ANGULAR DISTRIBUTION OF THE NEUTRONS FROM Li^7 (d.n.) Be^8 REACTION AND THE ENERGY LEVELS IN Be^8

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Introduction

THE neutrons produced on bombardment of lithium with deuterons have been studied by a large number of workers and, as in the case of other reactions leading to the same final nucleus, contradictory conclusions have been reached regarding the number of levels observed in Be^8. Some investigators[1-6] have reported besides the ground state, only one other level corresponding to about 3 MeV below the excitation levels of 10 MeV; others[7-9] have produced evidence for additional energy levels of Be^8 corresponding to excitation energies of 1·5, 2·1, 4·1, 5·4 and 7·5 MeV. However, no systematic study has been made of the angular distribution of the outgoing neutrons from the (Li,d) reaction. In view of this a further investigation of the above reaction seems desirable. The angular distribution of the neutrons would throw light on the mechanism of the reaction.

In the present work an 86 KeV thick target of ordinary lithium was bombarded with 500 KeV deuterons from the Cockcroft-Walton generator of the Tata Institute of Fundamental Research, Bombay.

Ilford G 5 Nuclear Research plates (7·62 × 2·54 cm.) with thickness of 400 μ were exposed to the emitted neutrons. The plates were held radially at a distance of 16·2 cm. from the target so as to receive neutrons proceeding at angles of 0°, 45°, 60°, 90°, 120°, 135° and 150° to the direction of the deuteron beam. After irradiation the plates were processed using the method of 'temperature development' suggested by Dilworth *et al.*[10]

The plates were examined on a Cooke, Troughton and Simms nuclear research microscope and the modified procedure used in our earlier work (Sah[11] and Saxena and Sah[12]) was followed. At each angle 750 tracks were measured. The criteria, set for accepting tracks, reduced the number of tracks running out of the plate. Only 6, 5, 6, 5, 6, 2 and 2 tracks ran out of the emulsion at angles of 0°, 45°, 60°, 90°, 120°, 135° and 150° respectively. These numbers being too small as compared to the number of tracks recorded, no correction was needed for loss of tracks from the plate. In all previous investigations a correction had to be applied for such tracks; the correction being approximate, the absolute yield of the reaction could not be estimated.

The Neutron Energy Spectrum

The energy corresponding to the measured ranges of the recoil protons was obtained from the range energy relations given by Wilkins.[13] The data for each angle were collected in the form of a histogram where the number of tracks were plotted against the neutron energy, using intervals of 0·1 MeV. For obtaining the real energy spectrum correction had to be made for the variation of the neutron-proton scattering cross-section σ. While ascertaining each recoil angle the change in the direction of the neutron incident on the plate with difference in position of the point of origin of the recoil proton track in the emulsion, has been taken into consideration. Correction has also been made for thickness of the target while calculating the Q-values.

The information regarding the energy levels of Be^8 has been obtained from a study of the individual Q-spectra at the various angles. Two such spectra for angles of 60° and 90° are shown in Figs. 1 and 2. Out of the large number of peaks observed some will arise due to statistical fluctuations. Only those peaks have been regarded as genuine which occur at all the seven angles at precisely the same Q-value. These will correspond to the formation of Be^8 at different excitation levels. It seems extremely unlikely that statistical fluctuations will give rise to homogeneous groups of particles at all the angles with exactly the same disintegration energy.

The data have been shown in Table I. Evidence has been produced for levels in Be^8 at excitations of 2·1, 2·8, 3·5, 4·1, 4·88, 5·96, 6·55 and 7·57 MeV besides the ground state. Information regarding levels with higher excitation cannot be obtained due to the presence of Li^6 in the target.

