

Effective production of positronium in a dielectric-metal system

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Using high-porosity dielectrics (zeolites) with metallic inclusions as an example, we were able to observe experimentally, for the first time, in metal-containing systems, the long-lived component of the temporal spectrum of positron annihilation, corresponding to positronium production.

It is known that under ordinary conditions no production of positronium is observed in metals.^[1] This is due to the high density of the free electrons in metals, which leads to a nondelayed ($\sim 10^{-10}$ sec) annihilation of the positrons. The free-electron density decreases exponentially on the metal boundary. Since the binding energy of the ground state of positronium (6.8 eV) exceeds the electron work function, which is not larger than ~ 5 eV for most metals, a thermalized positron in the region of the metal boundary, particularly if it is located inside relatively large defects, is capable of "drawing out" an electron from the metal and produce positronium.^[2,3] This phenomenon cannot be observed under ordinary conditions, since special processing is needed to produce a large per-unit surface of the metal. As will be shown below, great interest attaches from this point of view to a simple dielectric with metallic inclusions that are highly dispersed in it.

We took zeolite (NaY) with a silicate module 4.5 ($\text{SiO}_2/\text{Al}_2\text{O}_3$), in which about 5% palladium by weight was introduced via cation exchange. Type Y zeolite has a three-dimensional skeleton structure consisting of aluminum-oxygen and silicon-oxygen tetrahedra, which serve as elements of cubo-octahedra that form a lattice similar to that of diamond. The bridges connecting the cubo-octahedra consist of six oxygen atoms. The porous structure of the zeolite crystals contributes to a relatively free displacement of the slow positrons in it. Since the aluminum-oxygen tetrahedra carry a negative charge, an equivalent number of metal cations (usually Na^+ or Ca^{2+}) enter into the zeolite structure in the course of the synthesis, and can be exchanged by other cations, particularly those of palladium. The initial zeolite samples from which our metal-containing samples of PdNa Y were obtained contained about 62% SiO_2 , 23% Al_2O_3 , 14% Na_2O , 0.5% CaO and MgO , and many

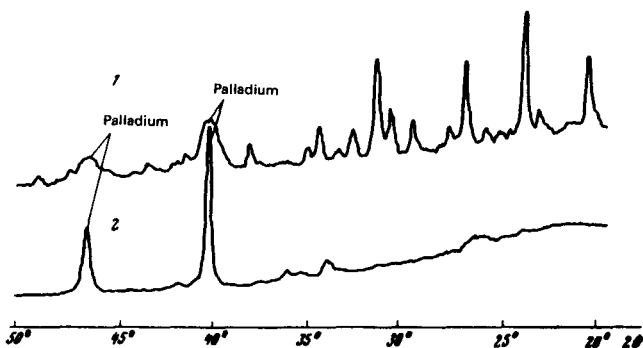


FIG. 1. X-ray diffraction patterns of samples of zeolite NaY + 5% Pd: 1 - reduced in hydrogen at 500°C, 10 hours; 2 - reduced and roasted in air at 1000°C, 2 hours.

other oxides in the form of slight impurities.

To produce the metallic-palladium particles imbedded in the zeolite matrix, samples in which the palladium was contained in cation form were reduced in a hydrogen stream at 500°C for 10 hours. The presence of palladium crystallites in the sample was revealed after the reduction by the appearance of the lines of metallic palladium on the x-ray diffraction pattern (Fig. 1). The figure shows diffraction patterns of samples of the zeolite NaY + 5% Pd reduced in hydrogen (1) and roasted in air (2). The group of peaks in the 20–35° region corresponds to the zeolite structure. The effective dimension of the palladium crystallites is 100 Å for sample (1) and 450–700 Å for sample (2). The dimensions of the palladium crystallites were determined from the broadening of its diffraction peaks by the Selyakov-Scherrer formula.

