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Proposal for Detecting the Polarization of Slow Protons[1])

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Summary. A method is proposed for measuring the polarization of protons with a kinetic energy of about 10 keV. It is based on the properties of metastable hydrogen atoms.

In view of the current interest in sources of polarized protons, a method for detecting the polarization of slow (about 10 keV) protons would be useful in testing such sources.

It is here proposed that the protons, whose degree of polarization is P, be partly converted into metastable hydrogen atoms by acceleration to about 10 keV and passage through a suitable donor gas [1][2]). For brevity the hyperfine components ($F = 1$, $m_F = +1$), (1, 0), (1, $-$ 1), and (0, 0) of the 2 S state are denoted by 1, 2, 3, and 4, respectively. The fractional populations of the states 1, 2, 3, and 4 will be $(1 + P)/4$, $1/4$, $(1-P)/4$, and $1/4$, respectively. Any one of the three tests described below will reveal the differences between these populations and result in an approximate determination of P. The metastable atoms may be detected by quenching them in an electric field and observing the Lyman-alpha photons with a Geiger counter [1, 2] or an Allen tube [3]. Let I_0 be the detector signal in the absence of perturbing fields.

1. The simplest test is to insert a magnetic analyzer [4] between the donor gas and the detector. Let A, A-a, B, and B-b denote the probabilities that atoms in states 1, 2, 3, and 4, respectively, are *not* quenched in passing through the analyzer, where $0 < a \ll A$ and $0 < b \ll B$ for analyzing fields below 575 gauss. Then the detector signal in the presence of the analyzing field is

$$I_m = \frac{I_0}{4}\left[2\,(A + B) - (a + b) + P\,(A - B)\right].$$

Let $K_p \equiv I_m/I_0$. Next measure the corresponding ratio K_u for a proton beam known to be unpolarized. Then

$$P = \left(\frac{K_p}{K_u} - 1\right)\frac{2\,(A + B) - (a + b)}{A - B}.$$

1) Work performed under the auspices of the U. S. Atomic Energy Commission.

2) Numbers in brackets refer to references, page 142.

It would be exceedingly difficult to compute A, B, a, and b because among other reasons the existing theory [4, 5] of magnetic analysis is valid only for motional electric fields so weak that the rate of quenching is very much smaller than the decay rate γ of the $2\,P$ state. This condition is not realized in the present case because of the relatively high velocity of the atoms. LAMB and RETHERFORD [5] show that for increasing electric fields the quenching rates of all the metastable states approach $\gamma/2$ so that A becomes equal to B. For the present purpose, however, it is essential to achieve the condition $B \ll A$ by reducing the electric field experienced by the atoms. This can be done by operating the magnetic analyzer well below 575 gauss, by reducing the angle between the beam direction and the magnetic lines of force, and by providing a compensating electric field.
Then

$$P \approx 2\left(\frac{K_p}{K_u} - 1\right)\left[1 + \frac{2\,B}{A} - \frac{a}{2\,A}\right],$$

where the bracketed expression is nearly equal to one.

2. A more convincing test is to induce a magnetic resonance [4]. An rf magnetic field of frequency ν is inserted between the donor gas and the magnetic analyzer with the rf field perpendicular to the very weak magnetostatic field. As the resonances are very wide because of the high velocity, it is possible by setting $\nu = \Delta_\nu\,(2\,S) = 177.6$ Mc/s to induce the (1, 4) and (4, 3) resonances simultaneously with the result that the populations of states 1 and 3 are exchanged at optimum rf amplitude. Then the detector signal is

$$I' = \frac{I_0}{4}\,[2\,(A + B) - (a + b) - P\,(A - B)]$$

and

$$P = \frac{I_m - I'}{I_m + I'}\;\frac{2(A + B) - (a + b)}{A - B}$$

$$\approx 2\left[1 + \frac{2\,B}{A} - \frac{a}{2\,A}\right]\frac{I_m - I'}{I_m + I'}\,.$$

The same result is obtained by setting $\nu = (x/2)\,\Delta\nu$ (where x is the usual magnetic-field parameter) and inducing the (1, 2) and (2, 3) resonances. At either frequency the optimum rf current is about 60 A rms for 10-keV protons.

3. In place of the magnetic analyzer, an rf state selector [6, 7] may be employed to detect a magnetic resonance. The frequency and intensity of the rf electric field in the state selector are so adjusted that state 1 is quenched more strongly than state 4. The frequency of the rf magnetic field is set on the (1, 4) resonance; the static field must be

large enough to separate the (1,4) from the (4,3) line. The optimum *rf* current is smaller than that in the second test by a factor $[2 + 2x/(1 + x^2)^{-1/2}]^{-1/2}$. According to the theory [7] of *rf* state selection, turning on the *rf* magnetic field will change the detector signal by an amount

$$\Delta I = \frac{PI_0}{4} \left[\exp(-\lambda_4 t) - \exp(-\lambda_1 t)\right]$$

This change is at a maximum, $\Delta I = 0.190\ PI_0$, when the frequency of the state selector is set at 1100 Mc/s and the amplitude is adjusted so that $U^2t/\gamma = 0.769$. The notation not defined here is that of NOVICK and COMMINS [7].

Since the required *rf* powers are proportional to the proton energy, it would be advantageous to perform these tests at a lower proton energy if sufficient intensity of metastable atoms can be obtained.

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