forming atomic "channels." The experimental results can be explained perhaps even better by applying Mott's model of a grain boundary.[3] In this picture, which is particularly suitable for angles of the order of 20° and up, the grain boundary is made up of islands of fit surrounded by areas of misfit. The angle between the grains determines the distribution and shape of these islands, as is very schematically illustrated in Fig. 2. The diffusion would occur along the areas of misfit and would always be preferred in a direction parallel to the long axis of the generally elliptical areas of fit. This is, of course, also the direction of the edge dislocations in the other model and agrees with experiment.

* This work was sponsored by an AEC contract; the first author had an AEC Predoctoral Fellowship.

† Now with the Atomic Power Division, Westinghouse Electric Corporation, Pittsburgh, Pennsylvania.

[1] M. R. Achter and R. Smoluchowski, Phys. Rev. 76, 470 (1949); Proc. Natl. Research Council Conference on "Lattice Imperfections," Pocono Manor, October, 1950.
[2] J. M. Burgers, Proc. Phys. Soc. (London) 52, 23 (1940); W. T. Shockley, Phys. Rev. 78, 275 (1950); T. H. van der Merwe, Proc. Phys. Soc. (London) 63, 616 (1950).
[3] N. F. Mott, Proc. Phys. Soc. (London) 60, 391 (1948).

Angular Distribution of Protons from $Li^6(d,p)Li^{7*}$, Li^7

D. N. F. DUNBAR AND F. HIRST
Physics Department, University of Melbourne, Melbourne, Australia
(Received April 12, 1951)

RECENT determinations[1,2] below 1-Mev deuteron energy of the angular distributions of the two groups of protons emitted in this reaction do not agree with one another. Since the forms of the distributions help in the allocation of spin to the excited state of Li^7 near 480 kev, it is important if possible to resolve this difference.

Ilford Type C2 photographic plates have been used in a camera previously described[3] to record the two groups of protons at all angles simultaneously. The total emission of protons at each of 10 angles between 13° and 167° is determined by counting the tracks with a $\frac{1}{4}''$ objective and ×6 eyepieces in a binocular microscope. At least two plates are exposed and some 20,000 tracks counted at each energy. The total emission is then divided into the long and short range groups by constructing representative histograms of 600 tracks at five of the ten angles of observation at each deuteron energy. The ratio of long to short range protons varies both with angle and energy. Typical angular distribution curves are shown in Fig. 1.

The angular distributions of the total emission and the long and short range groups are expressed in the form

$$N(\theta) = a_0P_0 + a_1P_1 + a_2P_2 + \cdots + a_6P_6,$$

where $N(\theta)$ is the intensity at an angle θ, P_n is the Legendre polynomial of order n, and a_n is the coefficient of the polynomial of nth order. The coefficients, a_n, are evaluated from

$$a_n = \tfrac{1}{2}(2n+1)\int_{-1}^{+1} N(\theta)P_n d(\cos\theta),$$

by numerical integration using Simpson's rule. When expressions of this form are fitted to the results, it is found that terms as far as a_4P_4 are required to fit the long-range proton curves, while terms as far as a_2P_2 are sufficient for the short-range protons. The simpler expression for the short-range distribution may be partly due to the relatively poor statistics of these results. There is no evidence for the approximate spherical symmetry in the long-range proton distribution at low energies observed by Krone *et al.*[2] The results are of the same form as those of Whaling and Bonner[1] although the asymmetry of the short-range group is more marked in the present results.

The variations of the ratios a_1/a_0, a_2/a_0, a_3/a_0, $\cdots$, with energy for the total emission and the separate groups have been compared with other published results. The agreement between Whaling and Bonner[1] and the present results is in general satisfactory. The greatest discrepancies arise, as may be expected, in the short-range group. Except for a low value at 400 kev, the values of a_1/a_0 for the short-range protons obtained by Whaling and Bonner agree well with the present results, while only the 780-kev point of Krone *et al.* agrees with the other experiments. The values of a_2/a_0 for the short-range protons obtained by both Whaling and Bonner and Krone *et al.* are scattered between 0.2 and −0.2. The present values form a consistent set at about −0.06, however, and appear to be more probable. The decrease in a_4/a_0 observed in all three experiments suggests that the term a_4P_4 is, in fact, significant in the short-range distribution, although this is not substantiated on statistical grounds. The observed distributions indicate that the

