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PREPARATION OF POLARIZED HYDROGEN TARGETS

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A method is proposed for obtaining polarized hydrogen targets.

IN recent years several nuclear investigations have been carried out with macroscopic samples in which the nuclei were oriented. It would be of great interest for elementary particle physics to obtain polarized hydrogen targets, but the known methods of polarizing the nuclei in macroscopic samples are unsuitable, except for the obvious but at present unfeasible "brute force" method based on the combination of an extremely strong magnetic field H and a very low temperature $T \lesssim \mu_p H/k$.

However a detailed theoretical examination[1] of the paramagnetic resonance of the conduction electrons in massive metallic samples and of the related nuclear polarization changes the usual notions about the possibilities of the Overhauser method[2] and about the choice of an optimal mode. The following statements are essential for the remainder of this paper.

1. It is claimed by Overhauser[2] that the method allows one to polarize only very small samples (the thickness d must be of the order of the skin depth $\delta \sim 10^{-4}$ cm). Azbel', Gerasimenko, and Lifshitz[1], however, have shown that the limiting thickness of an effectively polarized sample is considerably greater. If the constant magnetic field is not strictly parallel to the metal surface, then

$$d \sim \delta_{eff} \sim v\sqrt{t_0 T_s}, \qquad (1)$$

where v is the average speed of the electrons on the Fermi surface, t_0 is the average relaxation time of the electrons without spin flip, and T_s is the same but with spin flip. For pure lithium, e.g., at liquid-helium temperature [$v \sim 10^8$ cm/sec, $t_0 \sim 10^{-11}$ sec, $T_s \sim 3 \times 10^{-7}$ sec (reference 3)] an estimate gives $d \sim 1$ mm. For the polarization of so thick a sample, an rf field

$$H_1 \gtrsim \frac{2\pi v}{c^2 |Z|}\sqrt{t_0/T_s}\, H_0, \qquad (2)$$

is required, and the power absorbed on a unit surface will be of the order

$$Q \gtrsim \frac{1}{|Z|}\left(\frac{H_0 v}{2c}\right)^2 \frac{t_0}{T_s}, \qquad (3)$$

where Z is the surface impedance of the metal, and H_0 is the intensity of the constant magnetic field perpendicular to the surface.

We note that the effective removal of the heat generated in the sample is entirely possible for thicknesses $d \sim 1$ mm.

2. In reference 1 there is predicted the phenomenon of selective transparency of metal foils in paramagnetic resonance: the dependence of the transmission coefficient k on the field H_0 has a resonant character, which is pronounced for $\delta \ll d \ll \delta_{eff}$. The resonant value of k is

$$k_m \sim (\chi T_s c^3 |Z|^2 / 2\pi d)^2, \qquad (4)$$

(χ is the magnetic susceptibility of the metal), and the width of the resonance curve $k(H_0)$ is given by

$$\Delta H / H_0 \sim 1/\omega T_s. \qquad (5)$$

These features of the phenomenon under consideration suggest the possibility of polarizing hydrogen dissolved in a metal foil. As is known, hydrogen is soluble in metals of the transition group and forms intrusion-type hydrides possessing metallic properties and a regular structure. If it were possible to polarize protons "embedded" in the lattice of a metal, such a foil could be used as a polarized hydrogen target. The scattering on protons is reliably separated from scattering on metal nuclei, if coincidences between the scattered particle and the recoil proton are registered, or if the scattered particles are discriminated according to energy.

The question about the feasibility of the method proposed here and about the choice of the most suitable metal can be decided only after an experimental study of the relevant physical properties of the hydrides. Below we outline a program of measurements.

For the foil under investigation (whose thickness must be small compared with δ_{eff}), the surface impedance $Z(H_0)$ and the transmission coefficient $k(H_0)$ will be determined as functions of

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*Deceased.

the constant magnetic field H_0. We obtain T_s and the ratio t_0/T_s according to formulas (3) and (5). Knowing t_0 and T_s, we determine the thickness δ_{eff} of the polarized layer according to (1). It is possible to check the data thus obtained by measuring the transmission coefficient through the polarized sample. The observed selective transparencies of the sample afford an additional method of controlling the polarization P, which can be determined from the formula of Sec. 5 of reference 1.

All the above statements obtain also for polarized deuterium and tritium targets.

We note a single difficulty which E. K. Zavoĭskiĭ brought to our attention. If the constant magnetic field is not strictly perpendicular to the metal surface, then the magnetic induction will depend on the depth, inasmuch as the nuclear polarization damps out with depth. If the magnetic field of the nuclei is so large that

$$H_{\text{nuc}} P(0)/H_0 \gtrsim 1/\omega T_s,$$

then by increasing the depth it is possible for the basic condition of resonance to be violated, and the polarization will be considerably smaller than predicted in reference 1. In order to avoid this, one can use either a constant field that is strictly perpendicular to the metal surface (then div $\mathbf{B} = 0$, and $\mathbf{B}$, normal to the surface, does not depend on depth; the induction obviously determines the resonant frequency) or a constant field so strong that the change in resonant frequency at the depth δ_{eff} would be small or of the order of the half-width of the resonance curve $k(H_0)$.

Estimates of the permissible angular deviation α from perpendicularity in the first case and of the magnitude of the field in the second case can be obtained from the formulas of reference 1. For the angle α we find

$$\alpha < H_0/\omega T_s H_{\text{nuc}} P(0),$$

and for the magnitude of H_0 under fulfillment of condition (2)

$$P(0) - P(\delta_{eff}) < \frac{H_0}{\omega T_s H_{\text{nuc}}}, \qquad \frac{\mu H_0}{kT} > e \ln \frac{2|e| T_s H_{\text{nuc}}}{m_0 c I},$$

where ω is the frequency of the rf field, H_{nuc} is the magnetic field of the nuclei at full polarization, I is the nuclear spin, and $P(0)$ is the polarization at the surface (see reference 1).

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[1] Azbel', Gerasimenko, and Lifshitz, JETP **32**, 1212 (1957), Soviet Physics JETP **5**, 986 (1957).

[2] A. W. Overhauser, Phys. Rev. **89**, 689 (1953), Phys. Rev. **92**, 411 (1953).

[3] Griswold, Kip, and Kittel, Phys. Rev. **88**, 951 (1952). G. Feher and A. F. Kip, Phys. Rev. **95**, 1343 (1954), Phys. Rev. **98**, 337 (1955).

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