The author wishes to thank Mr. A. Ghiorso for making pulse analyses of the samples and Dr. J. G. Hamilton and the crew of the Crocker Laboratory cyclotron for bombarding the sample.

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* This chemical method is not original with the author but its development was due to the efforts of many individuals on several branches of the Manhattan Project.

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The Gamma-Rays of W^{187} in the Low Energy Region*

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THE use of a very thin window g-m tube detector in a small 180° spectrometer has made it possible to extend our study of W^{187} to energies of about 3 kev. The beta-ray source consisted of a thin deposit of finely divided WO_3 about one mg/cm^2 thick backed by a 0.06 mg/cm^2 Zapon film. The 24-hour W^{187} was obtained from Oak Ridge. Figure 1 shows the electron spectrum in the low energy region. Conversion lines are found at 7, 66, 127, and 136 kev. The first of these appears low in intensity since it is close to the window cut-off and corresponds to a gamma-ray at 0.078 Mev, if it is assumed to be a K-line. The remaining three lines are found to be the K, L, and M components associated with the conversion of a gamma-ray at 0.138 Mev. Using photographic plate detection, Valley[1] has found conversion lines in this region which he attributes to three gamma-rays at 0.086, 0.135, and 0.101 Mev. Our results are in accord with the assignment of two of these, with somewhat different energy values, but the presence of a gamma-ray at 0.101 Mev cannot be inferred from our data.

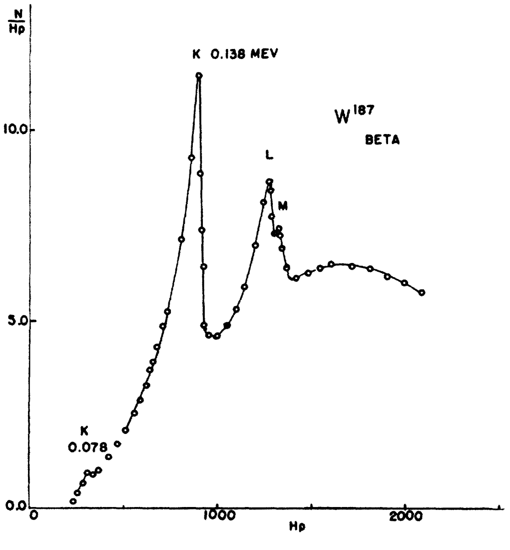

FIG. 1. Low energy electron spectrum of W^{187}.

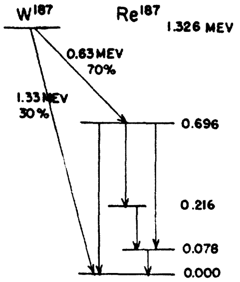

FIG. 2. Decay scheme of W^{187}.

From a study of the photoelectrons ejected from a thin lead radiator, gamma-rays at 0.14 and 0.21 Mev have been previously suggested.[2] The photoelectron line caused by the 0.14-Mev gamma-ray was very close to window cut-off and the energy assignment in doubt. It would now appear that the photoelectron line previously ascribed to a 0.21-Mev gamma-ray is really the L line of the 0.138-Mev gamma-ray. This correction makes the decay scheme previously given more consistent.[2] Figure 2 shows the decay scheme which is consistent with our earlier studies and the present low energy measurements. In addition, coincidence studies and an analysis of the relative intensities support this picture. However, since the decay is complex and cannot be inferred directly from the data, it is perhaps best to regard the scheme as a tentative one. In any case, Fig. 2 may be regarded as a summary of the radiations of W^{187} and their energies which we have obtained.

* Assisted by the joint program of the Office of Naval Research and Atomic Energy Commission.

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The Possible Magnetic Field of a Rotating Metallic Body Containing a Stress Gradient

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IN view of the recent interest in the magnetic fields of the earth, the sun and other astronomical bodies, and in mechanisms for producing magnetic fields by rotation,[1] it is perhaps worthwhile to draw attention to a possible mechanism for producing a *small* effect, which does not seem to have attracted much notice. The idea may be explained as follows.

