level width of the *K*-level, which can be determined from the line width of x-rays. We got 57 ev for the *K*-level width of Pb, extrapolating the most accurate value for Bi proposed by Mladjenović[6] (Z-dependence according to a Z^4 law). With this value, the mean life of the 3.403-Mev level of Pb^{206} is $\tau = 1.8\times10^{-15}$ sec. Compared with the transition probability of a single proton,[7] the 1.72-Mev electric dipole transition is slowed down by a factor of about 50.

We are deeply indebted to Mr. F. Stuber for the chemical preparation of the source. We would like to thank the cyclotron group of the University of Birmingham for the irradiations.

---

[1] L. A. Sliv, J. Exptl. Theoret. Phys. U.S.S.R. 25, 7 (1953); L. A. Sliv, J. phys. radium 16, 589 (1955).

[2] T. Novakov et al., Arkiv Fysik 13, 117 (1958).

[3] D. E. Alburger and M. H. L. Pryce, Phys. Rev. 95, 1482 (1954).

[4] Nuclear Data Sheets, National Research Council 58-6-60.

[5] H. Brysk and M. E. Rose, Revs. Modern Phys. 30, 1169 (1958).

[6] M. Mladjenović, Arkiv Fysik 8, 27 (1954).

[7] A. H. Wapstra et al., Nuclear Spectroscopy Tables (North-Holland Publishing Company, Amsterdam, 1959).

PRODUCTION OF POLARIZED PROTON BEAMS*

L. Madansky and G. E. Owen
Department of Physics,
Johns Hopkins University,
Baltimore, Maryland
(Received January 23, 1959)

Several techniques[1] have been proposed to provide beams of polarized protons. One of the earliest proposals was put forward in a paper by Lamb and Retherford[2] where a basic outline was given for a method utilizing the Lamb shift. This technique had been considered to be unfeasible because of the problems of obtaining intense beams of metastable hydrogen atoms.[3]

In this note a method is proposed to produce relatively intense beams of metastable hydrogen atoms and their subsequent ionization. In addition, preliminary experiments related here indicate the feasibility of the proposed technique.

A proton beam can be formed by conventional methods with a beam energy of the order of 10 kev. The metastable hydrogen atoms are then produced by passing this proton beam through a chamber of hydrogen gas, or another appropriate gas at pressures of the order of 10^{-4} to 10^{-3} mm Hg. The high cross sections[4] (of the order of $0.5\pi a_0^2$) for pickup (or charge exchange) of an electron by a proton in the beam provides an efficient mechanism for the production of metastables.

After one removes the residual charged particles by deflection, the neutral beam, consisting of metastables and ground-state atoms, is then passed into a magnetic field of the order of 575 gauss. In the magnetic field the lower component of the 2*S* state becomes degenerate with a 2*P* level and decays to the ground state. Since the upper 2*S* state also possesses a hyperfine splitting, an appropriate rf field enables one to quench out the desired hyperfine component. The resultant neutral beam now consists of metastable atoms having polarized nuclei and ground-state atoms and molecules.

The metastable state can be preferentially ionized by the introduction of ultraviolet radiation in the region of 3650 A using a high-pressure mercury arc source. At this point the emerging charged particles consist of polarized protons. These can be separated from the neutral beam into an accelerator by an appropriate deflecting field.

Preliminary experiments have been performed to test this proposal for the method of producing a beam of metastable hydrogen atoms. In these experiments a 10-kev beam was used from a standard radio-frequency-excited ion source. A diaphragm having an aperture of 1-mm diameter, 50 cm from the ion source, defined a low-intensity beam. This diaphragm also served to provide a back pressure of hydrogen gas at 2×10^{-4} mm Hg in the volume nearest the ion source. Although the mean free path at these pressures was many times the path length in the gas volume, a reasonable amount of pickup into the 2*S* state was detected. Both magnetic and electric fields were provided at the point where the beam of neutral and charged particles emerged from the diaphragm (the prequenching region). These fields, which could be applied independently, served to deflect the charged particles from the beam, as well as to quench the neutral metastable beam. An adjustable electrostatic or magnetic field was placed 50 cm from the diaphragm behind a second aperture. These second fields provided a quenching region for the detection of the metastable beam. A small region in the center of the volume containing the second quenching fields was viewed by a Lyman alpha Geiger counter.[5] The purpose of the experiment was to measure the decay of the atoms from the 2*S* state as a function of the intensity of the electrostatic and magnetic quenching fields at the position of the detector and in the prequenching region.

Since the atoms were in the quenching field before they passed the field of view of the Lyman alpha counter, one would expect the counting rates to reach a maximum at a given field strength and then to drop off as the field is increased further, since at high field intensity the metastables would be quenched before they could reach the region viewed by the counters.

