

Influence of a Static Electric Field on Positronium Formation in Polymers

A. BISI, F. BISI, A. FASANA, AND L. ZAPPA
Istituto di Fisica del Politecnico, Milano, Italy

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The effect of a static electric field on positronium formation in some polymeric materials was detected by a study of the time delay spectrum of the annihilation γ rays. Typical nonpolar polymers, like polyethylene and Teflon, show a strong decrease in positronium formation with increasing electric field, (33% and 13%, respectively, at 50 kv/cm), while no effect was found in polar polymers, like Lucite, nylon, and polyvinyl chloride.

VARIATIONS of the long lifetime of positronium and of its intensity in solids as a function of temperature and density have been repeatedly observed¹; however, no information is yet available on the role played by some other simple experimental variables, such as a static electric field. We report here the results of our investigation, which show that in some cases the electric field strongly affects the positronium formation in various insulators.

Na^{22} was used as the positron source, and the samples were prepared by evaporating one drop of high specific activity Na^{22}Cl in aqueous solution directly on the target which is then covered with a second identical one. The targets, whose thickness was sufficient to stop the beta particles, were of polymeric materials. Each of these samples filled the gap between the parallel plates of a capacitor whose envelope was grounded to avoid spurious effects on the detection apparatus. The measurements were made in the customary way² with two counters consisting of plastic scintillators $1\frac{1}{2}$ -in. diam, 1 in. thick, viewed by RCA-6342A photomultipliers; the first was biased to accept only the pulses belonging to the Compton edge of the 1.28-Mev γ rays and the second was biased to accept only the Compton edge due to the annihilation radiation. The signals were sent into an nsec vernier time-delay analyzer and the output pulse heights were measured by means of a 200-channel pulse-height analyzer. The prompt resolution curve obtained with the γ rays of Co^{60} for the conditions of the present experiment fit a Gaussian curve with a full width at half maximum of 8.0×10^{-10} sec.

The measurements consisted of several 6-min recording runs, alternatively with and without the field, the two series of runs being stored, respectively, in the first and in the second hundred channels. From the time delay spectra, the ratio between the intensity of the longer-lived positronium component with and without the field was deduced for each value of the electric field. Typical results are shown in Fig. 1 for three commercially cured plastics. It appears that the materials have a strikingly different behavior with respect to the electric field which in no way affects the posi-

tronium formation in polymethyl methacrylate (Lucite), while strongly prevents it in polyethylene and in polytetrafluoroethylene (Teflon). This last behavior is displayed also in paraffin. Polyvinyl chloride and nylon 66, on the other hand, behave like Lucite, showing no electric perturbation.

As far as the long lifetime is concerned, our measurements seem to indicate that the electric field slightly quenches the triplet positronium; in the whole range of the applied field a decrease in lifetime was observed, whose amount does not exceed 5%. No attempt has so far been made to obtain better information on this feature of the question.

The following few comments can be made at present on the observed influence of the electric field on the positronium formation: Our effect is certainly quite different from that observed in gases by Marder and co-workers³ and theoretically studied by Teutsch and Hughes⁴; in fact, in this case the electric field gives rise to an increase of the positron fraction that forms posi-

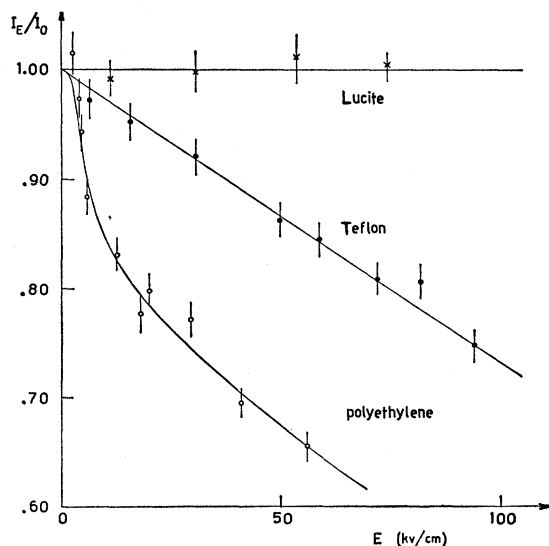


FIG. 1. Ratio between the intensities of the long-lived positronium component with and without the electric field for nonpolar polymers (polyethylene, Teflon) and polar polymers (Lucite).

¹ R. Wallace, in *Solid-State Physics*, edited by F. Seitz and D. Turnbull (Academic Press, Inc., New York, 1960), Vol. 10, p. 1.