Positronium formation in polycrystalline dielectrics, particularly SiO₂ and Al₂O₃, was observed earlier by

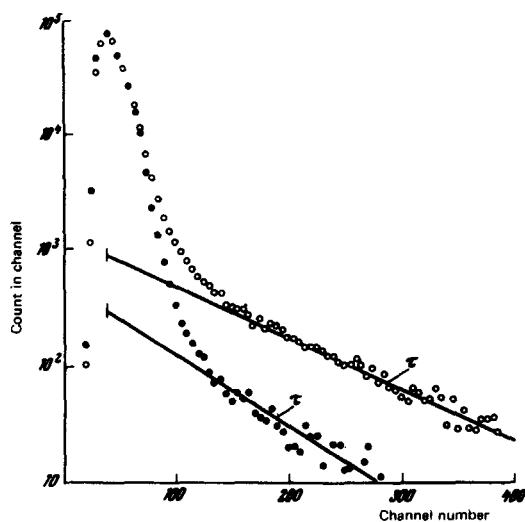


FIG. 2. Temporal spectra of positron annihilation in samples of zeolite NaY + 5% Pd (every fifth point of the histogram is shown): ● - palladium in cation form, $\tau = 3.5 \times 10^{-9}$ sec, $I = 1\%$; ○ - palladium reduced to metallic state, $\tau = 5 \times 10^{-9}$ sec, $I = 4\%$.

many investigators.^[4] By introducing a metal in finely dispersed state into the dielectric, one can expect an increase in the positronium yield.

In our measurement, the positron source (precipitate of the salt Na²²Cl) with an activity of several microcurie was contained in a thin Mylar film and placed in a glass ampul with the sample in powdered form (sample volume ~ 1.5–2 cm³). Measurements of the temporal spectra of the positron annihilation was carried out under normal conditions. The resolution of the apparatus (0.8×10^{-9} sec) makes it possible to determine reliably the intensity of the long-lived component of the temporal spectra (I , %), which is connected with the annihilation of orthopositronium. Figure 2 shows the temporal spectra of positron annihilation in nonreduced and reduced samples of zeolite NaY + 5% Pd. The results are highly instructive: the intensity of the positronium component in the reduced sample is four times larger than the intensity in the nonreduced sample.

We determined next the temporal positron-annihilation spectrum for a zeolite sample whose structure was damaged up to the x-ray amorphous state by roasting in air at 1000°C for two hours (Fig. 1, curve 2). This led, as seen from Fig. 3, to an almost complete suppression of positronium production. The strong decrease of the positronium yield after roasting can be attributed to a decrease of the surface area of the highly-dispersed metallic phase due to aggregation of the small particles, and also to the destruction of the zeolite structure.

The process of positronium production in a system consisting of a porous dielectric and a metal in the highly dispersed state can be visualized as follows: The positrons, with initial energy of about 100 keV, lose rapidly their energy in the sample, to a value less than the width of the forbidden band of the dielectric. When such a positron, which is still "hot," encounters the surface of the metal, it becomes thermalized rapidly,^[5] the

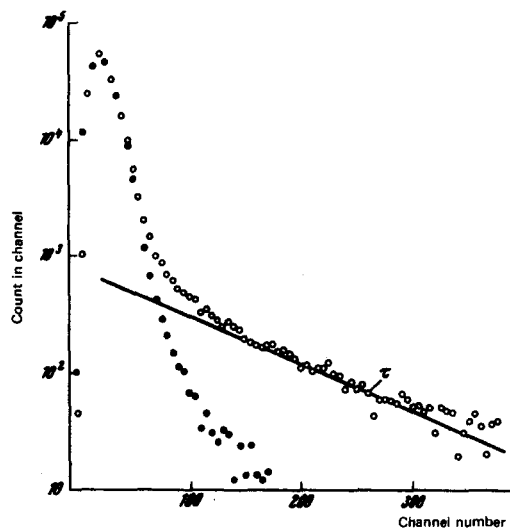


FIG. 3. Suppression of the formation of positronium after roasting the zeolite NaY + 5% Pd in air at 1000°C: ○ - dispersed palladium in zeolite matrix, ● - zeolite matrix destroyed, aggregation of palladium crystallites.

electron is "drawn out" of the metal, and positronium is produced. The positronium atoms are localized in the dielectric and therefore have a sufficiently large lifetime.

¹V. L. Sedov, *Usp. Fiz. Nauk* 94, 417 (1968) [*Sov. Phys. -Usp.*

11, 163 (1968)]

²C. H. Hodges and M. J. Scott, *Phys. Rev. B* 7, 73 (1973).

³K. Petersen, N. Thrane, G. Trumpy, and R. W. Hendricks, *Third Internatl. Conf. on Positron Annihilation*. Otaniemi, Finland, *Abstracts of Papers*, p. 65.

⁴V. I. Gol'danskii, B. M. Levin, and A. D. Mokrushin, *ZhETF Pis. Red.* 11, 38 (1970) [*JETP Lett.* 11, 23 (1970)].

⁵G. Lee-Whiting, *Phys. Rev.* 97, 1557 (1955).