Consider the possibility of separating a small amount of the electric charge in a solid metallic conductor, and hence establishing a small potential gradient in it, by compressing part of it. Such a separation of charge, caused by a stress gradient,* does not seem to have been directly observed. However, a closely related phenomenon was studied long ago by P. W. Bridgman,[2] when he found the Peltier heat between a number of compressed and uncompressed metals, by measuring the e.m.f. of a thermocouple consisting of a metal in its compressed and uncompressed state. The thermal e.m.f. E in a thermocouple is related to the Peltier heat π by the relation $\pi = T(dE/dT)$, where T is the absolute temperature. Thus, after measuring E as a function of T in the temperature range 0°C to 100°C, Professor Bridgman was able to calculate π at a number of pressures up to 12,000 kg/cm². This existence of π would seem to imply that some charge flows on compressing part of a conductor.

One may also discuss the possibility of a small charge separation in terms of the behavior of the electrons in a metal. Consider the maximum energy of the electrons constituting a degenerate Fermi-Dirac gas in a piece of metal at 0°K. This energy may be written[3]

$$E_{\max} = h/2m(3n/8\pi)^{\frac{2}{3}} \tag{1}$$

where h = Planck's constant, m = the *effective* mass of the electron and n = the number of electrons per cm³. Suppose we now uniformly compress the whole piece of metal so that we have $n+\Delta n$ electrons per cm³. We can calculate the increase in $E_{\max}$ by differentiating Eq. (1) with respect to n, and on so doing we find that, if $\Delta n \ll n$,

$$\Delta E_{\max} = \tfrac{2}{3} E_{\max} \Delta n/n \tag{2}$$

nearly, provided that m is a constant.

If we now imagine the compressed piece of metal to be directly connected to an uncompressed piece of the same material, all the metal being at the same temperature, electrons might be expected to flow from the compressed piece until a potential difference corresponding to $\Delta E_{\max}$ is established.[4] On computing $\Delta E_{\max}$, however, from Eq. (2), one finds predicted potential differences (for metals about as compressible as copper) of the order of 10^{-2} volts between uncompressed metal, and metal hydrostatically compressed to 10^4 kg/cm²; whereas the observed Peltier heats[2] never exceed 0.003 joules/coulomb (Bismuth) at this pressure, and are mostly a factor of 10 to 1000 less; some compressed metals even have a negative Peltier heat. However, the use of Eq. (2) for a *quantitative* estimate of $\Delta E_{\max}$ is unwise, possibly for a number of reasons. For example, m varies from metal to metal,[5] and on compressing a metal one might expect m to vary. In this connection it is worth pointing out that, should m vary on compressing in such a way that $dm/dn = \frac{2}{3}m/n$, $\Delta E_{\max}$ would be zero.

Also, there is some question to what extent the potential jump between the interiors of two dissimilar metals (or a metal in its compressed and uncompressed state), which are in contact, can be identified with the Peltier heat effect.[6]

However, if *some* charge separation occurs, it introduces the possibility of a magnetic field being associated with a rotating metallic body containing a stress gradient, and it gives rise to an interesting relationship between gravitation and electromagnetism. This may perhaps best be visualized by considering the possible existence, somewhere in space, of a cool metallic body having, say, the dimensions of a small planet or a large meteor. The interior of such a body, like the interior of the earth, would be under pressure, due to its own gravitational field. A small radial charge separation should occur, positive charge remaining, in general, near the center of the body. A static separation of electric charge would thus have been brought about in a conductor by its own steady gravitational field. And it has been shown that if a body containing such a radial charge distribution rotates, there will be an accompanying magnetic field.[7]

The connection described here between gravitation and electromagnetism would not, however, have the fundamental or general nature of the one which has been sought for so long. No time dependence nor "action at a distance" is involved. No new terms would appear in Maxwell's equations or the other fundamental equations of electromagnetism, for the same reasons that the fundamental equations do not contain special terms to account for the thermo-electric effects. Also, to be effective, the mass would have to conduct.

These ideas do not explain the primary magnetic fields of the earth and the sun. The magnetic field to be expected from the mechanism suggested here, for a cool metallic body of appropriate astronomical size, cannot be calculated without a quantitative knowledge of the charge distribution in the body, but it would clearly have an intensity many orders of magnitude less than the observed magnetic fields of the earth and sun, though it would in general have the right sign and shape. Nevertheless, the ideas may be of some interest at a time when considerable attention is being paid to the magnetic fields of the earth and various other astronomical bodies.

A measure of the lack of quantitative agreement may be seen by considering some papers of H. Haalck,[8] who also had the idea of a separation of charge due to a pressure gradient. He attempted to apply it to the hot interiors of the earth and the sun, in order to try to explain the magnetic fields of these bodies. But in so doing it was necessary for him to imagine electric fields of the order of 10^{18} or more times greater than are considered here, and a vast charge separation. The large electric charge separation that would be needed to explain the primary terrestrial and solar magnetic fields has been attacked and criticized as a serious weakness of Haalck's ideas, on the grounds that no known mechanism can quantitatively account for it.[9]

In conclusion, I wish to thank a number of colleagues, in particular Professor P. W. Bridgman and Professor E. M. Purcell, for several helpful discussions.

