periments the nuclear particles are accelerated by a Cockroft-Walton set, magnetically selected and then scattered at 90° from a thin film of gold on a beryllium button to produce the monoenergetic beam incident on the foils. The beam energy is then measured by an electrostatic analyzer, once with the foil in the beam path, and twice with the foil withdrawn.

At present the accuracy of the measurements is limited by two factors: non-uniformity of the foils, and deposition of diffusion pump oil on the foil and on the target as was noted by Wilcox. In the newer measurements, we have given these factors more attention, using more efficient dry ice, acetone traps in an attempt to freeze out the oil before it could reach the foil, and measuring the loss through more foils in an attempt to average out the non-uniformity. Some of Wilcox' conclusions[1] must be changed.

Protons and deuterons of the same velocity were reported by Wilcox as having different rates of energy loss in gold, although he could find no such effect in aluminum. To check this point closely, we have admitted a mixture of hydrogen and deuterium gases to our ion source; the H_2^+ and the D^+ components are selected together magnetically from the accelerated beam and, after scattering from the target button, give a beam of mono-velocity H^+ and D^+. It is possible to study these protons and deuterons separately and almost simultaneously, since the analyzer selects each at a different voltage.[2]

The pairs of values obtained in this way never differed by more than 3 percent, and the difference was never consistently either more or less for the deuterons over the protons. This deviation is less than the dispersion of the proton points over the whole curve. Therefore, it can be concluded that the deuterons and protons both have the same rate of energy loss.

Wilcox suggested that "hard" atomic collisions might have accounted for his observed difference at low energies. However, Bohr[3] gives a formula for this effect:

$$\left.\frac{dE}{dx}\right|_{\text{"hard"}}=N\frac{4\pi e^4 Z_1^2 Z_2^2}{M_2 v^2}\log\left[\frac{M_1 M_2}{M_1+M_2}v^2\frac{a_{12}^{\text{scr}}}{Z_1 Z_2 e^2}\right]\text{erg/cm},$$

where $N=$atoms/cm^3 in the foil, $M_1=$mass of incident nucleus, $Z_1=$effective charge, $M_2=$mass of foil nucleus, $Z_2=$charge, $v=$velocity of incident nucleus, $a_{12}^{\text{scr}}=$internuclear distance: the distance where the electronic screening cancels the nuclear force, taken to be just the Bohr radius ($a_0=0.53$A) in this calculation. Actually a_{12}^{scr} is smaller than a_0 and the effect is even more negligible. Direct substitution shows that protons incident on gold at 100 kev would lose only 0.6 kev/mg/cm^2 or less due to hard sphere collisions, while deuterons would lose only about 20 percent more from the same cause. This mechanism could, therefore, hardly account for a 10 percent difference in the total loss rates, which are about 80 kev/mg/cm^2.

Preliminary results indicate that the rate of loss in aluminum is somewhat less (about 25 percent) than that reported by Wilcox, while the shape of the curve is substantially the same. The rather large discrepancy is presumably due to local non-uniformities in the foils used, and an attempt will be made to eliminate this source of error.

We hope to publish a complete report of these measurements soon, including beryllium as a stopping substance, and possibly including other incident nuclei. In acknowledgement, we would like to thank S. K. Allison for suggesting the work and for his help in its progress.

[1] H. A. Wilcox, Phys. Rev. 74, 1743 (1948).
[2] One objection to this procedure is that the counted beam consists of deuterons or protons alone, while the input monitor beam contains both deuterons and protons so that a fluctuation in beam composition would affect the data. However, this could produce only random effects, and the consistency of our results makes it certain that no error has been introduced by this possibility. It is also possible to use the HD^+ beam obtained when our ion source is run on commercial deuterium gas; on scattering from the target, this beam breaks up into mono-velocity H^+ and D^+. While the use of this convenient two-component, mono-velocity beam would eliminate any monitoring question, we have not, because of technical difficulties, been able to run with it successfully.
[3] N. Bohr, Phys. Rev. 59, 270 (1941).

Erratum: The Cosmic-Ray Intensity Above the Atmosphere

[Phys. Rev. 75, 57 (1949)]

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On pages 67 and 68 the name of Pomerantz should be substituted for Primakoff. Inasmuch as Dr. Pomerantz' work appeared in the same issue of the Physical Review, reference 20 may be revised as follows:

[20] M. A. Pomerantz, Phys. Rev. 75, 69 (1949).

On the Origin of Cosmic Rays

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The discovery of highly charged nuclei among cosmic rays makes it appear probable that cosmic rays are due to electromagnetic acceleration processes. The great total energy present in cosmic rays would require very efficient methods for the production of these rays if one assumes that cosmic rays are spread uniformly throughout the galaxy,[1] and even more so if they are spread uniformly throughout intergalactic space. One way out of this difficulty is to assume that cosmic rays are generated on or in the neighborhood of the sun and are kept near the solar system by extended magnetic fields. These fields could also account for the isotropy and constancy of cosmic rays by repeatedly reflecting and homogenizing the charged particles. The assumption of the presence of such a field considerably simplifies the problem of the generation of cosmic rays.

Feenberg and Primakoff[2] have shown that Compton scattering processes eliminate the faster electrons from cosmic rays that are evenly distributed through intergalactic 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
	$<5\times 10^{-6}$	—	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.