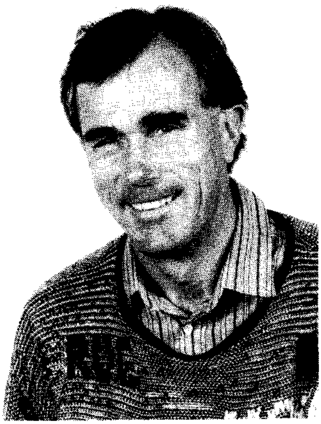
TESTS OF THE PAULI EXCLUSION PRINCIPLE FOR NUCLEONS AND DETECTION OF $\beta\beta$ DECAY PRODUCTS WITH ACCELERATOR MASS SPECTROMETRY

E. Nolte, T. Brunner, T. Faestermann, A. Gillitzer, G. Korschinek, D. Müller
Faculty of Physics, Technical Univ. of Munich, D-8046 Garching, Germany
V.N. Novikov, A.A. Pomansky
Institute for Nucl.Research, Academy of Sciences of the USSR, Moscow, USSR
A. Ljubicic, D. Miljanic
Institute Rudjer Boskovic, Zagreb, Yugoslavia



ABSTRACT
Accelerator mass spectrometry has been used to test the Pauli exclusion principle for nucleons and is proposed for the detection of $\beta\beta$ decay products. For the test of the Pauli exclusion principle, non-Paulian nuclei of $^5\widetilde{Li}$ and of $^5\widetilde{He}$ with three protons and three neutrons, respectively, in the nuclear $1s_{1/2}$ shell were looked for. The following limits were deduced:
$\frac{[^5\widetilde{Li}]}{[^6Li]} < 10^{-16}$ and $\frac{[^5\widetilde{He}]}{[^4He]} < 2 \cdot 10^{-15}$ for binding energies between 0 and 50 MeV and 0.7 and 32 MeV, respectively. The probability $\beta^2/2$ of having two protons in the symmetric state was deduced to be $\beta^2/2 < 7 \cdot 10^{-32}$. The feasibility of radiochemical $\beta\beta$ decay experiments with accelerator mass spectrometry is discussed.

1. TESTS OF THE PAULI EXCLUSION PRINCIPLE FOR NUCLEONS

The Pauli exclusion principle (PEP) is one of the fundamental principles in physics. It forbids that two identical particles with half-integral spin, fermions, occupy the same quantum state. It follows from a wavefunction which is completely antisymmetric under the exchange of two identical fermions. In no theory, a violation of the PEP is postulated and there is only one theory so far without contradiction which describes a small violation of the PEP [1]. (see also references cited in [1] and [2]).

Several experiments and considerations have been performed or proposed to look for a violation of the PEP. Goldhaber type experiments [3] in which radiation of transitions from electrons or from nucleons from higher shells to the filled $1s_{1/2}$ shell is looked for do not test the PEP since in quantum mechanics transitions from one type of statistics (Fermi) to another type are absolutely forbidden [4,5,6]. References for these experiments can be found in [2]. In other experiments, limits for the probability $\beta^2/2$ of finding two electrons or two protons in the symmetric state with respect to exchange were deduced to be in the range $10^{-13} - 10^{-26}$ [7,8,9].

The principle of this experiment is to look with AMS for non-Paulian atoms with three electrons in the K shell or for non-Paulian nuclei with three protons or three neutrons in the nuclear $1s_{1/2}$ shell. The search for non-Paulian atoms is described in [2,10]. Non-Paulian $^5\widetilde{Li}$ would have the configuration shown in Fig.1. Normal ^{5}Li is by two MeV unstable against disintegration into ^{4}He + ^{1}H. Because of the energy difference of 20 MeV between the $1p_{3/2}$ and the $1s_{1/2}$ shell [11], $^5\widetilde{Li}$ would be bound by about 18 MeV. Similar arguments hold for non-Paulian $^5\widetilde{He}$ with three neutrons in the $1s_{1/2}$ shell.