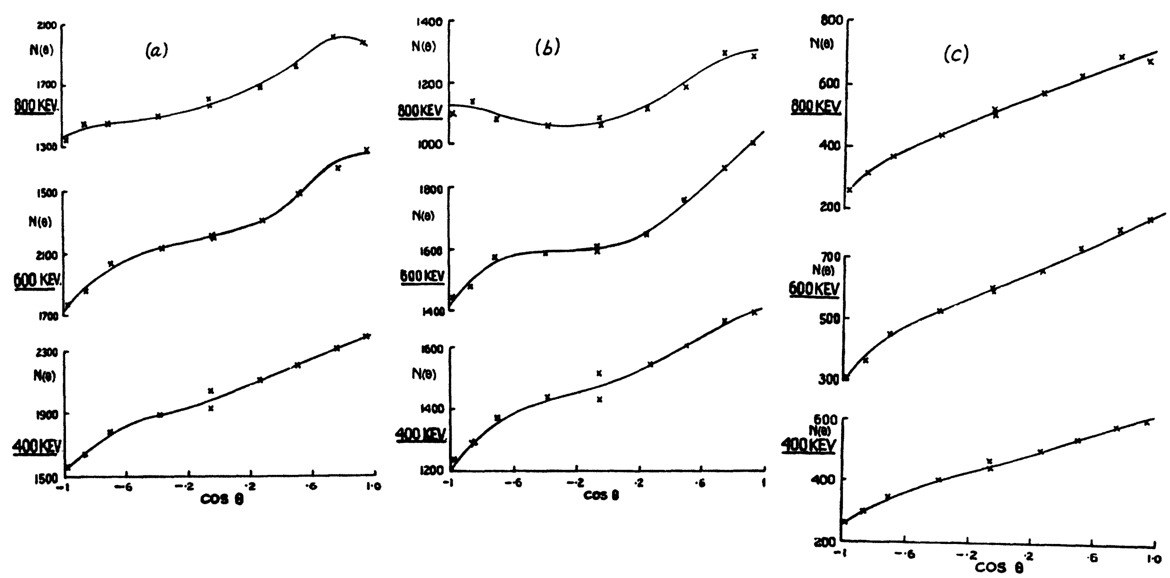

FIG. 1. Relative yield curves (a) for the total proton emission, (b) for the long-range proton group, and (c) for the short-range proton group.

angular momentum of the excited level in Li^7 is $\frac{1}{2}$, rather than 5/2 as suggested by Hanna and Inglis.[5]

The angular distribution of the alpha-particles from the reaction $Li^6(d,\alpha)He^4$ has also been determined for deuteron energies between 200 kev and 1 Mev. The distribution is of the form $1+A(E)\cos^2\theta$, and the variation of $A(E)$ with energy shown in Fig. 2 confirms the earlier results of Heydenburg *et al.*[4]

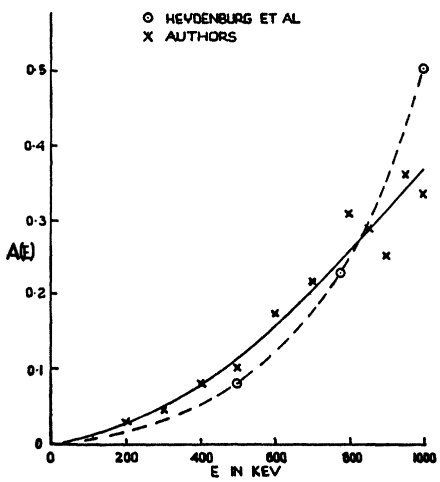

FIG. 2. Variation with energy of the asymmetry in the angular distribution of alpha-particles from the $Li^6(d,\alpha)He^4$ reaction.

A full description of the investigation will appear in the *Australian Journal of Scientific Research.*

[1] W. Whaling and T. W. Bonner, Phys. Rev. 79, 258 (1950).
[2] Krone, Hanna, and Inglis, Phys. Rev. 80, 603 (1950).
[3] Martin, Bower, Dunbar, and Hirst, Australian J. Sci. Research A2, 25 (1949).
[4] Heydenburg, Hudson, Inglis, and Whitehead, Phys. Rev. 74, 405 (1948).
[5] S. S. Hanna and D. R. Inglis, Phys. Rev. 75, 1767 (1949).

