comes nearer to c_1 as the temperature is decreased (i.e., as the mean free path becomes longer) and as the sensitivity of the receiver is increased.

In this picture, the sharp rise in velocity at intermediate temperatures is caused by the disappearance of the high temperature excitations (bosons or rotons). As soon as these have disappeared, the velocity of heat pulses should become $c_1/\sqrt{3}$, and remain there until the mean free path for phonon-phonon collision becomes long, at which temperature it should rise to near c_1. The pressure dependence should be in the direction found experimentally, since (as mentioned by Maurer and Herlin) the number of phonons at a given temperature decreases with pressure, and hence any long mean-free-path effect should increase with pressure.

The shape of the received pulse at low temperatures and at all pressures observed shows the behavior reported by Pellam and Scott[9] and by Atkins and Osborne. At the lowest temperatures, where the velocity is high and does not vary rapidly with temperature, the pulse shape is essentially that reproduced in the letter of Atkins and Osborne. The rise is fairly sharp, with a well-defined foot, but the tail is extremely long. At the intermediate temperatures, coincident with the rapid drop in velocity with temperature, the tail becomes shorter, the rise longer, and the foot less well defined, so that the pulse becomes symmetrical and assumes a roughly Gaussian shape. At the higher temperatures the entire pulse becomes well defined. The extremely large dispersion in the intermediate-temperature region may possibly be due to the interaction of the phonons and the higher temperature excitations, since in this region they are competing for dominance.

* This work was supported in part by the Signal Corps, the Air Materiel Command, and the U. S. Office of Naval Research.

[1] C. J. Gorter, Phys. Rev. **88**, 681 (1952).
[2] K. R. Atkins and D. G. Osborne, Phil. Mag. **41**, 1078 (1950).
[3] L. Landau, J. Phys. (U.S.S.R.) **5**, 71 (1941).
[4] H. A. Kramers, Proc. Int. Conf. on Low Temp. Phys., Oxford, 1951, p. 93 (unpublished).
[5] J. R. Pellam, Phys. Rev. **74**, 841 (1948).
[6] R. D. Maurer and M. A. Herlin, Phys. Rev. **76**, 948 (1949) and **81**, 444 (1951).
[7] DeKlerk, Hudson, and Pellam, read at ONR-GE Cryogenics Conference, Schenectady, October 6, 1952 (unpublished).
[8] See J. C. Ward and J. Wilks, Phil. Mag. **42**, 314 (1951) and **43**, 48 (1952).
[9] J. R. Pellam and R. B. Scott, Phys. Rev. **76**, 869 (1949).

Activities in Light Nuclei from Nitrogen Ion Bombardment

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(Received October 14, 1952)

RECENTLY Breit, Hull, and Gluckstern[1] have pointed out the possibility of obtaining information regarding nuclear structure by bombarding nuclei with heavy nuclei. A cyclotron has been constructed at Oak Ridge National Laboratory to accelerate triply ionized nitrogen ions to an energy of approximately 25 Mev. The machine is designated the Oak Ridge National Laboratory 63-inch cyclotron, since its pole pieces are 63 inches in diameter. Beam currents of approximately 1 μa have been measured at maximum radius. During the time devoted primarily to the "tune-up" and adjustment of the accelerator, several light elements were exposed to the internal beam, to investigate induced radioactivities. The targets bombarded and the activities observed are shown in Table I. Several activities may be interpreted as resulting from the fusion of a substantial portion of the nuclear matter in the two nuclei.

TABLE I. Observed activities.

Isotope bombarded	Half-lives observed	Reaction products Observed	Remaining
Deuterium	124 sec	O^{15}	n
Beryllium	110 min	F^{18}	He^5
Carbon	15 hr	Na^{24}	$2H^1$
	110 min	F^{18}	Be^8
	long	Na^{22}	He^4
Nitrogen	10 min	N^{13}	N^{15}
	2 min	O^{15}	C^{13}
Oxygen	113 min	F^{18}	C^{12}
	2.4 min	Al^{28}	$2H^1$

TABLE II. Observable activities.[a]

