developed.

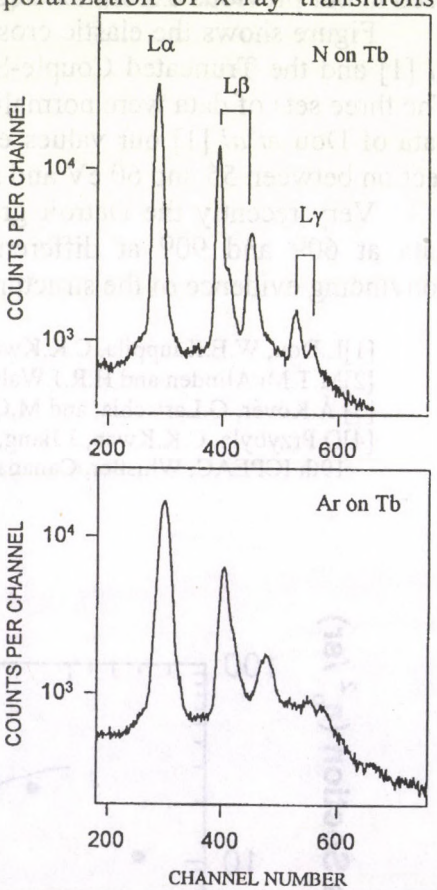


**Fig. 1**. The L x-ray spectra of terbium following 28 MeV nitrogen (upper part) and 80 MeV argon (lower part) ion impact.

[1] R. Mehta et al. J. Phys. B 28 (1995) 1187
[2] T. Papp and L. Kocbach, J. Phys C9 (1987) 245
[3] T. Papp, Y. Awaya, A. Hitachi, T. Kambara, Y. Kanai, T. Mizogawa and I. Török, J.Phys. B 24 (1991) 3797

# On the accuracy of the L-subshell ionization cross sections for proton impact. I. Spectrum fitting.

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The L x-ray spectrum of thorium following 1 MeV proton impact has been measured using a Si(Li) detector. The spectrum was analysed by various commonly used procedures. It is shown that the separation of the Lγ group into x-ray transitions of $L_1$ and $L_2$ subshells is affected by the natural lineshape model. The common practice of neglecting the natural lineshape (Lorentzian or other shapes where are many body effects) introduces systematic errors which are larger than the frequently cited error bars. In the example used here, the effects of neglecting natural lineshape are similar in size to the difference in theoretical $L_1/L_3$ and $L_2/L_3$ subshell ionization cross section ratios predicted for protons by the ECPSSR and coupled channel calculations [1]. Similar systematic errors will arise in other contexts. The optimum accuracy inherent in Si(Li) spectroscopy will only be realised if full account is taken of natural lineshapes in the treatment of the X-ray spectra.

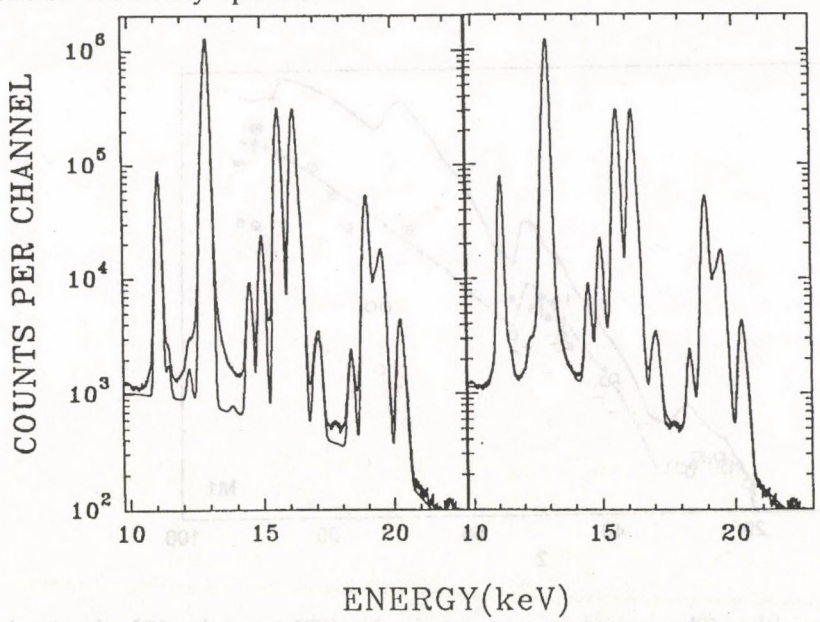


**Fig. 1**. L x-ray spectrum of thorium target bombarded by 1MeV protons and measured with a Si(Li) detector at 57.5° observation angle. The continuous line corresponds to the best fit. In the left side of the figure the natural lineshape was neglected, while in the right side figure the peaks were represented by Lorentzians and convoluted with the detector response function. The comparison demonstrates the importance of the natural lineshape in the analysis of x-ray spectra.

[1] Ž. Šmit and I. Orlić, Phys. Rev A50 (1994) 1301

# Atomic Level Widths for X-ray Spectrometry

J.L. Campbell[$] and T. Papp

[$]Guelph-Waterloo Program for Graduate Work in Physics,University of Guelph, Guelph, Ontario, Canada N1G 2W1

A self-consistent set of level widths for the K-N7 subshells is assembled [1] using lite-rature experimental data from a variety of spectroscopies. A typical example for the M1 subshell is presented in Fig. 1. The bulk of our data are obtained from X-ray photo-electron spectroscopy (XPS) and X-ray emission spectroscopy (XES). The former provides level widths directly and the latter provides the sum of the two widths involved in the X-ray transition. In cases where Coster-Kronig processes contribute significantly, the widths differ from the predictions of the atomic single-particle model (SPM) [2]; in the restricted regions where atomic many-body predictions are available [3], the agreement is much better. The assembled widths will be useful to Si(Li) spectroscopists who wish to include natural width in the description of spectrometer lineshape; such inclusion will improve accuracy in both fundamental and analytical work. The present database is also of value in identifying where improvements to our presently incomplete knowledge of natural widths are most critical.

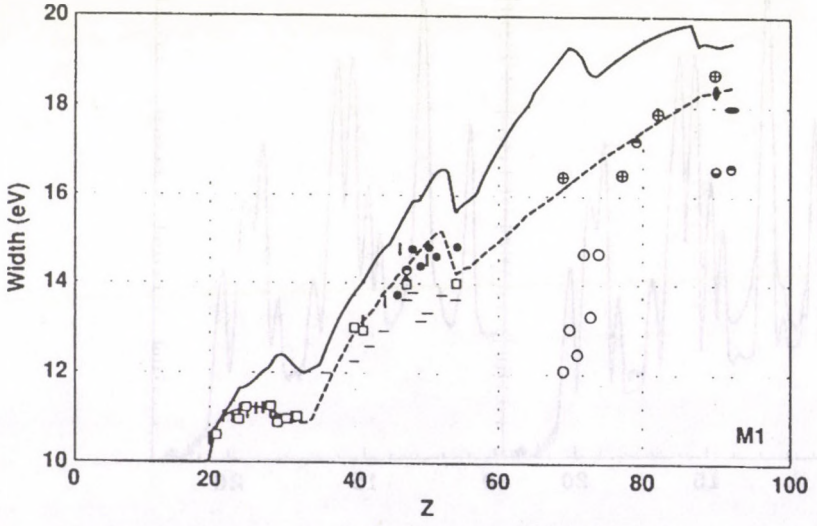


**Fig. 1.** M1 level widths. The continuous curve is the SPM results [2], the broken curve represents our database. Horizontal bars give the many-body predictions [3].

[1]J. L. Campbell and T. Papp X-Ray Spectrometry, **24** (1995) 307-319

[2]S.T. Perkins, D.E. Cullen, M.H. Chen, J.H. Hubbell, J. Rathkopf and J.H. Scofield, Tables and graphs of atomic subshell relaxation data derived from the LLNL evaluated atomic data library Z = 1-100. Lawrence Livermore National Laboratory report UCRL50400 Vol. **30**, 1991.

[3]M. Ohno, Phys. Rev. **B29**, (1984) 3127

# $M_4$ and $M_5$ Level Widths of Tungsten

T. Papp, D. Varga, J. Végh and G. Kalinka

The atomic level widths are basic parameters in electron and x-ray spectroscopy and they are also important in analytical applications. The usual technique, to determine the level width in x-ray emission spectroscopy, applies crystal diffraction spectrometers. The transmission function of the crystal diffraction spectrometers is close to the Lorentzian line shape. The deconvolution of this Lorentzian contribution from the Lorentzian distribution of the atomic level width is necessary to determine the widths of the x-ray transition. This method resulted in large scattering of the level widths [1].

An alternative approach could be the PAX spectroscopy (photoelectron spectroscopy for the analysis of x-rays), where the transmission function of the electron spectrometer is close to a Gaussian distribution. We have carried out a feasibility PAX study on the M-shell x-rays of tungsten. The halfwidth of the spectrometer function was smaller by an order of magnitude, than the natural width of the tungsten M x-rays. Beside the improvement in resolution, the deconvolution of Gaussian and Lorentzian functions is much more straightforward.

Our first results are presented in fig 1. with full diamond symbols. We have obtained almost the same width for the $M_4$ and $M_5$ levels. The continuous curves represent the most up to date theoretical calculation from ref. [2]. The theoretical calculation indicated an increased width of the $M_4$ level, compared to the $M_5$, in the atomic number (Z) range of $60<Z<80$. This predicted large increase is the consequence of the large probability of the $M_{4,5}$ Coster-Kronig transition [2]. Our measurement suggests that the Coster-Kronig decay channel has much smaller strength at least in solid state.

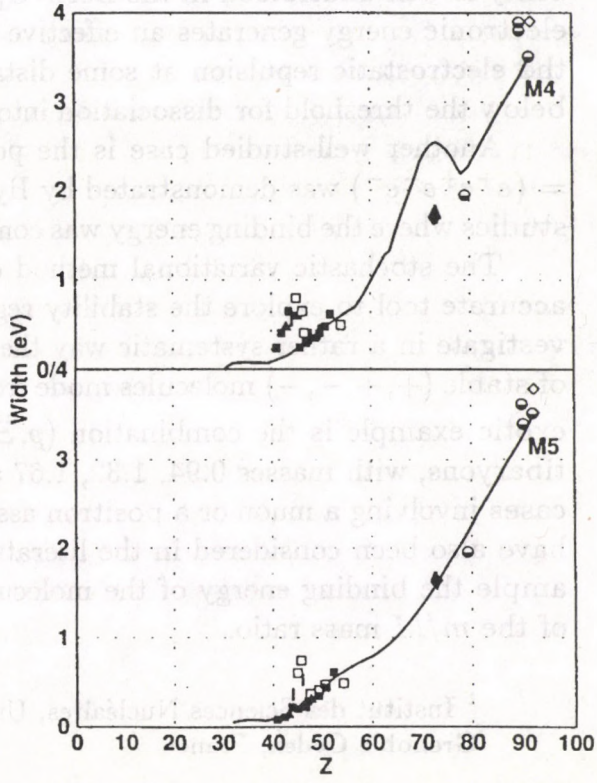


**Fig. 1.** $M_{4,5}$ level widths. The result of the present measurement is shown by the ◆ symbol. The other experimental data are taken from ref. [1]. The continuous curves are the SPM results [2].

[1]J. L. Campbell and T. Papp X-Ray Spectrometry, **24** (1995) 307-319
[2]S.T. Perkins, D.E. Cullen, M.H. Chen, J.H. Hubbell, J. Rathkopf and J.H. Scofield, Lawrence Livermore National Laboratory report UCRL50400 Vol. **30**, 1991.

# The stability domain of hydrogen-like molecules

K. Varga and Jean-Marc Richard[1]

The problem can be phrased very simply: given four structureless masses $m_i$, two with electric charge $+1$ and two with charge $-1$, do they form is there a molecule $(m_1^+, m_2^+, m_3^-, m_4^-)$ which is stable, i.e., lies below the lowest dissociation threshold? We restrict ourselves to non-relativistic quantum mechanics, and neglect strong interaction, spin forces, etc., as well as electromagnetic annihilation if for instance $m_1 = m_3$.

The best-known example is the hydrogen molecule $(p, p, e^-, e^-)$ whose stability is well understood in the Born–Oppenheimer–Heitler–London approach: the electronic energy generates an effective proton–proton potential which overcomes the electrostatic repulsion at some distances and succeeds in binding the system below the threshold for dissociation into two hydrogen atoms.

Another well-studied case is the positronium molecule. The stability of $Ps_2 = (e^+e^+e^-e^-)$ was demonstrated by Hylleraas and Ore, and confirmed in further studies where the binding energy was computed with improved variational methods.

The stochastic variational method on correlated Gaussian basis provides an accurate tool to explore the stability regions. In the present study, we wish to investigate in a rather systematic way the mass ratios of interest, and display a list of stable $(+,+,-,-)$ molecules mode from the known elementary constituents. An exotic example is the combination $(p, \overline{\Xi}^+, \Omega^-, \Sigma^-)$ of long-live baryons and antibaryons, with masses 0.94, 1.32, 1.67 and 1.20 Gev/$c^2$, respectively. Less exotic cases involving a muon or a positron associated with ordinary nuclei and electrons have also been considered in the literature and studied experimentally. As an example the binding energy of the molecule $(m, M, m, M)$ is shown as the function of the $m/M$ mass ratio.

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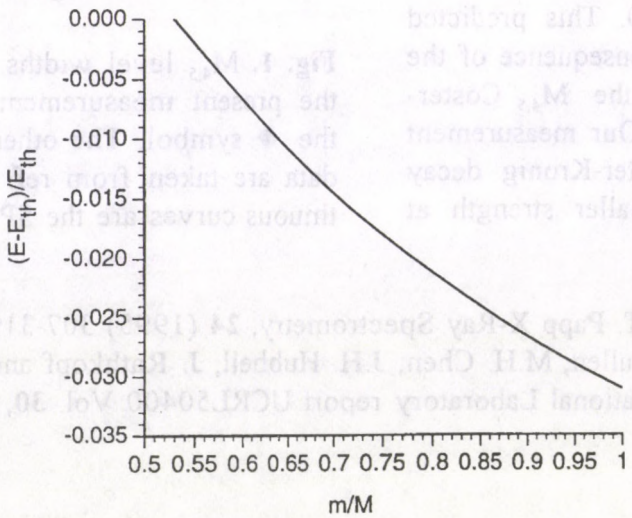

# Vacancy Sharing in L-shell Ionization of Gold and Bismuth by Boron Ions

L. Sarkadi, T. Mukoyama † and Ž. Šmit ‡

In a recent work Padhi *et al.* [1] studied the ionization of the L subshell of Au and Bi at impact of B ions in the energy range 0.48–0.88 MeV amu$^{-1}$. Their goal was to investigate further the anomalies which have been found in previous L-shell ionization works using heavy projectile ions. In these works large deviations (up to one order of magnitude in some cases) were observed between the measured cross section values (subshell cross section ratios) and the predictions of the first-order ionization theories. As an attempt to account for the anomalies, Sarkadi and Mukoyama [2] introduced the idea of the *vacancy rearrangement* (vacancy sharing): for heavy-ion impact and at relatively small collision velocities the vacancy produced by the direct ionization in one of the L subshells may transfer to another subshell with a considerable probability as a result of a secondary interaction between the projectile and the target electrons, i.e., a redistribution of the vacancies may take place between the subshells. Model calculations based on this idea could reproduce the main tendencies of the L-subshell cross section data (including $L_3$-subshell alignment parameters) in a broad range of the collision energy, target and projectile atomic number.

On the base of their experimental results, however, Padhi *et al.* questioned the idea of the vacancy rearrangement mechanism. According to these authors, the energy dependence of the cross sections obtained by them shows a *plateau structure* for all three subshells. Such a plateau is known to appear for the $L_1$-subshell cross section at impact of light ions. The structure is well understood as a consequence of a node in the radial part of the 2s ($L_1$) wave function. Padhi *et al.* explained their observation by *Stark mixing* of the target 2s and 2p wave functions: due to the mixing the node structure appears also in the ionization of the subshells characterized by 2p wave function, i.e., $L_2$ and $L_3$.

In this work we showed that the experimental data by Padhi *et al.* can be satisfactorily reproduced by the so-called 'coupled-states model' [3]. Since this model is a dynamical approach of the subshell couplings, our results support again the correctness of the idea of the vacancy rearrangement mechanism. At the same time, we demonstrated that the observations of Padhi *et al.* cannot be understood assuming only static Stark mixing of the initial 2s and 2p states.

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‡ J. Stefan Institute, University of Ljubljana, Ljubljana, Slovenia

1. H. C. Padhi, B. B. Dhal, T. Nandi and D. Trautmann: J. Phys. B **28** L59 (1995)
2. L. Sarkadi and T. Mukoyama: J. Phys. B **14** L255 (1981)
3. L. Sarkadi: J. Phys. B **19** L755 (1986)

# Butterfly States of the He Atom

G. Hock and K. Tőkési

New stability islands are observed in the classical collective motions of the two electrons of the *planar* He atom. These states are characterized by—in terms of the hyperspherical coordinates—the hyperangle $\alpha = \text{const.} = \pi/4$, i.e., $r_1 = r_2$, and its conjugate momentum $p_\alpha = 0$, strictly, with total angular momentum $L = 0$, which means symmetric motions along the Wannier ridge [1, 2]. In contrast to the commonly known Langmuir's orbits, however, the dynamical stabilization of these orbits seems to be caused by the oscillation in the hyperradius, $R = [r_1^2 + r_2^2]^{1/2}$ around an equilibrium position. In this case, an effective Hamiltonian can be constructed which consists of the kinetic energy and a time dependent effective potential energy terms, with $R$ regarded as the function of $\theta$, the angle between the electron radii, which describes the bending oscillation [2].

The calculations are done by numerically integrating the full 3-body Coulomb problem restricted to two dimensions. Two typical representatives of such states are illustrated in Fig. 1a and 1b. The long-term behavior of these states shows a definite stability in spite of the repulsion between the electrons. A butterfly shaped motion can be seen in these two cases, plotted in the 3-body center-of-mass reference frame and in the $(x,y)$ plane of the motions. The electrons remain on the same side of the nucleus during the symmetric motion. Interesting to observe in Fig. 1a the two distinct regions of the oscillations in $\theta$.