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The Angular Distribution of the Neutrons

From the proton track densities found in the different plates the angular distribution of the neutrons was obtained. The neutron yield corresponding to the formation of Be^8 in the ground state has been calculated in terms of

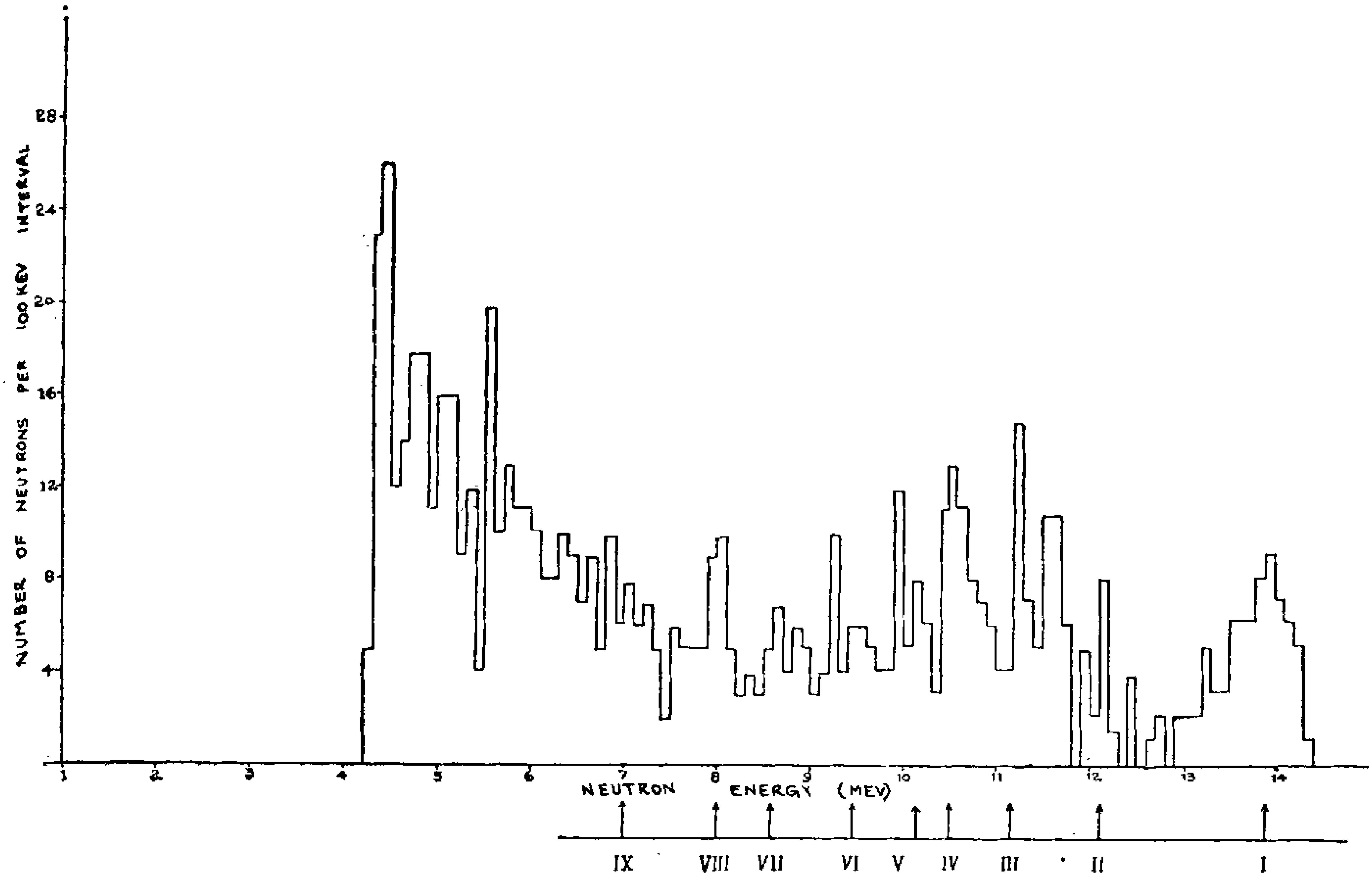

FIG. 1. Energy spectrum of neutrons at 60°

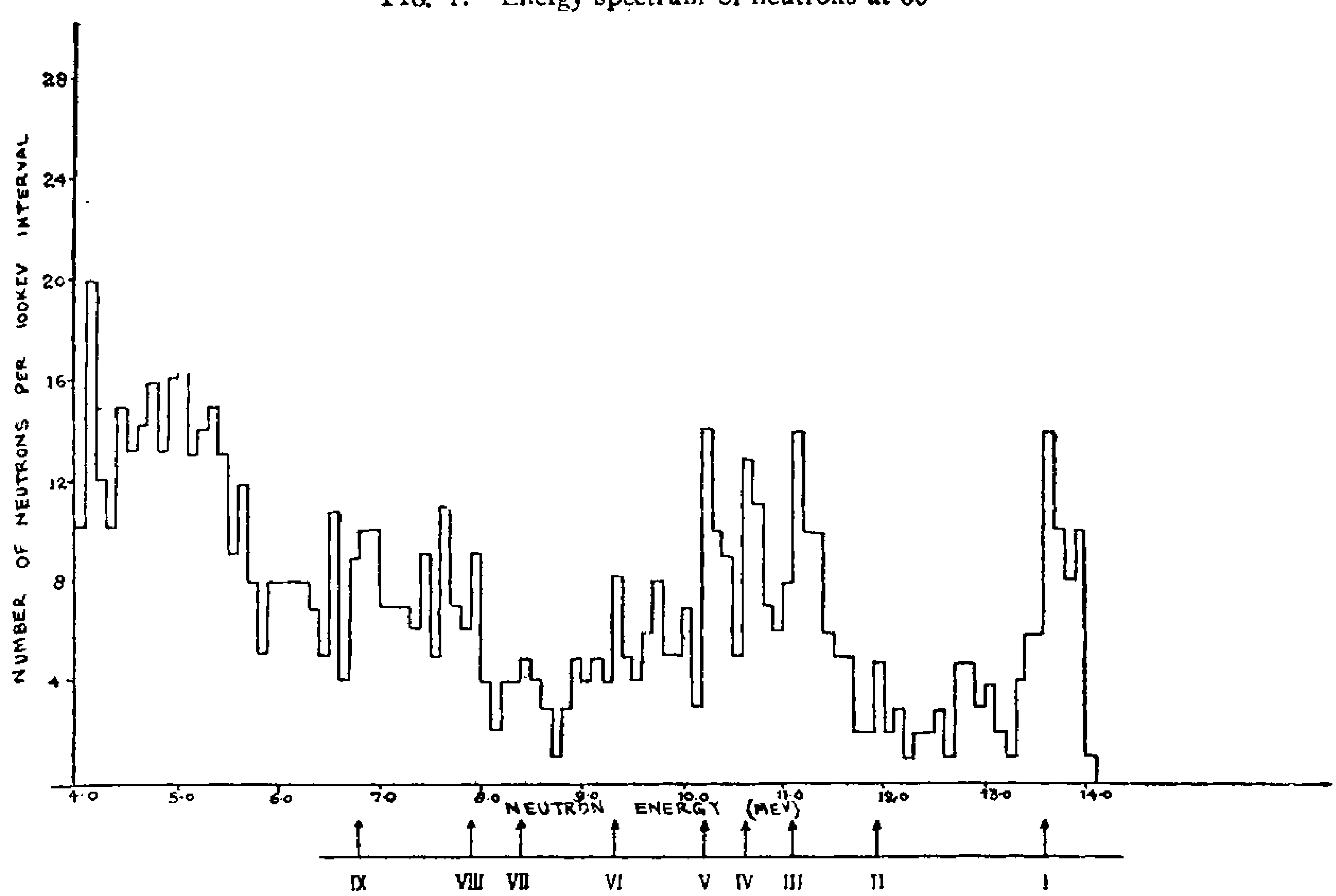

FIG. 2. Energy spectrum of neutrons at 90°

TABLE I

Excitation energy E_x in MeV for the energy levels of Be^8 at different angles with respect to the deuteron beam