This behavior was observed for both electric and magnetic quenching. The effective quenching rates are of course different, since the magnetic quenching field not only provides a motional electric field perturbation, but also changes the energy of the states. The magnetic quench curve implies that electric quenching does not produce additional excited states giving rise to Lyman alpha radiation. The results given in Fig. 1 show a typical electrostatic quenching curve and the field dependence seems to agree with expectation. The qualitative agreement of the theoretical and experimental curves supports the evidence that the electric fields are not giving rise to extraneous excited states which would then provide Lyman alpha radiation.

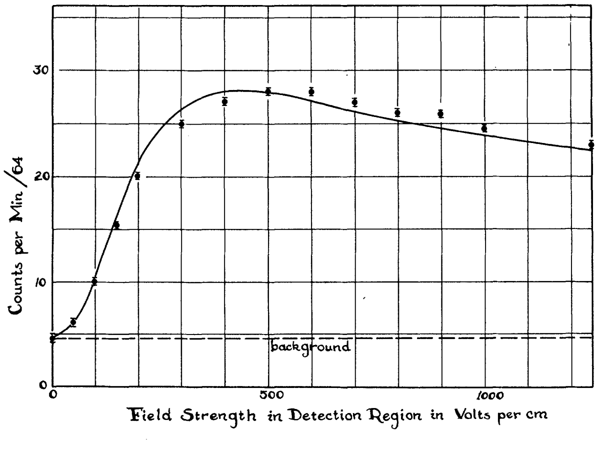

FIG. 1. The detection rate of Lyman alpha radiation from the beam as a function of the electrostatic field strength in the detector quenching region. The parameters used in the solid theoretical curve correspond to a proton beam energy of 10 kev, a path length in the viewing region of 0.4 cm, and a path length preceding the viewing region of 0.2 cm.

One can set the detector quenching fields so that the counter records the maximum rate, and subsequently observe the effect on this rate due to the field intensity in the prequenching region. Figure 2 shows the effect of prequenching electrostatically, where an electric field was used in the detector quenching region. It is important to notice that the theoretical predictions are very sensitive to the precise field configurations, the viewing region, and the beam velocity. The comparison of theory to experiment therefore does not represent high precision, but rather the fact that the experiments behave correctly in a qualitative way. A rough estimate of Lyman alpha intensity indicates that the pickup cross section is $>0.01\pi a_0^2$.

The results of the preliminary experiments seem to indicate that a beam of metastable atoms can be achieved by the pickup process. The ionization of these metastables will provide a 50% polarized beam without the introduction of radiofrequency quenching. It is of interest to notice

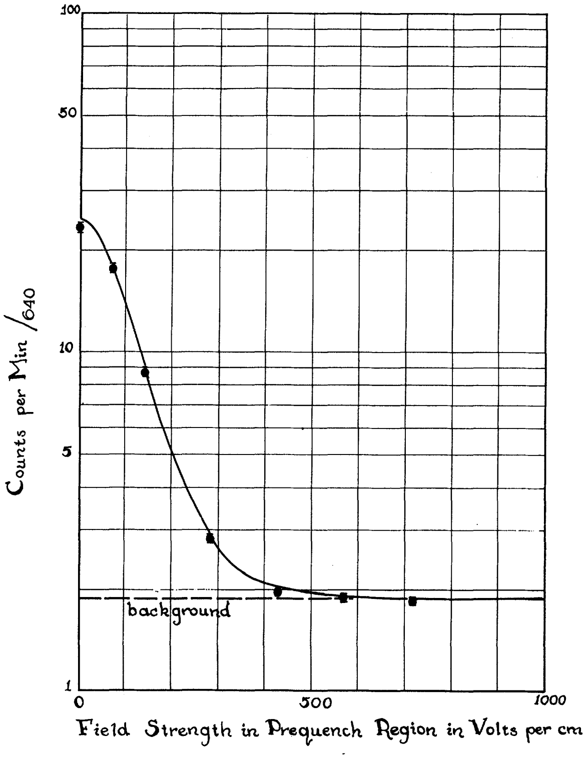

FIG. 2. The rate of Lyman alpha radiation from the beam as a function of the electrostatic field strength in a prequenching region 50 cm before the detector quenching region. The parameters used in the solid theoretical curve correspond to a beam energy of 10 kev and a path length in the prequenching region of 3.3 cm.

that the photoelectrons from the metastables are also polarized, and in principle could be collected to form polarized electron beams. Further experiments on the production of metastables, photoionization, and acceleration are now in progress in cooperation with N. Heydenburg, G. Temmer, and J. Weinman at the Department of Terrestrial Magnetism.

The authors wish to thank Dr. Donald E. Kerr for many helpful suggestions. They are also indebted to Dr. N. Heydenburg, Dr. G. Temmer, and Dr. J. Weinman for valuable discussions concerning the problem of producing polarized beams in an accelerator.

