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PROPOSAL FOR A SOURCE OF POLARIZED NEGATIVE HYDROGEN IONS

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Because polarization phenomena are important in low-energy nuclear physics, it would be desirable to have a source of negative hydrogen ions with polarized nuclei for use in tandem electrostatic accelerators. One approach to this problem has been described by Gruebler, Haeberli, and Schwandt,¹ who started with a beam of polarized deuterons and produced polarized negative deuterium ions by charge exchange in a foil. The intensity of the beam was small, however, since about 1% of the deuterons are converted to negative ions.

Our proposal for a polarized negative hydrogen-ion source² is as follows: (a) produce H(2s) by the reaction³ $H^+ + Cs \rightarrow H(2s) + Cs^+$; (2) polarize the H(2s) atoms by selectively quenching the $m = -\frac{1}{2}$ states in a 575-G magnetic field⁴; and (3) selectively attach an electron to the H(2s) atom, by the process to be described in this paper, in a weak magnetic field. This sequence of processes should yield negative ions with a nuclear polarization of 50%. Of course, if a radio-frequency transition⁵ is interposed between steps (2) and (3), a nuclear polarization of 100% could be obtained.

The primary purpose of the work reported here was to find a way to accomplish step (3). In particular, we sought a charge-exchange process by which metastable hydrogen atoms could pick up an electron, forming a negative hydrogen ion. A reaction of the type $H(2s) + X \rightarrow H^- + X^+$ is complicated by the fact that

both of the products are charged and therefore the molecular potential energy contains a large contribution from Coulomb forces. Thus if we tried to choose a nearly resonant reaction by selecting an atom or molecule X that would make $H(2s) + X$ nearly degenerate with $H^- + X^+$ for large internuclear separation, the Coulomb interaction would cause the energies to be quite different for small separations. However, by choosing X such that the potential-energy curve for $H^- + X^+$ lies above that for $H(2s) + X$, we hoped to get a pseudocrossing of the potential-energy curves⁶ which would cause the reaction $H(2s) + X \rightarrow H^- + X^+$ to have a high cross section at a hydrogen-atom kinetic energy low enough so that the reaction $H(1s) + H^- + X^+$ would have a low cross section. The potential-energy curve for $H^- + X^+$ lies above that for $H(2s) + X$ for large internuclear separations provided that the ionization energy of X is greater than 10.94 eV, but to produce a crossing of the potential-energy curves at internuclear distance at which a transition can occur readily, the ionization energy of X must be a few electron volts higher than 10.94 eV.

The apparatus used to demonstrate H^- production from H(2s) is diagrammed in Fig. 1. Protons produced in an electron-bombardment ion source were separated from other ions by a 60° sector magnet and were directed through a one-inch-long cavity containing cesium in equilibrium with its vapor. Metastable hydro-

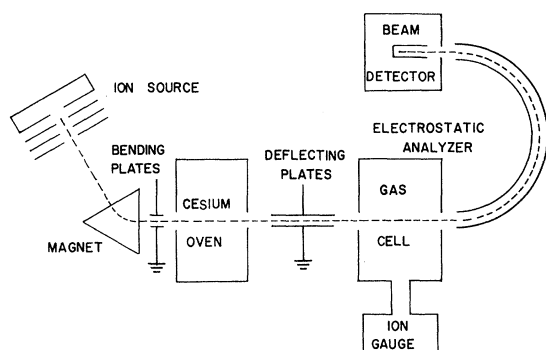


FIG. 1. A schematic diagram of the experimental apparatus.

gen atoms were produced in this cell by the reaction $H^+ + Cs \rightarrow H(2s) + Cs^+$. The density of cesium atoms was controlled by the temperature of the cell. Emerging from this cell were protons and negative hydrogen ions in addition to the neutral components, $H(2s)$, and probably $H(1s)$. The deflecting plates, 4.7 cm long, following this cell were used to deflect the charged particles from the beam. An electric field of 700 V/m in the deflection region was adequate to remove 1500-eV ions. A field of this strength quenched only about 1.5% of the metastable atoms. When it was desired, a higher electric field applied to the deflection region quenched the $H(2s)$ as well as deflected the charged components. The components of the beam remaining past the deflection region entered a gas cell in which negative hydrogen ions and protons were formed. The negative hydrogen ions were then separated from the neutral and positively charged components of the beam by a cylindrical electrostatic analyzer, and were detected by an electrometer circuit.

The data shown in Fig. 2 were taken in the following way: The negative-ion yield was measured as a function of proton energy with a field of 1100 V/m between the deflecting plates. Thus the charged components were deflected, but only about 3.5% of the metastable atoms were quenched. The results are shown in Fig. 2 by the curve marked A. (2) The negative-ion yield was measured as a function of proton or deuteron energy with a field of 24 kV/m between the deflecting plates. Thus the charged particles were deflected and the metastable atoms were quenched to the ground state so that there were at least as many ground-state atoms in the beam entering the gas cell as the original number of metastable atoms. The results are shown

