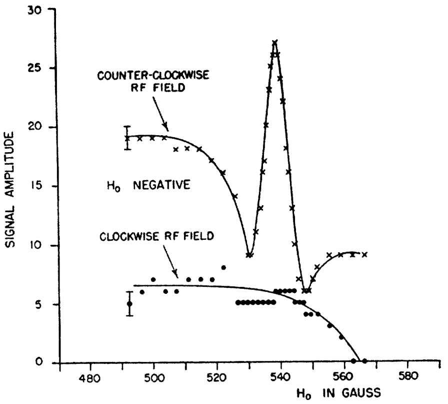

FIG. 1. Proton nuclear induction signals for the two directions of rotation ($\nu = 2.300$ mc).

Figure 1 shows the result of reversing the direction of r-f field rotation in the nuclear induction effect. (The notation "H_0 negative" simply refers to an arbitrarily assigned H_0 field direction. Similarly, the words "counter-clockwise r-f" and "clockwise r-f" refer to arbitrarily assigned directions of rotation of the radiofrequency field about the direct current field.) It will be observed that the proton nuclear induction signal appears only for a particular combination of the two magnetic fields, and is completely absent for the reverse combination.

After establishing the sign dependence of the nuclear induction effect, we removed the proton sample and passed a beam of partially polarized neutrons through the rotating field region. Figure 2 shows the results of this experiment. (Smooth curves were drawn to fit the experimental points.) It will be observed that for the same direction of the H_0 field as for the protons, the neutron resonance occurs for the *opposite* direction of rotation of the r-f field. The immediate conclusion is that the neutron and proton have magnetic moments of opposite sign. The slight hump to the right of the main neutron resonance dip can be explained by the known inhomogeneities of the r-f and H_0 fields. This has been verified by an approximate calculation.

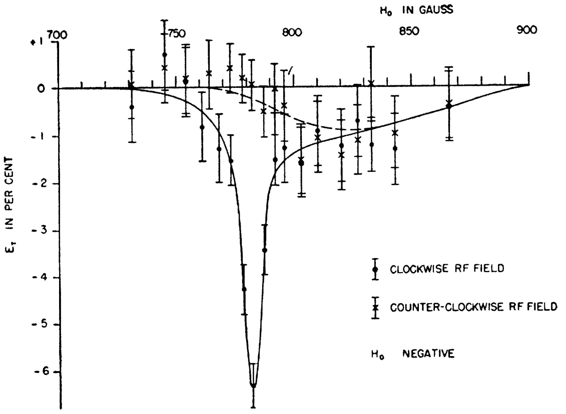

FIG. 2. Neutron transmission effect for the two directions of rotation ($\nu = 2.278$ mc).

The absolute signs of the moments were determined by establishing the actual direction of the H_0 field and the true sense of rotation of the r-f field. The former was ascertained in two ways: first, from the known direction of the cyclotron magnetic field as inferred from the relative positions of target and deflector; and secondly, from the observed deflection of a current-carrying wire. The direction of rotation was determined as follows: two small probe coils oriented at right angles to one another were placed in the center of the r-f field, and the induced voltages therein mixed with a single local oscillator voltage. The resultant 80 kc voltages, for which relative phase shifts as to sign and magnitude were preserved, were applied separately to an oscilloscope whose linear sweep was synchronized with one of these voltages. The observed phase difference of the two voltages, combined with a knowledge of the sense of the probe coil windings, provided the information desired. We assumed the convention that a rotating positive charge will have a positive magnetic moment $\underset{\to}{\mu}$ parallel to its angular momentum $\underset{\to}{J}$. The absolute determination showed unambiguously that the proton moment is positive and the neutron moment is negative.

A detailed account of this work will appear in a forthcoming issue of Helvetica Physica Acta. One of us (E.H.R.) is indebted to the National Research Council for a Predoctoral Fellowship.

* Assisted by the Joint Program of the ONR and the AEC.

[1] F. Bloch, Phys. Rev. **70**, 460 (1946).

[2] I. I. Rabi, Phys. Rev. **51**, 652 (1937).

[3] P. N. Powers, Phys. Rev. **54**, 827 (1938).

[4] S. Millman, Phys. Rev. **55**, 628 (1939).

[5] Bloch, Nicodemus, and Staub, Phys. Rev. **74**, 1025 (1948).

