Penetration of Low-Energy Positrons through Thin Metallic Foils

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The penetration of positrons (0.544-MeV maximum) from a Na^{22} source through absorber foils of Al, Cu, Sn, and Au has been measured in vacuum (10^{-3} torr). It was found that the transmitted-positron intensity decreases exponentially with the thickness of the absorber over different ranges of transmission for different absorbers. Measurements on Al foils were performed at atmospheric pressure and vacuum to determine the effect of the air path on the mass-absorption coefficient. It was found that the onset of the exponential absorption occurs at a higher relative transmission value when the experiment is performed in air. However, there is no significant effect on the slope of the straight-line portion of the graph which is proportional to the value of the mass-absorption coefficient. At transmitted-positron intensities below 4%, the Z dependence can be described by $t/A = KZ^{-4/3}$, where t is the thickness in mg/cm^2, A is the mass of the atom, and K is a constant.

INTRODUCTION

Thontadarya and Umakantha[1] have found that the transmitted intensity of positrons (and of electrons) from radioactive sources decreased exponentially as a function of the absorber thickness in the transmission range 20–1% for Al and 10–0.5% for Sn. However, as for other recent measurements by Takhar,[2] and Patrick and Rupaal,[3] in their experimental arrangement the positrons travelled through a few cm of air at atmospheric pressure before passing through the absorber foils and also before reaching the detector.

The Z dependence of the absorption of positrons has also been reported by Takhar[4] and Rupaal and Patrick[5] to fit an empirical relation of the form

$$t(Z/A) = Ke^{-mZ^{1/3}} ,$$

where t is the thickness in mg/cm^2, A is the mass of the atom, and K and m are constants. Their measurements indicate that the value of m is energy dependent. The fact that $t(Z/A)$ is not a constant independent of A, a quantity that is equal to the number of electrons per cm^2, was interpreted to reflect the degree of nuclear scattering present.

Rohrlich and Carlson[6] have theoretically calculated the energy loss, multiple scattering, and the relative transmission of positrons in Al and Pb for different energies. However, their theory does not yield any simple relationship for the Z dependence of the transmitted intensity of positrons through matter. Since it is well known[7] that the values of mass-absorption coefficients and the Z dependence for β particles are influenced by the geometry, we have chosen to make our measurements in vacuum (10^{-3} torr).

APPARATUS AND RESULTS

A schematic diagram of the experimental arrangement is shown in Fig. 1. Positrons with maximum energy of 0.544 MeV from a 1-mCi Na^{22} source were collimated with lead bricks into a $\frac{1}{8}$-in.-diam beam. This beam was incident upon absorber foils of various thickness placed midway between the source and the detector. The transmitted positrons annihilate in an aluminum disk and the resulting 0.511-MeV photons were detected with a standard fast-slow coincidence system. The fast-slow coincidence system reduces the γ-ray background from the source. The possibility that two photons from different annihilations in the absorber foils would be counted is minimized by making the distance from absorber foils to detector disk 10 cm. These factors allow measurements of transmitted intensities below 1%. Measurements were made with source, foils, and detector in vacuum (10^{-3} torr), where the mean free path of the positrons is much greater than the distance between source, foils, and detector. The detector, a 5-cm-diam aluminum disk, subtends a linear angle of 28° with respect to the point where the positrons strike the foil. Coincidence count rates varied from 1800 counts per min at 100% transmission to approximately 6 counts per min at 0.1% transmission with a background of 4 counts per min. Counting times were adjusted from 10 min

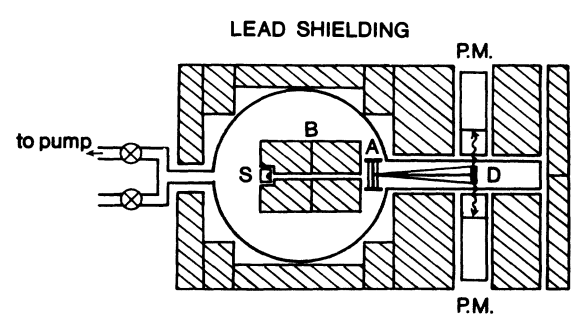

FIG. 1. Experimental arrangement showing the source S, the collimating bricks B, the absorber foils A, and the annihilation disk D inside the vacuum chamber.

to approximately 12 h to achieve a total number of coincidence counts of approximately 6000. For these experimental conditions, the random statistical error is less than the size of the data points shown.

Since air scatters and absorbs low-energy positrons out of the incident and the transmitted beam, the number of positrons reaching the detector is thus significantly decreased. This effect is more pronounced for a smaller absorber thickness since the transmitted beam contains relatively more low-energy positrons. The net result is that the exponential decrease of the transmitted intensity appears to occur over a greater transmission range at atmospheric pressure. This is evident in Fig. 2 where the relative transmission in Al is plotted against the absorber thickness. The exponential decrease occurs over a range from 40 to 1% when the experiment is performed at atmospheric pressure and from 4 to 0.1% when it is repeated in vacuum (10^{-3} torr). There is no significant effect on the slope of the straight-line portions of the curves. This is to be expected as the slope is porportional to the mass-absorption coefficient for a given absorber and energy.

Figure 3 shows the results of the transmitted intensity of positrons versus absorber thickness for foils of Al, Cu, Sn, and Au. For all absorbers, the transmitted intensity of positrons decreases exponentially with the absorber thickness in the 4–0.1% transmission range. The mass-absorption coefficients, determined from these curves, are given in Table I and agree well with those reported by Thontadarya and Umakantha.[1] The transmitted intensity curves in Fig. 3 seem to reflect the shape of the positron spectrum from a radioactive source. Initially, there is a greater decrease of transmitted intensity of positrons for the smaller thicknesses of absorbers. One can roughly interpret the shape of these curves by making the simplifying assumption that the effect of a given thickness of absorber is to absorb all positrons with an energy less than a certain value. Thus, the total number of positrons from the source with an energy less than a given value increases at different rates for energies less than or greater than the most probable energy of the positron spectrum.

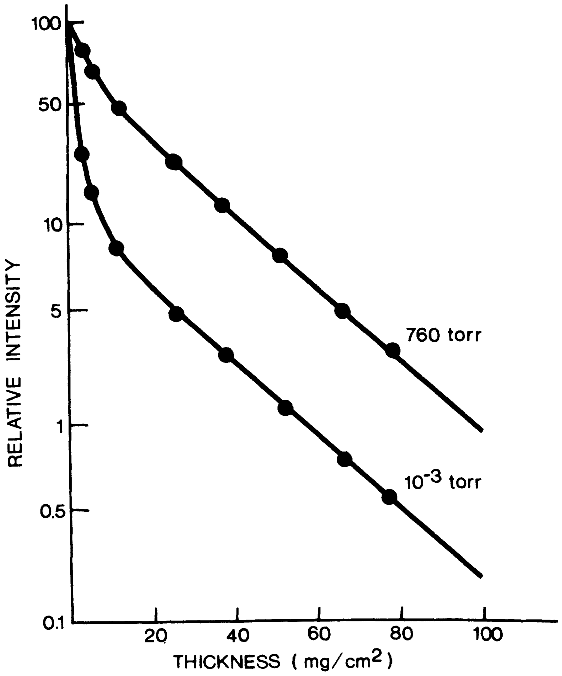

FIG. 2. Relative transmission of positrons in aluminum at atmospheric pressure and in vacuum (10^{-3} torr). The two curves are normalized to 100% transmission.

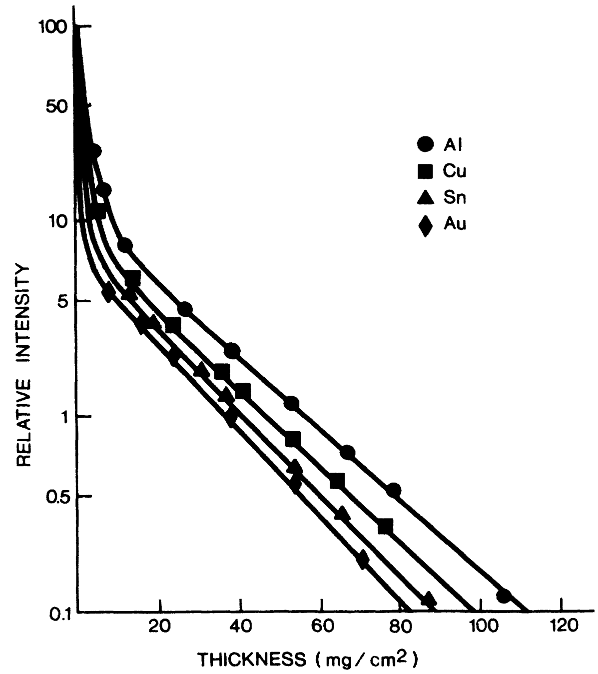

FIG. 3. Relative transmission T of positrons in Al, Cu, Sn, and Au at 10^{-3} torr.

TABLE I. Experimentally determined values of mass-absorption coefficients μ/ρ (cm^2/g) for 0.544-MeV positrons.

Absorber	μ/ρ (cm^2/g) Present	Ref. 1
Al	41.2	41.0
Cu	43.4	···
Sn	46.9	46.7
Au	50.1	···

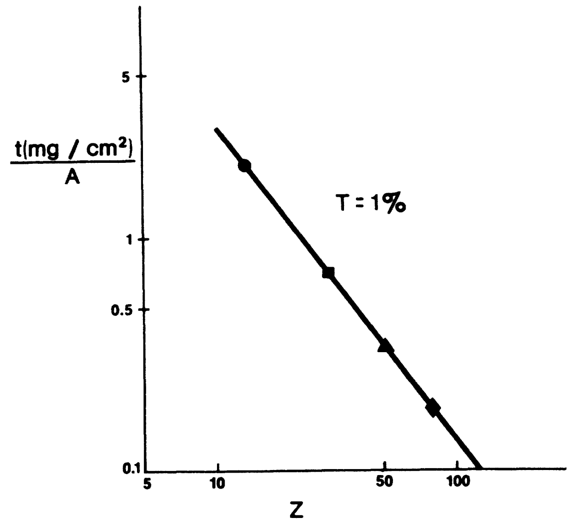

FIG. 4. Plot of t/A vs Z showing the Z dependence for transmission intensity $T=1\%$.

The data can be represented by the empirical relation for the Z dependence of the absorption of positrons reported previously.[4,5] However, as shown in Fig. 4, the data also fit an equation of the form

$$t/A = KZ^{-4/3}, \quad (1)$$

where t is the thickness of the foil in mg/cm^2, A is the mass of the atom, and K is a constant. The quantity t/A is proportional to the number of atoms per cm^2 of the absorber foil. Landau and Lifshitz[8] have calculated the effective cross section (σ) for the elastic collisions between electrons and atoms and found σ proportional to $Z^{4/3}$ for a given energy of incident electrons. Under certain simplifying assumptions,[9] this leads to the Z dependence given by Eq. (1).

Similar measurements of the penetration of low-energy electrons through thin foils are planned to determine positron-electron differences in range, that is, in their passage through matter.

[1]S. R. Thontadarya and N. Umakantha, Phys. Rev. B **4**, 1632 (1971).
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[3]J. R. Patrick and A. S. Rupaal, Phys. Lett. A **35**, 235 (1971).
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[7]See, for example, E. Bleuler and G. J. Goldsmith, *Experimental Nucleonics* (Holt, Rinehart & Winston, New York, 1963), pp. 84 and 159.
[8]L. D. Landau and A. M. Lifshitz, *Quantum Mechanics–Non-Relativistic Theory* (Addison-Wesley, Reading, Mass., 1958), p. 426.
[9]A. S. Rupaal and L. E. Spanel, Phys. Rev. A (to be published).