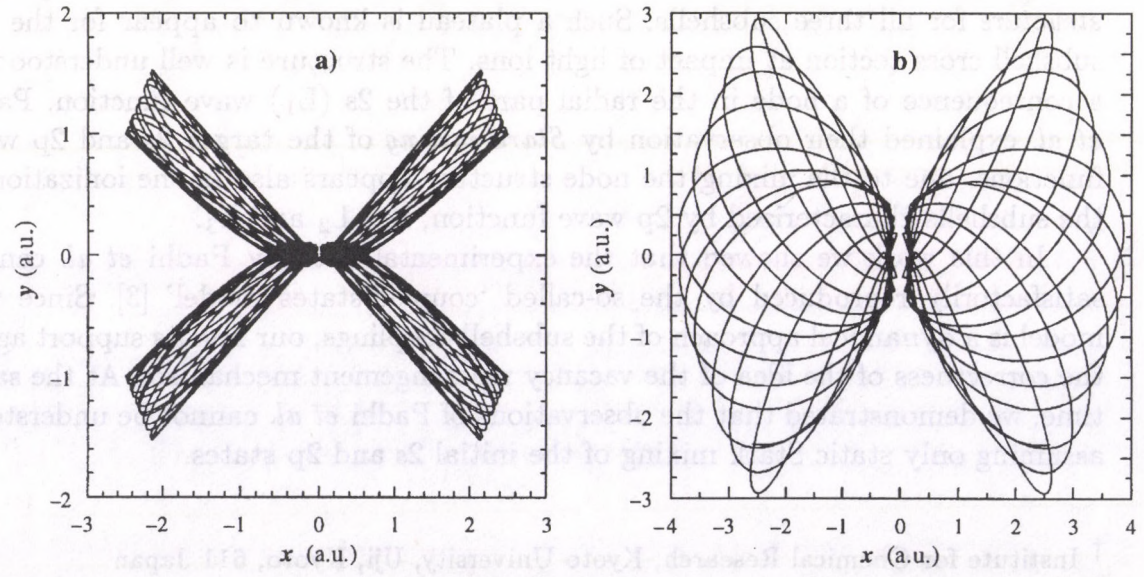


**Fig. 1.** Butterfly shaped classical collective motions of electrons in the planar He atom

## References

[1] K. Richter and D. Wintgen, *J. Phys B: At. Mol. Opt. Phys.* **23** (1990) L197
[2] J. Müller, J. Burgdörfer and D. Noid, *Phys. Rev.* A**45** (1992) 1471

# CTMC Description of the Electron Capture to the Continuum States of Scattered Projectiles

K. Tőkési, L. Sarkadi and J. Pálinkás

In a recent experiment the ECC (electron capture to the continuum) cusp peak has been observed in coincidence with the scattered projectile for 75 keV $H^+$ + Ar collisions [1]. In this work a three-body classical trajectory Monte-Carlo (CTMC) model was used to calculate doubly (DDCS) and the triply differential cross sections (TDCS) obtained in the above measurement. The three particles in the present CTMC model were as follows: the projectile ($H^+$), an atomic electron ($e^-$), and the remaining argon ion ($Ar^+$). The core of the argon ion was represented by a model potential developed by Green [2] based on Hartree-Fock calculations. A three-dimensional calculation was performed as described by Olson and Salop [3] using the initialization parameters developed by Reinhold and Falcón [4] for non-Coulombic systems.

The DDCS were calculated at four different observation angles. Comparing the shapes of the electron spectra, good agreement between the experimental and CTMC results can be observed. The amplitude of the peaks decreases rapidly with increasing observation angles. The intensity ratios are well described in the CTMC picture, but the absolute experimental intensities are larger than the CTMC ones by about a factor of 2.

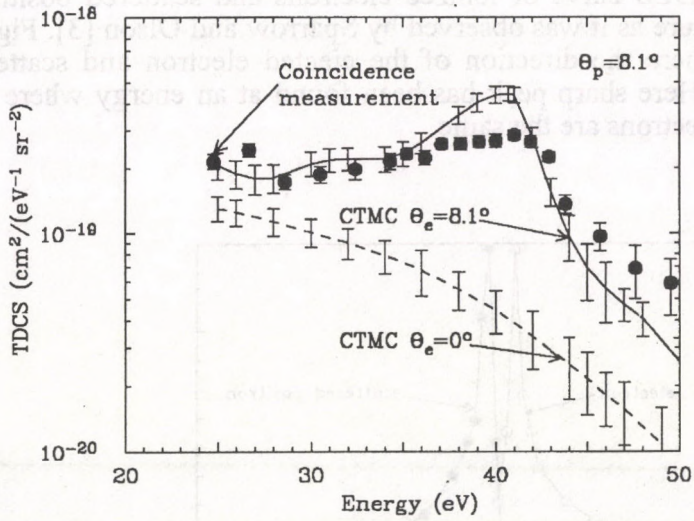


**Fig. 1.** Triply differential cross section for ejection of electrons from 75 keV $H^+$ + Ar collisions as a function of the electron energy. The angular acceptance for detection of electrons was $\theta_e$=±1.6° and $\varphi_e$=±5°. The angular acceptance for detection of scattered projectile was $\theta_p$=±3.0 and $\varphi_p$=±5°.

The calculated triply differential cross sections have been compared with the experimental data taken at 3.7° and 8.1° scattering angles. There is a satisfactory agreement between the measured and the calculated spectra. In addition, Fig. 1 shows the TDCS also for the case when the electrons emitted at zero degree and the angle of the scattered projectiles was 8.1°.

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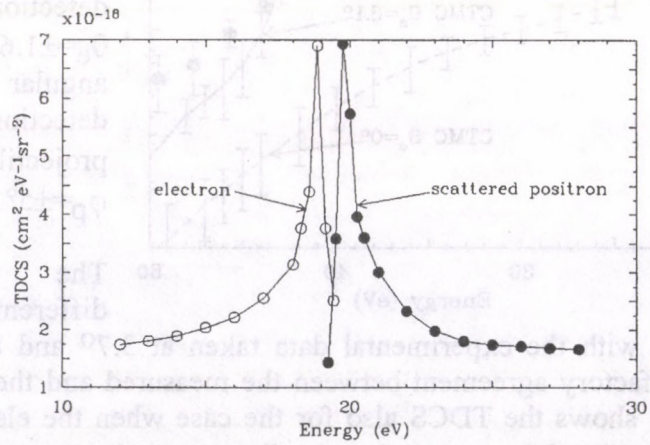
# Existence of the Electron Capture to the Continuum Peak in the Triply Differential Electron Spectrum at 54.2 eV $e^+ \rightarrow$Ar Collisions

K. Tőkési and Á. Kövér

The electron capture to the continuum (ECC) process is a special case of ionization when the ionized electron is strongly influenced by the projectile. Up till now it has not been discovered experimentally in the case of positron impact while it is well studied at ion - atom collisions. Only theoretical predictions are existing for $e^+$ impact. For H target Bandyopadhyay *et al* [1] found pronounced cusp at every ejection angle in the double differential cross section (DDCS) while Schultz *et al* [2] for H and Sparrow and Olson [3] for Ar target do not expect any structure using the classical trajectory Monte Carlo (CTMC) calculations. By using first order Born calculations Brauner and Briggs [4] showed that the cusp like structure exists in the triple differential cross section (TDCS) at H target.

In this paper the three-body CTMC method is used to determine the DDCS and TDCS for Ar target. The core of the argon ion was taken into account by a model potential developed by Garvey [5]. Due to the limited computer capacity the calculations were performed only for one impact parameter (1 au) and impact energy (54.2 eV) where the ionization cross section has a maximum. $\theta$=20° ($\Delta\theta$=±10°, $\Delta\varphi$=±20°) scattering angle was chosen for the calculations because most of the positrons scattered into this angle with the above mentioned parameters.

In our calculation the DDCS curve of ionized electrons and scattered positrons show similar "ridge-like" structure as it was observed by Sparrow and Olson [3]. Figure shows the TDCS spectrum where the direction of the ejected electron and scattered positron are almost the same. Here sharp peak has been found at an energy where the velocity of the positrons and electrons are the same.

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# Impact parameter dependence of the ionization probability in the CDW-EIS approximation

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It is well known that any study of the angular distribution of the ejected electrons must account for its interaction with the projectile in the final stage of the collision (Fainstein et al. [1]). The most successful method accounting for this effect is the CDW-EIS approximation first introduced by Crothers and McCann [2]. In our recent work (Gulyás et al.[3]) we have shown how it can be extended to arbitrary targets when using a Hartree-Fock description of the target bound and continuum states. In the present contribution, we extend the latter theory to the calculation of impact-parameter dependent ionisation probabilities. Fig. 1 shows the comparison of the first Born and CDW-EIS results for electrons ejected in the forward direction, where the two center-effects play an important role.

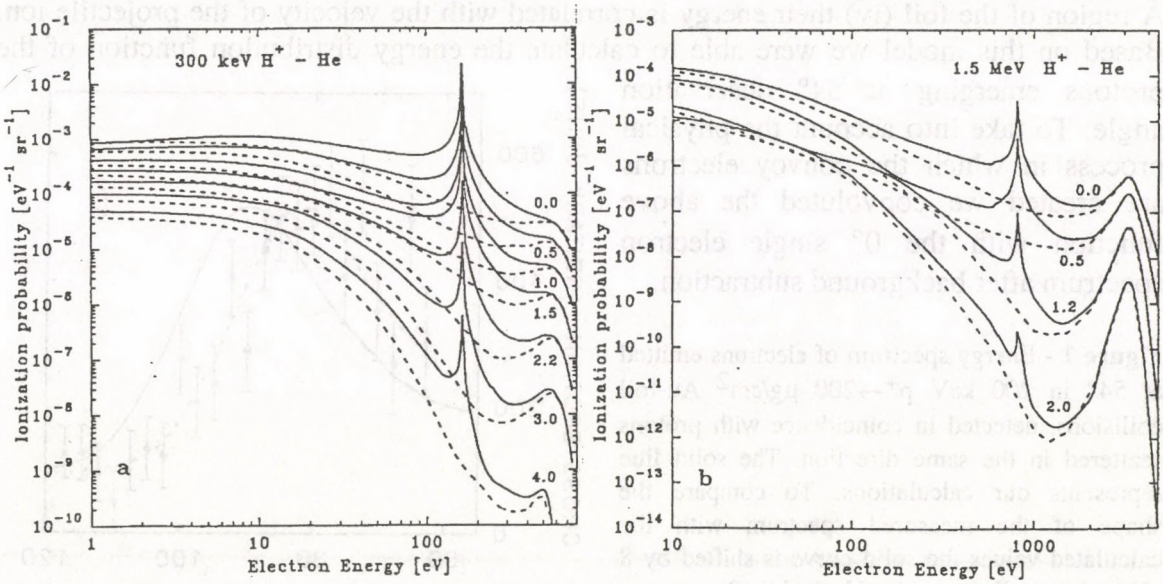


**Fig. 1.** Probability (per eV and steradian) for $0^0$ ejection of electrons from Helium by protons as a function of electron energy for various impact parameters. The impact energy is (a) 300 keV, (b) 1.5 MeV. Solid line: present CDW-EIS results, broken line: Born approximation. The curve labels give the impact-parameter value.

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# A model calculation to describe the spectrum of convoy electrons induced by Rutherford-scattered projectiles

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In a recent measurement we demonstrated the convoy-electron[1] production by ions scattered at large angles[2]. We bombarded a 200 μg/cm$^2$ vacuum-evaporated Au-foil with 200 keV protons and measured the electron energy spectrum at 0° and 54° relative to the beam direction in coincidence with the projectiles scattered into the same direction. The convoy electron peak in the 0° single electron spectrum appeared at 96 eV. In the 54° coincidence spectrum the convoy electron peak was shifted to smaller electron energies by 13±1 eV and it was broader than the peak in the 0° spectrum. We attribute this effect to the larger energy loss of the projectile scattered at larger angles.

To interpret the measured data we used the following simple model: (i) the 54° angle scattering of the protons on the crystal lattice is due to one hard collision, instead of several smaller ones (ii) the change of the kinetic energy of the incoming ion is entirely due to the electronic stopping power (iii) the convoy electrons originate from the last 100 Å region of the foil (iv) their energy is correlated with the velocity of the projectile ion. Based on this model we were able to calculate the energy distribution function of the protons emerging at 54° observation angle. To take into account the physical process in which the convoy electrons are created we convoluted the above function with the 0° single electron spectrum after background subtraction.

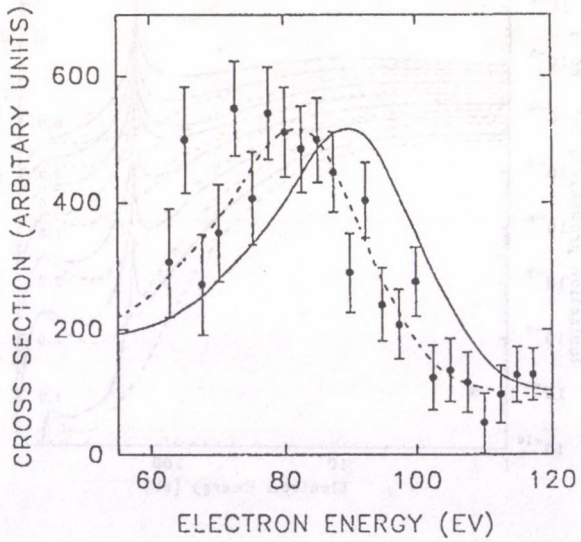


**Figure 1** - Energy spectrum of electrons emitted at 54° in 200 keV $p^+ \rightarrow$200 μg/cm$^2$ Au-foil collisions, detected in coincidence with protons scattered in the same direction. The solid line represents our calculations. To compare the shape of the measured spectrum with the calculated values the solid curve is shifted by 8 eV to the smaller energies (dashed line).

Our model calculation describes the shape of the measured convoy electron peak well (see Figure 1). However, only 5.2 eV of the 13±1 eV shift of the peak can be explained within the framework of this simple picture.

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# The moments theorem for Auger transitions

Zs. Kovács, L. Kövér and J. Pálinkás

The moments theorem, derived by Cyrot-Lackman [1], relates moments of the local density of states to the topology of the local atomic environment. The *n*th moment of the density of states is defined as :

$$\mu_j^{(n)} = \int_{whole-band} (E - H_{jj})^n d_j(\vec{r}, E) dE$$

where $d_j(\vec{r}, E)$ is the local density of states (LDOS), $H_{jj}$ are the diagonal matrix elements of the many-body Hamiltonian. The LDOS is given by :

$$d_j(\vec{r}, E) = \frac{1}{\pi} \mathrm{Im}\, G_0(\vec{r}, \vec{r}, E + i\delta)$$

where $G_0$ is the one particle Green function. The one-particle Green function satisfies the inhomogeneous Schrödinger equation. The centre of gravity of the local density of states is $H_{jj}$. Each moment can be determined exactly in *real space* in terms of hopping energies simply by counting closed paths around the *j*th atomic site. Each moment represents a property of the LDOS. $\mu_j^{(0)} = 1, \mu_j^{(1)} = 0$. The square root of $\mu_j^{(2)}$ is a measure of the width of the LDOS. The third moment measures the skewness of the LDOS about the centre of gravity. The fourth moment measures the tendency for gap in the middle of the band. The higher moments determine the structural stability of the crystal.

In the case of Auger transitions which have final state holes in valence band, instead of the total DOS, the LDOS is involved . For Auger transitions in moments theorem the one particle Green function is replaced by a two-particle Green function. In the original Cini-Sawatzky theory if the valence band is completely filled the two-particle Green function *G(E)* is given by the following expression:

$$G(E) = \frac{G_0(E)}{1 - UG_0(E)}$$

where *U* is the final state hole-hole interaction. In the presence of final state interaction the on-site matrix elements $\langle \varphi_j | H | \varphi_j \rangle = \alpha$ are increased by *U*. According to the moment theorem the centre of gravity is shifted with *U*. The off-site interaction term in the final state will have an influence on the width of the Auger transitions and an additional shift because of the increased hopping matrix elements. All these results are in concordance with the results of the extended [2] Cini-Sawatzky theory.

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# Electrostatic view of the nonlocal screening mechanism

Zs. Kovács, L.Kövér and J. Pálinkás

In the case of oxides which are insulators the screening mechanism following photoionization can be given in terms of an electrostatic model [1]. The hole present in the final state of the transition will polarize the neighbouring atoms. The electrostatic field $\vec{F}_{Li}$ on the *i*th ligand will be :

$$\vec{F}_{Li} = \vec{F}_i + \frac{1}{4\pi\varepsilon}\sum_{j\neq i}\left[\frac{3(\vec{M}_j\vec{R}_{ij})}{R_{ij}^5} - \frac{\vec{M}_j}{R_{ij}^3}\right]$$

where the sum is over all (N) ligands, $\vec{F}_i$ is the Coulomb potential of the central cation hole on the *i*th ligand, $R_{ij}$ is the distance between the *i*th and *j*th ligand and $\vec{M}_j$ is the dipol moment of the *j*th ligand. Rearranging the N equation on the right side we will have a matrix with electrostatic field on ligands due to the central hole:

$$[F_{Li}][D_{ij}] = [F_j]$$

Solving the system of linear equations, the total external relaxation energy is:

$$R^{ea} = \sum_i \int_0^{F_i} M_i \, dF_i' = \sum_i \alpha_i F_i (F_{Li} - \frac{F_i D_{ii}^{-1}}{2})$$

where $D_{ii}^{-1}$ are the diagonal matrix elements of the inverse of the matrix *D*. For calculating $R^{ea}$ a C code was developed [2]. The screening energy can be obtained from XPS measurements and from Auger parameter calculations [1].

In the case of narrow gap p-type semiconductors the Coulomb potential of the central hole must be replaced with a Thomas-Fermi type potential:

$$F_{FT}(\vec{r}) \approx \frac{1}{\vec{r}}\exp(-\vec{r}/l)$$

where *l* is the caracteristic screening length for the semiconductor. The screening length is proportional with the product of Fermi velocity ($v_F$) and $1/\omega_p$, where $\omega_p$ is the plasmon frequency. In this case the screening mechanism is divided into two processes, the polarisation of the occupied levels below the energy gap and the screening of the free electrons which are present either with doping or thermal excitation [3].

In metals the screening is almost perfect which will depend only on the DOS at the Fermi level so we have only Thomas-Fermi type screening of the free electrons.

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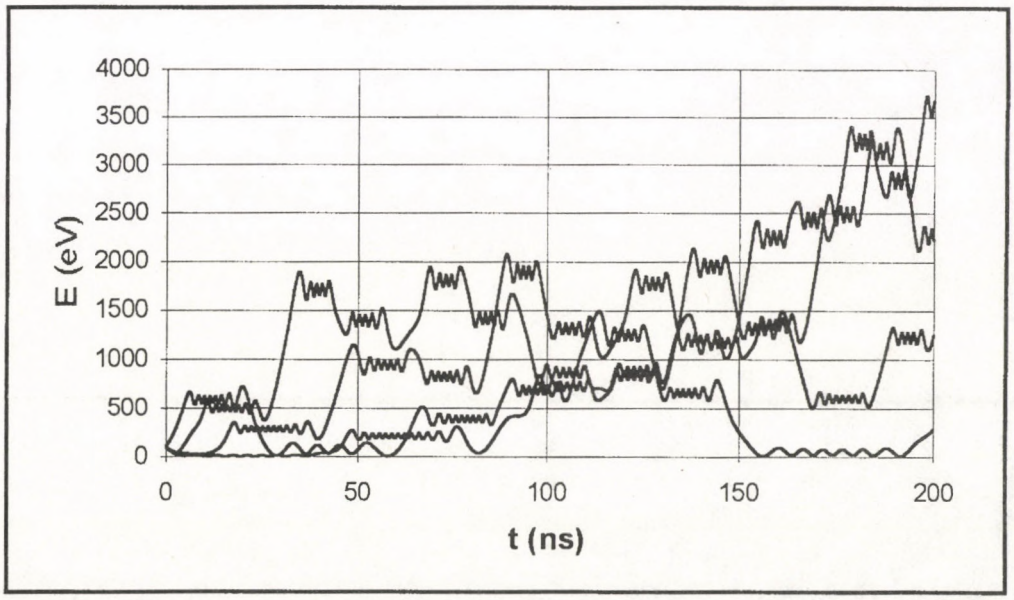
# Electron heating simulation in ECR ion sources

J. Vámosi, S. Biri and A. Valek

The simulation of the electron heating process in an ECR ion source was carried out using the TrapCAD code [1]. The long-term goal of this investigation is to get information on the elementary processes (that can be used e.g. in fusion research) and to find the relation between the micro- and the macro-parameters of the ion source.