	Q (Mev)	M_3	M_4	$T_{\frac{1}{2}}(M_3)$
$N^{14}+Be^9\rightarrow M_3+M_4$	+ 1.8	F^{18}	He^5	112 min
$E_{Av}=9.78$ Mev	− 3.8	N^{13}	Be^{10}	10.1 min
$E_B=6.4$ Mev	− 5.3	F^{17}	He^6	72 sec
	− 9.6	O^{15}	Li^8	118 sec
	−10.0	C^{11}	B^{12}	20.5 min
$N^{14}+C^{12}\rightarrow M_3+M_4$	− 3.0	F^{18}	Be^8	112 min
$E_{Av}=11.5$ Mev	− 3.1	Na^{24}	$2H^1$	15 hr
$E_B=9.2$ Mev	− 5.7	N^{13}	C^{13}	10.1 min
	− 7.9	C^{11}	N^{15}	20.5 min
	− 8.6	O^{15}	B^{11}	118 sec
$N^{14}+N^{14}\rightarrow M_3+M_4$	+ 0.2	N^{13}	N^{15}	10.1 min
$E_{Av}=12.5$ Mev	− 0.3	O^{15}	C^{13}	118 sec
$E_B=10.5$ Mev	− 4.1	C^{11}	O^{17}	20.5 min
	− 4.9	F^{17}	B^{11}	72 sec
	− 5.4	O^{14}	C^{14}	76 sec
	− 6.5	Na^{25}	$3H^1$	60 sec
	− 7.2	F^{18}	B^{10}	112 min
$N^{14}+O^{16}\rightarrow M_3+M_4$	+18	P^{30}	γ	2.5 min
$E_{Av}=13.3$ Mev	+ 0.73	Al^{28}	$2H^1$	2.3 min
$E_B=11.7$ Mev	− 2.9	F^{18}	C^{12}	112 min
	− 4.8	O^{15}	N^{15}	118 sec
	− 6.4	N^{13}	O^{17}	10.1 min
	− 7.0	F^{17}	C^{13}	72 sec
	− 8.8	Mg^{27}	$3H^1$	9.6 min
	−11	C^{11}	F^{19}	20 min
	−23	Na^{24}	$2He^3$	15 hr

[a] E_{Av} is the energy available in the center-of-mass system, assuming a 25-Mev beam. E_B is the Coulomb barrier: $z_1z_2e^2/(r_1+r_2)$, where $r=1.4\times10^{-13}A^{\frac{1}{3}}$ cm.

The beam energy, corresponding to the $H\rho$ at the target radius of 24.25 in., is 25 Mev for N^{+++} ions. The range of these ions in Ilford C-2 emulsions has been measured. The maximum range of the ions is approximately 16 microns with the peak of the beam energy distribution at 10.5 microns. The half-width at half-maximum is 4 microns. From the calculation of Knipp and Teller[2] we find the maximum energy of the nitrogen ions to be approximately 26 Mev, with the peak of the distribution at 21 Mev. Since the range-energy relations for heavy ions in solids are not well known, these energy determinations may not be final.

The target is mounted on a water-cooled brass probe which is inserted into the upper dee. Bombardments are from 2 to 30 minutes. Upon termination the probe is immediately removed through a vacuum lock, and the target is inserted in a lead-shielded Geiger counter; the transfer usually requires only two or three minutes. This method does not detect all reactions produced, but only those which lead to radioactive products with half-lives between one minute and a few days.

The deuterium target was prepared by evaporating a zirconium film on a platinum backing and heating it in an atmosphere of deuterium. The activity observed is that expected from the $N^{14}(d,n)O^{15}$ reaction. We may conclude that the cyclotron beam does indeed contain N^{+++} ions, since N^+ ions, accelerated by the third harmonic of the rf, would have insufficient energy to produce reactions with deuterium. Owing to the energy carried by the center of mass, 25-Mev nitrogen ions correspond to 3.6-Mev deuterons on a stationary nitrogen target.

The beryllium target was a 5-mil foil, obtained commercially, and the carbon targets were graphite plates $\frac{1}{32}$ in. thick. Oxygen was bombarded in two forms, as oxidized copper and as TiO_2 powder pressed into a zirconium backing; identical activities of 113 minutes and 2.4 minutes were found in both targets. Since no 15-hour activity was found in oxygen targets, we may conclude that there is no carbon contamination and, conversely, since there was no short half-life in the carbon we may assume it to be oxygen free. The assignment of the 2.4-minute activity to Al^{28} is not

unquestionable; as a possible alternative, P^{30} would be a radiative capture of nitrogen on oxygen, a reaction which is not as probable as one involving emission of two protons.

Nitrogen was bombarded in the form of tantalum nitride, prepared by passing nitrogen over clean tantalum at 1000°C. Upon bombardment, the target showed 2-minute, 10-minute, and 112-minute activities. It is possible that the TaN target contains oxygen contamination. The 2-minute activity may be a mixture of O^{15} produced from the nitrogen in the target and of Al^{28} produced in the oxygen contaminant. The 10-minute half-life can be assigned to N^{13} and arises from a nitrogen-nitrogen reaction. The 110-minute half-life is assigned to F^{18}, which may be due entirely to oxygen contamination in the target.

The observable activities are listed in Table II, in the order of decreasing Q values. The Q values were computed from the mass values of Mattauch and Flammersfeld.[3] It is to be noted that in general the reactions observed are the most exoergic ones. For this reason the F^{18} found in the nitrogen is attributed to oxygen contamination. We did not find a 10.1-minute, 20.5-minute, or 118-second activity in any of the carbon targets, even though the formation of the respective isotopes is energetically possible, and easily observable.

We wish to thank Mr. J. B. Dial for the preparation of the deuterium target. It is a pleasure to acknowledge the many fruitful discussions with Dr. J. L. Fowler. We are indebted to Dr. H. L. Reynolds for the beam energy determination in nuclear emulsions.

[1] Breit, Hull, and Gluckstern, Phys. Rev. **87**, 74 (1952).
[2] J. Knipp and E. Teller, Phys. Rev. **59**, 659 (1941).
[3] J. Mattauch and A. Flammersfeld, *Isotopic Report* (Verlag der Zeitschrift für Naturforschung, Tübingen, 1949).

