Letters to the Editor

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Temperature Effects in the Annihilation of Positrons*

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A COMPONENT of anomalously long lifetime was first observed by Bell and Graham[1] in the decay of positrons in several condensed materials. In order to account for this component, which we shall call the τ_2 component, they postulated the existence of triplet state positronium which was being converted to the singlet state and subsequently annihilating. Several of the substances which exhibited the τ_2 component also showed a dependence of τ_2 on the temperature of the annihilation medium. This was particularly true in the case of Teflon. Graham and Stewart[2] further observed that as the temperature was reduced, the three-photon annihilation rate in Teflon decreased, thus establishing a correlation between τ_2 and three-photon annihilations as a function of temperature. We have further investigated the effects of reduced temperature in several other substances which show a τ_2 component. Among these were methyl alcohol, water, and glycerine, each containing a small amount of $Na^{22}Cl$ in solution.

The $Na^{22}Cl$ of about one mC activity was first dissolved in 5 ml distilled water, this aqueous solution later being evaporated to the salt residue and redissolved in methyl alcohol and glycerine for the determinations in these liquids. The active solution was placed in a small Pyrex volumetric flask and submerged in the various refrigerating agents such as liquid helium, liquid nitrogen, solid carbon dioxide in alcohol, and freezing mixtures of ice and salt. The refrigerants were placed inside a Dewar which was contained in a second Dewar. NaI(Tl) scintillation counters placed at 120° relative to one another were used as radiation detectors. A fast triple coincidence circuit was built to record the number of three- and two-photon coincidences. Provisions were made to lift one of the counters out of the coplanar position of source and counters by 45° in order that triple coincidences other than from the three-photon annihilation of positrons could be measured. The coplanar to noncoplanar ratio was 1.86. Twofold coincidences were measured by placing two of the counters at 180° with respect to one another and coplanar with the source. The counting rates thus obtained were not absolute rates inasmuch as the counter efficiencies had not been determined. Care was exercised in maintaining a constant mass of material surrounding the sample when changing refrigerants. For example, at higher temperatures wood alcohol (density 0.806 g/cm^3) replaced the liquid nitrogen (density 0.804 g/cm^3) used in the outer Dewar for the measurements at 4.2°K. Also, the constancy of the twofold coincidence rate for the various refrigerants showed that the absorptivity of the different refrigerants did not change. Room temperature twofold and threefold coincidences were taken first, followed by the rates at the reduced temperature, and finally the room temperature rates were remeasured to assure that counting rates had not drifted during the course of a determination. The results are plotted in Fig. 1, where the normalized threefold coincidence rate has been shown as a function of temperature. The normalization factor was determined by comparison of twofold coincidence rates for the various runs.

A decrease in the threefold coincidence rate is apparent after the annihilation medium has become solid due to freezing. In this connection, the water solution solidified at 260°K, methyl alcohol at 176°K, and glycerine began to solidify at about 290°K. The threefold rate was also measured for annihilation of Zn^{65} positrons in the zinc. No temperature effect was found, which observation is consistent with the absence of a τ_2 component in metals.

These data then support the correlation between the anomalous τ_2 component and the increased three-photon counting rate. A similarity in the effects of temperature on these two phenomena is also apparent. The most significant aspect of the data presented here is the indication that the temperature effect occurs only

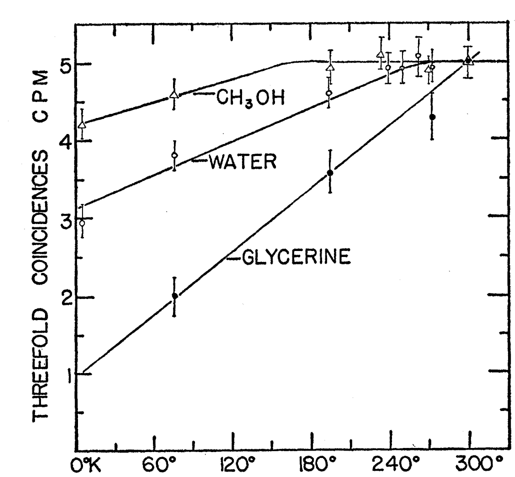

FIG. 1. Three-photon annihilation rate as a function of temperature. Open circles—annihilation in water; closed circles—glycerine; triangles—methyl alcohol. Rates for different materials were arbitrarily normalized at 300°K.

after solidification of the materials. Sufficient experimental data are not yet available to draw definite conclusions about the nature of the state responsible for the τ_2 lifetime and increase three-photon rate nor about the mechanism of its destruction. However, our results suggest the importance of the order and structural state of the materials and perhaps such factors as the dielectric constant which is known to be temperature-dependent.