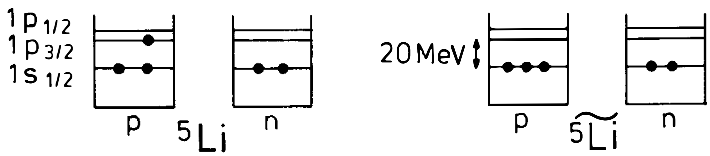


Figure 1: Configuration of nucleons in non-Paulian $^5\widetilde{Li}$

In AMS experiments with a time-of-flight set-up, non-Paulian nuclei of $^5\widetilde{Li}$ and $^5\widetilde{He}$ were looked for in samples of isotopically enriched ^{6}Li (95%) and of atmospheric helium obtained from raw neon, respectively. The results are

$\frac{[^5\widetilde{Li}]}{[^6Li]} < 2.1 \cdot 10^{-15}$ for binding energies of $^5\widetilde{Li}$ between 0 and 50 MeV and

$\frac{[^5\widetilde{He}]}{[^4He]} < 2 \cdot 10^{-15}$ for binding energies of $^5\widetilde{He}$ between 0.7 and 32 MeV. The measured mass spectrum for $^5\widetilde{Li}$ is shown in Fig. 2. Concerning the original unenriched Li sample, the following limit is deduced: $\frac{[^5\widetilde{Li}]}{[^6Li]} < 10^{-16}$ with an enrichment factor of 20 for hypothetical Lithium with A=5 with respect to ^{6}Li.

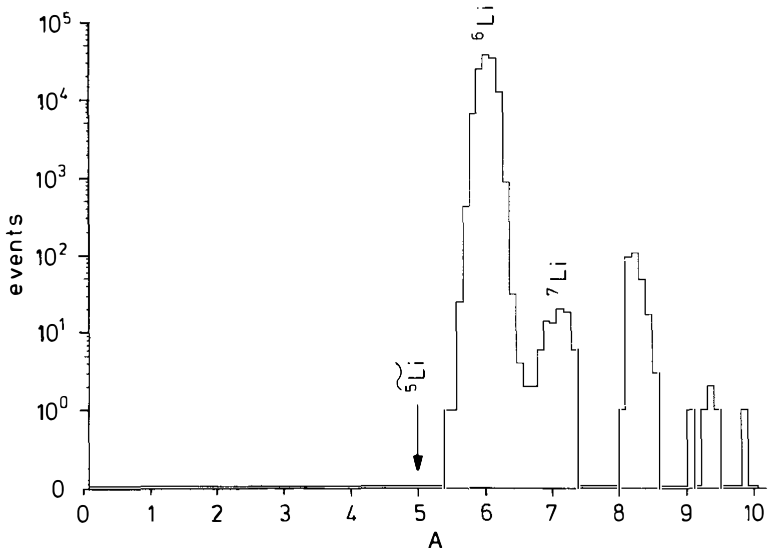


Figure 2: Mass spectrum measured for the search for non-Paulian $^5\widetilde{Li}$

The result for $^5\widetilde{Li}$ can be used to set a limit for the probability $\beta^2/2$ of having two protons in the symmetric state with respect to exchange in a collision. The processes considered are $^6\mathrm{Li} \rightarrow {}^6\widetilde{Be} + e^- + \bar{\nu}_e$ (1) where $^6\widetilde{Be}$ has three protons in the $1s_{1/2}$ shell and $^6\widetilde{Be} \rightarrow {}^5\widetilde{Li} + {}^1\mathrm{H}$ (2). In the considered case, we have $\frac{\beta^2}{2} = \frac{1}{2}\frac{\tilde{\lambda}}{\lambda_\beta}$ [12], where $\tilde{\lambda}$ characterizes the β decay of ^{6}Li to $^6\widetilde{Be}$: $[^6\widetilde{Be}] = [^6\mathrm{Li}] \cdot \tilde{\lambda} t$ and where λ_β would be the decay constant for a normal β decay with the same decay energy as for (1). With $[^6\widetilde{Be}] = [^5\widetilde{Li}]$, $t = 10^{10}$ y and $\frac{1}{\lambda\beta} = 400$ s, we deduce $\beta^2/2 < 7 \cdot 10^{-32}$ which is by many orders of magnitude smaller than the limits deduced in other experiments [7,8,9].

2. FEASIBILITY OF $\beta\beta$ DECAY EXPERIMENTS WITH AMS

Till today, AMS is used to detect cosmogenic radioisotopes as e.g. ^{10}Be, ^{14}C or ^{36}Cl in samples of Be, C or Cl, respectively. The detection limits [radioisotope]/[element] are typically in the range of 10^{-15}. Because of the low concentrations of about 10^{-12} of these radioisotopes in nature, the danger of contamination of the samples during the chemical processing or in the ion source is small. Complementary AMS with stable isotopes would allow the detection of $\beta\beta$ decay products or of impurities in high-purity semiconductor materials as Si or Ge or in low-background detectors. Especially attractive would be the detection of EC-EC decay products.

