Evidence for the Expulsion of Two Neutrons from Copper and Zinc by One Fast Neutron

COPPER and zinc were bombarded with neutrons from different sources. The results are represented in the following table:

Source of neutrons	Periods	
	Copper	Zinc
$^2H + {}^2H$	6 m. (weak)	No activity
$^2H + {}^2H + P$ $Be + {}^2H + P$	6 m.	60 m.
$Be + {}^2H$	6 m. (weak)	No activity
$Li + {}^2H$	10·5 ± 0·5 m.	6 m. 60 m.
$Li + {}^2H + Ag + Cd$	10·5 ± 0·5 m.	6 m. 60 m.

P means that paraffin was used to slow down the neutrons. Ag + Cd means that a sheet of 0·2 mm. silver and one of 0·2 mm. cadmium were placed between source and bombarded material in order to stop slow neutrons.

The 6-minute period of copper most probably corresponds to the 5-minute period reported by Fermi and his collaborators[1]. The 10·5-minute period appears with the fast neutrons from (Li + ^{2}H) only. An initial activity of 1,200 impulses per minute was measured. An activity of about 11 minutes observed in cobalt bombarded with slow neutrons and in nickel with fast neutrons (which may be the same as the 20-minute period reported by Rotblat[2]) might lead to the assumption that an active cobalt isotope is produced here. We found, however, that this assumption is not justified.

The 60-minute period of zinc induced by slow neutrons probably corresponds to the 100-minute period reported by McLennan, Grimmet and Read[3], the 6-minute period to that reported by Fermi and his collaborators[1].

The same 60-minute period appears, however, with the fast neutrons from the (Li + ^{2}H + Ag + Cd) source, and not with those from the (^{2}H + ^{2}H) or (Be + ^{2}H) source, which excludes the possibility of ascribing this activity to the action of slow neutrons; it indicates that neutrons of considerable energy are essential here.

A chemical separation of the radioactive substances was attempted by Mr. R. W. P. de Vries. As to copper (10·5-minute period): cobalt and nickel precipitated in different ways were found to be inactive. Copper precipitated electrolytically was active. As to zinc (60-minute period obtained with fast neutrons): precipitated nickel was inactive. Copper showed a 6-minute and a 10–12 hour period, as was to be expected. Zinc precipitated electrolytically from the solution showed the 60-minute period. Both activities must therefore be ascribed to isotopes of the irradiated elements.

An investigation of the particles emitted by copper (10·5-minute period) by means of magnetic deflection *in vacuo* and a Geiger-Muller counter proved these to be positrons. A period of about 10 minutes was found for these deflected positrons. The intensity of the 60-minute period of zinc was too small to observe the deflected particles with certainty.

From these data we may infer that the following reactions take place with fast neutrons:

$$^{63}Cu + {}^1n \rightarrow {}^{62}Cu + 2\,{}^1n \quad {}^{62}Cu \rightarrow {}^{62}Ni + e^+$$
$$^{66}Zn + {}^1n \rightarrow {}^{65}Zn + 2\,{}^1n \quad {}^{65}Zn \rightarrow {}^{65}Cu + e^+$$

We found the same zinc isotope to be formed by capture of a slow neutron:

$$^{64}Zn + {}^1n \rightarrow {}^{65}Zn.$$

The possibility of the type of reaction described was discussed by Fermi[4] but up to the present it had not been observed with certainty (cf. L. Meitner and O. Hann[5] and Johnson and Hamblin[6]).

Further details and a description of our apparatus will appear elsewhere.

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[1] *Proc. Roy. Soc.*, A, **149**, 522 (1935).
[2] NATURE, **136**, 515 (1936).
[3] NATURE, **135**, 505 (1935).
[4] *Proc. Roy. Soc.*, A, **146**, 483 (1934).
[5] *Naturwiss.*, **24**, 158 (1936).
[6] NATURE, **138**, 504 (1936).

Thermal Properties of Helium, Hydrogen and Deuterium

IT has been shown by F. Simon[1] and F. London[2] that the abnormally large specific volume and compressibility of helium and hydrogen can be understood by considering the influence of the zero point motion. Clusius and Bartholome[3] pointed out that this zero point motion is also responsible for the fact that the specific heat of hydrogen is nearly equal to that of deuterium. They remarked that it is no longer legitimate here to represent the potential energy as a quadratic function of the deviations of the particles from their equilibrium positions.

As at low temperatures only long heat waves, which are harmonic, contribute to the specific heat, and the frequencies of these waves are determined by the velocity of sound, the specific heat near the absolute zero can be calculated if the velocity of sound is known.

It is possible to derive a 'Schrodinger equation' for a crystal deformed by a long wave. The deformation energy, derived with the help of this equation, contains not only a change in the potential energy but also in the kinetic energy. An expression for θ is obtained in which the two effects are separated:

$$\theta^2 = \frac{1}{2\pi^{2/3}} \, \frac{h^2}{mk^2} \left[\frac{s}{2} + \frac{\pi^2\hbar^2}{2^8 m l^4}\right],$$

where m is the mass of the particle, s the second derivative of the molecular field at a lattice point and l is a length which is equal to or smaller than $a - \sigma$ (a is distance between nearest neighbours, σ is molecular diameter).

Taking $l = a - \sigma$, and omitting s (which means that the molecules are replaced by hard spheres) the following results are obtained:

	Mol. vol.	σ	l	θ calc.	θ exp. (0° K.)
He	19·88	2·35	1·24	29·2	34·0 [4]
	19·32	,,	1·21	30·8	36·0 [4]
	18·35	,,	1·15	33·9	39·5 [4]
H_2	23·31	2·80	0·98	93·7	91 [5]
D_2	20·48	,,	0·83	65·7	89 [3]

The rather large deviation shown by deuterium may be due to the fact that it is not permissible to omit s in this case, and the value of l is only an upper limit.

Some conclusions about the thermal expansion can also be deduced by this formula. According to Debye's