

FIG. 1. (a) Internal conversion electron spectrum for the 513-keV gamma-ray from 65-day Sr^{86} . (b) Photo-electron spectrum for the same transition.

To check for the existence of positrons, two scintillation counters were used in coincidence. When separated by an angle of 180° at the source, coincidences between annihilation quanta should be recorded if positrons are present. This method and the apparatus used has been described in an earlier paper.⁴ If the electromagnetic radiation is caused by the annihilation of positrons, there should be a sharp peak of coincidences when the two detectors and the source lie in the same straight line.⁴ The results for this experiment are shown in Fig. 2. As a reference a known positron

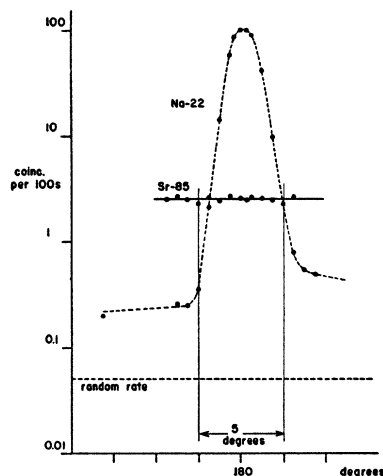


FIG. 2. Results of the experiment showing the absence of annihilation radiation in Sr^{86} . The constant coincidence counting rate for strontium may be compared to the increase in the coincidence counting rate for Na^{22} when the two detectors are separated by an angle of 180° at the source, this increase being caused by annihilation-annihilation coincidences. From this one deduces that Sr^{86} decays only by orbital electron capture.

emitter (Na^{22}) has been used. Whereas Na^{22} presents a very definite peak when the detectors are situated at an angle of 180° with the source, nothing similar can be observed for the Sr^{86} . Therefore, it can be concluded that the Sr^{86} decays by orbital electron capture without the emission of positrons, and that the 513-keV electromagnetic radiation is true gamma-radiation.

Internal conversion electrons associated with the shorter lived strontium activities were also observed. Internal conversion lines were found which corresponded to transition energies of 152 and 233 keV, and which decayed with a half-life of approximately 70 min. This half-life has previously been attributed¹ to Sr^{86m} . Also, there were internal conversion electron peaks corresponding to K and L shell conversions of a 388-keV transition energy. This ap-

peared to decay with a half-life of about $2\frac{1}{2}$ hours, and would, therefore, be associated with Sr^{87m} .¹

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Resonance in Antiferromagnetics

K. W. H. STEVENS

The Clarendon Laboratory, Oxford, England

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IN a recent communication¹ Bleil and Wangness have given an explanation of the disappearance of microwave resonance signals in antiferromagnetics below the curie temperature. An alternative explanation can be given as follows. The total absorption of energy in a resonance experiment on free spins is given by²

$$K \text{ Spur}[\exp(-\mathcal{H}/kT)(S_x \mathcal{H} - \mathcal{H} S_x) S_x] / \text{Spur}[\exp(-\mathcal{H}/kT)],$$

where $S_x = \sum_i s_x^i$, and K is a numerical constant. In a model in which $\mathcal{H} = g\beta H \sum_i s_z^i + \sum_{i < j} J_{ij} s^i \cdot s^j$, it is found readily that the area reduces to $\frac{1}{2} K H \bar{M}$, where \bar{M} is the magnetic moment of the sample in the field, H . The value of \bar{M} is known to decrease very sharply at the curie temperature as the temperature is lowered, so that the intensity of absorption will decrease correspondingly. In cases where this model can be applied there is no question of the resonance line moving outside the range of microwave experiments, as the exchange energy commutes with the measuring perturbation term, and the line should remain fixed in position. Thus, we prefer to explain the decrease in absorption at the curie temperature as an effect arising from the fact that the system occupies states from which the transition probabilities are small.

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Positron Search in K^{40}

MYRON L. GOOD

Department of Physics, Duke University,* Durham, North Carolina

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THE gamma-ray of K^{40} is associated with K -capture, because its energy is greater than the beta-ray end-point energy, and its intensity is much less than that of the beta rays.¹⁻³ The gamma-ray energy is greater than $2m_0c^2$. Under these conditions positron decay is to be expected.