Electric Forming in *n*-Germanium Transistors Using Phosphorus-Alloy Contacts

J. P. STELMAK
Radio Corporation of America, Harrison, New Jersey

(Received May 4, 1951)

THE use of temporary large currents through the collector contact of *n*-type transistors to produce permanent improvements in performance has been reported by Bardeen and Brattain.[1] During this forming operation, the role of the contact material, which was stated to be phosphor bronze, was not particularly indicated. Very recently, Pfann[2] has submitted data on the effect of the presence of antimony in the contact material when the contact is electrically formed. With increasing concentration of antimony, a donor impurity, an increase in γ, the current gain, was noted.

Some time ago it was suggested by Mr. L. E. Barton, of RCA Laboratories that the phosphorus content of the collector contact point played an important role in improving transistor gain, when pulse forming was used. Barton's experimental data were of a preliminary kind; the present letter presents more convincing evidence of this hypothesis by tests with specially prepared alloys.

Table I summarizes results obtained with electrical forming of collector contacts containing varying amounts of phosphorus. Average results and range values are given for five transistors in each group in which the collector contact consisted of the copper alloy shown, with emitters of phosphor bronze being the same in all cases.

TABLE I. Pulsing response in transistors to equal pulses applied to collector using phosphorus-alloy collector contacts. Average gain before pulsing = 10 db.

Alloy	Weight % phosphorus	Average power gain after pulsing (db)	Power gain range after pulsing (db)
OFHC Cu (Pure)	0.00	10.5	9–12
No. 3	0.03	17	15–24
No. 5	0.9	24	23–26
No. 7	1.1	25	22–28
Commercial phosphor bronze	0.1	21	20–24

The response to equal forming pulses is presented as the improvement in power gain from an average of 10 db as measured at 5 kilocycles in class *A* amplifier operation. An increase in power gain in all cases was accompanied by an increase in the current gain γ, and in collector current. For comparison, the results obtained with relatively pure OFHC copper and a commercially available phosphor bronze are included. Pulsing response increases rapidly with phosphorus content up to a concentration of about 0.1 percent, beyond which there follows a more gradual rise to what may be a limit.

In another series of experiments, in which phosphor bronze was used for both emitter and collector contacts, the effect of direction of voltage pulse was investigated. In Table II are shown the results of pulsing under the various conditions; the values for each line are the average for five transistors.

TABLE II. Transistor pulsing response under various conditions of pulsing. Average gain before pulsing = 10 db.

Collector pulsing voltage	Emitter bias voltage during pulsing	Average power gain after pulsing (db)	Power gain range after pulsing (db)
−180 (reverse direction)	0	23	19–24
+22 (forward direction)	0	24	21–25
−90 (reverse direction)	+0.4	22	20–25

As the data show, it has been possible to obtain equivalent effects with voltage pulse in the forward and in the reverse direction; the voltage required in the forward direction is considerably lower since the resistance is also lower in this direction. In both of these cases, the improvement in power gain was accompanied by an increase in reverse current of the pulsed contact, apparently in disagreement with the conclusions of Bardeen and Pfann[3] as to the effect of direction of forming. It has also been observed that the pulsing voltage required to obtain a forming effect is smaller if a positive emitter bias is maintained during forming. This observation is plausible when the effect of positive emitter bias on collector impedance is considered.

In view of these results, pulsing response appears to increase with phosphorus concentration in the contact material and with pulse power input, and, as such, is a function of the heat generated at the point contact. Some fusion at the metal-germanium junction is observable under a microscope after successful forming. A superficial diffusion of phosphorus, or other donor, into the germanium surface under the contact point may account for the change in the height of the potential barrier observed to give increased power and current gain.

[1] J. H. Bardeen and W. H. Brattain, Phys. Rev. 75, 1209 (1949).
[2] W. G. Pfann, Phys. Rev. 81, 882 (1951).
[3] J. H. Bardeen and W. H. Brattain, Phys. Rev. 77, 401 (1950).