On the Angular Distribution of D−D Reaction Products

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THE angular distribution of the D−D reaction products was given hitherto by

$$I(\theta) = A(1 + B\cos^2\theta).$$

The dependences of A and B on the energy of the incident deuteron have been explained theoretically by Konopinski and Teller,[1] taking up to the incident P waves into account. According to the recent experiment of Blair *et al.*,[2] however, an alternative formula

$$I(\theta) = A(1 + B\cos^2\theta + C\cos^4\theta)$$

holds in the region of the higher energy of the incident deuteron, i.e., 1–3.5 Mev, where the calculation of Konopinski and Teller does not seem to be sufficient. Thus, the present author has taken up to the D waves in their line of calculation. Precisely, the transitions

$$^1S_0 - {}^1S_0,\ {}^3P_2 - {}^3P_2,\ {}^3P_1 - {}^1P_1,\ {}^3P_2 - {}^3F_2,\ {}^1D_2 - {}^1D_2,\ {}^1D_2 - {}^3D_2$$

have been considered. With the same notations as Konopinski and Teller, the differential cross section becomes

$$\begin{aligned} d\sigma = d\omega \,|\, &(\sigma_0/9)^{\frac{1}{2}}\alpha_0 Y_{0,0} + (\sigma_1/3)^{\frac{1}{2}}(\textstyle\sum_m \alpha_{1,m} Y_{1,m} + (\frac{5}{9}\,\frac{1}{2})^{\frac{1}{2}}\alpha_{P-F} Y_{3,-1}) \\ &+ (\sigma_2/9)^{\frac{1}{2}} \textstyle\sum_m \alpha_{2,m} Y_{2,m} \,|^2 \\ = d\omega&(4\pi)^{-1}\pi\lambda\!\!\!^{-2} A'(1 + B\cos^2\theta + C\cos^4\theta), \end{aligned}$$

$\cos^6\theta$-terms being neglected, where

$$\begin{aligned} A' &= A_0P_0 + A_1P_1 + A_2P_2 + A_{02}(P_0P_2)^{\frac{1}{2}}, \\ B &= B_1P_1 + B_2P_2 + B_{02}(P_0P_2)^{\frac{1}{2}}, \\ C &= C_1P_1 + C_2P_2. \end{aligned}$$

The coefficients A_0, etc. are the definite functions[3] of $\alpha_{l,m}$'s and phase angles. The nuclear penetrabilities P_l's have been evaluated numerically as functions of the incident energy by means of Bethe's formula,[4] assuming the value $7\cdot 10^{-13}$ cm for the distance of the closest approach. The following values of the coefficients

$$\begin{aligned} &A_0 = 0.849\cdot 10^{-3}, \quad A_1 = 1.313\cdot 10^{-3}, \quad A_2 = 17\cdot 86\cdot 10^{-3}, \\ &A_{02} = 4.40\cdot 10^{-3}, \quad A'B_1 = 5.12\cdot 10^{-3}, \quad A'B_2 = -144.8\cdot 10^{-3}, \\ &A'B_{02} = 27.9\cdot 10^{-3}, \quad A'C_1 = -4.83\cdot 10^{-3}, \quad A'C_2 = 197.2\cdot 10^{-3} \end{aligned}$$

can reproduce the experimental data of Blair *et al.*, and furthermore, in the lower energy region, the earlier experiments as well

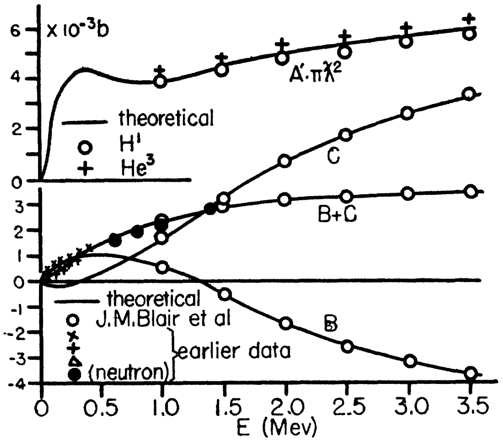

FIG. 1. Isotropic cross section $A'\cdot\pi\lambda\!\!\!^{-2}$ and anisotropic coefficients B and C as functions of the energy of the incident deuteron.

as the theoretical curve of Konopinski and Teller, as shown in Fig. 1. The vanishing of C at *ca.* 0.3 Mev corresponds to Blair's statement that it happens between 0.5 and 1.0 Mev. It should be added that the above numerical values give the correct signs and the reasonable orders of magnitude for all $\alpha_{l,m}$'s.

The author wishes to thank Professor K. Umeda for his advice and encouragement.

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[1] E. J. Konopinski and E. Teller, Phys. Rev. **73**, 822 (1948).
[2] Blair, Freier, Lampi, Sleator, and Williams, Phys. Rev. **74**, 1599 (1948).
[3] The full expressions will be given shortly in J. Faculty Sci. Hokkaidô University, Sapporo, Japan.
[4] H. A. Bethe, Rev. Mod. Phys. **9**, 178 (1937).