Annihilation quanta from K^{40} were, therefore, sought. The apparatus has been described previously.⁴ The only modification was that the K_2CO_3 source was a shell $1\frac{1}{4}$ in. thick. (See Fig. 1 of reference 4.) The absorber between the crystal and position *II* (which is outside the K_2CO_3 container) was about 7 g/cm². Under these conditions, with a strong Zn^{65} source at position *II*, the curve B (Fig. 1) was obtained. Curve A is a Zn^{65} curve in which position (*I*), which is inside the container, was used, so that scattering effects were minimized. The effect of scattering in curve B is so severe that the beta-shield was changed (to a Pyrex beaker), and the inner support of the K_2CO_3 shell was made thinner. The Zn^{65} source was also made thinner and placed about 3 cm out from the masonite box wall instead of against it as before. These changes resulted in a total absorber thickness of about 4.3 g/cm². Under these conditions the data of curve D (Fig. 1) were obtained. It is

seen that the effect of the scatterer is to raise the low energy side of the peak. The Zn^{65} was removed and the K^{40} distribution observed (curve E). A background of about 10 percent was subtracted. The K^{40} curve shows two partially resolved lines identified with annihilation quanta (0.511 Mev) and with pair production in the crystal followed by escape of the annihilation quantum pair resulting therefrom [$1.46 - 2(0.511) = 0.44$ Mev]. The latter effect was calculated from the pair cross section for gamma-rays of 1.46 Mev on NaI, the total cross section for 0.511 Mev, and the crystal dimensions. The result is that 1 percent of the area under the K^{40} curve should consist of such a peak. A gaussian curve having this area and the same width as the Zn^{65} positron line was subtracted from the experimental points of the K^{40} curve at 0.44 Mev. The result of this treatment of the data is shown on curve C.

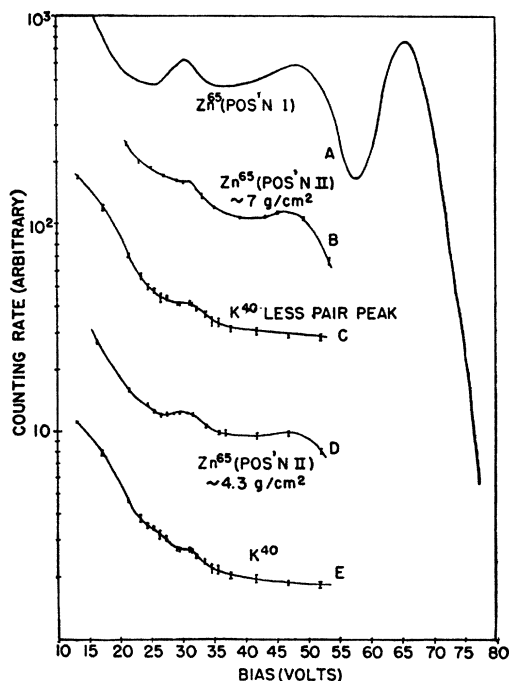


FIG. 1. Differential pulse height distributions. The energy scales are all the same; the relative heights are arbitrary.

It is clear from either curve E or C that there are some annihilation quanta present. By comparison with the Zn^{65} curves, one obtains an apparent (β_+/ γ) ratio for K^{40} . This result is 1.6 percent by comparison with curve D, or 1.4 percent with curve B (which the K^{40} data resemble the most). Some of the annihilation quanta must arise from pair production in the lead shield and the sample by the K^{40} gamma-ray, as mentioned by Bell.⁵ This effect was calculated roughly and found to be about 40 percent of the observed effect. It is concluded that as many as one positron per hundred gamma-rays may be present. The use of Zn^{65} as a sensitive comparison source was suggested by Bell's earlier work.⁶

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² D. Alburger, Phys. Rev. **78**, 629 (1950).

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⁶ P. R. Bell and J. M. Cassidy, Phys. Rev. **77**, 409 (1950).