² A. Bisi, G. Faini, E. Gatti, and L. Zappa, *Phys. Rev. Letters* **5**, 59 (1960).

³ S. Marder, V. W. Hughes, C. S. Wu, and W. Bennett, *Phys. Rev.* **103**, 1258 (1956).

⁴ W. B. Teutsch and V. W. Hughes, *Phys. Rev.* **103**, 1266 (1956).

tronium in some simple gases while no effect was found when the electric field was applied in polyatomic gases. On the other hand, a decrease was observed with increasing electric field for the gas SF_6 alone, but this fact remained unexplained. However, it is doubtful at present that a connection can exist between this result obtained in gas with our results obtained in solids.

It is interesting to note that the investigated polymers which display the electric effect are typical nonpolar

polymers, i.e., structures in which there are no permanent dipole moments, while the materials where the positronium formation is unaffected by the field are typical polar polymers.

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Magnetic Coupling in Pd-Dilute Iron Group Alloys

E. O. WOLLAN

Oak Ridge National Laboratory, Oak Ridge, Tennessee

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The magnetic properties of palladium and its alloys with iron group elements are discussed in terms of the splitting of the d orbitals. The paramagnetic properties of pure palladium are accounted for on the basis that the holes in the d shell are associated with the nonoverlapping e orbitals, whereas the ferromagnetic coupling in the face-centered $3d$ elements and their alloys is associated primarily with holes in the overlapping t orbitals. On this basis and on the basis of a change in the splitting when palladium is alloyed with $3d$ metals, it is possible to account for the paramagnetic and ferromagnetic properties of the Pd-dilute iron group alloys. Because of the larger amount of available data, attention is given primarily to the Pd-Fe system.

IN a recent paper¹ dealing with magnetic coupling in the $3d$ metals it was suggested without elaboration that the absence of magnetic ordering in palladium in contrast to nickel might be associated with a difference in the orbital location of the holes in the d shells.

It is the purpose here to bring recent experimental evidence to bear on this point and on the palladium problem in general.

On the previously suggested basis the ferromagnetic coupling in the face-centered $3d$ metals is to be associated with electron sharing among the t orbitals which have strong overlaps between nearest neighbor atoms and to which the holes (~ 0.6 per atom) in the d shell are ascribed. The e orbitals in the face-centered $3d$ metals have negligible overlaps between neighboring atoms and hence unpaired electrons in these orbitals should play no direct role in magnetic coupling.

Palladium which has about 0.65 holes in the d shell remains paramagnetic down to 0°K and hence the d orbital overlaps pertinent to magnetic coupling must be of a different character than in the case of pure nickel. It was suggested that in pure palladium the orbital splitting might be reversed over that in nickel, and the holes in the d shell would then be located in the e orbitals. The negligible overlap of these orbitals with those of neighboring atoms would then account for the absence of ferromagnetic coupling in pure pal-

ladium. That this might well be the case is suggested by the observation² that hydrogen dissolved in palladium in the β phase goes into the octahedral sites which are most intimately associated with the e orbitals of the surrounding palladium atoms. It is, of course, true that the octahedral holes are the largest in the fcc structure, but for a hydrogen atom which essentially gives up its electron to the surrounding palladium atoms, it is conceivable that the location of the holes in the intimately associated e orbitals would play the more important role in determining the rather unique properties of palladium with regard to hydrogen uptake and proton diffusion in the lattice. This is an essential point on which new evidence will be brought to bear.

Let us now consider first some measurements by Burger, Vogt, and Wucher³ on Pd-dilute iron alloys with and without hydrogenation. It was observed that a Pd-Fe alloy having 7 atomic percent iron had a maximum hydrogen uptake $\text{H}/\text{Pd}=0.44$ as against 0.65 for pure palladium. This suggested to the authors that each of the iron atoms in the crystal had lost about $(0.65-0.44)/0.07 = (0.21/0.07) = 3$ electrons which went to fill holes in the d shell of the palladium atoms and hence the iron atoms would be present in the crystal with a spin of $\frac{5}{2}$. This deduction which holds equally

² J. E. Worsham, M. K. Wilkinson, and C. G. Shull, *J. Phys. Chem. Solids* **3**, 303 (1957).

³ Jean-Paul Burger, Eckhart Vogt, and Jules Wucher, *Compt. rend.* **249**, 1480 (1959).

¹ E. O. Wollan, *Phys. Rev.* **117**, 387 (1960).