The exact, mathematical description of the electron heating by electron cyclotron resonance is quite complicated because of the many high frequency modes inside the chamber. However, the stochastic process can be studied and one can get valid values for the energy gaining assuming a much simpler RF field but using a realistic magnetic field configuration. In the TrapCAD a circularly polarized plane wave is assumed that is propagating along the $z$ axis. The electric vector of this type of wave is rotating in the $x$-$y$ plane of the chamber. The amplitude of this field is calculated from the applied microwave power assuming a value of 2.5 for the quality factor of the loaded cavity. The initial phase difference between the rotating electric field and velocity vector of the particle can be specified by the user. The figure below shows the energy change of the electron during multiple crossing of the resonant surface. The four curves represent four different starting phases. One can see that the shape of the energy function near the crossings is quite similar to the one that can be deduced analytically [2] where, however, strong simplifications for the magnetic field were assumed. It has to be also noticed that the time between the passes becomes shorter if the particle energy is increasing.

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# Evaluated cross section and thick target yield data bases of Zn+p processes for practical applications

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In order to supply more accurate data bases for different practical purposes such as radioisotope production, nuclear analytical applications and nuclear wear and/or corrosion measurements, we have evaluated the cross sections/thick target yield data of Zn+p processes which were partly compiled in our recent contributions [1]. Since the preliminary overview of the status of these nuclear data showed that for some reactions the cross sections/thick target yields in the middle energy range are insufficient and/or contradictory, we performed cross section measurements to complete the above literature results with new experimental data [2].

We have measured the cross sections of the following reactions using highly enriched target materials: $^{66}Zn(p,x)^{65}Zn$ from 14 to 26 MeV; $^{66}Zn(p,n)^{66}Ga$ from 6 to 26 MeV; $^{67}Zn(p,n)^{67}Ga$ and $^{67}Zn(p,2n)^{66}Ga$ from 15 to 26 MeV; $^{68}Zn(p,2n)^{67}Ga$ from 20 to 26 MeV; and $^{68}Zn(p,3n)^{66}Ga$ from 24 to 26 MeV. All irradiations were performed with the external beam of the Mount Sinai CS-30 cyclotron using beam currents of ~200-600 nA. The Zn targets, some Cu and Ti foils for proton energy and intensity measurements were activated using the same primary proton energy of 26 MeV. Using all the acceptable experimental data sets we also fitted the evaluated values of the Zn+p processes to provide "standard" data sets for the above mentioned areas. In this work we present cross sections and integral thick target physical yield values for the $^{66}Zn(p,x)^{65}Zn$, $^{nat}Zn(p,x)^{65}Zn$, $^{66}Zn(p,n)^{66}Ga$, $^{67}Zn(p,2n)^{66}Ga$ $^{68}Zn(p,3n)^{66}Ga$, $^{nat}Zn(p,xn)^{66}Ga$, $^{67}Zn(p,n)^{67}Ga$, $^{68}Zn(p,2n)^{67}Ga$, $^{nat}Zn(p,xn)^{67}Ga$, $^{68}Zn(p,n)^{68}Ga$, $^{nat}Zn(p,xn)^{68}Ga$ processes below 30 MeV.

For thin layer activation (TLA) purposes we have calculated - on the basis of our fitted excitation curves - the total activity versus penetration depth as well as the distibution of activity as a function of the penetration depth for $^{65}Zn$, $^{66}Ga$, $^{67}Ga$ which are produced by different incident proton energies in a material which contains homogeneously distributed natural zinc. The fitted yield values are also compared with the available experimentally obtained ones used for production of $^{66}Ga$, $^{67}Ga$ and $^{68}Ga$, and in the field of nuclear analytics.

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# Ion Beam Analysis Applied in Art and Archaeology

Á.Z. Kiss, I. Borbély-Kiss, I. Rajta, Zs. Fülöp, E. Somorjai

The institute participates in the COST Action G1 "Ion Beam Analysis Applied in Art and Archaeology" started this year. Its first experimental workshop has been held in the Van de Graaff Laboratory between 27 March - 2 April. The aim of the workshop was to perform study of archaeological artefacts including both measurements (PIXE, PIGE and $\mu$-PIXE) and evaluation of the measured data by a staff formed from the representatives of various laboratories participating in the Action. Actually 11 European laboratories were represented on the workshop. The Chairman was Prof. Guy Demortier (Namur, Belgium).

The following experiments were performed during the workshop:

1. *Ancient metallurgy of bronze and silver sheets from the 3rd century BC (Proposed by Dr. A. Climent-Font, Universidad Autonoma, Madrid).* From the elemental composition (major, minor and trace elements) of a bronze sheet from Ternel and of a silver sheet used as a decorative inlay on a celtiberic bronze brooche it was possible to obtain information on their provenance.
2. *Colour in glass and beads (Dr. M. F. Guerra, CNRS Orléans).* The aim of the experiments was to determine the trace elements correlated to the cobalt pigments used in the manufacture of a 14th century colourless glass with a blue filament and to try to give the geographical origin of the pigment relying also on written sources.
3. *Copper depletion at surface of gold jewelry (Prof. G. Demortier, LARN, Namur).* Two gold jewelry artefacts (a noze pendant and a butterfly figure) of Meso American origin have been studied. It could be certified that the second artefact is made of brass and covered with a thin gold layer, but the determination of the thickness of this layer needs further measurements.
4. *Analysis of glass, silver and gold samples (Dr. D. R. Hook, The British Museum, London).* Among the numerous results e.g. PIXE analysis identified the colorants/opacifiers in the Byzantine tesserae and showed them to have compositions similar to Roman glasses.
5. *Mordants in ancient textiles (Dr. Á. Z. Kiss, ATOMKI).* From the preliminary study it was concluded that as no "blank" material is available in many cases, the microPIXE analysis of single fibres using the scanning proton microprobe would be necessary.
6. *Study of pottery by microPIXE (Dr. M. A. Respaldiza, Universidad de Sevilla).* The elemental maps showed Ti granules of about 50 micrometers, nevertheless further studies are needed on an extended number of samples to find a correlation between the Ti distribution and a certain clay material.

As a conclusion the great number of experimental results gave a lot of further work to interpret them, and also initiated new and complementary measurements to be performed in other laboratories during the following years.

# MATERIALS SCIENCES AND ANALYSIS

# Thin Layer Activation of Non-metallic Materials by Using Nuclear Implantation

F. Ditrói[1], I. Mahunka

Nuclear implantation of cyclotron produced $^{7}Be$ isotope was used for labelling of plastic and other non-activable materials in the nuclear wear measurements [1]. In our experiments boron of natural composition was used in the form of NiBSi metallic-glass foil as implantation-target through the $^{nat}B(p,x)^{7}Be$ nuclear reactions [2,3]. Kapton ($C_{22}H_{10}O_5N_2$) and beryllium targets are also suitable by using $^{3}He$ beam (through $^{12}C(^{3}He,2\alpha)^{7}Be$ and $^{9}Be(^{3}He,\alpha n)^{7}Be$ reactions respectively [4]) to produce high flux of radioactive $^{7}Be$ in order to implant a very thin surface layer of the secondary target with $^{7}Be$ isotope. The chosen secondary target should have such a composition which does not contain activable element by the bombarding beam. This condition was controlled separately by the bombardment with the same beam. This control-irradiation is also useful to make corrections for the possible interferences. As a result of the implantation we could gain a several μm thick labelled layer on the surface of the sample. By measuring the change of the activity of the sample and correcting with the natural decay one can determine the loss of very little amount of material.

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# The $N_{6,7}O_{45}O_{45}$ Auger transitions in metallic Au and in $Au_3Cu$, $AuCu_3$ and AuZn alloys

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The profile of the Au $N_{6,7}O_{45}O_{45}$ Auger spectra of metallic Au was extensively studied previously [1,2]. Applying the Cini-Sawatzky theory ,it was found that by varying the on site correlation parameter $U(^1G_4)$, one can get an agreement with either the spectral shape or with its energy position. If the agreement with position is good the reproduced shape is poor. One possible solution is including extra-atomic interaction terms in the Auger Hamiltonian [2,3]. The proposed off-site interaction term has a Thomas-Fermi potential: $F_{FT}(\vec{r}) \approx \frac{1}{\vec{r}} \exp(-K \cdot \vec{r} \cdot \sqrt[6]{n})$ where $\vec{r}$ is the distance between the two final state holes and $n$ is the density of electrons, $K = \hbar/e \cdot \sqrt{\pi/m} \cdot \sqrt[3]{3/8\pi}$ . By choosing alloys with the same structure type we vary only the parameter $r$ and $n$. Because of the exponential dependence of F(r) upon the parameters the energy of the Au $N_{6,7}O_{45}O_{45}$ transitions will be shifted. In general, as for 3d and 4d elements, the influence of the crystal field on the final states can be neglected. The Au, $Au_3Cu$, $AuCu_3$ and AuZn have cubic structure [4] with a=4.07, 3.75, 3.98 Å and 3.14 Å. The measurements of the Al Kα X-rays excited Au $N_{6,7}O_{45}O_{45}$ Auger spectra of polycrystalline Au, $Au_3Cu$, $AuCu_3$ and AuZn samples were performed using a SCIENTA ESCA 300 spectrometer with a base pressure of $5.10^{-10}$ mbar and with an energy resolution of 0.1 eV and a home built spectrometer (AuZn sample) [5] with an energy resolution of 0.18 eV. The $N_{6,7}O_{45}O_{45}$ spectra of various alloys in the two electron binding energy scale are shifted with respect to pure Au metal with -0.1 eV ($Au_3Cu$) and -0.43 eV ($AuCu_3$). The intensity of the $^1G_4$ multiplet component of the $N_7O_{45}O_{45}$ Auger transition is increased substantially in the case of $AuCu_3$ alloy. Possible explanation for the intensity variation and energy shift is that the off-site potential is not Thomas-Fermi like or the influence of the crystal field on the final state is not negligible. For an accurate determination of the off-site potential more Au alloys should be studied.

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# Charge Transfer in $Al_3Ni$ and $AlNi_3$ Alloys

L. Kövér, Zs. Kovács, R. Sanjinés[1], P. Weightman[2], G. Margaritondo[1], D. Varga, J. Pálinkás and H. Adachi[3]

Charge transfer between the constituent atoms of crystals is thought to determine the stability of these structures. The method developed by Thomas and Weightman for the determination of charge transfer in alloys [1] from Auger parameter shifts, is based on potential parameters obtainable from atomic structure calculations.

Photoelectron and Auger spectra were excited by Mo, Ag $L_{\beta 1}$ and Al $K_\alpha$ X-rays from polycrystalline $Al_3Ni$ and $AlNi_3$ as well as high purity Al and Ni metal samples. The Al KLL Auger and Al 1s photoelectron spectra were measured with a home built electron spectrometer (0.4 eV analyzer resolution)[2]. Core XPS and Auger spectra were measured using a SCIENTA ESCA-300 spectrometer (0.4 eV spectrometer resolution). Alloy-metal Auger parameter shifts were calculated from the measured Auger kinetic and photoelectron binding energies using the definition given by Williams and Lang [3]:

$$\Delta\xi(j) = \Delta E_k(ijj) - \Delta E_b(i) + 2\Delta E_b(j) \qquad (1)$$

where $\Delta E_k(ijj)$ is the environmentally induced shift in the Auger kinetic energy from a transition involving the $i$ and $j$ core levels and $\Delta E_b$ is the difference in the binding energy of a core level between two environments. For estimating charge transfer analyzing $\Delta\xi$, model parameters were obtained from atomic structure calculations [4,5]. Table 1 contains the obtained alloy-metal Auger parameter shifts. The estimated accuracy of the values is 0.06 eV.

**Table 1.** Measured Auger parameter shifts, $\Delta\xi$(alloy-metal, eV)

| | $AlNi_3$ | $Al_3Ni$ |
|---|---|---|
| Al($\Delta\xi$(2p)) | -1.19 | -1.6 |
| Ni($\Delta\xi$(3p)) | $L_3$ 0.37 | $L_3$ 0.44 |
| | $L_2$ 0.12 | $L_2$ 0.24 |

In the case of $AlNi_3$ our experimental results and the atomic structure model give a charge transfer of *0.37 e* from the Al to the Ni, in agreement with the difference in the electronegativities. The value obtained from the Ni Auger parameter shifts is consistent with the charge conservation. In the case of $Al_3Ni$, our measurements indicate a larger electron transfer to Ni and show inconsistency with the charge conservation. Our results suggest, that *d* to *s* configuration changes on a Ni site can have as much influence on the potential in the atomic core as the effect of charge transfer between Al and Ni and that we might expect that the influence of this hybridization effect would be larger for $Al_3Ni$ than for $AlNi_3$.

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# Transversal voltage measurements of BSCCO (2212) single crystals

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Transport measurements on $Bi_2Sr_2CaCu_2O_x$ single crystals were performed in order to investigate the anisotropic magnetoresistivity tensor in normal and superconducting state. Single crystal samples were cloven mechanically from a bulk piece and electrical contacts to the sample were made by silver paste. The dimensions of the sample were 1x1.8x0.015 $mm^3$. A 6 $h$ heat treatment in oxigen flow at 600 $^oC$ was applied to get the optimum oxigen concentration. Two current and four voltage contacts on both $a-b$ plain sides of the samples were attached in 'dc flux transformer' configuration. In order that we could collect the maximum information about the electric field generation and energy dissipation mechanism, we measured the temperature dependence of longitudinal and transversal voltages on the $a-b$ plains and voltages in the $c$ axis direction simultaneously at three different current densities and four current feeding configurations. The temperature ranged from room temperature to liquid helium temperature. The magnetic field was changed up to $18T$. The angle between the direction of the measuring current, magnetic field and $c$ axis was changed systematically in order that we could calculate the Hall constant in different positions of the $a-b$ plains in the magnetic field. We also measured current-voltage characteristics at selected temperatures. As a result of the experiment, above $T_c$ we could determine the magnetic field dependence of the normal state resistivity tensor, in mixed state we could detect and identify a sign change in transversal voltages both on $a-b$ plains and in the $c$ direction, and guided motion of Josephson vortices between the plains. In the mechanism of the interlayer superconducting coupling we could identify the temperature range where the tunneling mechanism changed from normal tunneling type to superconducting one.

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# Phase Transitions in Cu-Sb Systems Induced by Ball Milling

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Mechanical alloying with ball mills is a well established process for achieving the formation of amorphous, metastable and nanocrystalline alloys starting from elemental metallic powders. The defects introduced by deformation during milling must be responsible for raising the free energy of the system and thus for the formation of these metastable phases. For the case of mechanical alloying of elemental metallic powder mixtures a simple general condition is given in [1]. This model predicts amorphization over a wide concentration range, among others, for Cu-Sb system supposing that the formation of all other (stable compound) phases is excluded by kinetic constraints.

$Cu_XSb_{100-X}$ binary mixtures with X=0, 10, 25, 50, 75 and 90 at %, and arc melted CuSb alloys with X=60 and 82 at % concentration were ball milled in vacuum. The phase transitions and the decrease of crystallite size during milling was studied by X-ray diffractometry. Formation of nanocrystalline $\eta Cu_2Sb$ phase and partial amorphization of Sb was observed in samples with Sb content $\geq$ 50 at %. The XRD patterns of the two phases showed different behaviour with increasing milling time, i.e. a rapid decrease of intensity and increase of line width of Sb phase, while a moderate change in the pattern of $\eta Cu_2Sb$ was obtained during a milling period of cca. 500 hours. By increasing the copper content, the formation of $\eta$ phase completed within shorter milling time, and a nanocrystalline structure of that phase was achieved after 200 hours milling of $Cu_{75}Sb_{25}$. For X $\geq$ 87 at % Cu concentrations, extended Cu-base solid solutions were obtained with average grain size of cca. 10 nm. The ball milling of arc melted $Cu_{60}Sb_{40}$ alloy resulted in similar structure to that of Sb-rich powder mixtures, and the XRD patterns of arc melted $Cu_{82}Sb_{18}$ alloy indicated the same phase transition as the $Cu_{75}Sb_{25}$ sample prepared from elemental components.

Our experimental results are in a qualitative accordance with the prediction of [1] allowing the coexistence of the amorphous phase with solid solution or with the stable $\eta$ compound. The formation of the $\eta$ phase proved to be very favourable under milling conditions used.

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# Monte Carlo Modeling of the Backscattered Electron Spectrum of Silver at the 2 keV Primary Electron Energy

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The backscattered electron energy distribution from a silver sample, obtained from REELS measurement and from the Monte Carlo simulations, using the dielectric function formalism, in which the experimental optical dielectric data were used to describe the electron energy loss function, is presented in this work. In our present simulations, three atomic layers were taken into consideration as surface layers. The information depths ($3\lambda_{tot}$) in the present calculations were found to be larger than the thickness of estimated surface layer for 2 keV primary energy. This assumption seems to be a good approximation for simulation of our experimental results, although we have no experimental confirmation. The silver sample was prepared from a silver rod and the surface of the sample is not smooth.

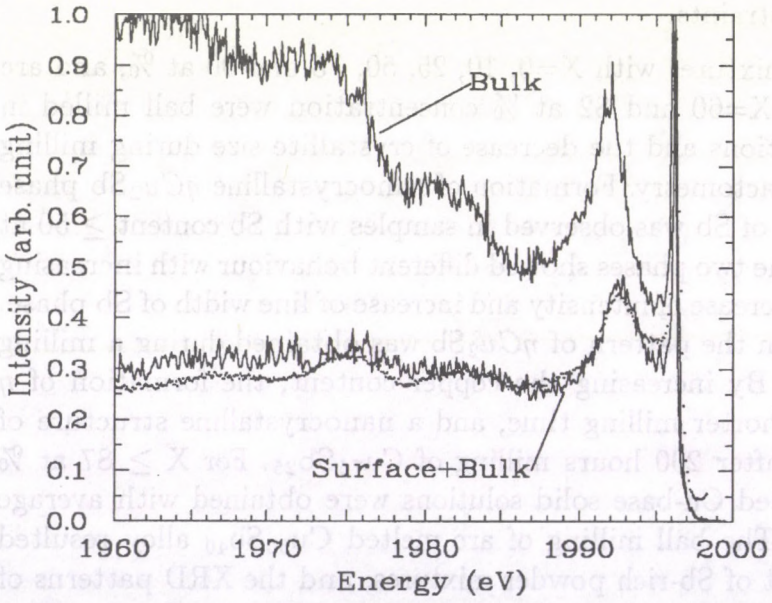


**Fig. 1.** Backscattered electron spectra of silver near the elastic peak at 2000 eV primary energy. Points: experimental results, solid lines: calculated results.

It is confirmed that the backscattered electron energy distribution calculated using the Monte Carlo simulation method can reproduce well the fine structures (intensities and shapes) in the measured backscattered energy spectrum near the elastic peak in the case of homogeneous silver samples using the surface and bulk loss functions in the simulation and completely wrong using the bulk loss function only. Our results allow speculations on the possibilities for extracting information on the roughness of the surfaces as well as on the presence and thickness of surface contamination layers by comparing the experimental and modeled backscattered electron spectra however, further investigations are needed for confirming the applicability of this approach.