Measurement of Semiconductor Impurity Content

CARL N. KLAHR AND L. P. HUNTER
Westinghouse Research Laboratories, East Pittsburgh, Pennsylvania
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IN investigating the properties of impurity semiconductors, it is desirable to know the impurity concentration. This is useful not only from the viewpoint of theory but as an aid in developing the technology of purifying semiconductors. The measurement of impurity concentration by ordinary means is very difficult, since in a semiconductor it is often less than one part in 10^7 and may be a mixture of chemical impurities and lattice defects. Our purpose is to describe an electrical means of measuring total impurity concentration and to indicate a method for the experimental determination of the effective mass of the current carriers.

The electrical conductivity depends on the total impurity concentration through the mobility factor, which in turn depends on the mean free path of carriers. There are three contributions to the mean free path: ordinary lattice scattering which yields an energy independent mean free path; ionized impurity scattering from ionized donor and acceptor centers; non-ionized impurity scattering from non-ionized centers. The mean free path due to ionized impurities has been discussed by Conwell and Weisskopf¹ and is found to be $l_i = ae^2/\epsilon$, where ϵ is the energy, and a varies reciprocally with ionized impurity concentration. The non-ionized mean free path has been discussed by Erginsoy² and varies as $\epsilon^{1/2}$ and reciprocally with concentration of non-ionized centers. With these assumptions we have calculated the Hall constant and the conductivity in the intermediate and low temperature ranges for electronic and hole carriers. The carrier concentrations n_e and n_h can be eliminated between these expressions and the appropriate form of the mass action law.³ There results a system of curves of mobility vs conductivity which at constant temperature would be parametrized by the total impurity content-donor plus acceptor centers. By measuring Hall constant and resistivity of a given sample at a given temperature, its impurity content can be determined from this system of curves.

To simplify the application of this method one can combine low and intermediate temperature measurements of conductivity, σ , and Hall constant, R . Both sets of measurements should be made at sufficiently low temperatures for n_h to be negligible in N -type samples. This can be assured by inspecting graphs of R and σ vs T^{-1} . First, the Hall effect should be measured in the exhaustion range at a sufficiently high temperature that impurity scattering is negligible. From it n_e^* , the electron concentration in the exhaustion range, can be determined as $(3\pi/8)(1/Re\epsilon)$. At low temperatures, i.e., 10 to 20°K for Ge, we have calculated

$$R\sigma = \mu = A\gamma f(\gamma)/Bn_e^* = AT^{\frac{1}{2}}f(\gamma)/N_I, \quad (1)$$

where

$$\gamma = \frac{\text{average ionized impurity mean free path}}{\text{average non-ionized impurity mean free path}} = B \frac{n_e^*}{N_I} T^{\frac{1}{2}}$$

and

$$N_I = \text{ionized impurity concentration.}$$

$\gamma f(\gamma)$ is a function of γ given in curve a of Fig. 1, while A and B are constants for Ge and which are independent of the impurity content. Once these are determined, the theory permits simple measurement of the impurity content of any sample. The determination of A and B may be carried out as follows:

$$(\partial\mu/\partial T)N_I = (3\mu/2T)[1 + \gamma d \ln f(\gamma)/d\gamma], \quad (2)$$

$$(\partial\mu/\partial N_I)_T = -(\mu/N_I)[1 + \gamma d \ln f(\gamma)/d\gamma]. \quad (3)$$

$(\partial\mu/\partial T)N_I$ should be measured at low temperatures on one sample, while $(\partial\mu/\partial N_I)_T \approx (\Delta\mu/2\Delta N_P)_T$ could be measured, though probably with difficulty, by adding a known amount of P -type impurity, ΔN_P , to an N -type sample. By measuring $(\partial\mu/\partial T)N_I$, μ , and T , one can calculate γ from Eq. (2) and curve b of Fig. 1. Then N_I can be determined from Eq. (3). The value of B can now be calculated as $B = \gamma N_I/n_e^* T^{\frac{1}{2}}$. From this, A can be calculated from Eq. (1). Once A and B have been determined