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* One may think of it as something like the Thomson Effect of thermoelectricity, with a stress gradient taking the place of a temperature gradient.

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[5] F. Seitz, *Modern Theory of Solids* (McGraw-Hill Book Company, Inc., New York, 1940), Chap. 4.

[6] P. W. Bridgman, *The Thermodynamics of Electrical Phenomena in Metals* (The Macmillan Company, New York, 1934).

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On the Production of Nuclear Polarization*

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THE spin dependence of nuclear forces (in particular, the $n-p$ interaction) has hitherto been investigated at thermal energies by the scattering of neutrons in ortho- and para-hydrogen.[1] For other nuclei the neutron interaction is ascertainable from neutron diffraction experiments.[2] A possible method of studying the spin dependence of the forces over the entire energy range so that the interactions for both spin orientations are, in principle, deducible, would involve the use of targets of polarized nuclei for scattering and absorption experiments with polarized neutrons.[3] The production of polarized neutrons at each energy above the thermal region may be achieved by using the target with aligned nuclear spins as polarizer as well as analyzer.

In the following we consider the process of aligning nuclear spins in order to estimate the expected order of magnitude of the nuclear paramagnetism.[4] In all cases except ordinary paramagnetic substances the alignment of the nuclear spins must be achieved by direct coupling of the nuclear moments with an external magnetic field H. The nuclear polarization factor f_N is given by

$$f_N=\frac{1}{I}\frac{\Sigma m_i \exp(-W(m_i)/kT)}{\Sigma \exp(-W(m_i)/kT)} \tag{1}$$

where I is the nuclear spin, m_i the component of spin in the direction of the field and the sums in (1) are over all magnetic substates of energy $W(m_i)$. For direct coupling $W(m_i)=-m_i\mu H/I$ where μ is the magnetic moment and f_N is given by the well-known Brillouin formula. For all practical cases ($\mu H/kT \ll 1$) we have

$$f_N=\frac{1}{3}\,\frac{I+1}{I}\,\frac{\mu H}{kT}. \tag{2}$$

To cite a few examples, the values of H/T in kilogauss/degree required to produce 20 percent nuclear polarization of H^1, H^3, He^3, Li^7, F^{19}, In^{115} all lie between 2000 and 3000 so that with a temperature of 0.01°K a reasonable magnetic field would suffice. For such nuclei a polarization of about 40 percent is perhaps within the realm of practical possibility if suitable arrangements are made for cooling by establishing thermal contact with the paramagnetic salt. Preliminary considerations indicate that a metallic contact between salt and nuclear sample may be entirely adequate from the point of view of both relaxation time and thermal conduction.[5]

In the case of nuclei in paramagnetic substances the field produced at the nucleus by hyperfine structure coupling should be sufficiently large, in some cases at least, to produce the required nuclear alignment in the range of temperature 0.1 to 0.01°K. The applied field is, therefore, used merely to align the electronic moments. If ΔW is the over-all splitting of the ground state multiplet and J_e the electronic angular momentum we find, in sufficient approximation,

$$f_N=\tfrac{1}{3}f_e\frac{I+1}{I}\,\frac{J_e}{2J_e+1}\,\frac{\Delta W}{kT};\quad J_e \geqslant I$$

$$f_N=\tfrac{1}{3}f_e\,\frac{I+1}{2I+1}\,\frac{\Delta W}{kT};\quad J_e<I \tag{3}$$

where f_e is the fractional saturation for the electronic moments. For present purposes we can take $f_e \sim 1$ so that $f_N=0.2$ requires $\Delta W/kT \sim 1$. Estimates of ΔW for the rare earth ions based on spectroscopic data for screening constants and average radius of the $4f$ shell (0.5A) indicate a splitting varying from 0.01 to 0.1 cm^{-1} so that the required temperature range would appear to be feasible. The situation in the case of the transuranic rare earths would appear to be about as favorable.

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Scattering and Absorption of Neutrons by Polarized Nuclei*

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IN the following we consider scattering of S neutrons by a nucleus with spin I so that the interaction between neutron and nucleus is described by the two phase shifts η'