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# Inelastic Background Correction for KLL Auger Spectra of Manganese

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The knowledge of the background from inelastically scattered electrons is fundamental in the quantitative Auger spectroscopy. In our earlier work [1] a good agreement was obtained between the theoretical and experimental spectra of high energy ($E_{primary}$= 5 keV) electrons backscattered from manganese thick and thin film samples using Monte Carlo simulation in the calculations. Here the results of our Monte Carlo simulation of the inelastic background of the Mn KLL Auger lines excited from manganese films of 30 Å thickness, deposited on silicon substrates are presented.

The electron energy distribution of the Auger electrons from a polycrystalline Mn sample was studied at $0^o$ with respect to the surface normal of the specimen. The simulation was based on the application of the dielectric function formalism [2,3]. Both the individual elastic and inelastic scattering events in the solid were taken into account. For the simulation of the complete spectrum, the energy values of the Mn KLL transitions were taken from the reference [4].

The simulated electron energy distributions of Mn KLL Auger lines are compared to the measured X-ray induced Auger spectra [4]. Effects of the silicon substrate to the background formation are discussed. Our results show that the shape of the inelastic background of the Mn KLL Auger lines depends strongly on the length of the electron trace in the silicon substrates.

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# EARTH AND COSMIC SCIENCES, ENVIRONMENTAL RESEARCH

# Geochronological studies with the K/Ar method in 1995

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In the Bükkium Upper Jurassic - Lower Cretaceous ages were measured for the uplift and Lower Cretaceous ages for the metamorphism of the area (Coop.: Geochem. Res. Lab. Hung. Acad. Sci., 1, 2). Ages from 150.6 to 127.3 Ma were published for the polymetamorphic complex of the Batocina area (C.: Univ. Belgrade, 3, 4). Magmatites of the Hanzesti - Drinava region, Poiana Rusca Mts., Romania, resulted ages in the 91 -74.9 Ma range (C.: Inst. Geol. Res., Bucharest, 5).

Along the W-E traverse in the Central Balcan Peninsula 7 volcanic areas resulted ages in the 32 - 26 Ma interval (6). In the Rogozna (Central Serbia) volcanism started with dacites 31 Ma ago and ended with latites 28 Ma ago (C.: Univ. Belgrade, 7). 16 - 14 Ma has been obtained for the consolidation of the S-type granites in the Cer Mts., Yugoslavia (C.: Univ. Belgrade, 8). 11.0 Ma has been established for the tectonism in the Bisciario Formation in the Apennines (C.: Univ. Urbino, 9). The Neogene volcanic range of Vihorlat (E-Slovakia) has been dated (C.: GUDS, Bratislava, 10). An older (30 - 15 Ma) and a younger (10 - 0 Ma) magmatic phase were distinguished in Yemen (C.: Eötvös Univ. Budapest, 11).

Neogene volcanics in Lavanttal, Styria and Southern Burgenland have been classed in 3 well distinguishable groups: Karpatian - Lower Badenian, Pannonian and Upper Pliocene (C.: MÁFI, Budapest, Geol. Budesanstalt, Wien, 12). Ages on additional alkali basalt occurences in Central and Southern Slovakia have been measured and presented (C.: GUDS, Bratislava, 13). The young alkaline basalts of the Persani Mts. and Banat in Romania are contemporaneous with the subduction related volcanism of Harghita (C.: Inst. Geol. Res., Bucharest, 14).

By dating < 2 μm clay minerals the Miocene age of tectonism was obtained in the Glarus Alps, Switzerland (C.: Geochem. Res. Lab. Hung. Acad. Sci.), and Upper Cretaceous age for the tectonism has been suggested for the Boda Aleurolite Formation (C.: Ore Mining Comp., Pécs). It has been shown, that in Fuerteventura, Canary Islands, Miocene volcanism did not release completely the radiogenic Ar from the older magmatic and sedimentary rocks of the basal complex (C.: Univ. La Laguna).

It has been confirmed, that Mesozoic basic magmatism in the Mecsek Mts. started in the Upper Jurassic (C.: Dept. Petrol., Eötvös Univ., Budapest). Study of the crystalline basement of the Great Hungarian Plane was continued and new areas with Jurassic and Cretaceous metamorphism were distinguished (C.: József Univ., Szeged).

Dating of Miocene volcanic rocks in the Apuseni Mts. was continued (C.:Inst. Geol. Res., Bucharest), and a study was started on the intrusions in the Gutii Mts. (C.: CUART S. A., Baia Mare). Lower Oligocene ages were measured on volcanic rocks from the East Rhodope, showing that volcanism in Central and Eastern Rhodope was contemporaneous (C.: Geol. Inst. Bulg. Acad. Sci.)

A relatively old age of 7-8 Ma has been proved for the basaltic tuff of the Tihany Volcano (C.: Dept. Petrol., Eötvös Univ., Budapest).

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# Radon exposures in caves in Hungary

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Higher doses of inhaled radon daughters are known to be causative factor in inducing fatal lung cancer. Typical radon levels in caves are between 1 an 10 $kBqm^{-3}$, about 100 times higher than typical levels in homes. Some groups of people (cavers, tour guides, patients and staff) usually spend longer periods in caves, therefore, are exposed to higher radon doses.

We have measured radon activity exposures in caves using track etch and semiconductor based radon monitors. The track etch detectors were changed approximately in every 30 days. Usually 3-20 measuring sites were established in each cave investigated. Since 1991 we use Dataqua type "real time" radon monitors, too, to measure fast temporal variation of radon at characteristic sites.

We used equilibrium factor of F=0.4 between radon and its short-lived daughters and used dose conversion factor as given in ICRP-65 for members of the public. The detriment per unit effective dose is $7.3 \cdot 10^{-5}$ per mSv for the general public (ICRP-60). The principal detriment due to the inhalation of radon and its progeny is that associated with the fatal lung cancer.

Currently we are continuously monitoring radon in more than 15 caves, including all five caves, where therapeutic treatment of asthma patients is going on. Some caves open to tourists are also monitored. In the case of the best known of these (Baradla cave), we have estimated doses of tour guides between 1990-1994. Summary of results is presented in table I.

Table I. Summary of results.

| | | | Annual effective dose, mSv | |
|---|---|---|---|---|
| **Cave name** | **Period** | **Sample size** | **Mean (Range)** | **Geometric mean (Geometric STD)** |
| Abaliget | 1994 | 127 patients | **0.54** (0.03-1.26) | 0.40 (0.77) |
| Béke | 1994 summer | 56 patients | **1.91** (1.86-1.97) | 1.91 (0.02) |
| Szemlőhegy* | 1990-1992 | 229 patients | **0.85** (0.10-5.00) | 0.62 (0.76) |
| Szent István | 1994 | 360 patients | **0.06** (0.01-0.17) | 0.04 (0.88) |
| Tapolca | 1994 | 481 patients | **0.87** (0.04-2.19) | 0.45 (1.32) |
| Baradla | 1990-1994 | 12 tour guides | **2.66** (0.12-5.55) | 2.13 (0.80) |

*In the case of Szemlő-hegy cave cumulative effective doses over 1990-1992 are given in mSv.

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# Radon transport in fractured porous media - experimental study in caves

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We have measured the spatial and temporal variation of $^{222}Rn$ concentration in underground caves in order to study the influence of different morphological and meteorological parameters on the forming of airborne radon concentrations inside.

We found that in horizontal caves, the daily mean radon concentration as a function of the daily average surface temperature shows a step-function type dependence. The transition pattern between the two steps is gradually linearized as the number of fractured zones communicating to the surface is increasing.

The number of fracture zones effects the widening of the transition phase, too. While in the Vass Imre cave this width is around 5 °C, in the Abaliget cave it is around 10 °C. This step by step widening of the transition state in dependence on the number and size of openings is further supported by the data obtained in the Szemlő-hegy cave. Here, the S-type curve is practically reshaped to a line. However the turn in the radon curve measured at the upper situated passage indicates the proximity of the surface. From the point of view of radon transport the equilibrium (saturation) value is not yet reached at this level of the cave.

The radon levels are increasing with the distance from the cave entrance. The observed pattern unambiguously reflects the change in the main direction of underground air flows. The difference among studied caves can be attributed to the differences in the number of vertical fractures .

This work was supported in part by the National Scientific Research Fund contract Nos. T 016558 and T 017560.

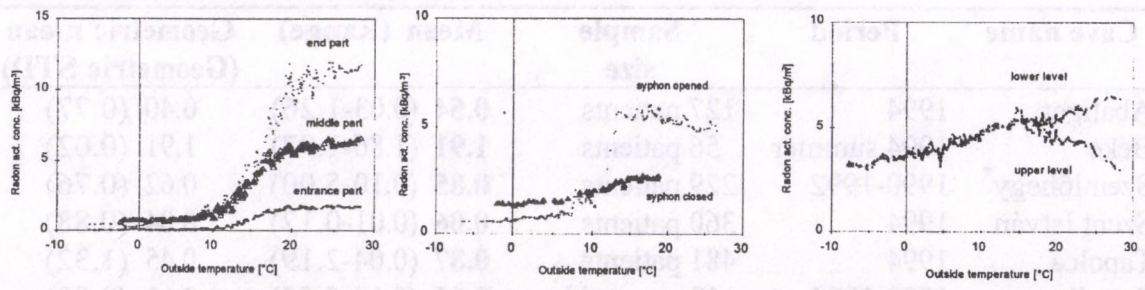


**Fig.** Radon concentration in cave as a function of surface temperature in the case of Abaliget cave (left), Vass Imre cave (center) and Szemlőhegy cave (right).

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# Field verification of modeling pressure effect on soil gas transport

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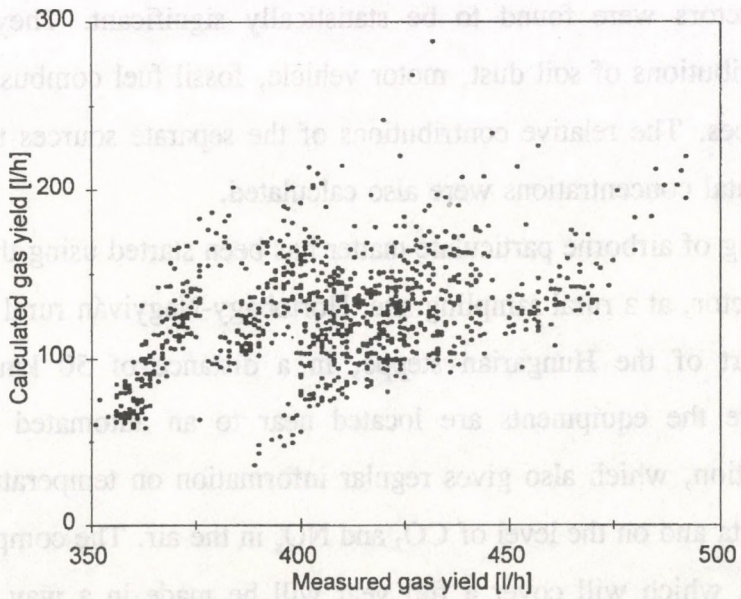
Modeling radon transport in soil is a long term aim of today's environmental physics. Models have difficulties reproducing experimental data, mostly because the difficulties to handle the extremely variable field an meteorological conditions.

Our present model aims to predict the time evolution of radon concentration in soil, taking measured time series of the atmospheric pressure as input parameter. Other parameters (soil porosity and permeability, dynamic viscosity of the carrier gas) are taken constants. First, the velocity field of the carrier gas is computed. This part of the model was tested against experiment. The gas yield from a 20 m deep drilled hole - situated in the village of Mátraderecske -, and the atmospheric pressure was recorded for over a 10 weeks period with a 1 hour sampling time. The theoretically calculated gas yield data points were plotted against the measured ones (Figure).

Although the data points are not grouped along a single linear correlation curve - as we would expect in the case when the experimental data were reproduced accurately by the model -, they are not scattered randomly thorough the graph either. Instead we have found grouping of the data along several well defined directions. As the slope of the correlation curve is defined by the above mentioned constant parameters, this suggest that one of these parameters occasionally changed its value. This parameter is, most probably, the permeability of the soil, since it is very sensitive to the water content of the soil, i.e. to rainfall. This indicates, that for a more accurate modeling the permeability needs to be considered as a time-varying input parameter for the model, and accordingly, a continuous monitoring of it (or of the precipitation) is necessary.




**Correlation between measured and calculated gas yields**

This work was supported by the National Scientific Research Fund, No. 7603.

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# Aerosol Sampling and Analysis by PIXE

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Aerosol sampling has been continued in urban air by means of Nuclepore polycarbonate membrane filters with a one stage aerosol sampler. Now these data cover the period 1991.10.29-1995.12.21. Changes in the elemental concentrations have been followed during the last four years, together with seasonal variations average concentrations and enrichment factors have been determined. The airborne particulate mass concentration has been measured in $\mu g/m^3$, too.

Sampling with a "GENT" stacked filter unit has been done in collaboration with the IAEA (CRP) at a sampling site in the residential area of Debrecen, Hungary. 186 samples have been collected. They represent coarse and fine aerosol fractions at 93 sampling days. Samples have been analysed by PIXE and elemental concentrations have been received in both fractions for the elements Al, Si, P, S, Cl, K, Ca, Ti, V, Cr, Mn, Fe, Ni, Cu, Zn, As, Br, Ba and Pb. These data were evaluated in terms of seasonal variations and enrichment factors. To find the probable sources of elements in the aerosol sample, principal component analysis with row varimax rotation has been done. Four factors were found to be statistically significant. They represent the separable contributions of soil dust, motor vehicle, fossil fuel combustion and mixed industrial sources. The relative contributions of the separate sources to the observed average elemental concentrations were also calculated.

Sampling of airborne particulate matter has been started using the Gent stacked filter unit collector, at a rural sampling site. Hortobágy-Nagyiván rural station is in an uninhabited part of the Hungarian steppe, in a distance of 50 km upwind from Debrecen. Here the equipments are located near to an automated meteorological observation station, which also gives regular information on temperature, wind, and precipitation data and on the level of $CO_2$ and $NO_x$ in the air. The complete evaluation of the data set, which will cover a full year will be made in a way similar to that followed in the case of urban sampling.

# An XPS and EPMA study of size-fractionated ambient aerosol particles collected in urban and industrial areas

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Ambient aerosol particles were studied by XPS and Electron Probe Micro-Analysis–Energy Dispersive X-ray Spectrometry (EPMA–EDX). For sampling polytetrafluoroethylene (PTFE) samplers were used in Battelle type cascade impactors.

Sampling locations and times were: 1. Visonta (North Hungary), at a coal fired power plant at two sites, 23. Sep. 1992; 2. Debrecen city center, in three hour periods as a function of day time, 11. Nov. 1992.

From XPS the chemical states of the compounds of the particles could be identified mainly as $NH_x$, $SO_4^{2-}$, soot and $SiO_2$.

By XPS, correlation could be found between the N and C content of the particles of 0.5 and 1 $\mu$m size fractions.

The concentration ratios of S distribution between the 0.5 and 1 $\mu$m particles showed higher S content in the smaller fraction. In Visonta these EDX S ratios were similar at both sites, while the XPS ratio was smaller far from the plume. In Debrecen the ratios were smaller than in Visonta with both methods. In Debrecen during the day periods the EDX ratios showed maximum at the noon period, while the XPS ones decreased.

Surface enrichment of S was very changeable as a function of sampling places and time periods. The S enrichment factors changed from 1.5 to 5.5 in the 0.5 and 1 $\mu$m particle fractions.

EDX elemental (Al, Si, Cl, K, Ca, Fe, Cu, Zn) concentrations of the particles were discussed as tracers of different sources of aerosols.

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2. To be published in the international journal: Surface and Interface Analysis.

# Reliability of methods used for characterisation of radioactive waste

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In 1992 a comprehensive characterisation program was initiated at Paks Nuclear Power Plant to determine the inventory of the low level and intermedier level waste prior to conditioning or disposal. In the framework of this program radiochemical programs were started to determine the concentration of long-lived non-gamma emitting radionuclides. The radionuclides of interest have been $^{3}H$, $^{14}C$, $^{90}Sr$, $^{55}Fe$, $^{59}Ni$, $^{99}Tc$, $^{129}I$ and TRUs. Sample preparation and activity measurement techniques have been developed and used. The reliability of the methods were confirmed by an international intercomparison test organised by KFA Jülich. Evaporator concentrates and used ion exchange resin samples were sent to the participants. The result of the Hungarian teams are in a good agreement with average of activity concentration obtained for "key nuclides" by the participants (Fig. 1 and 2)

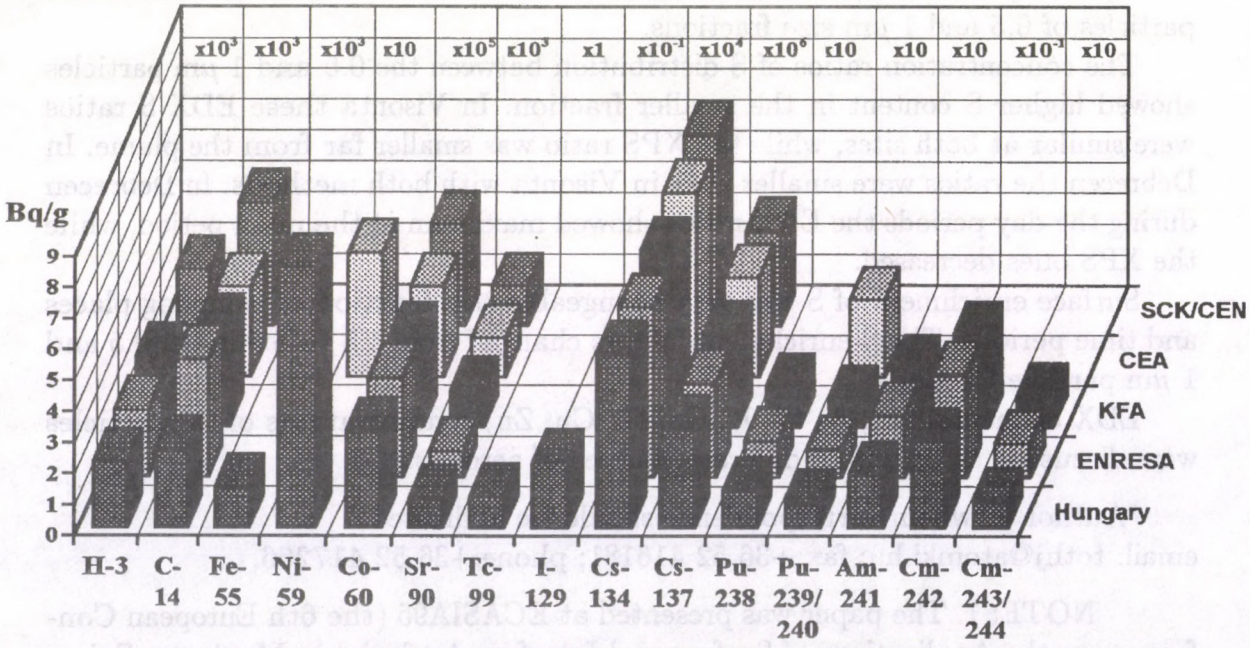


**Fig. 1.** Activity concentration of key nuclides in used ion exchange resin samples obtained by Hungary (INR/HAS, INT/TUB, DPC/TUB, Paks NPP), Empresa Nacional de Residuos Radioactivos (ENRESA), Kernforschungsanlage Jülich (KFA), Commissariat à l'énergie atomique (CEA) and Studicentrum voor Kernenergie (SCK/CEN)

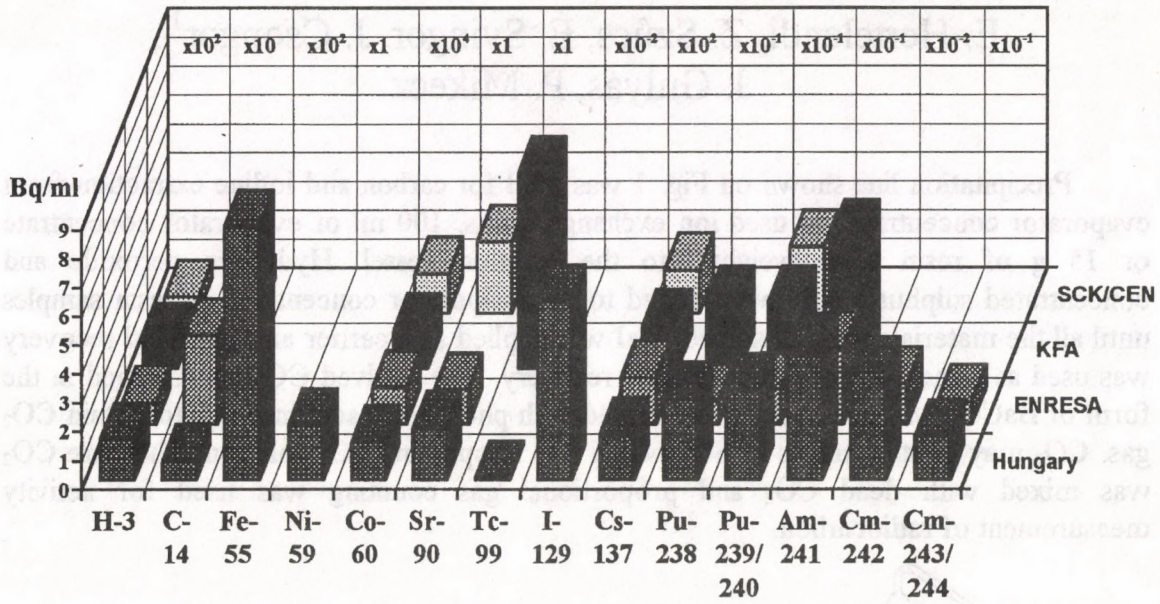


**Fig. 2.** Activity concentration of key nuclides in evaporator concentrate.

## Reference

1. Inventory and characterisation of important radionuclides for safety of storage and disposal. Correlation with key nuclides which are easy to measure in typical waste steams. CEC project No. FI 2W-0034-0109. Final Report, CEA Cadarache, Cadarache, 1995.

