On the Theory of Neutron Scattering by Magnetic Substances

In a note submitted for publication to the *Physical Review* we have suggested a new method for detecting magnetic scattering of neutrons which is based on a comparative study of paramagnetic substances with identical nuclei but varying magnetic moments. As a theoretical basis we used a letter by Bloch[1] who was the first to point out and quantitatively describe the magnetic scattering of neutrons. His results were later rederived in a quantum-theoretical treatment by Schwinger.[2]

Both authors have essentially treated the magnetic atom as an external field which is uninfluenced by the collision process. A complete quantum-mechanical treatment leads to the following results which for clarity, we state for different special cases.

(A) Unmagnetized paramagnetic bodies (with the magnetic ion in an S state)

The magnetic cross section is

$$\sigma=(8\pi e^4/3m^2c^4)\gamma_n^2 j(j+1). \quad (1)$$

Wherein γ_n denotes the magnetic moment of the neutron in nuclear Bohr magnetons and the other symbols are self-explanatory. The result is independent of the spin-state of the incident neutron beam. It raises all values of the magnetic cross sections given in our previous note in the ratio $(j+1)/j$.

(B) Ferromagnetic bodies

Here the result depends on the energetic possibility of the atomic moment changing direction during the course of the collision. If this possibility is excluded the old result is obtained. If on the other hand the energy difference between the magnetic sublevels is small the total magnetic cross section of an unpolarized beam becomes

$$\sigma=(\pi e^4/m^2c^4)\gamma_n^2 j\{(j+\tfrac{1}{2})(3-\cos^2\Theta)+1+\cos^2\Theta\}. \quad (2)$$

In (2) Θ denotes the angle between the direction of the incident neutrons and the direction of magnetization; it is assumed that the scattering body is magnetically saturated.

Comparison of (2) with the old result

$$\sigma=(\pi e^4/m^2c^4)\gamma_n^2 j^2(3-\cos^2\Theta) \quad (3)$$

indicates (for sufficiently large magnetic cross section) a simple method of experimentally determining whether or not these transitions take place. The ratio of the scattering cross sections for magnetization parallel and normal to the direction of incidence is for (3) 2/3 whereas according to (2) it is very nearly one if j is less than 3/2. These transitions would reduce all polarization effects by the increase of the total scattering cross section (incoherent with the nuclear scattering). They also lead to polarization effects because the neutrons with spins antiparallel to the spin of the atom will be scattered more frequently. Whether this increases or decreases the total polarization depends on the sign of the phase of the nuclear wave and the sign of the neutron's magnetic moment.

The magnitude of the polarization effects is further reduced by the inelastic collisions involving atomic transitions to neighboring spectroscopic levels, the presence of isotopes and the existence of spin-dependent nuclear forces. The magnetic cross section on the other hand, is increased by transitions of the atoms to neighboring energy states.

In the above considerations we have refrained from including form factors which can considerably influence the results, even for thermal neutrons, but which are taken into account in our detailed calculations.

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New York University,
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May 13, 1937.

[1] F. Bloch, Phys. Rev. **50**, 259 (1936).
[2] J. Schwinger, Phys. Rev. **51**, 544 (1937). Bloch's formula seems to be distorted by misprint; we could not verify the interpretive correction given by Schwinger.

The Ionosphere and Magnetic Storms*

It has been recognized for many years that there was some relation between magnetic storms and poor radio transmission conditions at high frequencies. It was believed that disturbances of the ionosphere produced both the magnetic storms and poor radio transmission conditions. The ideas concerning this relation were somewhat nebulous because of a lack of specific information concerning either normal or abnormal conditions of the ionosphere.

In two previous Letters to the Editor[1, 2] we have described in detail many of the specific effects which we have observed to occur in the ionosphere during and following magnetic disturbances. Our observations and conclusions have been confirmed by many other observations at the National Bureau of Standards and by published data,[3–7] from distant parts of the earth which have led us to believe that these effects can be observed over most of the earth.

The observations indicate that the ionosphere disturbances associated with magnetic storms occur principally in the night F and daytime F_2 layers, and to a lesser degree in the daytime F_1 layer. No such disturbances have been observed in the E layer. The principal effects are a marked increase of virtual heights, decrease of ionization densities and increased diffusion of the night F and daytime F_2 layers, an increased separation of the F_1 and F_2 layers and a sharpening of the F_1 critical frequency. This indicates an expansion and diffusion of the F and F_2 layers such as might be produced by heating. The ionization density of the daytime F_1 layer is also decreased. These effects are regularly observed during the night of and the day following a severe magnetic disturbance recorded at the Cheltenham observatory. Another effect which has been observed is an increase of ionization density of the F_2 layer during the beginning of or preceding the magnetic storm.

Ionosphere disturbances associated with magnetic storms are especially pronounced during the transition periods of spring and fall, somewhat less pronounced during the summer and least pronounced during the winter at Washington.

From April 24 to May 5, 1937, there was a series of very severe magnetic storms, during which the phenomena described above occurred to a greater degree than hereto-