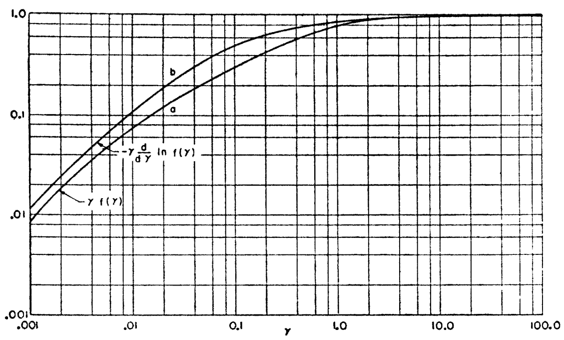

FIG. 1. Functions related to impurity concentration *versus* γ.

for the semiconductor, it is necessary only to measure n_e^* at an intermediate temperature, and T and μ at low temperatures, to obtain N_T. From these data and Eq. (1), one can obtain $\gamma f(\gamma)$, and from Fig. 1, the value of γ can be found. Then, $N_I = Bn_e^* T^{\frac{3}{2}}/\gamma$ and the total impurity content can be calculated as $N_T = N_I + n_e^*$.

A knowledge of A and B should also enable one to calculate the effective mass, m, of the current carrier in Ge and the effective dielectric constant, p, in Ge from the equations

$$A = \frac{p^2 k^{\frac{3}{2}}}{4\pi c e^3 (2m)^{\frac{1}{2}}} \left[\ln\left(1 + \frac{36 p^2 (kT)^2}{N_I^{\frac{2}{3}} e^4}\right)\right]^{-1},$$

$$B = 20 p \hbar^2 A / m e^2,$$

where k is Boltzmann's constant.

Thus, such experiments allow one, in principle, to measure the total impurity concentration in a semiconductor and also to measure the effective mass and the dielectric constant.

[1] E. Conwell and V. F. Weisskopf, Phys. Rev. **77**, 388 (1950).
[2] C. Erginsoy, Phys. Rev. **79**, 1013 (1950).
[3] R. H. Fowler, *Statistical Mechanics* (Cambridge University Press, Cambridge, 1936), second edition, p. 398.

The Mechanism of Star Production by Gamma-Rays

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THE cross section for star production has been determined with the synchrotron bremsstrahlung beam for maximum energies of 300, 250, 200, and 150 Mev by a comparison of the number of stars produced in a photographic emulsion with the number of radioactive atoms produced in a carbon plate exposed to the beam simultaneously. The spectrum of the bremsstrahlung is assumed to be of the form Q/E, where Q is a constant and E is the quantum energy of a gamma-ray. The cross section, $\sigma(\gamma,n)$, of C^{12} was assumed to have a sharp resonance maximum at 30 Mev and an integrated value 1.48×10^{-25} cm^2-Mev, following Lawson and Perlman.[1] The values of the cross section averaged over all types of atoms in the emulsion, except hydrogen, are shown in Table I.[2] Stars with more than two prongs were counted.

The value at 300 Mev was also determined directly from the value of Q as measured by a pair spectrometer by DeWire and Beach of this Laboratory. It was found to be 4.2×10^{-27} cm^2 with an error of about 30 percent. As an absolute measurement the latter value may be more reliable than is the former. The earlier value[3] of 5×10^{-28} cm^2, with an error of a factor of 5, was too low. The discrepancy seemed to have come from a rather ambiguous assumption as to the relation of the value of Q with our r-meter readings.

TABLE I. Average cross sections.

Energy (Mev)	300	250	200	150
Cross section (mb) (McMillan)	6.04 ±0.41	5.63 ±0.56	2.55 ±0.19	1.95 ±0.18

Looking at the results shown in Table I and taking into account the general character of the bremsstrahlung spectrum, it is reasonable to consider that the interaction of a photon with a nucleus, which leads to star production, is mesonic rather than an electromagnetic interaction leading to an ordinary type of photodissociation, when the photon energy is well above the threshold for meson production.

Another, more direct, bit of evidence for a mesonic interaction can be seen in the fact that there are certain cases in which a meson actually emerges from a star. This has been confirmed in two different ways. First, the stars were observed in electron-sensitive plates, and among about 450 stars produced by 300-Mev bremsstrahlung, at least three of them were observed to emit such a thin track (less than 1.5 times the minimum grain density) that they cannot be protons. They were very likely mesons of some 50 to 100 Mev. The multiple scattering of one of them also provided strong evidence that it was a meson. Second, there were 7 cases out of about 3500 in which a low energy meson (of a few Mev) emerged from a star and stopped in the emulsion with the production of another star. This type of event has been observed also by Miller.[2] Considering the cross section for meson production and the frequencies of the types of events discussed here, it seems that a good part of the mesons are associated with stars, indicating the complex nature of the meson producing process from heavy nuclei.

Many thanks are due Professor R. R. Wilson and the other members of the Laboratory for discussions, and to Mrs. M. R. Keck and Mrs. C. A. Lipetz for valuable assistance in the scanning of plates and the measurement of multiple scattering.

[1] J. L. Lawson and M. L. Perlman, Phys. Rev. **74**, 1190 (1948).
[2] Similar results have been obtained by R. D. Miller in Berkeley, using a somewhat different method. I am much indebted to Mr. Miller for information concerning his work before the start of these measurements.
[3] S. Kikuchi, Phys. Rev. **80**, 492 (1950).

A Note on Exchange Magnetic Moments

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RECENT papers by Sachs[1] and by Osborn and Foldy[2] have treated the expressions for the exchange currents arising from the exchange forces between nucleons. With two nucleons, 1 and 2, the equation for these currents is

$$\operatorname{div} \mathbf{j}(\mathbf{r}) = V(\boldsymbol{\tau}_1 \times \boldsymbol{\tau}_2)_z \{\delta(\mathbf{r}-\mathbf{r}_1) - \delta(\mathbf{r}-\mathbf{r}_2)\}, \quad (1)$$

where V is a constant proportional to the nuclear potential. The solutions to be found are particular integrals of this equation. Two points may be noted in connection with this equation and the expressions for the exchange moment listed by Osborn and Foldy, and also by Dalitz[3] in a forthcoming note.

The first is that the covariance properties of the expression should include invariance under time reversal. The current vector and the magnetic moment both change sign with time reversal. Now according to Wigner, under time reversal $\tau_x \rightarrow \tau_x$, $\tau_y \rightarrow -\tau_y$, so that the isotopic spin factor $(\boldsymbol{\tau}_1 \times \boldsymbol{\tau}_2)_z$ is antisymmetric under time reversal. Consequently, many expressions listed can be dropped, since apart from the isotopic spin the expression must be symmetric under time reversal; e.g., expressions of the type $(\boldsymbol{\sigma}_1 + \boldsymbol{\sigma}_2) \times p$, $\boldsymbol{\sigma}_1 \times \boldsymbol{\sigma}_2$ rather than $\boldsymbol{\sigma}_1 \pm \boldsymbol{\sigma}_2$.

The second point is that Eq. (1) is more easily considered following a fourier transformation. If $\mathbf{J}(\mathbf{k})$ is the transform of $\mathbf{j}(\mathbf{r})$, we easily find that

$$k^2 \mathbf{J}(\mathbf{k}) = -iV(\boldsymbol{\tau}_1 \times \boldsymbol{\tau}_2)_z [\exp(-i\mathbf{k}\cdot\mathbf{r}_1) - \exp(-i\mathbf{k}\cdot\mathbf{r}_2)]\mathbf{k} + \mathbf{k} \times \mathbf{Q}(\mathbf{k}), \quad (2)$$