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# Methods of measurement of $^{129}I$, $^{99}Tc$, $^{14}C$ and T in real waste samples of Paks Nuclear Power Plant

E. Hertelendi, Z. Szűcs, É. Svingor, J. Csongor[1], J. Gulyás, P. Mikecz

Precipitation line shown on Fig. 1 was used for carbon and iodine extraction from evaporator concentrates or used ion exchange resins. 100 ml of evaporator concentrate or 15 g of resin were weight into the reaction vessel. Hydrogen peroxide and concentrated sulphuric acid were added to the evaporator concentrate or resin samples until all the materials were dissolved. NaI was applied as a carrier and chemical recovery was used as a measure of radiochemical recovery. The evolved $CO_2$ was trapped in the form of $BaCO_3$ which was dried and mixed with phosphoric acid in order to obtain $CO_2$ gas. $CO_2$ may contain traces of $SO_2$ which was trapped in $H_2O_2$ solution. The pure $CO_2$ was mixed with dead $CO_2$ and proportional gas counting was used for activity measurement of radiocarbon.

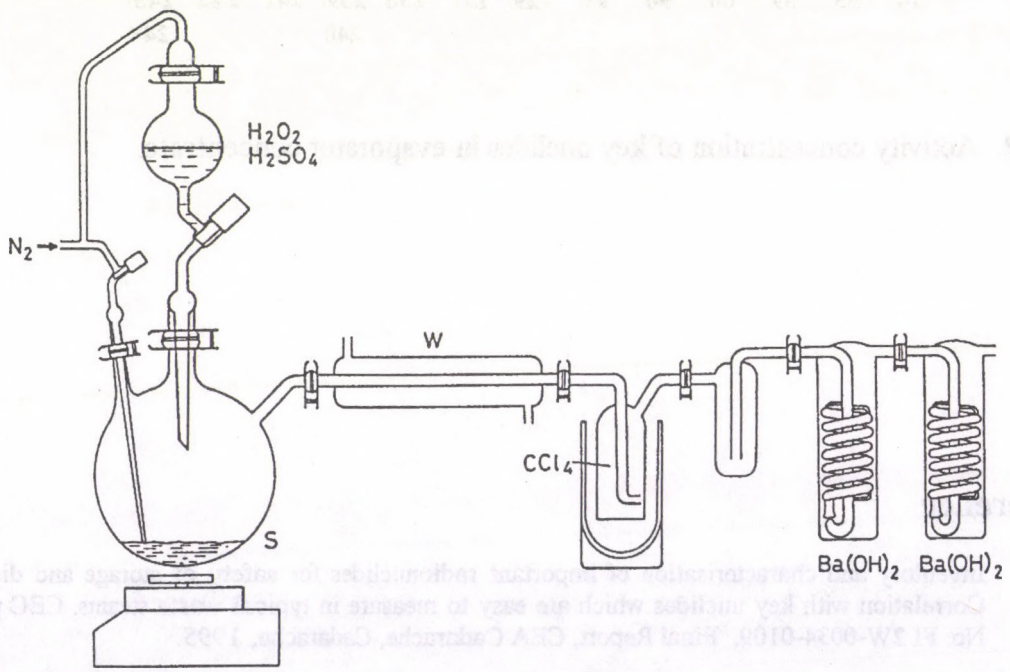


**Fig. 1.** Precipitation line for extraction of carbon and iodine from evaporator concentrates and used ion exchange resins

The elemental iodine collected in the $CCl_4$ trap was washed with nitric acid, reduced with bisulphite and back extracted into water. Acidified silver nitrate solution was added to precipitate silver iodide. Again chemical recovery was used as a measure of radiochemical recovery. The silver iodide precipitate was mounted for gamma counting.

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After one week of counting with a low energy germanium detector the samples were dispergated in water and the $^{129}I$ activity was determined by liquid scintillation counting technique.

The remaining material in the reaction vessel was used for measurement of $^{99}Tc$. The solution was neutralised with sodium hydroxide. The sodium sulphate precipitation was removed by filtration. $KReO_4$ was added as a carrier. The rhenium together with the technetium were precipitated in the form of $Re_2S_7$ and $Tc_2S_7$ which were filtrated and dissolved in $H_2O_2$. TEVA•Spec column was used for separation Tc from the remaining radionuclides after decreasing the ion concentration of the solution. The $^{99}Tc$ was removed from the column with 8N $HNO_3$ and whole enrichment process was repeated once again. LSC technique was used for activity measurement. Radioisotopes not separated from technetium may bias the results of LSC, therefore the gamma activity of the TEVA Spec columns were checked by low level gamma spectrometry before measuring the total beta activity of the TEVA•Spec resin.

Vacuum destillation was used to determine tritium activity of the evaporator concentrates and used resin samples. The tritium activity of the collected water was measured with LSC technique. $^3H$ concentration of the dried resin was measured after burning its hydrogen content into water with CuO in a glass ampoule. Tritium in other form than water have not been measured in evaporator concentrates.

The radiochemical methods were used for activity measurement of samples coming from various waste streams of Paks NPP. Table 1 shows the number and type of samples have been measured up till now.

| The measured isotope | Number of samples | |
|---|---|---|
| | evaporator concentrate | resin |
| $^3H$ | 10 | 1 |
| $^{14}C$ | 22 | 45 |
| $^{99}Tc$ | 11 | 1 |
| $^{129}I$ | 39 | 1 |

**Table 1.** Isotopes measured in evaporator concentrates and resins

## Reference


1. D. Bodizs, J. Csongor, I. Gresits, J. Gulyás, A. Fritz, E. Hertelendi, P. Mikecz, Zs. Molnár, P. Ormai, T. Pintér, J. Solymosi, É. Svingor, Z. Szűcs, S. Tölgyesi, N. Vajda, P. Zagyvai, Inventory and characterisation of important radionuclides for safety of storage and disposal. Correlation with key nuclides which are easy to measure in typical waste steams. CEC PECO project No. FI 2W-0034-0109. Final Report, ATOMKI, Debrecen, 1995.

# BIOLOGICAL AND MEDICAL RESEARCH

# Progress report about a EC project for study of hair Ca in UK

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The Ca level of human hair has been proved to be useful for diagnostic purposes as an indicator of body stores and the assessment nutritional status. Many publications have reported connection between elevated or decreased Ca concentration in hair and the occurrence of various diseases. For example, hair Ca concentration may be related to cystic fibrosis [1], myocardial infraction [2] and/or nutritional status [3,4]. It appears now that hair analysis may prove exceptionally useful in the identification and treatment of those diseases which are being linked to disorders of Ca metabolism, such as arteriosclerosis, heart and cerebral diseases, hypertension, osteoporosis or bone demineralisation (osteopenia).

Approximately for years ago, in co-operation with the Scottish Agriculture College, we started to investigate the hair Ca level in populations with different Standardised Mortality Ratios for Coronary Heart Disease (SMR-CHD) in five different areas of Scotland. Hair samples were collected from apparently healthy employed males aged over 20 years and resident in one of the following areas: Kyle and Carrick, Edinburgh, Aberdeen, Cumnock & Doon Valley and Bearsden & Milngavie. Approximately 100 samples were collected from each area and measured by XRF method in the ATOMKI [5]. In accordance with our earlier findings in Hungarian, Japanese and Zambian population, the distributions of the log of hair Ca concentrations are of bimodal character, except Kyle & Carrick where the distribution is unimodal (see Fig. 1). In addition, a negative correlation was found between average Ca concentration and SMR which is also consistent with our earlier observations that post myocardial infarction and acute myocardial infarction patents have lower hair Ca concentrations (350 mg/kg) than healthy people (1500 mg/kg).

Based on these results, the authors submitted a project proposal to the European Community in order that hair-Ca survey could be extended for a larger population of UK. Meeting with a favourable reception, this research project has been supported financially by the EC since the beginning of 1994. Within the framework of this project a representative survey is being carried out in UK. According to the plan, 5000 sample with relevant personnel health status reports of male subjects will have been collected till the end of this year. Though XRF analysis is performed continuously, statistical evaluation of data and preliminary results are expectable not sooner than the beginning of the next year.

This work is being supported by the European Community (CIPACT 930168).

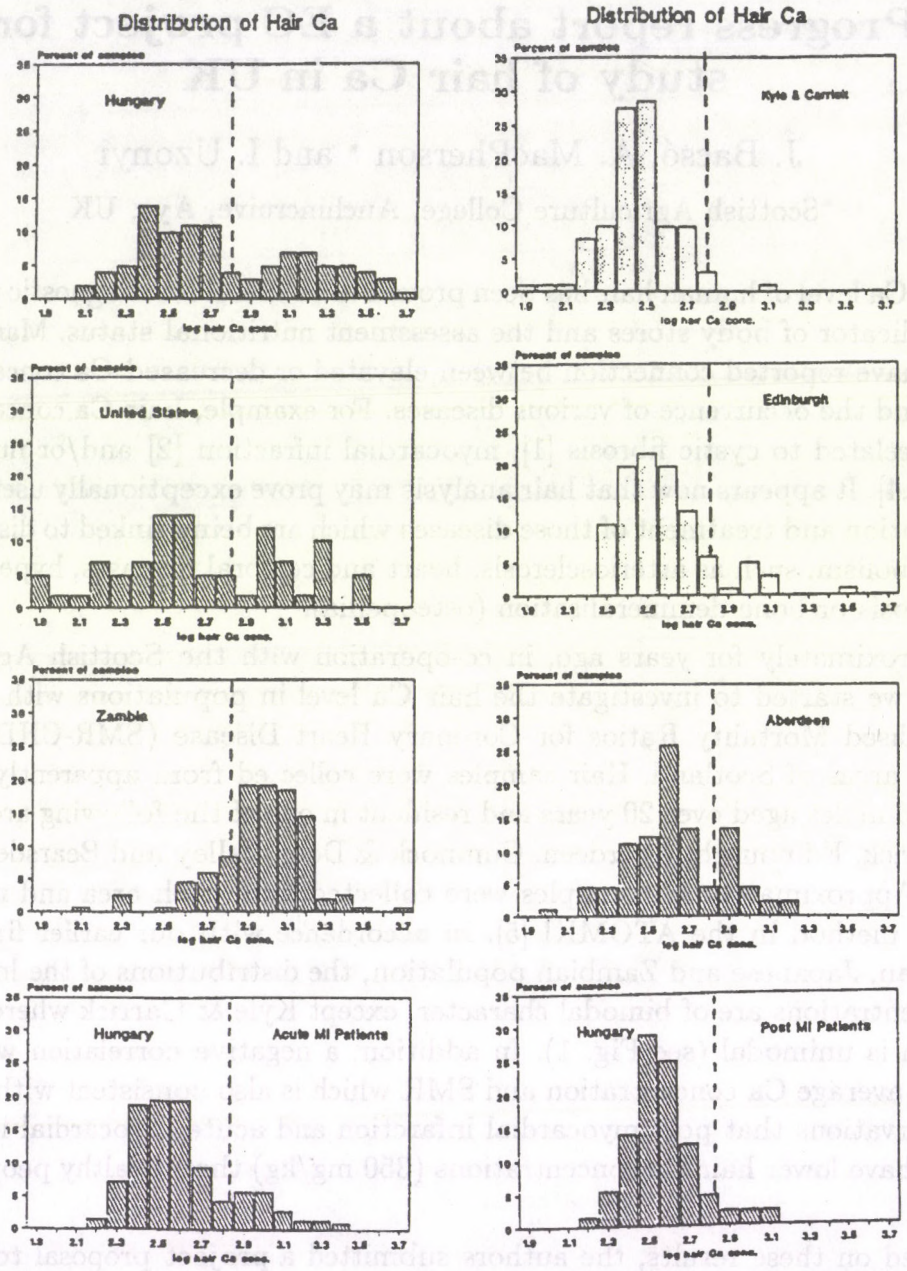


**Fig. 1.** The distribution of hair Ca concentration in some countries and Hungarian acute and post miocardial (MI) patients compared with those found for three Scottish districts.

## References

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2. J. Bacsó, P. Kovács and S. Horváth, Radiochem. Radioanal. Letters 33 (1978) 273-280.
3. A. Perkons, J. Valendia and M.J. Dienes, Fotens. Sci. 22 (1977) 95-105.
4. A. Chatt and S.A. Katz, Hair Analysis, Application in the Biomedical and Environmental Sciences, New York, VCH.
5. A. MacPherson and J. Bacsó, in: Proceedings of the First International Conference on Trace Elements in Health and Diseasa with Special Emphasis on Atherosscleroses, Sept. 14-16, 1992, Lisbone, Portugal, chapter 24, p. 129-133.

# Routine Production of [$^{11}CH_3$]Methionine for Medical Diagnostic Purposes

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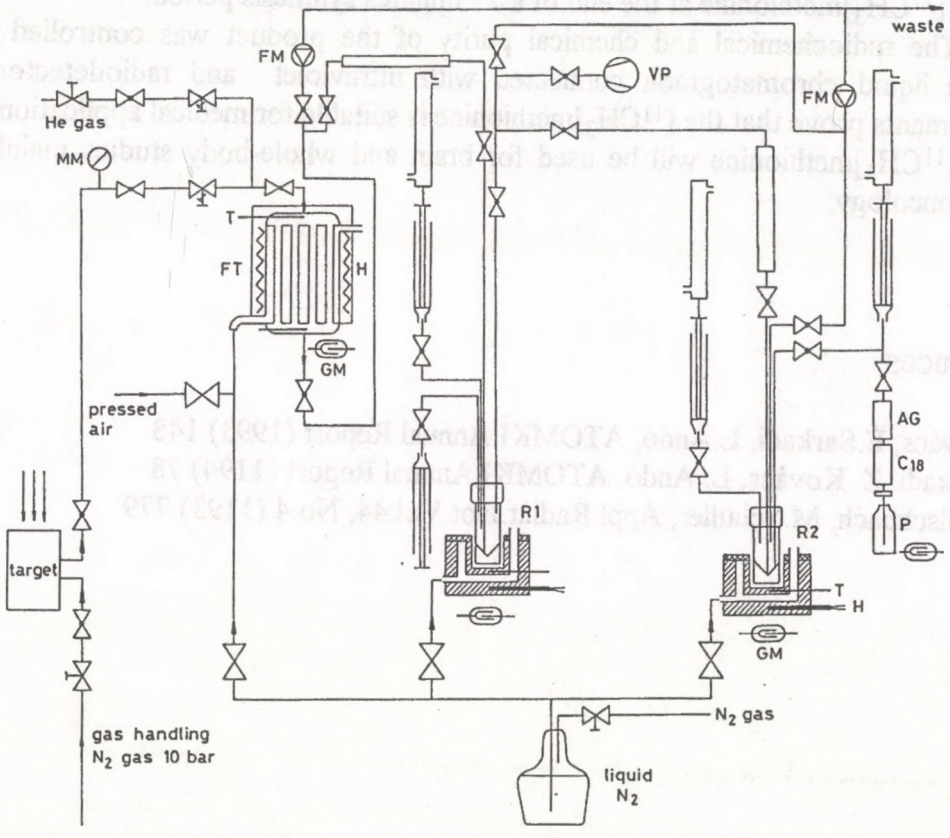
J.Szádai, M.Emri, Zs.Molnár

A new project was started two years ago in our laboratory to produce labelled compounds for PET (Positron Emission Tomography) investigation. In 1996 the automatic production of [$^{11}CH_3$]methionine is scheduled to start. In 1995 a synthesis-panel was built (Fig.1.) for routine production. The system was installed on the basis of repeated experiments in order to establish production guidelines ensuring safety and efficency as well as good reproducible yield and analitical purity of the product.




**H**: heating element
**T**: thermocouple
**FT**: freezing trap
**MM**: manometer
: valve
**FM**: flow meter
**GM**: GM counter
**VP**: vacuum pump
**R**: reaction vessel
**P**: product

Fig.1. [$^{11}CH_3$]methionine preparation (panel)

The $^{11}CO_2$ is produced by $^{14}N(p,\alpha)^{11}C$ reaction in nitrogen gas contaning $O_2$ traces [1]. This product is trapped in a special temperature controlled unit (FT). After warming up the FT unit the $^{11}CO_2$ is introduced into the R1 reaction vessel and reduced with $LiAlH_4$ in tetrahyrofuran[2]. The solvent is evaporated and the $^{11}CH_3I$ is synthesised by adding HI and distilled into the R2 reaction vessel. The $^{11}CH_3I$ is trapped in homocysteine thiolactone dissolved in ethanol . After adding basic ethanol to the solution the final product is obtained. After pH-adjustment [$^{11}CH_3$]methionine in isotonic saline solution is transported through AG-11 ion exchange column and $C_{18}$ cartridge to purify the product[3].