---

[*] This work has been supported by the U. S. Atomic Energy Commission.

[1] R. L. Garwin, Rev. Sci. Instr. 29, 374 (1948); A. Abragam and J. M. Winter, Phys. Rev. Lett. 1, 374 (1958); R. Keller, CERN Report No. 57-30, August, 1957 (unpublished); R. Fleishman, Bull. Am. Phys. Soc. Ser. II, 3, 317 (1958).

[2] W. Lamb and R. C. Retherford, Phys. Rev. 79, 549 (1950), Sec. 16.

[3] E. K. Zavoiskii, J. Exptl. Theoret. Phys. U.S.S.R. 32, 731 (1957)[translation: Soviet Phys. JETP 5, 603 (1957)] has proposed the use of an intense discharge.

[4] D. R. Bates and A. Dalgarno. Proc. Phys. Soc. (London) A66, 972 (1953). The peak cross section is computed for hydrogen atoms as a target. Hydrogen molecules were used in the preliminary experiments.

[5] T. A. Chubb and H. Friedman, Rev. Sci. Instr. 26, 492 (1955).

SEARCH FOR THE DECAY $\mu^+ \rightarrow e^+ + \gamma$*

H. F. Davis, A. Roberts, and T. F. Zipf
University of Rochester,
Rochester, New York

(Received February 5, 1959)

It has been pointed out recently that the existence of a heavy charged boson with the properties required to give couplings consistent with the universal *V-A* Fermi interaction will lead to the occurrence of the decay $\mu^+ \rightarrow e^+ + \gamma$.[1,2] The branching ratio $\rho = R(\mu \rightarrow e + \gamma)/R(\mu \rightarrow e + \nu + \bar{\nu})$, when calculated by assuming such an intermediate meson coupling, is of order 10^{-4}. Previous experiments have given a value of $\rho \leqslant 2\times10^{-5}$.[3] This note is to report the results of an experiment in progress at the University of Rochester synchrocyclotron, designed to obtain a more precise value of ρ.

The arrangement of the detection apparatus is shown in Fig. 1. A 32-Mev π^+-meson beam is stopped in the carbon target. The μ^+-mesons arising from π^+ decay also stop and decay in the target. The stopped π^+ beam had an intensity of 5×10^5 mesons/minute. Two counter telescopes are placed so as to observe coincident positrons and gamma radiations emitted in opposite directions from the target.

The positron telescope consists of two scintillation counters e_1 and e_2 followed by a water Čerenkov detector, e_3 (see Fig. 1). Only positrons with energy $E \geqslant 35$ Mev were counted by this telescope. The solid angle subtended by this counter array at the source was 5% of 4π.

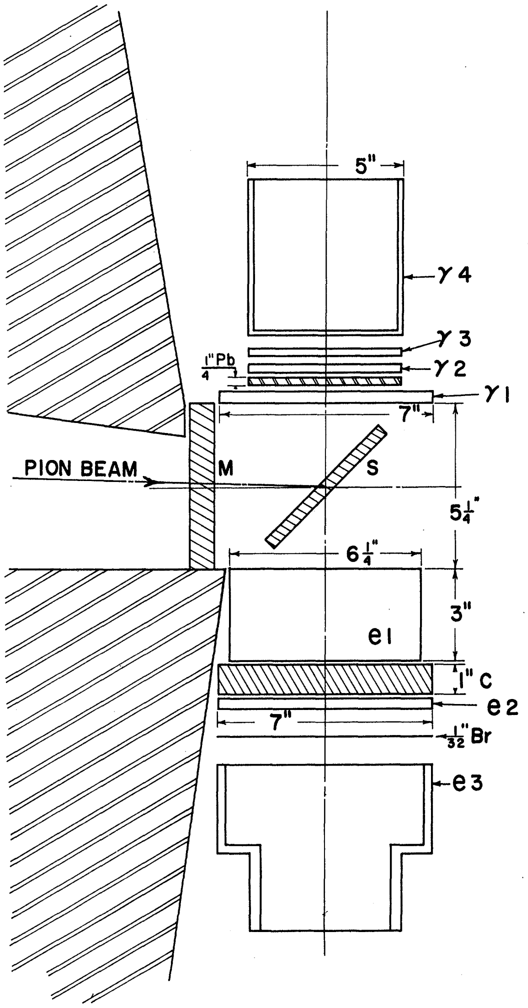

FIG. 1. Arrangement of detection apparatus with respect to the 32-Mev pion beam. *M* is the meson moderator and *S* is the target in which the pion beam stops. One inch of carbon absorber is placed between e_1 and e_2, 1/32 in. of brass between e_2 and e_3, and 1/16 in. brass between γ_2 and γ_3 (not shown).