Current Densities in the Cathode Spots of Transient Arcs

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IT has recently been suggested that the current densities of arc cathode spots may exceed hitherto accepted values by at least an order of magnitude. From observations of the tracks left by rapidly moving cathode spots on oxidized metal surfaces, Cobine and Gallagher[1] derived current densities of the order of 5×10^4 amp./cm². Using a Kerr cell shutter and exposures of the order of a microsecond to photograph the cathode spot, Froome[2] obtained current densities of about 10^6 amp/cm².

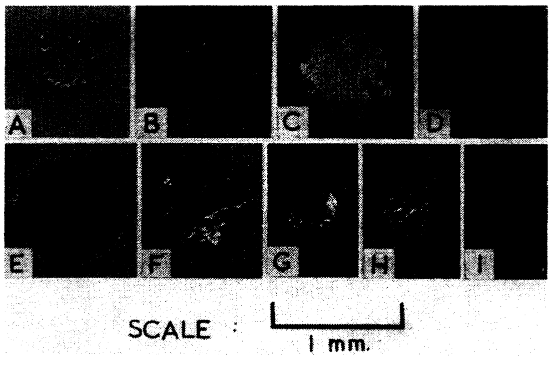

FIG. 1. Cathode markings for high current transient arcs in air at atmospheric pressure.
Top.—Cathode material: (A) copper; (B) magnesium; (C) aluminium; (D) nickel. Current: 80 amperes. Duration: 20 μsec.
Bottom.—Cathode material: Tin. Current: 50 amperes. Duration: (E) 200 μsec.; (F) 50 μsec.; (G) 20 μsec.; (H) 5 μsec.; (I) 1 μsec.

We have struck high current arcs of short duration in air at atmospheric pressure on aluminum, copper, magnesium, nickel, tin, and tungsten cathodes. Using a number of pulse-forming lines, we could pass currents of up to 200 amperes in square pulses varying in duration from 1 to 200 microseconds.

The arc strikes readily and leaves a clear, well-defined spot on clean tin, on aluminium which has not recently been scraped clean, and on oxidized copper, nickel, magnesium, and tungsten cathodes. The spots are roughly circular in shape, some typical examples being shown in Fig. 1. A single pulse usually gives a single spot although cases of multiple spot formation occur in aluminium, copper, and tungsten, particularly at high currents. Measured areas of spots obtained with the same current and pulse length vary about the mean with a standard deviation of 0.05 to 0.1 of the mean.

For a given pulse length the mean spot area is proportional to the current strength and so for each metal the ratio (current/spot area), which we may call the apparent current density, is a function of the pulse length. In all cases the apparent current density increases as the pulse length falls, as shown in Table I.

TABLE I. Current density (amp/cm²).

Pulse length	1 μsec.	5 μsec.	20 μsec.	50 μsec.	200 μsec.
Aluminium	160,000	65,000	40,000	40,000	Unreliable
Copper	780,000	390,000	114,000	90,000	35,000
Magnesium	>10⁶	1,000,000	320,000	140,000	35,000
Nickel	480,000	175,000	67,000	56,000	18,000
Tin	340,000	33,000	19,000	19,000	9000
Tungsten	1,600,000	340,000	75,000	22,000	Unreliable

Our experiments are in agreement with those of Froome is indicating that, in arcs of short duration at least, current densities of the order of 10^6 amp/cm² may prevail. It is possible, of course, that the markings on our cathodes for longer pulse lengths are the result of the motion of one or more smaller spots like those observed by Froome, but our experiments give no information about this. It may also happen that, particularly in the case of the lower melting point metals, an area is melted greater than the area from which the current is drawn, leading to low apparent current densities. For these reasons we regard our measurements as giving only a lower limit to the real current density.

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[1] J. D. Cobine and C. J. Gallagher, Phys. Rev. **74**, 1524 (1948).
[2] K. D. Froome, Proc. Phys. Soc. **60**, 424 (1948).

The Beta-Spectrum of Tl^{204}, Magic Numbers, and Neutron Pairing

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THE β-spectrum of the 3 yr. Tl^{204} is of special interest because the nuclei involved lie close to the magic numbers 82 for protons and 126 for neutrons.[1] According to the most recent nuclear shell work,[2] Tl^{204} may be useful in deciding whether high angular momentum neutrons are added in pairs in the heavy element region. Both the neighboring isotopes Tl^{203} and Tl^{205} have the low spin $\frac{1}{2}$, while the daughter substance Pb^{204} probably has spin 0. Therefore the shape of the β-spectrum of Tl^{204} will give strong evidence for or against the high angular momentum neutron pairing.