Every step of the chemical processes is controlled by computer. The system can work fully or partly automatically with the possibility of immediate interaction. The optimal parameters of the processes (transport, pneumatic injection, freezing, warming) as well as temperatures and time of the chemical reactions were determined by preliminary experiments. The decay corrected yields of the radiochemical syntheses are 60-75 %. According to our experiments a 10 minutes irradiation with 10 μA beam current supplies 40 mCi [$^{11}CH_3$]methionine at the end of a 27 minutes synthesis period.

The radiochemical and chemical purity of the product was controlled by high pressure liquid chromatograph connected with ultraviolet and radiodetector. These measurements prove that the [$^{11}CH_3$]methionine is suitable for medical application.

[$^{11}CH_3$]methionine will be used for brain and whole-body studies mainly in the field of oncology.

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1.Z.Kovács, É.Sarkadi, L.Andó, ATOMKI Annual Report (1993) 148
2.É.Sarkadi. Z. Kovács, L. Andó, ATOMKI,Annual Report (1194) 78
3.M.Holschbach, M.Schüller, Appl.Radiat.Isot.Vol.44, No.4 (1193) 779

# DEVELOPMENT OF METHODS AND INSTRUMENTS

# A new low energy single-charged heavy ion accelerator in ATOMKI

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A. Nagy and J. Pálinkás

The 1 MV Van de Graaff accelerator of ATOMKI is mostly used for basic atomic physics experiments. To study even lower energy ion-atom and ion-surface collisions in this laboratory a hollow-cathode type ion source (DANFYSIK 911A) has been installed on the beam line of the 1 MV VdG. The ion source operates at 5-30 kV acceleration potential independently from the VdG generator. Later an additional 50 kV acceleration stage will be built to reach a maximum 80 keV/q projectile energy, which is the lowest limit of the 1 MV VdG accelerator. The ion source was purchased without any accessories (extraction optics, power suppliers etc.). All these elements were designed and manufactured in ATOMKI during the last 3 years.

The source is a hot cathode type ion source which is able to produce single charged ions from most gases and solids (from H to U) up to a few tens μA. All the power suppliers (anode electrode, source magnet, oven and filament) as well as the whole gas control unit are separated from the ground by an isolated transformer and are mounted on the acceleration potential (presently max. 30 kV).

The extraction and focusing system consists of an accel-decel extraction optics followed by an Einzel triplet. The shape and potential of the electrodes were designed on the basis of the "cos+lin" method[1]. This theory gives a criteria for the potential distribution along the axis of the extraction system. The optimization of the optics was carried out by the SIMION computer code. We tested the extraction and focusing optics with $H^+$ and $Ar^+$ ions at different energies up to 30 keV[1]. The electrode potentials, optimized for the best beam parameters (largest intensity and smallest diameter), are in good agreement with the calculated values.

Presently the ion source is used for high resolution 0° electron spectrometry. A further development is in progress to change the polarity of the source potential. In this way the source will be able to produce both positive and negative ion beams.

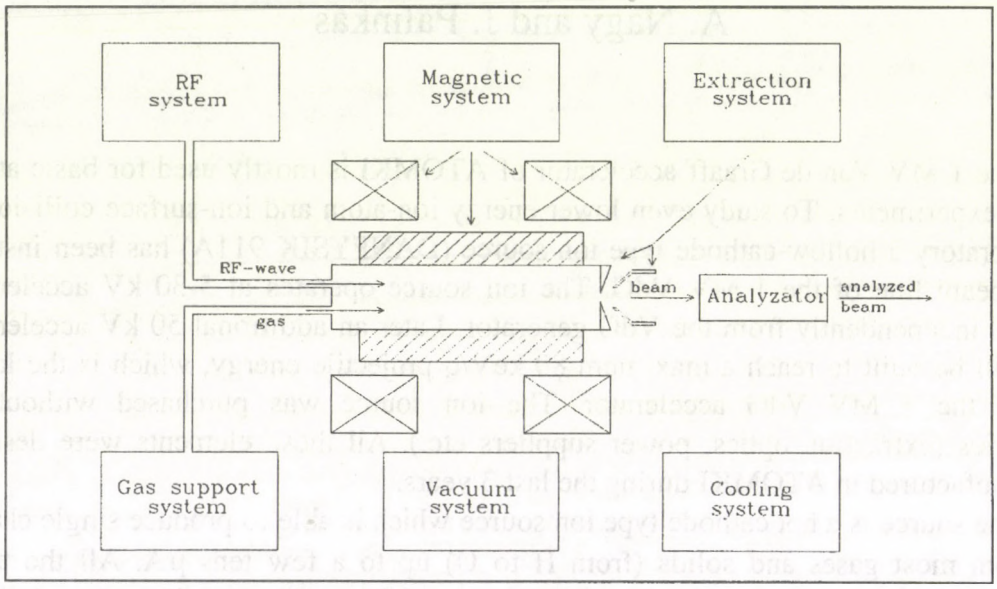
## References:

[1] S. Biri, A. Báder and J. Pálinkás: A simple model to describe ion source extraction optics - simulations and experimental test, accepted for publication in Rev. Sci. Instrum.

# Test measurements of the ECR ion source subsystems

S. Biri, F. Gáll, I. Szűcs, A. Valek and J. Vámosi

In 1995 the designing of the subsystems of the electron cyclotron resonance (ECR) ion source[1] has been finished, numerous test measurements of these subsystems have been carried out and the assembling of the whole ion source is in progress. The figure below shows the main subsystems of the ion source.




The waveguide connection (including vacuum window, high power circulator, measuring connections) between the 14.5 GHz transmitter and the plasma chamber has been designed and presently is being built. The two big coils with thick iron disks have been mounted on the stand. The measured peak axial magnetic field at full DC power (80 kW) was found to be 0.8 Tesla which is 10% higher than the calculated one (applying full iron shielding the magnetic induction is expected to be 1.2 Tesla). The vacuum system (turbomolecular pumps) is able to pump the ion source down to $2*10^{-7}$ mbar using viton O-rings everywhere. The closed water cooling system was tested in the hottest summer days with excellent result: having 32 degrees outside temperature the cooling fans were able to cool down the 60 degrees warm water (coming from the coils) to 35 degrees without any evaporation support. This means that the ECR ion source can be operated at any weather conditions in the future. In 1995 most of the vacuum elements (cross-pieces, connections, flanges) including the double wall plasma chamber have been manufactured in the workshop. The designing of the extraction system and the beam line is still in progress.

The 14.5 GHz microwave will be coupled into the plasma chamber within one month. This means that a hot, dense plasma containing highly charged heavy ions will be soon generated.

[1] The ECRIS program was supported by the 'Human Resources' project of the World Bank (OTKA Nr.: A077), by the OTKA (F013961 and F15088) and by the FEFA (HU-3313 697/2-AA-1and HU-1995).

# Profile Monitor System for the Cyclotron

Z.Kormány

The beam diagnostic tools of the MGC cyclotron have been extended by mounting helical wire scanners [1] in the transport lines. The units are driven by stepping motors and get the beam intensity distribution in horizontal and vertical planes within 1.7 seconds. The spatial resolution of the measurement is 1 mm over the whole aperture of the beam line. Profile distributions can be taken in the intensity range from 100 nA up to the maximum beam current of 50 μA.

The movement of the scanning wire and the evaluation of the picked-up signal are controlled by a personal computer equipped with plug-in data acquisition cards [2]. The control code provides a user friendly environment for the operators. The "Virtual Instrument"-like display picture shows not only the measured intensity profiles but the symbols and status of the control keys, too. It allows single or continuous scanning, driving one or two units simultaneously. Fig. 1 shows the display picture by using scanners Nr.1 and 3 together. The approximate total intensity is calculated from the measured signal values as well and is displayed in a bar graph between the horizontal and vertical profiles.

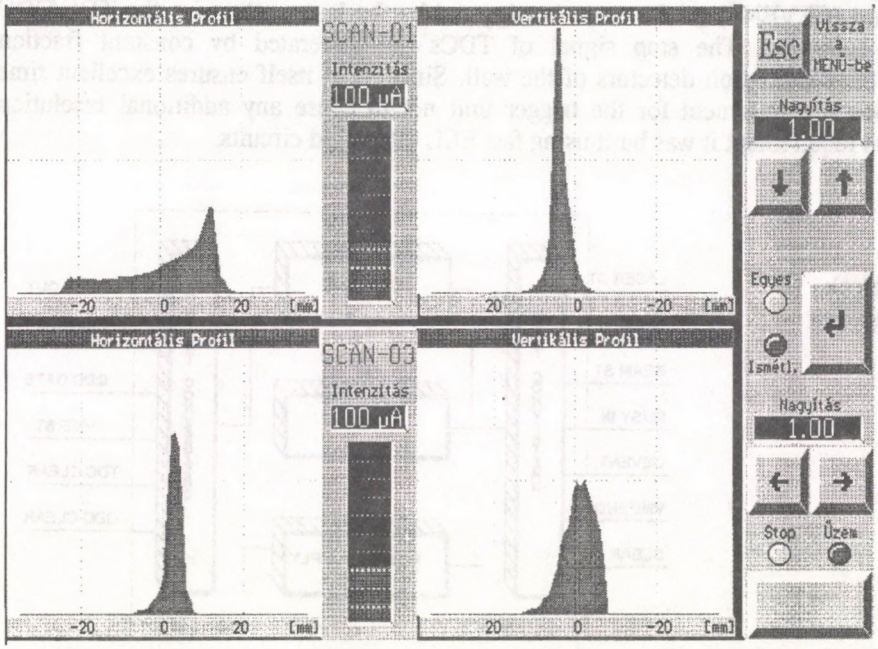



**Fig.1.** Measured beam profiles in two sections of the transport system

Three scanners have been put into operation until now. The first is in the main beam line near the exit of the cyclotron. The second one is located in the target room for nuclear spectroscopy and can be used by all experiments there. The third unit is mounted in the vicinity of the target on the vertical beam line used for isotope production.

This work was supported by the Fund for Further Development of Higher Education (FEFA No. 697/2.)

**References:**

[1] G. Hortig, Nucl. Instr. Meth. A30 (1964) 355.

[2] Z. Kormány, A. Valek, F. Dworschak, W. Kogler and W. Stellmacher, in Proc. EPAC 94, World Scientific (1994) 1524.

# Trigger Unit for the Time of Flight spectrometer used in the CERN NA49 experiment

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The CERN NA49 experiment intends to investigate the new physics offered by the Super Proton Synchrotron (SPS) lead (Pb) beams and will study the production of charged hadrons and neutral strange particles. The major detector components are a fine granularity Time Projection Chamber (TPC) and two high resolution intermediate size TPC. The hadron identification scheme is completed by a high resolution time of flight (TOF) wall (BUDAPEST WALL) [1].

Within the framework of the above mentioned experiment a NIM module (BUDATRIGGER UNIT) was developed and used successfully during the last physics run in November 95' at CERN. The unit is intended to control the different parts of the data acquisition system (Detectors & Front-End Electronics, VME-DAQ, ALEPH Event Builder) built around the TOF spectrometer. The module accepts different input signals and according to the experimental requirements it produces control and timing signals. The simplified block diagram of the unit is shown in Fig. 1.

The trigger unit responds to the LASER ST or the BEAM ST inputs producing both the start signals for the TDCs and the gate signals for the QDCs if there is no BUSY IN signal. The SPILL signal inhibits the LASER ST signal. The VME ST signal is valid and data are taken by VME-DAQ if the event comes from the central part (CEVENT) or the event is triggered by the laser, otherwise the TDC/QDC CLEAR is immediately generated. The stop signal of TDCs are generated by constant fraction discriminators driven by the scintillation detectors of the wall. Since TOF itself ensures excellent time resolution (< 60 ps) it was a requirement for the trigger unit not to cause any additional resolution degradation. To satisfy this requirement it was built using fast ECL integrated circuits.

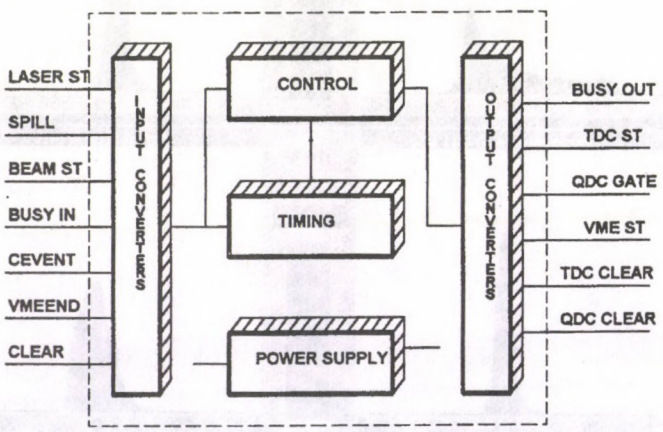


**Fig. 1.** Simplified block diagram of the trigger unit

The explanations of the input and output signals are as follows:

**Input signals:**
LASER ST: start command from the laser
SPILL: signal from the SPS
BEAM ST: start command from the beam
BUSY IN: busy signal from other detectors
CEVENT: central event identification signal
VMEEND: VME-DAQ acknowledge signal
CLEAR: external signal for reset.

**Output signals:**
BUSY OUT: busy signal of the trigger unit
TDC ST: start command for the time to digital converters (TDCs)
QDC GATE: gate signal for the charge to digital converters (QDCs)
VME ST: start command to the VME-DAQ;
TDC/QDC CLEAR: signal to reset the QDCs and TDCs

This work was supported by the Hungarian Research Fund (OTKA) under contract No. T013950.

## References

[1] Experiments at CERN in 1993, Geneva November 1993 p.105

# Position sensitive avalanche detector for fission fragment angular distribution measurements

M. Hunyadi and A. Krasznahorkay

The study of the hyperdeformed states in $^{236}$U has been started at our department by measuring transmission resonances in the $^{235}$U(d,pf)$^{236}$U reaction. In order to determine the spin of the resonances we have built a 85×94 mm$^2$ position sensitive avalanche detector (PSAD), which was found an adequate tool for angular distribution measurements [1].

The detector consists of two anode wire planes including 40 and 45 wires, with a spacing of 2 mm, corresponding to the horizontal and vertical directions, respectively. Gold plated tungsten wires with a diameter of 20 $\mu$m were used. The cathode of the front wire plane is a thin aluminized mylar foil, while of the rear wire plane is a massive copper plate, which are placed at the same distance of 2.5 mm from the wires. The detector was placed in a perspex box, which has an aluminized mylar entrance foil of 2.5 $\mu$m thickness.

The detector is continuously flushed with isobuthane at a pressure of 6 mbar, and operated at 550 V. We have used a delay-line read-out similar to the one developed by Crouzen [1]. The time signals are digitized by LeCroy 2228A TDC units and the read-out and data taking were performed by a PC.

As a result of our test measurements performed with $^{235}$U(d,f) reaction the identification of the wires in both directions was reliable as can be seen in Fig. 1.

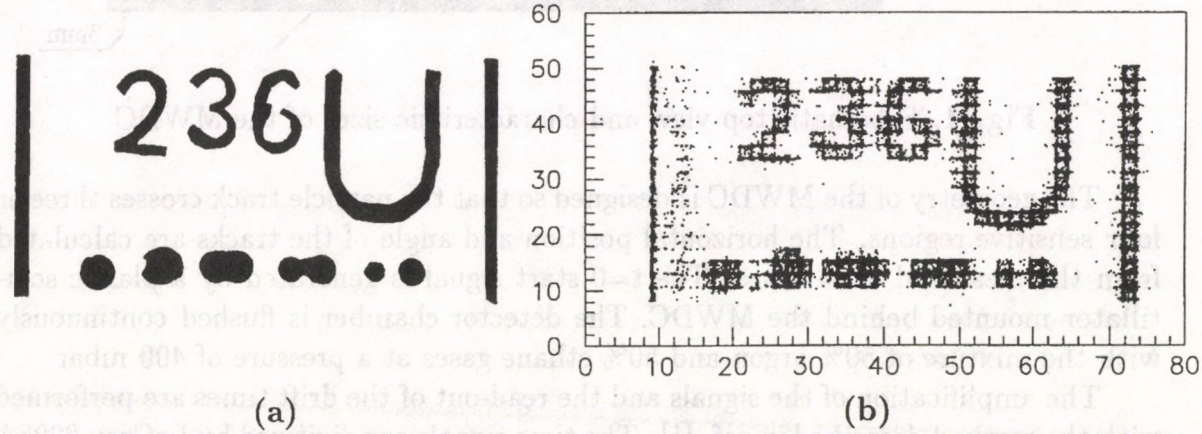


**Fig. 1.** (a) Al-mask; (b) resulted scatter plot of the fission fragments reaching the detector through the Al-mask

This work has been supported by the OTKA Foundation, No.:7486 and by the Nederlandse Organisatie voor Wetenschappelijk Onderzoek.

## References

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# Multiwire drift chamber as focal plane detector of the split-pole magnetic spectrograph

A. Krasznahorkay, M. Csatlós, J. Gulyás, M. Hunyadi, Z. Máté, J. Tímár and S.Y. van der Werf*

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The focal-plane detector is an essential and critical part of the magnetic spectrographs. The position resolution of such a detector must be better than dictated by the focusing properties of the spectrograph (≈0.4 mm). The ATOMKI split-pole magnetic spectrograph with its 120 cm long focal plane and small energy dispersion (10 mm/%) covers a large energy range ($E_{max}/E_{min}$ = 4.8). In order to cover a considerable fraction of the focal plane a 480 mm long multiwire drift chamber (MWDC) similar to the one described by Schippers et al. [1] has been constructed in our institute (see Fig. 1.).

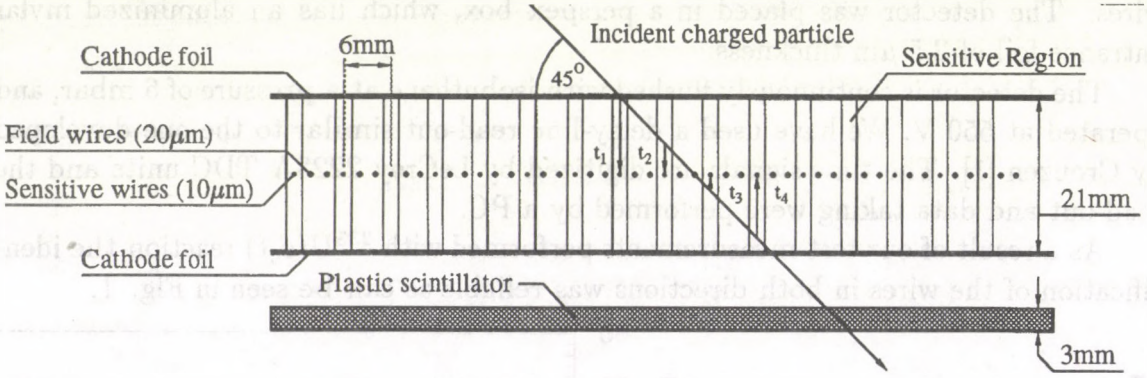


**Fig. 1.** Schematic top view and characteristic sizes of the MWDC

The geometry of the MWDC is designed so that the particle track crosses three or four sensitive regions. The horizontal position and angle of the tracks are calculated from the measured drift times. The t=0 start signal is generated by a plastic scintillator mounted behind the MWDC. The detector chamber is flushed continuously with the mixture of 50% argon and 50% ethane gases at a pressure of 400 mbar.