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[1] R. E. Bell and R. L. Graham, Phys. Rev. **90**, 644 (1954).
[2] R. L. Graham and A. T. Stewart, Can. J. Phys. **32**, 678 (1954).

Effect of Elastic Strain upon Electrical Resistance when Cold-Work Induced Imperfections are Present

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Molenaar and Aarts[1] have shown that the increase in electrical resistance produced in copper by cold work at liquid nitrogen temperature can be partially removed by annealing the specimen at room temperature. Experiments by Manintveld[2] indicate that the resistance contribution removable by this mild heat treatment is due to vacancies or aggregates of vacancies since the activation energies correspond closely with theoretically estimated values.[3] The experiment reported here is concerned with the effect of elastic strain upon the electrical resistance after the metal has been subjected to various amounts of cold-work. By means of simple tension, permanent elongation was produced in an annealed copper wire (diameter 0.001 inch) while submerged in liquid nitrogen. At certain increments of permanent elongation, an elastic strain cycle was performed during which the change in resistance per unit resistance, $\Delta R/R$, was measured as a function of elastic strain, $\Delta L/L$.

In Fig. 1 the quantity, G, defined by the ratio $(\Delta R/R)/(\Delta L/L)$, is plotted as a function of percent permanent elongation. Immediately preceding the measurement indicated by point A the wire was withdrawn from the liquid nitrogen and kept at room temperature for several hours. Without further cold work the specimen was again cooled and the ratio, G, represented by the point A, was determined. After a small increase in permanent elongation the wire was removed from the liquid nitrogen and the value of G was determined under room temperature conditions. This point is designated by B.

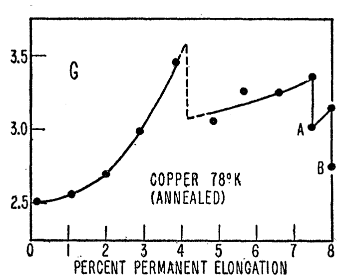

Fig. 1. The ratio, $G=(\Delta R/R)/(\Delta L/L)$, as a function of plastic elongation in copper at liquid nitrogen temperature. Each point represents the slope of an electrical resistance *versus* elastic strain relation measured at the indicated state of deformation.

The strain sensitivity factor, G, changes in much the same manner and degree as did the resistivity in the experiment of Molenaar and Aarts after the room temperature anneal. This behavior suggests that each type of imperfection makes its own contribution to the factor G. In this case vacancies generated by cold-work influence the relationship between elastic strain and resistivity to an easily measurable degree. The graph is also evidence that the factor G can experience large changes in magnitude during the deformation process, independently of the annealing treatment. Evidently there is a complicated interplay between the imperfection generation and escape or annihilation processes.

[1] J. Molenaar and W. H. Aarts, Nature, **166**, 690 (1950).
[2] J. A. Manintveld, Nature **169**, 623 (1952).
[3] T. Broom, Advances in Phys. **3**, 74 (1954).

Angular Correlation of Photons from Positron Annihilation in Solids

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Measurements of the angular correlation of photons from positron annihilation have been continued[1] with better resolution, and two new effects have been observed.

The shape of the angular correlation curve varies considerably throughout a series of some dozen metals from Be to Pt. Figure 1 shows typical coincident counting rates, $I(z)$, as a function of z, the angle between the annihilation photons. These data, when corrected for instrument resolution,[2] have yielded the average momentum distribution, $N(k)dk$, of annihilating electron-positron pairs by using the fact that zdI/dz is proportional to $N(k)$.

For the light metals the momentum distribution of annihilating pairs resembles that found by other means[3] for the conduction electrons alone. For the heavier metals a component of higher momentum appears.[4] Figure 2 shows typical distributions for Zn and Mg. Results for a number of metals show that the higher momentum component increases with the fractional volume occupied by the ion cores, possibly indicating an increased number of annihilations with bound electrons or an excluded volume effect[5] in the annihilation with conduction electrons.