statistics of the counting yielded a standard deviation of 0.073 percent. The ratio of the neutron intensities determined in this way came out

$$I_N/II_N=0.9871.$$

The variation with rotation amounted to 0.17 percent.

The number of neutrons emitted from these spheres should also be proportional to the mass of beryllium present. Although these spheres were machined to be as nearly identical as possible a small difference in weight was found. The ratio of masses is given by

$$I_M/II_M=0.9968.$$

We may now correct the observed ratio of neutron intensities for the differences in the radium and beryllium in the two sources. We obtain

$$\left(\frac{I_N}{II_N}\right)_{corr}=0.9871\times\frac{1}{0.9897}\times\frac{1}{0.9968}=1.0006.$$

This indicates that this type of source is reproducible with an accuracy depending on the precision with which the radium and beryllium in it can be measured.

Recently, Bretscher, Cook, Morton, and Wilkinson[3] have prepared radium beryllium fluoride ($RaBeF_4$) as a reproducible source of neutrons suitable as standards. They show that the rate of neutron emission from this compound is proportional to the radium present within ± 0.5 percent. The chemical preparation of this compound must be carefully controlled to secure uniform results. Also, since this compound is an α, n source, there will be a growth of neutron activity corresponding to the growth of polonium in the source, which at equilibrium amounts to approximately 9 percent. These authors state that this compound yields 3.15×10^6 neutrons per sec. per gram of radium in the compound. Preliminary measurements show that our standards yield approximately 1.1×10^6 neutrons per second per gram of radium. Therefore, the photo-neutron standards described above have about 1/3 the efficiency and roughly 3 times the diameter of a comparable $RaBeF_4$ standard. These disadvantages are comsated for, to a large extent, by the simplicity of the preparation, the accuracy with which they can be reproduced, and the elimination of the effect of the growth of polonium. Furthermore, the radium can be removed from the photo-neutron sources in its original condition if at any time the source is to be discarded. A chemical separation is required to remove the radium from the $RaBeF_4$ sources.

[1] G. R. Gammertsfelder and M. Goldhaber, Phys. Rev. 69, 369 (1946).
[2] A. O. Hanson and J. L. McKibben, Phys. Rev. 72, 673 (1947).
[3] Bretscher, Cook, Morton, and Wilkinson, Proc. Roy. Soc. 196A, 436 (1949).

Reflection and Polarization of Neutrons by Magnetized Mirrors

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WE have recently been studying the refraction of neutrons in magnetic materials by means of critical reflection from ferromagnetic mirrors. The original purpose of the experiments was to demonstrate the existence of two indices of refraction in iron[1-3] and to investigate the feasibility of production of polarized neutrons by reflection from magnetized iron. Since the work was begun, two valuable applications of the method have been suggested. Halpern[4] has pointed out that the critical angle observed with the mirror magnetized in the direction of neutron propagation is quite sensitive to the assumed form of the neutron-electron magnetic interaction and can be used to decide the correct form. Hamermesh[5] has suggested that completely polarized neutrons might be obtained by reflection from magnetized cobalt without the necessity of monochromatization because only one spin state will reflect regardless of neutron wave-length. Both suggestions have been followed successfully with results which are here reported briefly.

Neutrons from the thermal column of the Argonne heavy water pile were filtered through BeO and collimated by means of 0.1-in. slits 10 feet apart. The BeO filter transmits only those neutrons of the Maxwell distribution with $\lambda>4.4$A hence there is a sharp drop in the intensity reflected from a mirror when the critical angle θ_c for 4.4A is exceeded. As the mirror angle, θ, increases up to θ_c all incident wave-lengths are reflected and the intensity increases linearly with θ (because of the increasing number of neutrons intercepted by the mirror). Above θ_c the intensity drops off as $1/\theta^3$ because of the shape of the Maxwell distribution. Thus a single index is expected to give an intensity shown by the line marked "Bloch" in Fig. 1 while two indices (each operative for half the incident neutrons) would give the lower curve. As Halpern[4] has suggested, the dipole-dipole interaction used by Bloch[6] leads to the one index curve (with $\theta_c=23.8'$), while the Dirac interaction used by Schwinger[7] and by Halpern and Johnson[8] leads to the two index curve ($\theta_c=14.2'$ and $30.7'$). The curves of Fig. 1 are those calculated for the two interactions including slight corrections for the resolution of the apparatus and the finite reflectivity for angles just above critical. The experimental intensity points agree well with the two index curve and verify the correctness of the Dirac interaction. There is of course the possibility of short range forces which would give rise to angular distributions other than that of the Dirac interaction; it can only be said that their effect in the present experiment is much less than the normal magnetic scattering.[9]

