galactic space. If one assumes that the cosmic rays are confined to the planetary system, the intense solar radiation will give rise to a sufficient number of Compton scatterings to account for the absence of electrons including those of low energy.

During magnetic storms, cosmic-ray variations of up to 20 percent are sometimes observed. These variations cannot be explained as effects of disturbances of the earth's magnetic field. The only phenomenon that can account for these variations seems to be the electric field of the storm-producing beams. According to the corpuscular theory of magnetic storms, beams are emitted from the sun with a very high velocity. During their passage through the solar magnetic field these beams are polarized and the electric field generated in this way is probably responsible for the variations of cosmic ray intensity during magnetic storms.

It seems plausible to assume that cosmic rays are produced by repeated passages of particles through beams of the kind described above. During such passages the particles may be accelerated or decelerated by the electric fields in these beams. Further changes in the energy of the particles may occur as a result of the changes in the solar magnetic field connected with the storm-producing beams. On the average, the acceleration processes predominate and the particle may be accelerated to cosmic-ray energies.

A detailed discussion of these points will be published shortly.

[1] We are indebted to Professor E. Fermi for telling us of such an efficient method of cosmic-ray production. This work of Professor Fermi is now in press.

[2] E. Feenberg and H. Primakoff, Phys. Rev. **73**, 449 (1948).

Domain Interactions in the Theory of Ferromagnetic Resonance

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THE application of Kittel's theory[1] of ferromagnetic resonance to the experimental data obtained at microwave frequencies yields values of the Landé splitting factor, g, considerably larger than the value $g=2$ associated with a free electron spin. This apparent gyromagnetic anomaly has not yet been explained. In view of recent and relatively accurate experiments,[2-4] a deficiency in the theory is indicated. It will be shown that the g-values resulting from the application of the theory proposed below are smaller than two, and that they agree satisfactorily with those measured by the Barnett effect.

In his treatment of polycrystals, Kittel neglects magnetic anisotropy and assumes implicitly that the whole *sample* is a single domain.[5] This assumption does not seem justifiable for the relatively small fields ($H\approx 10^3$ oersteds) used in the experiments. Each *crystallite*, however, is known to be a single domain in these fields. Since the crystallites are oriented at random, the additional field arising from the magnetic interaction of the crystallites (i.e., domains) *cannot be parallel* to the magnetic moment of a given domain. Thus there must be an additional torque acting on the moment of each domain so that the g-factor derived from a resonance experiment at a fixed frequency should be smaller than that derived from the same experiment on the assumption of a single domain or non-interacting domains.

Although the quantitative determination of the local field is difficult, Néel[6] has solved just this problem in his ingenious theory of the approach to saturation in cubic, polycrystalline substances. He finds, *in effect*, that (to the order of $1/H^2$) the lining-up of the domains proceeds as if they were independent of each other but subject to a field

$$H'=H(2/P)^{\frac{1}{2}}, \tag{1}$$

where

$$P=1+\tfrac{1}{2}(r+1)+[\tfrac{1}{2}(r+1)^2][(r+1)/r]^{\frac{1}{2}}\tanh^{-1}[r/(r+1)]^{\frac{1}{2}}. \tag{2}$$

Here $r=4\pi M_s/H$, and M_s is the saturation value of the magnetization, M.

Since the microwave component of the magnetization is very small, the equations of motion show that the domain interactions in ferromagnetic resonance absorption may be accounted for by simply using the local field H', instead of the applied field H, in the equations of Kittel and Larmor. Thus the resonance conditions become

$$\omega=\gamma[H'(H'+4\pi M)]^{\frac{1}{2}} \tag{3}$$

for a plane sample, and

$$\omega=\gamma H' \tag{4}$$

for a sphere small compared to the skin depth. Here ω is the circular frequency at resonance and $\gamma(=ge/2mc)$ denotes the gyromagnetic ratio.

Table I compares the g-factors calculated by means of Eqs. (3) and (4) with those calculated on Kittel's theory. It is seen that the g-factors for nickel (Griffiths' new[4] experiment) and for Supermalloy now differ by only 2.6 percent from Barnett's[7] experimental values, whereas Kittel's theory leads to discrepancies of 12 and 14 percent. For zinc-manganese ferrite no Barnett-effect values are

TABLE I. Comparison of the g-factors calculated from Eqs. (3) and (4) with those calculated from Kittel's theory.

Material	Shape: plate thickness cm	Shape: sphere diam. cm	Resonant frequency c.p.s. $\times 10^{-10}$	Value of the Landé g-factor, calculated: Kittel's theory	Value of the Landé g-factor, calculated: present theory	Value of the Landé g-factor, measured: Barnett[d] effect
Supermalloy[a]	0.01	—	2.41	2.17	1.86	1.91
Nickel[b]	$>8\times 10^{-5}$	—	2.44	2.14	1.86	1.91
	$<5\times 10^{-5}$	—	2.44	2.00	1.75[e]	
Ferrite[c]	0.03	—	2.40	2.12	1.96	—
	—	0.15	2.37	2.16	1.98	—

[a] See reference 2.
[b] See reference 4. $M=M_s=500$ was assumed in the calculation.
[c] See reference 3. The material was $(ZnO)(MnO)\cdot 2Fe_2O_3$. The calculation for the spherical sample is based on the value $M_s=200$ given for the plane sample.
[d] See reference 7. Barnett's value for Supermalloy refers to an alloy of similar composition.
[e] See text for comment.

available, but the proposed theory leads to reasonable g-values ($g<2$). The difficulty in the case of Griffiths' very thin sample ($<5\times10^{-5}$ cm) may well be due to a lack of randomness in the crystallite orientations so that Eq. (1) may not apply.

