Low Energy Electron Resulting from a Stopped μ-Meson*

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IN the course of experiments in this laboratory, using a cloud chamber expanded at random, we have incidentally observed in approximately 10,000 expansions a stopped μ-meson resulting in the emission of a negative electron with an energy of 70 kev. The electron track is unfortunately so faint in both stereoscopic views that it does not lend itself to reproduction. A total of three stopped mesons were observed, of which only one was accompanied by the emission of a charged particle. The cloud chamber was horizontal, filled with 0.6 atmos helium and 0.4 atmos argon, and had a diameter of 24 cm and an illuminated region 3 cm deep. The magnetic field strength was 350 gauss, so that no statement can be made concerning the charge of any one of the stopped mesons.

The emission of electrons of such a low energy accompanying the stoppage of mesons could not have been observed in cloud-chamber experiments designed to study μ-meson decay, since magnetic fields of the order of 10,000 gauss have been used in investigations of this kind.

It seems to us worth while to report our finding in view of the frequent appearance of electrons of energies between 10 and 60 kev at the end of μ-meson tracks in photographic emulsions reported, among others, by Frey,[1] who interpreted them as atomic electrons ejected from the heavy elements in the emulsions during the capture of the meson. In the case of the evidence obtained from photographic emulsions there might, however, exist an alternative explanation for the appearance of at least a part of these electrons; namely, that they are internal conversion electrons or beta-decay of radioactive isotopes formed by the capture of μ-mesons in bromine or silver.

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[1] W. F. Frey, Phys. Rev. 79, 893 (1950).

Production of Highly Polarized Neutron Beams by Bragg Reflection from Ferromagnetic Crystals

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THE theory of magnetic scattering of neutrons, as given for instance by Halpern and Johnson,[1] predicts a polarization in the neutrons scattered by a lattice containing aligned atomic magnetic moments. For the particular case where the magnetization vector is perpendicular to the plane of scattering, the intensity of scattering for the two neutron spin states, respectively parallel and antiparallel to the magnetic field, is given as

$$I_1=b(C-D)^2$$
$$I_2=b(C+D)^2,$$

where C is the nuclear scattering amplitude, D is the magnetic scattering amplitude, and b is a proportionality constant. The greatest difference between I_1 and I_2, and hence the highest polarization, will be obtained when $C=D$, for which there will be scattered intensity for only a single spin state. This situation of balanced nuclear and magnetic amplitudes has been found in the (220) reflection of Fe_3O_4 described earlier,[2] for which $C=0.95\cdot10^{-12}$ cm and $D=0.97\cdot10^{-12}$ cm, and hence a very high polarization would be expected in this reflection.

We have looked for this polarization and find it to be indeed very high. A thin slice of Fe_3O_4 approximately one square centimeter in area and 0.1 cm in thickness was cut along the (220) planes in a natural, single crystal of magnetite. This slice was magnetized in the gap of a permanent magnet ($H=4500$ oersteds), and a monochromatic beam of neutrons ($\lambda=1.204$A) was reflected from the (220) planes with the crystal slice set in transmission orientation and with the magnetization vector perpendicular to the plane of scattering. The degree of polarization in the reflected beam was determined by passage through an analyzing block of polycrystalline iron which could be magnetized with a field of 8000 oersteds in the gap of an electromagnet. Single transmission measurements were taken of the analyzing block with analyzing field off and on (with field always parallel to the polarizing field in order to avoid any depolarization of the neutron beam in the intervening space) for both the polarized beam from Fe_3O_4 and an unpolarized beam from a copper crystal. These measurements permit evaluation of the degree of polarization after allowance for depolarization effects in the analyzing block according to formulas of Halpern and Holstein.[3] Analysis of the data showed the polarization in the (220) Fe_3O_4 reflection to be 100 percent within the experimental uncertainty of perhaps 5 percent. This means that the relative intensities of the two neutron spin states are in ratio at least 40 to 1.

Other crystal reflections are of interest as possible polarizing reflections. Some reflections from Co have very favorable amplitudes for this purpose; but this material is difficult to magnetize, and there may result internal depolarization of the beam. The (110) reflection from an Fe crystal is not too favorable for polarization purposes, since by calculation the expected polarization is only about 60 percent. We have studied this reflection with an Fe crystal (5 percent silicon) in the same fashion as for Fe_3O_4 above and find it to be about 41 percent polarized. This value, which is lower than calculated, could be explained on the basis of extinction effects, depolarization, or silicon impurity within the crystal lattice.

The above Fe_3O_4 (220) reflection is also interesting because *the polarization direction is just reversed from that obtained in the (110) Fe reflection*. This shows up in the sign of the single transmission effect in the analyzing block and results because only Fe^{+++} ions at tetrahedral positions in the magnetic lattice contribute to the intensity in the (220) Fe_3O_4 reflection. The iron atoms at the tetrahedral positions are coupled antiferromagnetically to those at the octahedral positions; and since the latter are in the majority and consequently will be aligned in the applied field direction, the tetrahedral ions will be aligned antiparallel to the external field. The polarization observation constitutes direct proof of the antiferromagnetic nature of the Fe_3O_4 lattice. Other Fe_3O_4 reflections, also highly polarized, are normal with respect to showing polarization parallel to the applied field direction.

It is possible by this method to produce a collimated beam of monochromatic, completely polarized neutrons with an intensity of about 10^6 neutrons/sec. The beam can also be pulsed as suggested earlier.[2]

[1] O. Halpern and M. H. Johnson, Phys. Rev. 55, 898 (1939).
[2] Shull, Wollan, and Strauser, Phys. Rev. 81, 483 (1951).
[3] O. Halpern and T. Holstein, Phys. Rev. 59, 960 (1941).

Thermal Expansion at Low Temperatures

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IN the customary derivation of the Gruneisen[1] relation between the thermal expansion and the atomic heat of an isotopic solid, namely,

$$3\alpha V/\chi=\gamma(C_V)_D, \quad \text{where} \quad \gamma=-d(\ln\theta)/d(\ln V), \tag{1}$$

one neglects the temperature dependence of the kinetic energy of the conduction electrons. It is fairly obvious that this is invalid at low temperatures as the electronic specific heat of the solid at these low temperatures becomes comparable with the Debye atomic heat.

We have

$$3\alpha/\chi=-\partial/\partial T[(\partial\Phi/\partial V)_T], \tag{2}$$