Angles \ E_x in MeV	0	2·1	2·8	3·5	4·1	4·88	5·96	6·55	7·57
0°	G.S.	2·19 ±0·1	2·73 ±0·2	3·33 ±0·17	4·04 ±0·16	4·86 ± ·17	6·00 ± ·16	6·43 ± ·17	7·52 ± ·18
45°	,,	2·14 ± ·12	2·65 ± ·21	3·42 ± ·15	4·08 ± ·18	4·85 ± ·16	6·07 ± ·18	6·71 ± ·18	7·59 ± ·15
60°	,,	2·10 ± ·15	2·89 ± ·14	3·60 ± ·18	4·21 ± ·16	4·93 ± ·18	5·87 ± ·15	6·53 ± ·13	7·64 ± ·16
90°	,,	2·01 ± ·1	2·82 ± ·14	3·38 ± ·19	3·88 ± ·18	4·84 ± ·17	5·85 ± ·18	6·42 ± ·15	7·60 ± ·12
120°	,,	2·29 ± ·2	2·98 ± ·2	3·54 ± ·18	4·00 ± ·17	4·93 ± ·14	6·01 ± ·17	6·52 ± ·16	7·56 ± ·12
135°	,,	2·24 ± ·11	2·99 ± ·2	3·68 ± ·18	4·11 ± ·16	4·84 ± ·15	5·99 ± ·13	6·57 ± ·14	7·62 ± ·13
150°	,,	2·14 ± ·11	2·83 ± ·14	3·35 ± ·21	4·20 ± ·15	4·92 ± ·14	5·85 ± ·13	6·66 ± ·15	7·18 ± ·10

the number of tracks per $10^9 \mu^3$ (This has been normalised to 1·0 for $\theta = 0°$). The angular distribution was transferred to the centre of mass system using the formula of Haxby *et al.*[14] The angles of emission of the neutrons and the yields in the C-co-ordinates are shown in columns two and four respectively of Table II, while the normalized yield is given in the last column.

TABLE II

Yield of the reaction Li^7 (d, n) Be^8 at the different angles

Angles in L-Co-ordinates	Angles in C-Co-ordinates	Yield in L-Co-ordinates	Yield in C-Co-ordinates	Normalised yield
0°	0	3·756	3·756	1·000
45°	46° 13′	3·361	3·223	0·856±0·07
60°	61° 29′	1·967	1·910	0·508±0·06
90°	91° 43′	2·614	2·814	0·695±0·07
120°	121° 29′	1·645	1·668	0·443±0·06
135°	136° 13′	1·304	1·333	0·355±0·06
150°	150° 52′	1·418	1·451	0·385±0·05

The yield shows a pronounced forward maximum indicating that the formation of Be^8 is mainly through the stripping process.

No theory for the angular distribution of the neutrons from *d-n* reactions has so far been worked out for low deuteron energies. For higher energies the coulomb barrier has been neglected and a theory of the stripping process has been given by Butler.[15] This theory has also been applied to low deuteron energies, but in this case the compound nucleus mechanism also makes an appreciable contribution to the angular distribution.

The observed data have been subjected to further analysis by applying Butler's theory. The differential cross-sections have been obtained at various angles for $l_p = 0$, 1 and 2 denoting the angular momentum transferred by the captured proton. The values for $l_p = 1$ show the closest fit with the observed data as shown in Fig. 3. There is agreement as far

