LETTERS TO THE EDITOR

Prompt publication of brief reports of important discoveries in physics may be secured by addressing them to this department. Closing dates for this department are, for the first issue of the month, the twentieth of the preceding month; for the second issue, the fifth of the month. The Board of Editors does not hold itself responsible for the opinions expressed by the correspondents.

Dependence of the Absorption of Neutrons on Their Velocity

The purpose of this experiment was to see if the penetrating power of neutrons changes with their velocity. The absorption of neutrons obtained in three different ways was determined: (1) neutrons ejected in the forward direction from Be, (2) neutrons ejected backward from Be, (3) neutrons ejected forward from B. In all cases the alpha particles from polonium were used to produce the neutrons.

J. Chadwick[1] has found the maximum velocity of the neutrons in these three cases to be as shown in Table I. The average velocity of the neutrons emitted in these three cases will probably vary roughly as their maximum velocities.

An ionization chamber filled with hydrogen at 20 atmospheres pressure was used and the radiation was filtered by 2.5 cm of iron before entering the ionization chamber. Hydrogen was used since it gives a high ionization for neutrons but very little ionization for gamma-rays.[2] Diminution of the ionization current was determined when six centimeters of lead were interposed. The geometrical arrangement of the absorbers was the same in each of the three cases. The results are shown in Table I. It will be seen that over this range of velocities the faster neutrons are more easily absorbed by lead than the slower ones. It is suggested that this may correspond to the Ramsauer effect in electron absorption by inert gases where there is a similar range of velocities in which the penetrating power increases with decrease in velocity. It is likely that the absorption coefficient will decrease again for velocities higher than those here studied.

TABLE I.

Neutron group	Maximum velocity (Chadwick) (cm/sec.)	Decrease in ionization in 6 cm of lead (percent)
Be, forward	3.3×10^9	43.2 ± 1.8
Be, backward	2.7×10^9	36.1 ± 1.9
B, forward	2.5×10^9	32.0 ± 2.4

The different penetrating powers of the neutrons emitted from the other elements are probably due to their different velocities but measurements of their velocities have not been made. If we assume then that there is one velocity for which there is a maximum absorption and a decrease in absorption for either faster or slower neutrons, then for the extremely penetrating neutrons from fluorine[3] we see that there are two possibilities: (1) that these neutrons are even slower than those from boron or (2) that they are much faster than those from Be in the forward direction; the former possibility seems the more likely of the two. Similarly the easily absorbed neutrons from lithium[3] would probably be faster than those from Be.

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June 20, 1933.

[1] J. Chadwick, Proc. Roy. Soc. **A136**, 692 (1932).
[2] T. W. Bonner, Phys. Rev. **43**, 871 (1933).
[3] I. Curie and F. Joliot, Comptes Rendus **196**, 397 (1933).

The Heat Capacity of Gadolinium Sulfate Octahydrate Below 1° Absolute

A series of adiabatic demagnetizations has been carried out on $Gd_2(SO_4)_3\cdot8H_2O$ for the purpose of determining the heat capacity below 1°K. The substance was repeatedly cooled from a common initial temperature to different final temperatures by the reduction to zero of various initial magnetic fields. From the value of the applied field and the initial temperature, the entropies at the lower temperatures were calculated in terms of the entropy at a standard temperature. The entropy of magnetization has been tabulated by Giauque and Clark.[1] 51.5 g of $Gd_2(SO_4)_3\cdot8H_2O$ were used in the measurements. The heat capacity of the glass container was neglected. The measurements extend from 1.7°K to 0.287°K. The apparatus and method of temperature measurement were the same as that previously mentioned.[2] The magnetic field used ranged to 8000 gauss.

The experimental results are shown graphically in Fig. 1. They are compared with a theoretical curve obtained by considering the interaction of two gadolinium ions, treated as simple magnets. For simplicity in calculation the magnets were assumed to have clockwise and counterclockwise directions along the interatomic direction and along three symmetrically placed lines, making an angle of 60° with the interatomic direction. The single unknown in the equation

[1] Giauque and Clark, J. Am. Chem. Soc. **54**, 3135 (1932).
[2] Giauque and MacDougall, Phys. Rev. **43**, 768 (1933).

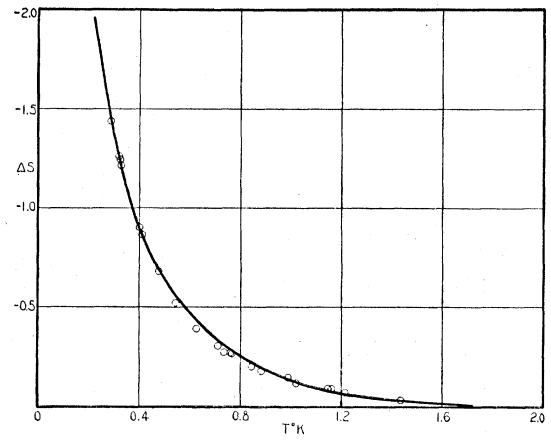

FIG. 1. Decrease in entropy below 1.7°K for $\frac{1}{2}$ mole of $Gd_2(SO_4)_3 \cdot 8H_2O$. The curve is calculated.