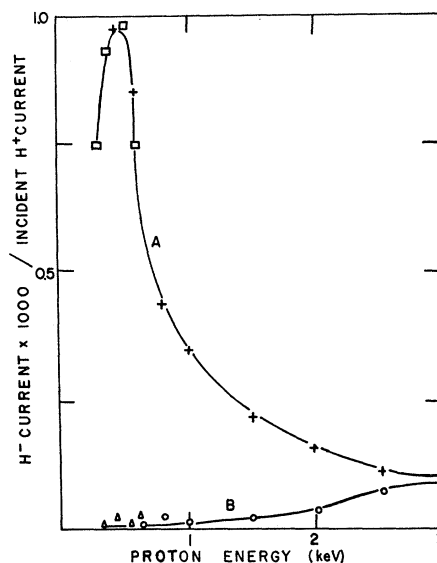


FIG. 2. The yield of H^- when argon is in the gas cell. Curve A is the fraction of protons converted to H^- by all processes. Curve B is the fraction of protons converted to H^- when the metastable atoms are quenched before they enter the gas cell. Curve B therefore represents an upper limit to the yield of H^- from processes other than collisions between $H(2s)$ and Ar. The data represented by squares and triangles are taken using deuterons instead of protons and are plotted at half the deuteron energy so that at a given abscissa, protons and deuteron velocities are the same.

in Fig. 2 by the curve marked B. Both curve A and curve B were measured with a cesium oven temperature of 90°C and a gas-cell pressure of 5×10^{-4} Torr.

In assessing the usefulness of a reaction $H(2s) + X \rightarrow H^- + X^+$ for a polarized negative hydrogen-ion source, two points are of crucial importance: (1) The yield of H^- must be large, i.e., a substantial fraction of the $H(2s)$ atoms must be converted to H^- ; and (2) the fraction of the H^- beam that results from reactions other than $H(2s) + X \rightarrow H^- + X^+$ must be small. Figure 2 shows that with argon in the gas cell, the negative-ion yield from $H(2s)$ is much greater than that from ground-state atoms for proton energies less than about 1500 eV. Figure 2 also shows that for energies around 500 eV, about 0.1% of the original protons were converted to H^- via $H(2s)$. At higher cesium oven temperature and greater pressure of argon in the gas cell, more than 0.5% of the protons were converted to H^- . Of the gases studied, argon best satisfied the criteria relating to yield and selectivity mentioned above.

Since intense proton beams can be produced, and since it is unlikely that the nuclear polarization would be disturbed by the collision of H(2s) with argon, it is probable that a polarized negative-ion source can be built with intensities in the microampere range.

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²Although this discussion explicitly mentions only hydrogen, the same processes work for deuterium

when it has the same velocity as the hydrogen, and therefore polarized negative deuterium ions can be produced by the same scheme.

³B. Donnally, T. Clapp, W. Sawyer, and M. Schultz, Phys. Rev. Letters 12, 502 (1964). L. Madansky and G. Owen, Phys. Rev. Letters 2, 209 (1959), first proposed charge exchange as a means of obtaining H(2s), but the explicit reaction they discussed, charge exchange in H₂, is unsuitable for use in this proposed source because of its low yield of H(2s) and its relatively high yield of H(1s) in the low-energy range.

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⁶J. B. Hasted, Physics of Atomic Collisions (Butterworths Scientific Publications, Ltd., London, 1964), p. 440.

OBSERVATION OF DIFFERENT LIFETIMES FOR ATOMIC STATES EXCITED WITH LINEARLY AND CIRCULARLY POLARIZED LIGHT*

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At very low atomic densities all Zeeman sublevels of an excited atomic state decay with the natural radiative lifetime of that state. Under these conditions the widths of the Hanle effect and optical double-resonance signals may be used to measure the lifetime of the state.¹ However, at higher atomic densities the Zeeman sublevels can relax to each other through collision and radiation trapping so that, in general, $(2J+1)^2$ parameters are necessary to specify the decay of the excited atoms. These processes result in a broadening or narrowing of the level crossing or optical double-resonance linewidths and can be ascribed to a change in the lifetime of the excited atomic state.^{2,3} In most experiments the requirements of symmetry reduce the number of different relaxation times from $(2J+1)^2$ to $(2J+1)$. Physically, these are the lifetime of the excited-state population, the lifetime (τ_{or}) of the magnetic moment of the excited state (the "orientation"), the lifetime (τ_{al}) of the "alignment" of the excited state (an atomic polarization with zero magnetic moment), and the lifetimes of other quantities which describe the angular configuration of the excited atoms. In contrast to classical nmr experiments where only the mag-

netic moment of the system is observed, an appropriate choice of polarizations in level crossing and optical double-resonance experiments allows one to observe the lifetimes of "orientation" and "alignment" separately.

For computational purposes it is most convenient to treat this problem using the density matrix formalism. Then each separate multipole component $\rho^{[L]}$ of the density matrix decays with a characteristic lifetime.⁴⁻⁶ The "orientation" of the atoms is proportional to $\rho^{[1]}$, while the "alignment" is proportional to $\rho^{[2]}$ so that level crossing lifetime measurements give τ_{al} . With circularly (elliptically) polarized exciting light, both $\rho^{[1]}$ and $\rho^{[2]}$ are excited, and with an appropriate choice of polarization for the detected light, τ_{or} can be measured.⁷

Under conditions where strong radiation trapping is operative, Omont⁸ has recently measured τ_{or} and τ_{al} for the first 3P_1 state of mercury. His results are in good agreement with theoretical calculations of Dyakonov and Perel.⁸ In this Letter we report on different values for τ_{or} and τ_{al} in the first $^3P_1^0$ state of lead where the difference in τ_{or} and τ_{al} is caused by collision effects rather than radiation trapping.