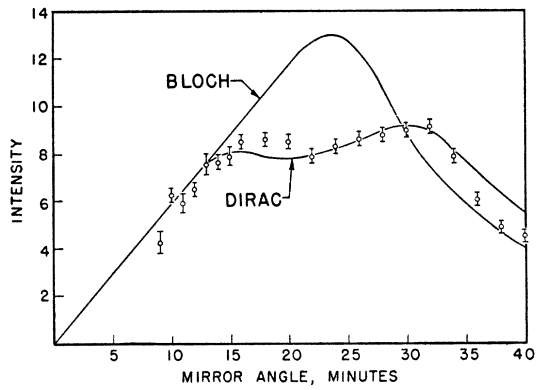

FIG. 1. Intensity of neutrons reflected from a ferromagnetic mirror.

The polarization of neutrons reflected from a mirror is measured by reflection from a second mirror. Ideally, a polarized beam will show complete reflection at a second mirror magnetized in the same direction as the first mirror, but zero reflection at a mirror magnetized in the reverse direction. This "double reflection" effect is completely analogous to the "double transmission" effect used to measure the polarization of neutrons produced by transmission. Actually, as for double transmission, it is extremely difficult to prevent depolarization and reorientation of the neutron spins in the stray fields between polarizer and analyzer. It is much simpler to keep both mirrors magnetized parallel and to measure the change in intensity resulting from depolarization of the beam between the mirrors. The depolarization is easily produced by insertion of a thin piece of unmagnetized iron in the beam, and the changes in intensity are just half those expected in the double reflection method, complete polarization being identified by a drop of one-half in intensity. This depolarization method of analysis was used in the production of polarized neutrons with cobalt mirrors. The cobalt mirrors (5 in.$\times$10 in.) were

produced by electroplating under the direction of H. Ross of the Argonne Shop. The first attempts resulted only in about 50 percent polarization but use of longer neutron wave-lengths (to reduce the possibility of non-adiabatic transitions) and of higher magnetizing currents, made complete polarization (within statistical accuracy of about 1 percent) attainable. Two distinct advantages of the reflection method of polarization are (1) no intensity loss occurs as in the transmission method, and (2) polarization of long wave-length neutrons is possible, unlike the transmission method which is applicable only for $\lambda<4.04$A (because iron becomes "transparent" to neutrons of longer wavelength).

The details of these and other mirror experiments will appear in a report now in preparation. Plans for the application of the mirror technique to other nuclear properties, such as the coherent hydrogen scattering amplitude are now being made. We wish to thank Dr. M. Hamermesh for his extremely helpful discussions during these experiments.

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[1] Halpern, Hamermesh, and Johnson, Phys. Rev. **59**, 981 (1941).
[2] A. Achieser and J. Pomeranchuk, J. Exper. Theor. Phys. USSR **18**, 475 (1948).
[3] Hughes, Burgy, Heller, and Wallace, Phys. Rev. **75**, 565 (1949).
[4] O. Halpern, Phys. Rev. **75**, 343 (1949).
[5] M. Hamermesh, Phys. Rev. **75**, 1766 (1949).
[6] F. Bloch, Phys. Rev. **50**, 259 (1936).
[7] J. Schwinger, Phys. Rev. **51**, 544 (1937).
[8] O. Halpern and M. H. Johnson, Phys. Rev. **55**, 898 (1939).
[9] A recent paper by H. Ekstein (Phys. Rev. **76**, 1328 (1949)) summarizes the question of the neutron-electron magnetic interaction and its relation to experimental verification.

New Low Mass Isotopes of Emanation (Element 86)

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AMONG the spallation products obtained from the 350-Mev proton bombardment of Th^{232} we have identified two gaseous alpha-emitters which apparently do not decay into any presently known alpha-decay chains. The half-lives observed for the decay of the alpha-activities are 23 minutes and 2.1 hours. These half-lives may be principally determined by an unknown amount of orbital electron capture. At least one alpha-emitting daughter (about 4 hours half-life) has been observed to grow from a gaseous parent, but it has not been determined whether it arises from alpha-decay or electron-capture.