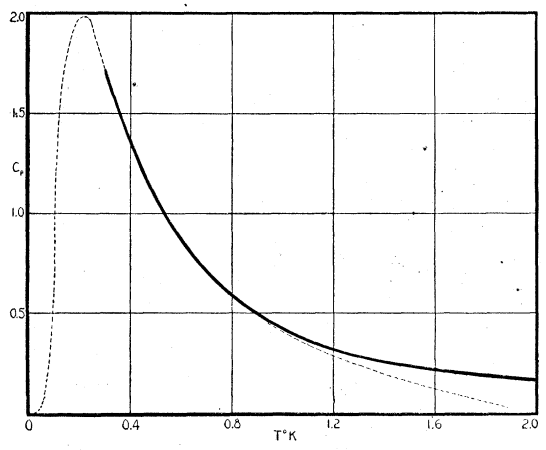

FIG. 2. Heat capacity in calories per degree for $\frac{1}{2}$ mole of $Gd_2(SO_4)_3 \cdot 8H_2O$.

was the distance between the coupled pair of gadolinium atoms. From the experimental data this was evaluated to be 3.5×10^{-8} cm. This is a reasonable order of magnitude since the distance would be 5.9×10^{-8} cm if uniform distribution of gadolinium atoms in $Gd_2(SO_4)_3 \cdot 8H_2O$ were assumed. The agreement shown by Fig. 1 is quite good but this should certainly not be taken as indicating that our geometrical assumptions are even approximately correct.

It is our purpose merely to show that any reasonable interaction theory will give an equation approximating the form indicated by our data. With the above assumption 64 states result from the possible couplings of the eight states known to exist in the case of a free gadolinium ion.

The data are also in quite good agreement with an equation proposed by Kürti.[3] Kürti assumed eight equally spaced levels with each atom acting independently. How ever, we believe that the extensive investigations of Kamerlingh Onnes and his associates on the effect of magnetic dilution on susceptibility measurements, demonstrate that the interaction mechanism is responsible for the observed heat capacity.

Heat capacities obtained from the data by means of the relation $dS/dT = C_p/T$ are in reasonably close agreement with those given by the theoretical equation. This is evident from Fig. 1. We have therefore shown that theoretical heat capacity curve in Fig. 2. The dotted portion below 0.28°K represents extrapolation. Above 1°K the dotted theoretical curve gives results that are too low. The upper solid curve above 1°K represents a junction of our experimental curve with that of Kürti, who has made calorimetric heat capacity measurements down to a temperature of 1.6°K. Our results near 1.6°K are lower than those of Kürti near this temperature, which probably marks the region of lowest accuracy in both investigations.

In connection with the theoretical equation it should be pointed out that an *a priori* weight of two is given to the lowest energy level by the assumption of isolated pairs of atoms. This leads to a zero point entropy of $\frac{1}{2}R\ln 2$ per gram atom of gadolinium. The consideration of more extensive atomic coupling would reduce this, until as a limit the zero point entropy would disappear from the expression. This would cause the heat capacity curve to drop off less rapidly on the low temperature side of the maximum.

It may be of interest to mention that the lower temperatures were measured with a precision of about three ten-thousandths of a degree. The principal uncertainty in the results was caused by fluctuations in the current available for the magnet.

The above results are preliminary and the work will be repeated and extended under more favorable experimental conditions. The temperatures which have been obtained from an extrapolation of magnetic data will be placed on the thermodynamic scale.

A rough estimate shows that with a field of 8000 gauss and a starting temperature of 1°K, $Gd_2(SO_4)_3 \cdot 8H_2O$ should produce a temperature slightly below 0.2°K. With a field of 20,000 gauss at 1°K, the final temperature should be about 0.1°K. With increasing magnetic dilution, it should be possible to extend these estimates to still lower temperatures.

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[3] Kürti, Zeits. f. physik. Chemie **20**, 305 (1933).

Disintegrations of Neon Nuclei by Fast Neutrons

Thirteen disintegrations of neon nuclei have been obtained in 3200 pairs of photographs of a Wilson cloud chamber through which neutrons were passing. In at least four of these the neutron seems to have been captured. The energy relations of these events were calculated on the basis of the assumption that the reaction which occurs is: