EFFECT OF ELECTRIC FIELD ON POSITRON LIFETIMES IN ARGON AND HELIUM†

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Several groups[1-3] have recently observed a nonexponential form for the direct component of positron annihilation in the noble gases. In particular, the annihilation spectrum [Fig. 2(a)] possesses a marked shoulder followed by an exponential decay. This effect has been interpreted[1-3] in terms of a velocity dependence of the positron annihilation rate, implying that the cross section for direct annihilation rises more rapidly at low positron energies than does the simple inverse velocity dependence.

The results presented in this paper indicate the velocity dependence in a more direct way by displaying the effect of an applied electric field on the lifetime characterizing the exponential portion of the annihilation spectrum. The observed annihilation rate is thus the velocity-dependent annihilation rate averaged over the positron equilibrium velocity distribution determined by the strength of the applied electric field. The effect of such fields on the energy-distribution functions of electrons in gases has been the subject of extensive investigation,[4,5] whereas the only consideration of such effects for the case of positrons in gases is contained in the work of Marder et al.,[6] which was concerned with an investigation of the effect of applied electric fields on the fraction of positrons forming positronium.

The experimental work described in this paper was performed using the chamber illustrated in Fig. 1. It is an aluminum chamber designed to withstand pressures of up to 1000 psi, the wall thickness in the hemispherical portions being $\frac{3}{8}$ in. The gas was continuously purified by allowing it to circulate by convection through a Ca-Mg eutectic purifier. The experimental configuration and analyzing equipment were similar to that described in an earlier paper.[2] NaI(Tl) gamma-ray detectors were used in conjunction with a transistorized time-to-pulse-height converter and a multichannel pulse-amplitude analyzer.

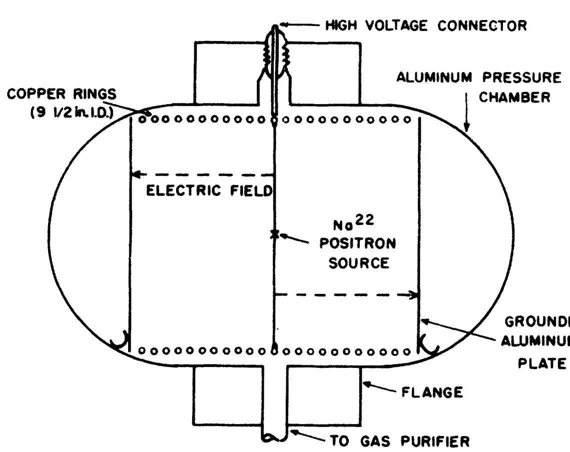

FIG. 1. Gas pressure chamber with field-defining electrodes.

A uniform, axial electric field was produced by mounting within the chamber, but insulated from it, a series of copper rings (Fig. 1) along which a uniform potential distribution was maintained by means of a resistive bleeder chain. The central ring contained the Na^{22} positron source deposited on a (0.2-mg/cm^2) aluminum backing at the center of a wire mesh electrically connected to the ring. This mesh defined the central high-potential plane within the chamber. The end rings were in turn connected to grounded aluminum plates. A potential difference between the central ring and grounded plates of up to 20 kV could be achieved.

Typical sets of curves obtained for argon and helium are shown in Figs. 2 and 3. In argon, the lifetime characterizing the exponential portion of the direct annihilation spectrum increases by a factor of two when a strong electric field is applied. For the case of helium, on the other hand, neither the shoulder nor field dependence of the exponential lifetime is evident to such a marked degree.

The relationship between the experimental results and the elastic-scattering and annihilation cross sections is readily obtained. The annihilation spectrum (neglecting positronium formation) is given by

$$\frac{dN(t)}{dt} = 4\pi \int_0^\infty r_a(v) v^2 f(v,t) dv, \quad (1)$$

where $r_a(v)$ is the velocity-dependent direct annihilation rate, related to the annihilation cross section, σ_a, by

$$r_a = N v \sigma_a, \quad (2)$$

where N is the atomic density of the gas, and $f(v,t)$ is the positron velocity distribution func-

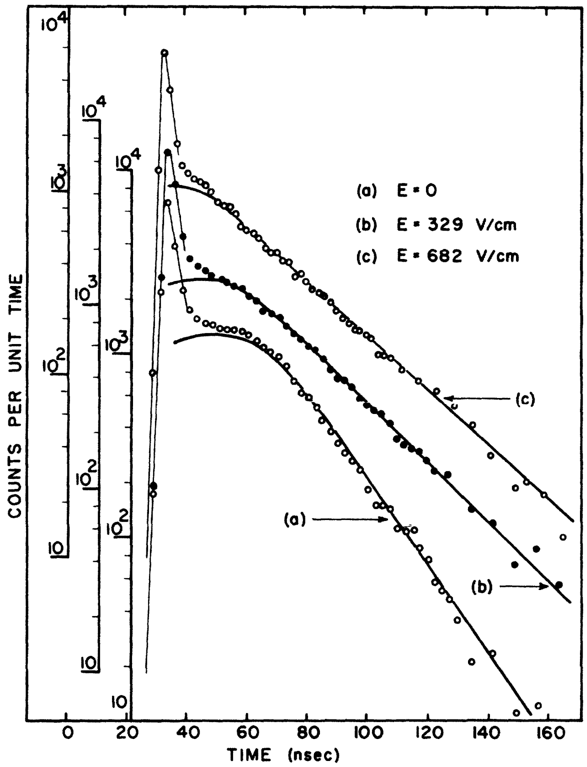

FIG. 2. Direct positron-annihilation spectra in argon for several values of applied electric field. Both the random coincidence background and the ortho-positronium component have been subtracted. The argon pressure was 10.5 atm at 25°C. Lifetimes of each of the exponential decays are (a) 17.9 ±0.7 nsec, (b) 26.9 ±1.0 nsec, and (c) 34.8 ±1.5 nsec.

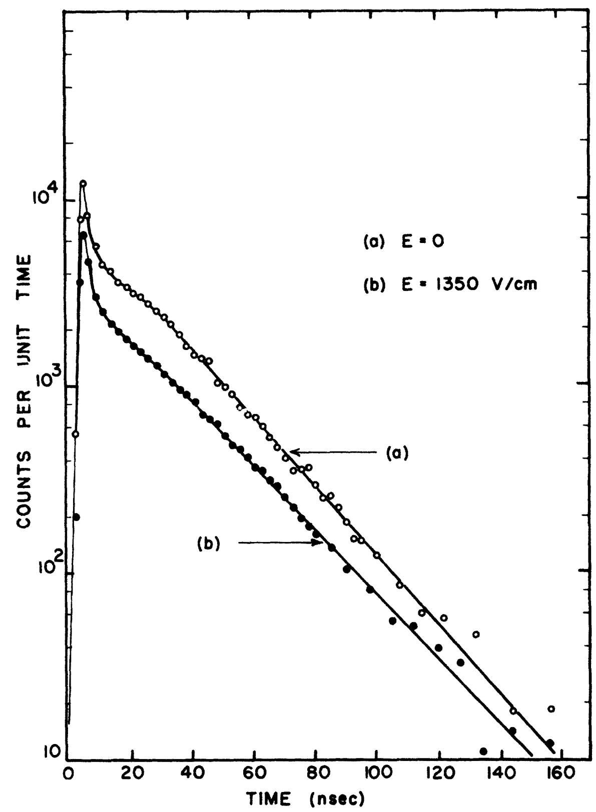

FIG. 3. Direct positron-annihilation spectra in helium with and without an applied electric field. Both the random coincidence background and the ortho-positronium component have been subtracted. The helium pressure was 59.7 atm at 25°C. Lifetimes of each of the exponential decays are (a) 9.6 ±0.5 nsec, and (b) 10.3 ±0.5 nsec.

tion. The latter is obtained by solving the diffusion equation[7]

$$\frac{\partial f}{\partial t}=\frac{1}{v^2}\frac{\partial}{\partial v}\left\{\left[\frac{a^2v^2}{3r_c(v)}+\frac{m}{M}v^3r_c(v)\frac{kT}{mv}\right]\frac{\partial f}{\partial v}+\frac{m}{M}v^3r_c(v)f\right\}$$
$$-[r_a(v)+r_f(v)]f, \tag{3}$$

where $r_c(v)$ and $r_f(v)$ are, respectively, the elastic-scattering rate and the positronium formation rate, related to their respective cross sections as indicated by Eq. (2); a is the acceleration of the positron in the electric field; m is the mass of the positron; and M is the mass of the gas atom. $f(v,t)$ is thus determined by Eq. (3), provided that the following four functions are defined: $r_c(v)$, $r_a(v)$, $r_f(v)$, and $f(v,0)$, the initial velocity distribution of the positron.

By considering only those situations for which the electric field is sufficiently weak that very little increase in positronium formation results, $r_f(v)$ may be neglected, leading to some reduction in the complexity of the problem. An independent determination of the velocity dependence of at least one of the three remaining functions would be required, however, before the existing results can be used to determine the other two functions in anything approaching a unique fashion. The only other experimental data available at this time yield values for the elastic-scattering cross section at energies near that of the threshold for positronium production.[8]

An example of the type of fit that is possible when suitable simple functions are assumed is illustrated in Fig. 2. The points are the experimental results for argon, whereas the solid lines indicate the spectra computed from Eq. (1) using the $f(v,t)$ obtained by solving Eq. (3) with the IBM-7040 computer at the University of

British Columbia. In this case, the assumed forms for the initial velocity distribution and the elastic-scattering and annihilation cross sections, σ_c and σ_a, were as follows:

$$f(v,0)=1, \quad v \leq V_{th},$$

$$=0, \quad v > V_{th},$$

where V_{th} is the positron velocity at the threshold energy for positronium formation, viz. 8.9 eV for the case of argon;

$$\sigma_c(v) = 1.32\pi a_0^2 V_{th}/v,$$

and

$$\sigma_a(v) = 3.80\times10^{-6}\pi a_0^2 (V_{th}/v)^{1.5}.$$

A more detailed presentation of both the experimental results and the extent to which the cross sections may be determined by such experiments will appear in a later publication.

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MEASUREMENT OF THE MOMENTUM SPECTRUM OF POSITRONS FROM MUON DECAY*

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Over the past decade many measurements have been made of the momentum spectrum of electrons from the decay of unpolarized muons.[1-3] The shape of this spectrum can be characterized by a number, ρ, the Michel parameter.[4] The two-component neutrino theory predicts that ρ is equal to $\frac{3}{4}$.[5-7] Bubble chamber experiments, which are relatively free of systematic errors, have shown agreement with this value of ρ within their 4% accuracy. In order to make a more precise measurement of the spectrum, we have performed an experiment using a magnetic spectrometer with sonic spark chambers on-line to an IBM 1401 computer. This technique[8,9] permitted analysis of a large number of events with high momentum resolution but without most of the systematic errors usually associated with magnetic spectrometers which use scintillation counters.

The experimental setup is shown in Fig. 1. Four single-gap spark chambers and all of the counters lie inside a large air-core magnet, so that the muon decay takes place in the region of uniform magnetic field. The field, pointing in the direction perpendicular to the plane of the figure, was corrected with current coils so that the average nonuniformity along a positron trajectory was about 0.05%, while the worst trajectories (near the outer radius) would meet nonuniformities not exceeding 0.1%.

A positive pion beam from the Columbia University Nevis synchrocyclotron is incident along the field direction and stopped in the 3-in.×3-in.×$\frac{1}{8}$-in. plastic scintillator target counter. About 80% of the decay muons stop and subsequently decay in this target. Approximately 5% of the resulting positrons reach