Since P, and especially $(2/P)^{\frac{1}{2}}$, is a slowly varying function of r in the range of interest, the remarkable constancy of Kittel's g-values (≈ 2.2) is easily understandable. It is also interesting that for large fields ($r\ll 1$) the local field becomes $H'=H+(4\pi M_s)/3$, which is just the Lorentz cavity field. Thus $H'=H$ for fields large compared to the ferric induction, and Kittel's theory is seen to represent the limiting case corresponding to the hypothesis of a single-domain sample.

[1] Charles Kittel, Phys. Rev. **71**, 270 (1947); **73**, 155 (1948).
[2] W. A. Yager and R. M. Bozorth, Phys. Rev. **72**, 80 (1947).
[3] W. H. Hewitt, Jr., Phys. Rev. **73**, 1118 (1948).
[4] J. H. E. Griffiths, Program of the Oxford Conference of the Physical Society, July 23 and 24, 1948.
[5] On pp. 160 and 161 of his 1948 paper, Kittel considers a space-dependent magnetization (and hence a multi-domain model) but the result is the same as that of his 1947 paper because the interactions between domains are neglected. Incidentally, the left side of his Eq. (30) should be − curl curl **H** instead of ∇^2**H**.
[6] L. Néel, J. de phys. et rad., [VIII], **9**, 193 (1948).
[7] For a review, see S. J. Barnett, Am. J. Phys. **16**, 140 (1948).

Differential Cross Section for Reaction $D(d,n)He^3$ for 10-Mev Bombarding Energy*

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THE subject reaction was produced in a thin gas target by the deuteron beam focused 15 ft. away from the Los Alamos cyclotron. He^3 particles, emitted at laboratory angles from 16° to 40° (to the direction of the beam) were detected by a proportional counter and the resulting pulses were fed through an amplifier and into a ten-channel pulse amplitude analyzer where they were separated and counted according to energy lost in the counter. The deuteron beam current was measured by means of a Faraday cup and current integrator. The accuracy of the current measurement was checked by the temperature rise of a copper block placed in the beam.

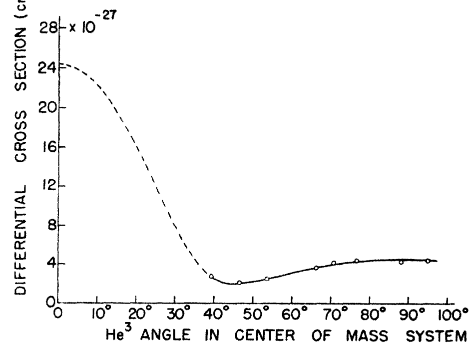

FIG. 1. Differential cross section for $D(d,n)He^3$ for 10-Mev deuterons.

The energy of the deuteron beam was measured by magnetic deflection immediately after the data for each angular point was taken. The cross section for all points was corrected to 10.3 Mev.

Preliminary results on this work have been previously reported;[1] however, since the time of that report several improvements have been made in equipment and technique which permit more accurate data to be taken. These include better angular definition of the beam (±0.5°), use of a palladium valve and deuterium gas of higher purity (99.3 percent), improved counter design, and better control over the energy lost by the He^3 in the counter. This last improvement was realized by placing a remote controlled foil system between the counter and the target.

Since, for any one angle, the foil system was adjusted to allow the He^3 particles to just traverse the counter, these particles lost considerably more energy in the counter than the other particles involved, and therefore resulted in a well resolved peak located (on curves from the ten-channel analyzer) well above the background. The minimum between the peak and background for most points was about one percent of the peak. These curves have been analyzed for possible excited states of the He^3 nucleus, and this analysis indicates that no such states exist up to three-Mev energy above the ground state. If a group of He^3 particles corresponding to such excited states were present to two percent of the main group, they would have been detected.

The cross section at zero degrees was obtained from the neutrons emitted by this reaction in the vicinity of zero degrees. This yield was determined by use of $Cu^{63}(n,2n)Cu^{62}$ detectors. Thus the $D(d,n)He^3$ cross section was obtained in terms of the 10-min. activation cross section of Cu^{63} which in turn was estimated from results of several unpublished measurements made at Los Alamos.

Figure 1 shows the differential cross section obtained as a function of angle in the center of mass system. The curve is dotted below 39° because of uncertainties in the determination of the cross section at zero degrees. The total cross section (obtained by integrating this curve through 360°) was found to be 0.07×10^{-24} cm^2.

* This document is based on work performed at Los Alamos Scientific Laboratory of the University of California under Government Contract W-7405-eng-36.
[1] B. R. Curtis, L. Rosen, and J. L. Fowler, Phys. Rev. **73**, 648 (1948).

Neutron Production by Cosmic Rays at Sea Level*

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THE rates of production of neutrons in paraffin, lead, and aluminum by cosmic rays at sea level have been measured. A cylindrical ionization chamber ten inches long and three inches in diameter filled with boron tri-