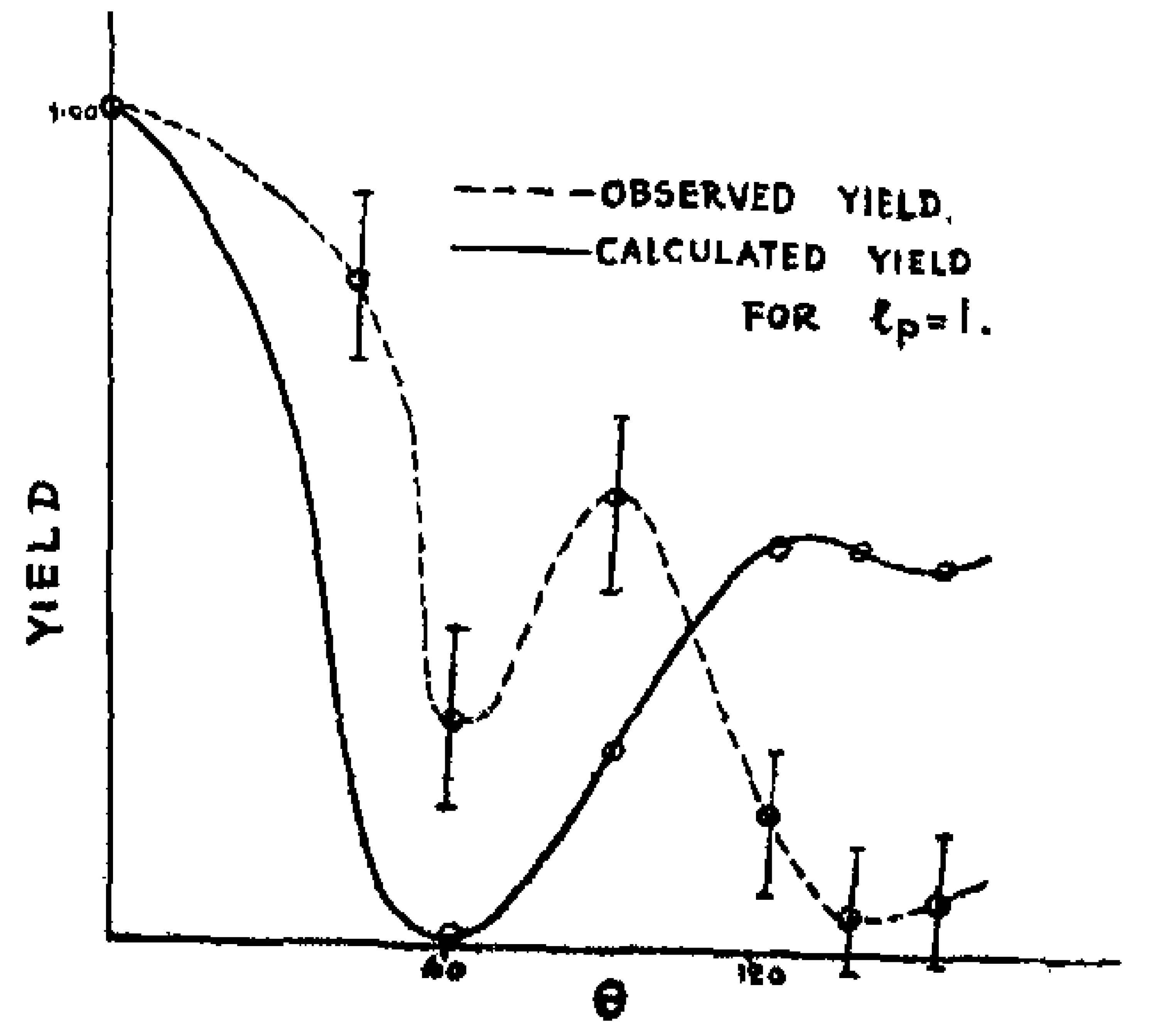

FIG. 3. Angular distribution in the centre-of-mass system of the reaction Li^7 (d, n) Be^8.

as the general nature of the curves is concerned namely in respect of the pronounced forward maximum, then a minimum at an angle of about 60° followed by a second maximum. There is however a considerable deviation in the observed and calculated yields in the backward direction. This may however be expected on account of Butler's theory being approximate at the small deuteron energy used in the present work.