Paramagnetic Resonance in Copper Acetate at 47 000 Mc/sec

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ANOMALOUS paramagnetic resonance absorption in copper acetate was first reported by Lancaster and Gordy.[1] Resonance experiments on single crystals of this substance were made by Bleaney[2] and Kumagai *et al.*,[3] and the experimental results were analyzed by Kambe.[4]

The present experiments were made on single crystals at a wavelength of 6.38 mm. The results were compared with the theory and were found in sufficient agreement with it. Figures 1 and 2 are, respectively, the changes in resonance field and g value with crystal orientation, when the direction of the applied field was varied by 180° in the $(11\bar{1})$ plane of the crystal from the [110] direction, which was perpendicular to the external field.

According to the theory by Kambe and Bleaney, four Cu^{++} ions in a unit cell comprise two pairs of ions and strong exchange forces are postulated between two ions in a pair; the resonance field for a

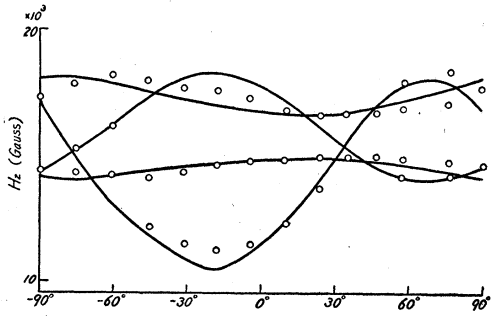

FIG. 1. Resonance field *vs* crystal orientation; the full lines denote the theoretical curves.

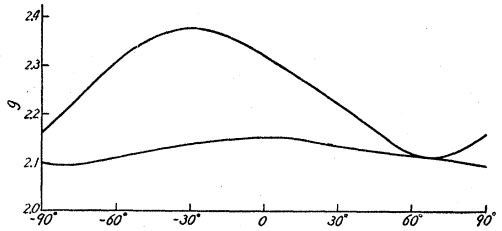

FIG. 2. Angular dependence of g value for each pair of Cu^{++} ions.

pair of Cu^{++} ions is expressed as

$$H=(h\nu/g\beta)\pm P(3\cos^2\theta-1), \quad (1)$$

where P denotes a constant having the dimensions of magnetic field and θ is the angle between the applied field and an axis passing through two Cu^{++} ions in a pair.

Substituting the observed values, $g_\perp=2.10$, $g_{II}=2.37$ in Eq. (1), where the value of P is taken to be 2000 gauss, the curves in Fig. 1 were obtained by projection on the $(11\bar{1})$ plane; for a pair of curves that had the larger amplitude, the angle between an axis passing through two Cu^{++} ions in a pair and the $(11\bar{1})$ plane was calculated to be 4°, and for another pair of curves that had smaller amplitude the angle was calculated to be 59°.

The authors wish to express their thanks for valuable discussions with Dr. H. Kumagai and Mr. E. Abe at the Institute of Science and Technology, Tokyo University.

[1] F. W. Lancaster and W. Gordy, J. Chem. Phys. **19**, 1181 (1951).
[2] B. Bleaney *et al.* Phil. Mag. **43**, 373 (1952).
[3] Kumagai, Abe, and Shimada, Phys. Rev. **87**, 385 (1952).
[4] K. Kambe (unpublished).

The Half-Life of W^{187}†

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(Received November 18, 1952)

THE half-life of W^{187} has been determined by a number of workers since it was first discovered in 1935.[1,2] Most of these measurements resulted in a half-life value of 24.0±0.1 hours.[3–6] More recently, however, Cork, Keller, and Stoddard[7] have published a value of 25.0 hours, well above previous readings. As a knowledge of the half-life of this isotope was considered important for some experiments carried out in this laboratory, a careful redetermination of the half-life has been carried out.

The measurements were performed by means of an argon-filled pressure ionization chamber, a vibrating reed electrometer, and a pen recorder. The stability of this apparatus has been described before[8] and is more than adequate for the purpose. Two samples were used, a chemically pure calcium tungstate powder and a piece of pure tungsten metal. Each sample was irradiated for one day with slow neutrons from a radium-veryllium source with paraffin moderator. The decay of each sample was plotted over a period of four half-lives, two different runs being carried out on both samples. Both samples were analyzed spectrographically for impurities. The calcium tungstate contained less than 0.1 percent Mg and trace amounts of Fe, Sn, Cu, and K. The tungsten metal contained trace amounts of Mo, Fe, Si, and Cu, all less than 0.05 percent.

The weighted mean obtained from the four determinations by least squares analysis of each decay curve was 23.85±0.08 hours.

Weighting was carried out by taking into account the probable error of the individual runs. The error includes contributions from the other wolfram isotopes which are very small, W^{181} has a half-life of 140 days and its production rate is very low; W^{183} has a half-life of 5.5 sec. W^{185} emits only very soft gamma-rays and in its normal isotopic abundance contributes not more than 0.08 percent of the total initial activity. Over three days its contribution to the