The considered $\beta\beta$ decay experiments are radiochemical. The parent nuclei of the element Z are given as a gaseous compound e.g. as a noble gas into a chamber. The product nuclei of the element Z ± 2 are collected as ions at an electrode to which a voltage is applied. The material of the electrode should be high-purity Si or Ge. Candidates are ^{36}Ar (Q_{ECEC} = 433 keV), ^{78}Kr (Q_{ECEC} = 2877 keV), ^{86}Kr ($Q_{\beta^-\beta^-}$ = 1256 keV), ^{124}Xe (Q_{ECEC} = 2866 keV), ^{126}Xe (Q_{ECEC} = 905 keV), ^{134}Xe ($Q_{\beta^-\beta^-}$ = 847 keV) and ^{136}Xe ($Q_{\beta^-\beta^-}$ = 2479 keV). For ^{78}Kr and ^{124}Xe, the predicted half-lives are in the range of 10^{20} y [13]. With a collection time of 1 y and with 24 moles of parent nuclei, 10^5 product nuclei are generated and can be collected. With several milligrams material of the electrode of the element Z', the concentration [Z$\pm$2]/[Z'] to be measured is of the order of 10^{-15}.

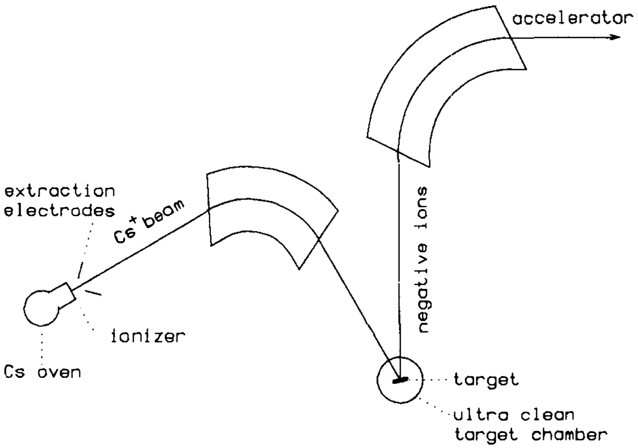


Figure 3: Injector for AMS with stable isotopes

In preexperiments with the Cs sputter source which is used in AMS experiments with cosmogenic radioisotopes, background concentration [Z"]/[Si] were measured to be in the range 10^{-10}....10^{-6}. This background is introduced by the Cs sputter beam and the impurities in the sample holder and by cross talk in the ion source. In order to reduce the background, the ion source has to be reconstructed drastically. The Cs sputter beam has to be analysed magnetically. Sample holders and slits have to be made of high-purity materials as Si or Ge and the sputter chamber has to have very ultra-high vacuum. Such a set-up is shown in Fig 3. This ion source is under construction at the Munich accelerator laboratory.

ACKNOWLEDGMENTS

We would like to thank Mr. E. Lohse from LINDE AG for his very friendly support by delivering us the raw neon.

REFERENCES

[1] R.N. Mohapatra : Phys.Lett. B242(1990)407

[2] V.M. Novikov, A.A. Pomansky, T. Faestermann, H. Gail, A. Gillitzer, G. Korschinek, D. Müller, R. Scheuer and E. Nolte: Phys.Lett. B240(1990)227

[3] G. Feinberg and M. Goldhaber: Proc.Nat.Acad.Sci.US 45(1959)1301

[4] W. Pauli : Handbuch der Physik 5 T.1(1958)Sect.14

[5] P.A.M. Dirac: The Principles of Quantum Mechanics, Clarendon Press, Oxford(1958) chapt.IX

[6] R.D. Amado and H. Primakoff: Phys. Rev.C22(1980)1338

[7] R. Plaga: Z. Phys. A333(1989)397

[8] E. Ramberg and G.A. Snow :Phys. Lett. B238(1990)438

[9] D. Miljanic, A. Ljubicic and B.A. Logan : Phys. Lett. to be published

[10] E. Nolte, T. Faestermann, H. Gail, A. Gillitzer, G. Korschinek, D. Müller, R. Scheuer, V.M. Novikov, A.A. Pomansky, D. Miljanic, A. Ljubicic and B.A. Logan: Nucl. Instr. and Meth., to be published

[11] A.G.M. van Hees and P.W.M. Glaudemans: Z. Physik A314(1983)323

[12] D. Kekez, A. Ljubicic and B.A. Logan: Europhys. Lett. 13(1990)385

[13] A. Kuliev : Proc. Workshop, Theoretical and Experimental Aspects of $\beta\beta$ Decay Problem, Kiev (1989), in press