It can therefore be concluded that the target nucleus Li^7 accepts a proton of orbital angular momentum $1_p = 1$ directly into the ground state of Be^8. This value of 1_p is consistent with the change of parity in the Li^7 (d, n) Be^8 reaction. It also implies that the ground state of Be^8 has spin 0 or 2, the odd values being not permitted on account of observed break up of Be^8 into two α-particles (Crussard[16] and Jones *et al.*[17]).

Conclusion

In the present investigation evidence has been found for the levels in Be^8 at 2·1, 2·8, 3·5, 4·1, 4·88, 5·96, 6·55 and 7·57 MeV. excitation besides the ground state. This is at variance with the results of most of the workers and is in agreement with the findings of Trumpy *et al.*[7] and Catala *et al.*[8]

The results obtained in the present experiment are more conclusive than that of Catala *et al.* as the latter studied the reaction at only two angles. In the work of both Trumpy et al. and Catala *et al.* a correction, which is approximate, had to be applied for the tracks running out of the plate. Due to the modified procedure of scanning and measurement followed in the present work no correction was needed for escape of tracks; it also avoided the determination of the shrinkage factor of the emulsion, whose value is ascertained approximately in the other investigations.

The angular distribution of the neutrons shows that the formation of Be^8 in the ground state is predominantly due to the stripping process. Analysis of data indicates this state of Be^8 to be 0^+ or 2^+. The problem regarding the relative importance of the stripping process and the compound nucleus formation can only be solved by a new theory for the stripping process at low deuteron energies.

The authors' thanks are due to Prof. B. G. Gokhale for his kind interest and helpful suggestions and to Dr. R. Ramanna for making available to us the facilities at the Tata Institute of Fundamental Research, Bombay, for the exposure and processing of the nuclear emulsions. The authors wish to express their indebtedness to the Council of Scientific and Industrial Research, New Delhi, for awarding a Research Fellowship to one of us (M. K. S.).

1. Spears, R. H., *Aust. J. Phys.*, 1958, **11**, 502.
2. Titterton, E. W., Gammell, D. S. and Morton, A. H., *Nucl. Phys.*, 1959, **10**, 33.
3. Juna, J., Horwalh, P. and Konecny, K., *Czech. J. Phys.*, 1960, **10**, 715.
4. Cerney, J., Harvey, B. G. and Phel, R. H., *Nucl. Phys.*, 1962, **29**, 120.
5. Purser, K. H. and Wildenthal, B. H., *Ibid.*, 1963, **44**, 22.
6. Browne, C. B. and Dorenbusch W. E., *Phys. Rev.*, 1963, **131**, 1212.
7. Trumpy, B., Grotdal, T. and Graue, A., *University of Bergen Yearbook No. 8*, University of Bergen, Bergen, Norway, 1953.
8. Catala, J., Aguilar, J. and Busquests F., *An. Real. Soc. Espan. Fis. Quim.*, 1963, **49 A**, 131.
9. Vlasov, N. A., Kalinin, S. P., Ogloblin, A. A. and Chnev, V. I., *Zh. eksper toer.*, USSR, 1960, **39**, 1468.
10. Dilworth, C. C., Occhialini, G. P. S. and Payne, R. M., *Nature*, London, 1948, **163**, 102.
11. Sah J. P., *Ind. J. Phys.*, 1965, **39**, 193.
12. Saxena, M. K. and Sah, J. P., *Ind. J. Pure Appl. Phys.*, 1964, **2**, 364.
13. Wilkins, J. J., *Atomic Energy Research Establishment Report G/R 664*, HM Stationary Office, London, 1951.
14. Haxby, Allen and Williams, *Phys. Rev.*, 1939, **55**, 142.
15. Butler, S. T., *Proc. Roy. Soc.*, 1951, **208 A**, 559
16. Crussard, J., *Nature*, 1950, **166**, 825.
17. Jones, Donahue, McEllistrem, Douglas and Richards, *Phys. Rev.*, 1953, **91**, 879.