The amplification of the signals and the read-out of the drift times are performed with the method described in ref. [1]. The time signals are digitized by LeCroy 2228A TDC units and the read-out and data collecting is performed by a personal computer.

A position resolution of ≈150$\mu$m has been achieved for the light ion beams of the K=20 cyclotron of ATOMKI.

This work has been supported by the OTKA Foundation No.:7486 and by the Nederlandse Organisatie voor Wetenschappelijk Onderzoek.

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[1] J.M. Schippers, W.T.A. Barghols and S.Y. van der Werf, Nucl. Instr. and Meth. **A247** (1986) 467

# Neutron radiation tolerance tests and activation studies for the FERMI collaboration

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In the frame of CERN RD-16 Project, neutron activation studies and radiation tolerance tests of different integrated circuits and structures were carried out at the p(18 MeV) + Be fast neutron irradiation facility of the ATOMKI [1] in the FERMI (Front-End and Readout MIcrosystem) Collaboration.

The FERMI is designed to perform dynamic range compression, digitisation up to 80 MHz, digital signal processing, trigger functions and buffering data up to second level triggering latency. The expected yearly flux is some $10^{14}$ n/cm$^2$ for FERMIs which are planned to be applied at detectors at the future Large Hadron Collider (LHC) at CERN, Geneva.

Major components of the microsystem are the analog dynamic range compressor and the fast Parallel Successive Approximation A/D converter (PAS-ADC). These parts together with test structures were modified for implementation in the so called DMILL rad-hard technology from Saclay (France) and then neutron tolerances of two engineer samples have been tested. The effect of flux of $1.1 \times 10^{14}$ n/cm$^2$ was a 7% (in ADC units) gain degradation in the case of the dynamic range compressor. Concerning the radiation tolerance of ADC's parameters, two typical diagrams are presented in Figs. 1 and 2. The total flux was $2.1 \times 10^{14}$ n/cm$^2$ for these cases.

The FERMI circuit is implemented as a thin-film Multi-Chip-Module (MCM) on a silicon substrate with four metal layers. Application Specific Integrated Circuits (ASICs) are flip-chip bonded to the substrate which can contain integrated resistors and capacitors. The flip-chip bonding is more performant and reliable than a conventional wire bonding due to the drastic reduction of parasitics associated with a solder bump. Neutron activation of an engineer sample of a multilayer substrate produced by ABB HAFO using the flip-chip bonding technology has been studied.

Two memories of high radiation tolerance were also studied. The first one, a THOMSON TSX4H6808MC70 8kx8 bits SRAM is a radiation hardened and fully static memory using 6-transistor cell structure. These CMOS devices are fabricated using the THOMSON HSOI3HD 1.2μm Silicon-On-Insulator (SOI) technology and they are based on a SIMOX substrate (Separation by Implantation of Oxygen). The silicon dioxide layer beneath the surface of the wafer of the SIMOX substrate is produced by implantation of oxygen ions and annealing. The active elements are then built in a monocrystalline silicon layer topping on the surface of the wafer. The isolating layer makes the product inherently latch-up free and brings dramatic improvements over epiCMOS concerning Single Event Upsets (SEU). No errors were observed during an irradiation with an overall flux of $2 \times 10^{14}$ n/cm$^2$.

The second one, a MATRA TEMIC M65656F 32kx8 bits is a very low power static RAM with 6-transistor cell structure. Extremely low standby supply current and fast accessing time are the other main features of this memory. This IC was produced using the MHS high performance radiation tolerant 0.85 μm CMOS technology called

as SCMOS1/2 RT. Extra protection against heavy ions is given by an epitaxial layer of a p-type substrate. The overall flux was $1.6 \times 10^{14}$ n/cm$^2$. The number of failed cells versus integrated neutron flux is presented in Fig. 3.

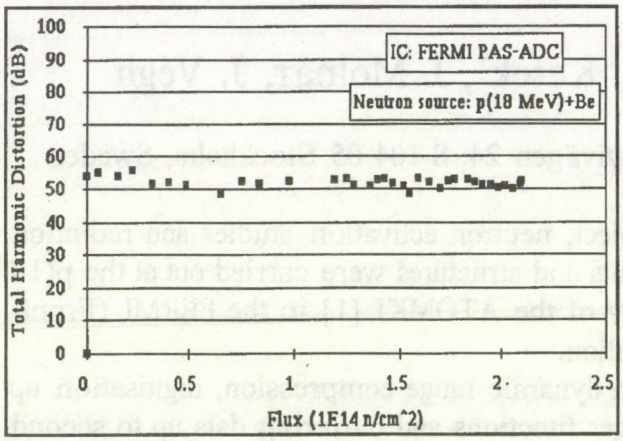


**Fig. 1** Total harmonic distortion vs. neutron flux for FERMI PSA-ADC.

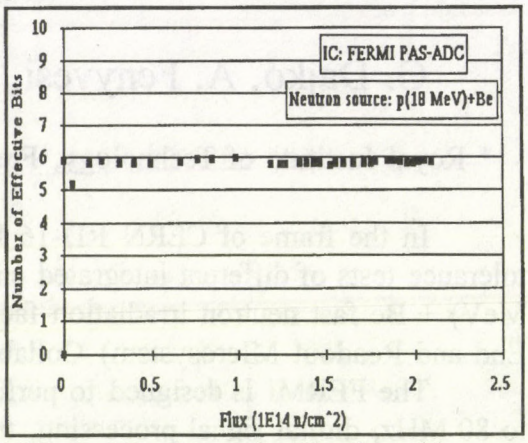


**Fig. 2** Number of effective bits vs. neutron flux for FERMI PSA-ADC

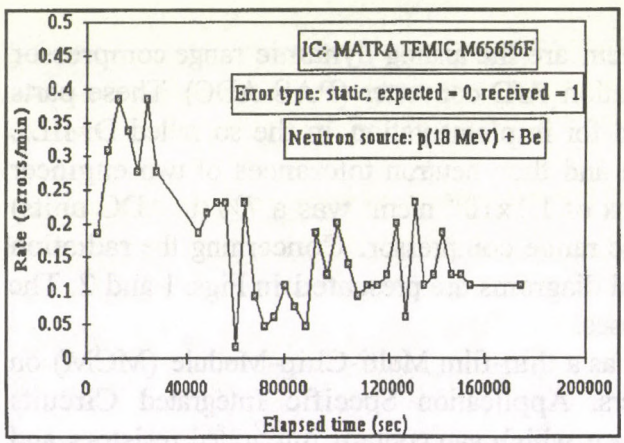


**Fig. 3** Rate of static errors versus irradiation time. Readings obtained with all bit patterns are included.

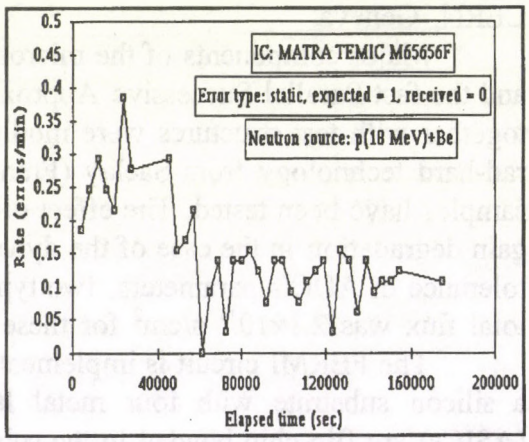


**Fig. 4** Rate of static errors versus irradiation time. Readings obtained with all bit patterns are included.

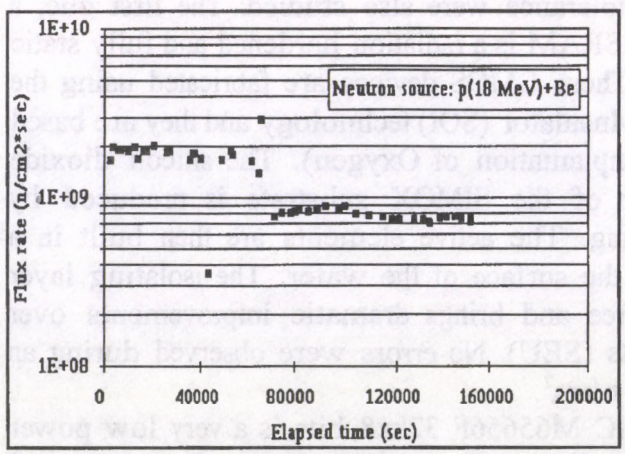


**Fig. 5** Flux rate vs. irradiation time.

**Reference:**

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# A Multi-Element Lens for an UPS Spectrometer

K. Tőkési and D. Varga

A special ultraviolet photoelectron spectrometer (UPS) has been developed in our department for studying free atoms and molecules. An electrostatic lens is placed between the sample and the electron energy analyzer (hemispherical electrostatic analyzer) for transporting and accelerating (retarding) the electrons to be analyzed.
The kinetic energy of the photoelectrons excited by ultraviolet (UV) radiation is rather small and at the same time the value of the remaining magnetic field is the highest in the place of the sample (i.e. gas target) because of the openings for different kind of sample introduction and the excitation source. Therefore it is better to decrease the electron energy to the given pass energy in the vicinity of the analyzer slit. These circumstances require avoiding the cross points of electron trajectories between the sample and the spectrometer slit. For these reasons the lens were separated into two parts (accelerating and retarding), thus avoiding to treat many parameters of the lens at the same time.
The task of the first stage is to change the initial kinetic energy of the electrons ($1 \le E_1 \le 50$ eV) to the output energy (25 eV). The size of the source is small enough compared to the size of the lens, therefore the source of the first 4 element lens at the beginning of our design was considered as a point source and required a parallel output beam of electron trajectories emitted from the object point with 4° with respect to the lens axis.
The second stage of the designed lens collects the electrons into the point at the input slit of the spectrometer and decreases its energy for a given pass energy of the analyzer ($1 \le E_p \le 10$ eV). Both stages were designed by the help of 4 element cylindrical lenses. The fourth element of the first stage is the first element of the second stage. Thus our lens system contain 7 elements. The four element lenses have enough free parameters – in our case two+two potential values ($V_2$,$V_3$) and ($V_5$,$V_6$) at a given length of the electrodes – to realize the fixed object and image distance. The potential values of $V_1$, $V_4$ and $V_7$ are determined by the acceleration and retardation ratios.
As a result of the optimization procedure the voltages for the first stage are the following: $U_1=0$, $U_2=2.625-0.947E_1$, $U_3=10.9-0.82E_1$, $U_4=25-E_1$. Using the linear dependence of the voltages for the first stage, $U_2(E_1)$ and $U_3(E_1)$, the focus voltages of the second stage were corrected and were found to be $U_5=9.896+0.11E_p$ and $U_6=3.29-E_1$. In this way operating the lens could be solved by using two controlled power supplies of the analyzer, and a third one operating at a fix voltage (25 eV) with suitable voltage dividers.
The linear magnification is about -1 and it is slowly changing in the wide range of the acceleration (retardation) ratio as the results by the calculations of emittance-acceptance of the lens. The properties of the built lens system were tested experimentally by measuring the intensity of Ar 3p photoelectron peak excited by the $HeI_\alpha$. In the test measurement one of the focus voltages ($U_5$) was adjustable independently to the value obtained by the help of voltage divider. The value of $U_5$ was optimized, at different pass energies, finding the maximum intensity of Ar 3p photoelectron line. The calculated potential values are in good agreement (5%-7%) with the experimentally optimized values.

# Efficiency curve for ESA-21 electron spectrometer

Gy.Vikor[$], Á.Kövér, S.Ricz, B.Sulik, L.Tóth

In order to determine absolute and relative double differential cross sections (DDCS) of electrons ejected from ion - atom collisions we have to know the efficiency of the ESA-21 electron spectrometer [1] in function of the pass energy and ejection angle. Several methods are exist to determine these function. We chose the simplest way i.e. to measure the intensity of ionized electrons ejected into different angles and compare it with known absolute DDCS. The energy distribution of these electrons is continuous therefore the efficiency curve of the measuring system can be determined for wide energy region. In this case the efficiency function reflects not only to the efficiency of the electron detector but the efficiency of the all system including i.e. the intensity decrease caused by the surface impurities and residual Earth magnetic field etc..

Figure shows the measured relative efficiency curve for different forward ejection angles normalized to one at 100 eV. The measured electrons originated from 1 MeV $H^+$ - He collision. The absolute DDCS data were taken from the table of Rudd *et al* [2]. It can be seen that the relative efficiency is sharply increase in the 0 to 40 eV energy region and then slowly decrease to higher energies. The shape of the curves measured at different angles are similar.

No significant change was found above 8 eV in the shape of the efficiency curve when the electrons were accelerated with 10, 20 30 and 40 V before entering the analyzer.

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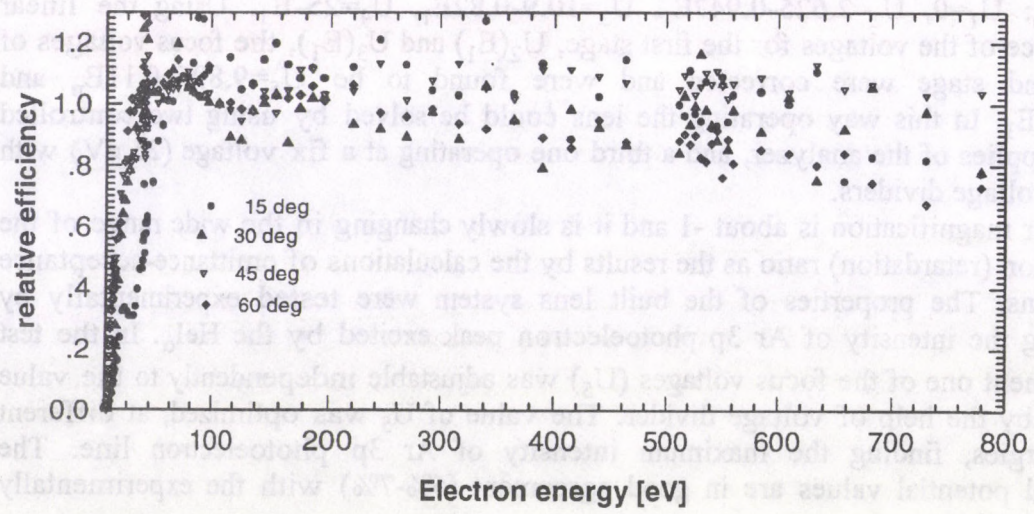
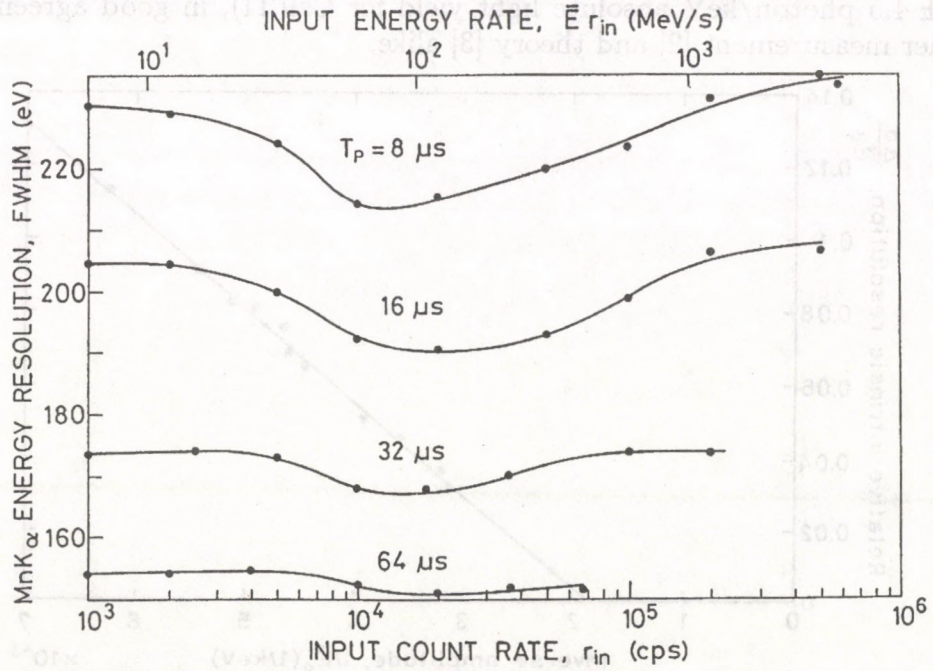


# Very high rate X-ray spectrometry with pulsed drain-feedback preamplifier and digital signal processor

T. Lakatos, G. Hegyesi, G. Kalinka

The drain-feedback method, based on impact ionization in the input JFET, as a charge restoration for Si(Li) X-ray spectrometers has long been known [1], and actually been used. Inherent to the operating principle there are, however, difficulties [2] with the realisation of a pulsed version to cope with high input rates. A relatively simple pulsed drain-feedback preamplifier (PDFB PA) [3] provided good low rate resolution and moderate degradation up to ca. 50 kcps $^{55}$Fe intensity with an analogue time-variant signal processor [3,4]. Using an adaptive digital signal processor (ADSP) with excellent high rate capability, however, the resolution degradation is no longer acceptable at very high rates [5].

A new version of the PDFB PA [6], in which the FET drain is controlled via the detector capacitance without using special driving circuits, and requires an ordinary three terminal JFET, has only 5 $\mu$s reset time. Although the PA has been tested up to 2 Mcps, due to large dead time losses in nonadaptive mode, spectra were evaluated up to only 600 kcps, where resolution degradation is still negligible if PA output is gated for 50 $\mu$s after every reset action to improve linearity. A systematic dip in the FWHM – input rate curves taken with an $^{55}$Fe isotope, a Si(Li) detector and an ADSP at different peaking time values (see the figure) is not explicable in terms of FET self heating or other reasonable effects.