Since these gaseous atoms emit alpha-particles it is assumed that they are isotopes of element 86 (emanation or radon) rather than a lighter rare gas. If they were heavy isotopes such as Em^{221} or Em^{223}, both unknown, they would decay into known alpha-decay series, the neptunium and actinium series, respectively, and so would grow known short-lived alpha-emitters which would have been detected. It thus appears reasonable that they must be lighter than the known emanation isotopes.

The lightest isotope of emanation observed prior to these experiments was Em^{216}, which arises from the U^{228} alpha-decay series[1] and which should have a half-life of approximately 10 microseconds as predicted by means of the new alpha-decay systematics.[2,3] The reappearance of longer half-lives, such as 23 minutes and 2.1 hours, with lower mass numbers is apparently due to the stable configuration of 126 neutrons. Thus these activities are to be assigned to the mass numbers 212 and lower (that is, Em^{212} and $Em^{<212}$). Therefore it appears that the plot of alpha-energy *versus* mass number for the isotopes of emanation goes through the same type of maximum and minimum as is observed for bismuth, polonium, and astatine.[2]

The method used to measure the emanation alpha-activities was very simple but designed to separate the emanation from tremendous amounts of other alpha-emitters, from bismuth to protactinium. The cyclotron target consisted of thin thorium metal strips sandwiched with thin aluminum foils to act as catchers for the transmuted atoms which were able to recoil out of the surface of the thorium. These aluminum foils were then heated at a very low temperature in a vacuum system. A slow stream of argon "carried" the emanation through two cold traps at -50°C and into a final trap at -90°C where the emanation should freeze out. From this storage trap it was possible to fill a cylindrical ion chamber in which alpha-pulses could be detected. In order to prove that a gas was involved it was shown that the activity could be quantitatively transferred back and forth many times by varying the temperature of the cold trap. After an emanation sample had been allowed to decay for some hours the gas was thoroughly pumped out of the chamber and the alpha-activity left behind (presumably due to the daughters) was followed for decay. It was not possible to measure alpha-energies in these first experiments and Geiger counter measurements were clouded by the probability of xenon and krypton fission product contaminants from which no careful separation had been made.

New equipment is now being built with which it should be possible to measure alpha-energies for these emanation isotopes and their daughters and to determine the proper mass assignments.

We wish to thank James Vale and the crew of the 184-inch cyclotron for their assistance in carrying out this work.

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[1] Meinke, Ghiorso, and Seaborg, Phys. Rev. **75**, 314 (1949).
[2] Perlman, Ghiorso, and Seaborg, Phys. Rev. **74**, 1730 (1948).
[3] Perlman, Ghiorso, and Seaborg, Phys. Rev. **75**, 1096 (1949).

Magnetic Moment of La^{139} *

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THE ratio of the frequency of the nuclear magnetic resonance of La^{139} to that of the proton has been measured at 6700 gauss. Both resonances were observed in a single sample consisting of an aqueous solution of lanthanum chloride. A double-bridge magnetic resonance absorption method, similar to that used for the recent measurement of the Be^9-H^1 frequency ratio,[1] was employed so that further detail is not necessary here. However in this measurement, although the two frequencies correspond very closely to a 7:1 ratio as in the Be^9-H^1 measurement, advantage was not taken of the increased precision in frequency ratio measurement made possible by heterodyning the seventh harmonic of the one frequency with the fundamental of the other. For Be^9 the observed line width was $\sim\frac{1}{2}$ gauss and since it was possible to determine the center of this line to within 0.1 gauss in a field of 7000 gauss, a frequency ratio precision of at least 1 part in 70,000 could be utilized. However, the observed line width for La^{139} was $\sim$3 gauss and since the true line center could be determined only to within $\frac{1}{2}$ gauss at best, the precision given by a Zenith BC-221-T frequency meter was sufficient.

A total of six determinations was made. From these the following value for the ratio of the resonant frequencies in the same magnetic field was obtained:

$$\frac{\nu(La^{139})}{\nu(H^1)}=0.141251\pm0.000014.$$

The uncertainty given represents limit of error; all six values fall within the above limits. This result is in agreement with that of Chambers and Williams.[2]