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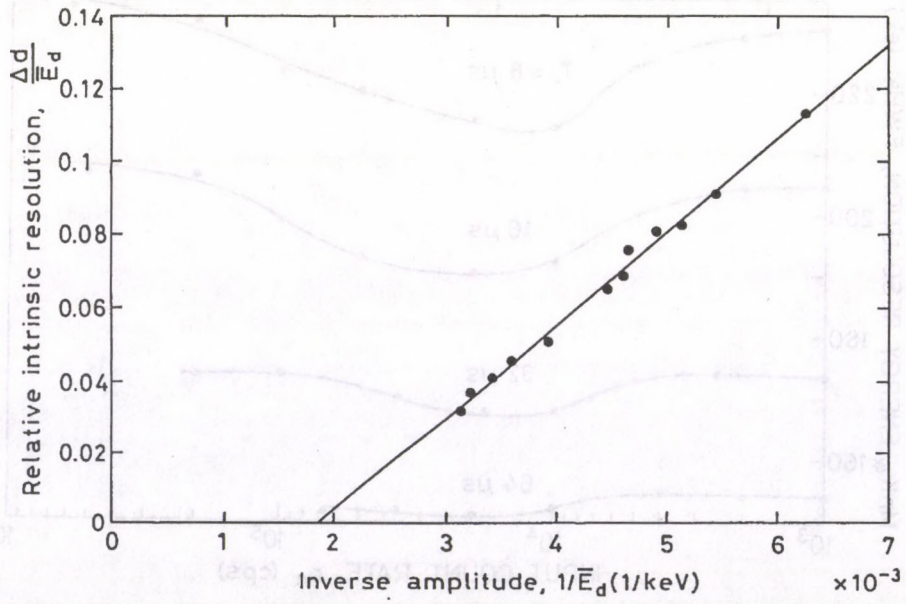
# Determination of light collection efficiency and absolute light yield of CsI(Tl) + photodiode detectors

G. Kalinka, J. Gál, B.M. Nyakó

Due to the relatively low (usually $\leq$ 80 %) light collection efficiency $\eta_L$, in scintillation detectors light creation statistics is negligible, thus resolution is largely determined by light collection nonuniformity, especially for charged particles, and for photodiode (PD) readout can be approximated as [1]:

$$\frac{\Delta_d}{\overline{E_d}} \approx 2.355 \frac{\sigma(\eta_L)}{\overline{\eta_L \eta_d}}, \qquad (1)$$

where $\overline{E_d}$ is the measured amplitude in the PD (Si in our case) energy scale, $\Delta_d$ is the corresponding FWHM resolution after correction for electronic noises, $\eta_d$ is the PD charge collection efficiency, overline and $\sigma$ designate mean value and standard deviation. That is, in the $\eta_L \to 1$ case, when $\sigma(\eta_L) \to 0$, $(\Delta_d/\overline{E_d}) \to 0$ is also expected. A small CsI(Tl) scintillator coupled to Si pin PD, developed for charged particle detection [1], with teflon tape side reflector was used to demonstrate the validity of (1): $\eta_L$, consequently $\overline{E_d}$ was varied by changing teflon reflector thickness. The measured $(\Delta_d/\overline{E_d})$ values showed good proportionality to $1/\overline{E_d}$ for 5.5 MeV $\alpha$ particles (see the figure). Thus an extrapolation to $(\Delta_d/\overline{E_d}) = 0$ results in $E^{\star}_{d,\alpha} = 542 \pm 37$ keV reference energy for the determination of $\eta_L$. A 5.5 MeV $\alpha$ – 662 keV $\gamma$ cross calibration, a ballistic deficit correction and $\eta_d$=0.91 [2] gives 65.8 $\pm$ 4.5 photon/keV absolute light yield for CsI(Tl), in good agreement with another measurement [2] and theory [3] alike.

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# Monte Carlo Code for the Study of the Response Function of Si(Li) Detectors for X rays

K. Tőkési and T. Mukoyama*

It is generally recognized that the Monte Carlo simulation is very useful tool to understand the lineshape of X-ray spectrum with a Si(Li) detector. We have developed a new Monte Carlo code and tested it to simulate the response function of the Si(Li) detectors in the range of primary X-ray energy less than 5 keV. The present Monte Carlo code differs from the well known Monte Carlo codes developed earlier. In our simulation we took into account the elastic and sum of the inelastic processes of produced electrons in the solid as well as the charge collection probabilities in the different region of Si(Li). The elastic scattering process is described by the Mott-scattering cross-section derived from the partial expansion method using the Garvey, Jackmen and Green potential [1]. The inelastic scattering process of electron penetrating into the solid was described in terms of the dielectric function formalism. For the detector model we used the same model as described in ref. 2.

As our preliminary results to demonstrate the validity of the approximations used in the present code, the calculation of the response function of Si(Li) detectors, using the same parameter as described in ref. 2. was performed and the obtained results were compared with the simulated data in ref. 2. It has been confirmed that our calculations are in good agreement with the results of Geretschläger.

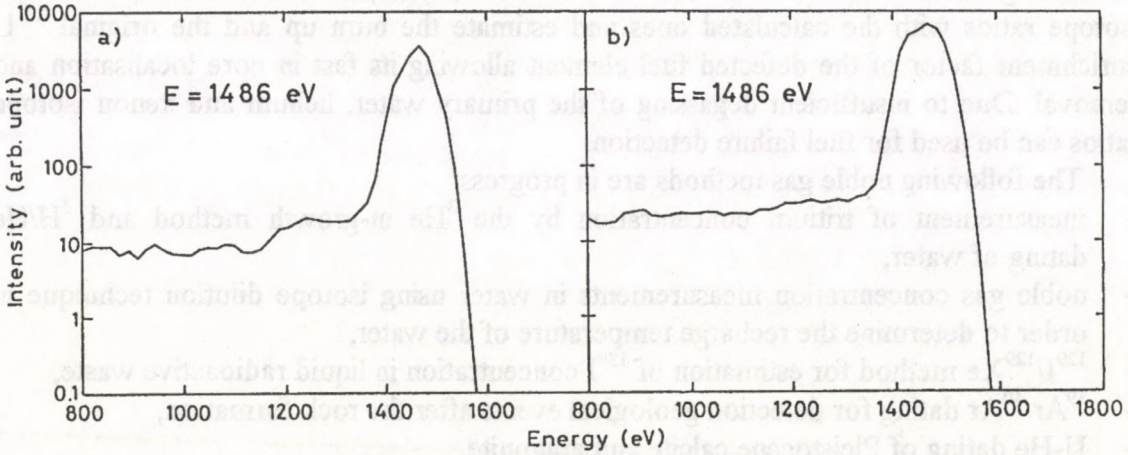


Fig.1. Monte Carlo simulation for K X-ray spectra. a: taken with Si(Li)#1 from ref. 2. b: taken Si(Li)#2 from ref. 2.

**Acknowledgments**

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# Installation of a static vacuum noble gas mass spectrometer type VG-5400

E. Hertelendi, K. Balogh, É. Svingor, I. Futó

The financial support of PHARE-ACCORD H-9112-0172 was used for the purchase of a VG-5400 mass spectrometer suitable for determination of isotope ratios of all noble gases. This is the first noble gas mass spectrometer in Hungary which has the sensitivity, accuracy and resolution required by various important fields of research, like environmental research, nuclear fission safety, waste disposal and geochronology. The mass spectrometer has a magnet of 90° deflection and 27 cm deflection radius with an extended geometry. The sensitivity is $1x10^{-3}$ A/mbar for Ar and $2x10^{-4}$ A/mbar for He. The resolution is adjusted to 600 which is sufficient for the resolution of $^3He^+$, $H_3^+$ and $HD^+$ beams. The abundance sensitivity measured as contribution from mass 40 at mass 39 is less than 0.5 ppm at $10^{-7}$ torr. The static vacuum level in the 1.3 l volume deflection chamber is $1x10^{-12}$ $cm^3$ STP/min at mass 40.

The first measurements with the mass spectrometer were carried out on noble gas samples obtained from primary water of a nuclear power plant. The aim of the measurements were to find correlation between the concentration as well as isotope ratios of noble gases and fuel failures. Further aim was to compare the measured noble gas isotope ratios with the calculated ones and estimate the burn up and the original $^{235}U$ enrichment factor of the defected fuel element allowing its fast in core localisation and removal. Due to insufficient degassing of the primary water, helium and xenon isotope ratios can be used for fuel failure detection.

The following noble gas methods are in progress:

- measurement of tritium concentration by the $^3He$ in-growth method and $^3H/He$ dating of water,
- noble gas concentration measurements in water using isotope dilution technique in order to determine the recharge temperature of the water,
- $^{129}I/^{129}Xe$ method for estimation of $^{129}I$ concentration in liquid radioactive waste,
- $^{39}Ar/^{40}Ar$ dating for detection geological events after the rock formation,
- U-He dating of Pleistocene calcite and aragonite,
- helium concentration and isotope ratio measurement in earth gas in order to determine connection among gas reservoirs.

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# A dual-port incrementing matrix memory card for 2-dimensional visualization

J. Molnár, J. Szádai, J. Gál , B.M. Nyakó, S. Ricz

The multiparameter (dimension) measuring technique is a commonly used method in physics experiments. In a frequently used solution of this technique the data gained from the experiments are stored for later evaluation. However, in a lot of real-time applications - e.g., beam profile and position monitoring, testing of new measuring techniques, etc. - this time-delayed off-line evaluation is very inconvenient. In these cases real-time visualization is required. In order to accomplish this, we have developed an IBM-PC based dual-port incrementing matrix memory card. The functional block diagram of the board is shown in Fig. 1.

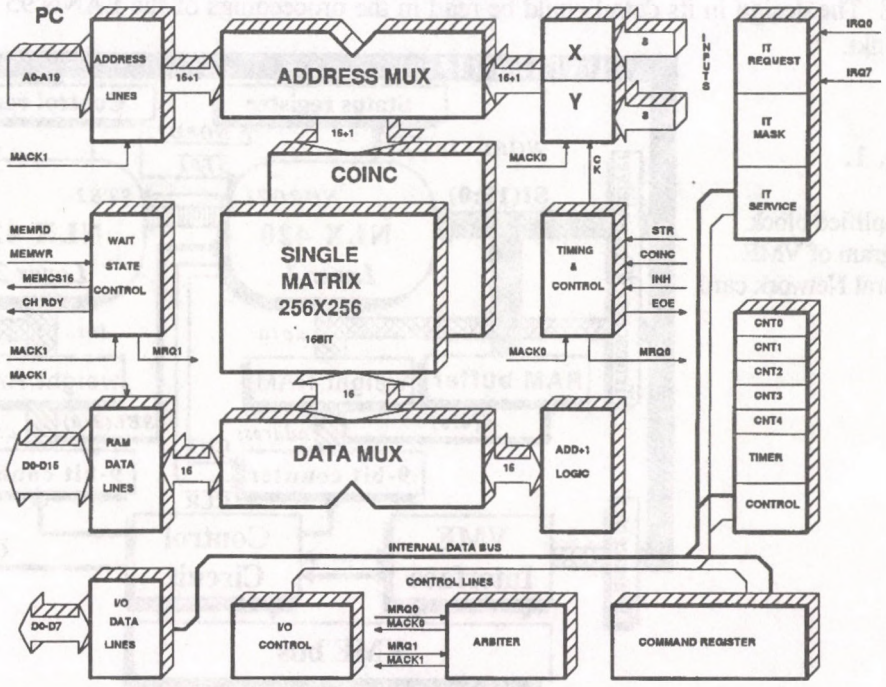


**Fig. 1.** Block diagram of the incrementing matrix memory card.

The most significant parts of the card are as follows: two blocks of SRAMs (COINC/SINGLE MATRIX) of 256x256x16 bit organization, temporary storage and access logic (X/Y, ADDRESS/DATA MUX, ADDRESS/RAM DATA LINES, I/O DATA LINES), control blocks (WAIT STATE CONTROL, I/O CONTROL, ARBITER, TIMING&CONTROL, ADD+1 LOGIC), programmable interrupt controller (IT), counter/timer (TIMER) and programmable peripheral interface (COMMAND REGISTER).

On its inputs the card accepts two 8-bit codes representing the two parameters of the measurement and they are stored temporarily in the X/Y latch. The ADD+1 logic increments the content of memory location addressed by the X/Y codes.

At any time the data accumulated in the memory can be non-destructively read out. A queuing logic (ARBITER) allows to accomplish the data accumulation and the readout simultaneously.

The on-board timer allows both time or count preset. When the selected preset value is reached the acquisition is stopped and the card sends an interrupt service request to the IBM-PC.

Depending on the system environment and on the specific measuring demands the operation modes of the card can be selected and controlled by a programmable register (COMMAND REGISTER).

The card is succefully used together with a two-dimensional position sensitive detector system, and with a particle discriminator, where the two parameters are the particle type and the particle energy [1].

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# A versatile neural network card for the VME bus.

M. Minerskjöld*, J. Molnár, G. Székely and Th. Lindblad*
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This work was initiated by the demand of a fast and versatile neural network for the VME bus standard. In this case a neural network (NNW) chip from the American NeuraLogix (NLX420) was used to implement the neural function. Although the company supplies a PC/AT card, it could only be used for evaluation. In real cases, such as real-time beam diagnostics, the performance of the NLX chip has to be stretched to its outer limits. Also, the use of large NNW's in control applications is not needed and this is why the card has 16 neurons in two layers; one hidden and one output layer. Besides this, the most common bus in the research community is the VME. The design in its detail could be read in the proceedings of the EANN'95 conference [1] in Helsinki.

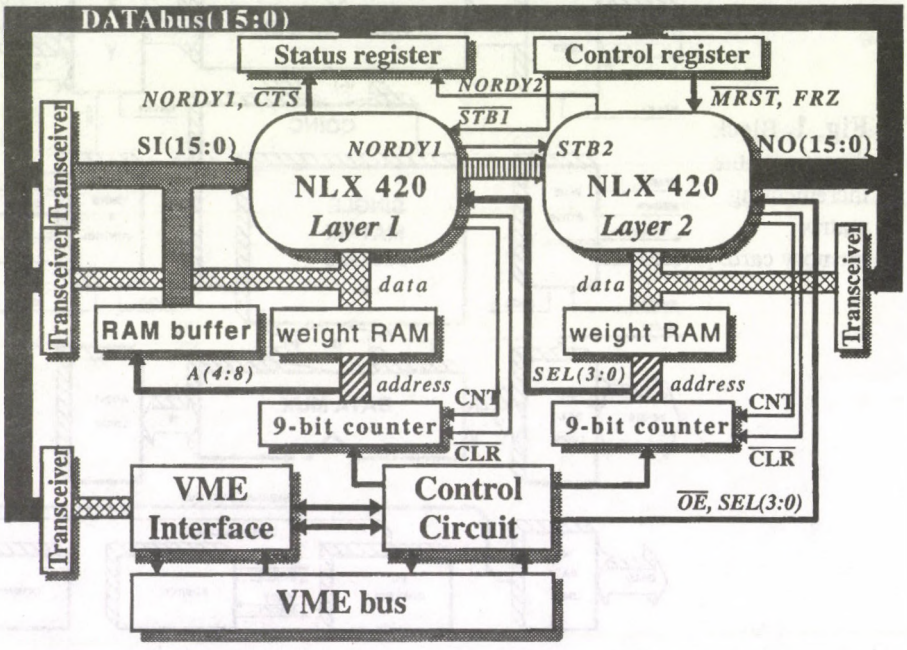


**Fig. 1.**

Simplified block diagram of VME Neural Network card

However, it was later found that the card for general purpose reasons needed a software program that could be operated by people not familiar with neural computing. Two approaches was done to meet these new demands. At KTH (Stockholm) a C++ program was written on a SUN Sparc station to provide a link between the S-bus and the VME crate. An assembler code for VME bus controller was also developed which is supervised by a PC monitor program. The second approach is an interactive program that initializes the NLX card and generates different threshold functions to be downloaded on the card. Since the card itself does not have learning on-board the program takes advantage of the computational speed of the card and uses it as an accelerator for the forward pass in the back propagation algorithm. The program also provides a simple way of generating test patterns for the learning phase.

The work was done in a collaboration between the Hungarian Academy of Science and the Swedish Engineering Academy (IVA).

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# Activities at the scanning proton microprobe

I. Rajta, I. Borbély-Kiss, L. Bartha, Gy. Mórik,
E. Koltay and Á.Z. Kiss

The scanning proton microprobe (SPM) [1] has started its regular operation at the beginning of the year. Since then analyses in the following subjects have been performed using the PIXE method:

*Mineralogy:*

Comparative SEM-EDAX and SPM study of spherules (micrometeorites) collected in the Little Hungarian Plain from different boreholes [2,3] and from the Crisu Negru (Fekete Körös) area, Romania [4]. The works were performed in cooperation with the Institute of Mineralogy, Kossuth Lajos University and the Geological Institute of Hungary.

*Archaeology:*

During the workshop of the COST action G1 "Ion beam analysis in arts and archaeology" (Debrecen, 1995) several artefacts have been investigated [5]. A medieval belt-mount from the 7th century A.D. was analysed from the collection of Somogy County Museum, Kaposvár, Hungary.

*Materials science:*

Preliminary study on a $Bi_2CaSr_2Cu_2O_x$ superconductive material [6].

*Aerosols:*

Measurements were started for mapping individual aerosol particles, collected for PIXE analysis in our IAEA Co-ordinated Research Programme [7], and those collected in Southern Chile during an eruption of the Lonquimay volcano.

The following developments have been performed on the facility during this year: A new Canberra Si(Li) detector with an active surface of 80 $mm^2$ is used, and a 17" monitor has been installed on the data acquisition computer. To meet the requirements of measuring large amount of spherules investigated in a global programme more instrumental developments are under progress.

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# Activities at the Van de Graaff Accelerator Laboratory

L. Bartha, Á.Z. Kiss, E. Koltay, Gy. Mórik,

E. Somorjai and Gy. Szabó

During 1995 the beam time of the VdG–1 machine amounted to 598 hours. The accelerator delivered proton and helium beams for atomic physics during 215 and 380 hours, respectively. In order to produce light and heavy ions in the low energy range a hollow-cathode ion source has been put into operation [1].

The 5 MeV Van de Graaff machine was operated for 1175 hours during this period. Mainly protons (99 %) and $^4He^+$ ions (1 %) were accelerated.

The beam time was distributed among different research subjects and education (laboratory practices for undergraduate and PhD students) as it is shown in table 1. Test runs (3 hours) remained much below 1 % of the total beam time.

| Field | Hours | % |
|---|---|---|
| Atomic physics: | 639 | 54 |
| Nuclear physics: | 18 | 2 |
| Analytical studies: | 225 | 19 |
| Analytics on the microprobe: | 263 | 22 |
| Education: | 30 | 3 |
| Total: | 1175 | 100 |

**Table 1.** Time distribution among different research activities at VdG–5

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# Status Report on the Cyclotron

A. Valek and Z. Kormány

The planned operation of the cyclotron was similar to that of the previous years. The utilisation of the machine was concentrated to 9 months; January, July and August were reserved for maintenance and holiday.

The overall working time of the cyclotron was 3927 hours with break down periods amounted to 108 hours. The cyclotron was available for users during 3454 hours, the effectively used beam time is summarised in Table 1. (FERMI: Front-End Readout MIcrosystem, Radiation hardness measurements, CERN RD-16). The time used for the beam preparation and waiting the start of an irradiation was collected separately and totalled to 819 hours.

New beam scanners were mounted to help the beam transportation on the most frequently used beam lines of the isotope production and nuclear spectroscopy experiments. This development was carried out in the frame of FEFA project No. 697/2.

**Table 1.** Effectively used beam time

| Projects | Beam time (hours) | % |
|---|---|---|
| Nuclear spectroscopy | 178 | 10 |
| Neutron physics | 127 | 7 |
| Particle spectroscopy | 222 | 12 |
| Nuclear astrophysics | 195 | 10 |
| FERMI | 100 | 5 |
| Detector development | 17 | 1 |
| Applications | 1041 | 55 |
| Total | 1880 | 100 |

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2. Szűcs L., Experimental study of the p-process in astrophysics. (in Hungarian) Supervisor: Somorjai E., Atomki, Debrecen (1995) 39
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4. Hudák A., Development of computer based mass-spectrometric measurement. (in Hungarian) Supervisors: Bohátka S., Szikora B., Debrecen, Atomki - Budapest, BME (1995) 76

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Exotic atomic nuclei
A. Csótó

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I. Development of a fast ion detector
II. Electron capture into continuum states of Rutherford-scatterred ions
A. Báder

February 9
Measurement in quantum mechanics
Z. Máté

March 2
Surface electron tomography
J. Tóth

March 16
Observing the Sun in X-rays from the Yohkoh Satelillite
Ch. M. Brown (Naval Res. Lab., Washinghton DC)

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Development of physics education in Debrecen by the FEFA project
D. Beke (Kossuth University, Debrecen)

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