Relative transmission of 0.324- and 0.544-MeV positrons and electrons in Be, Al, Cu, Ag, and Pb

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The transmission of positrons from ^{65}Zn (E_{max}0.324 MeV) and ^{22}Na (E_{max}0.544 MeV) in Be, Al, Cu, Ag, and Pb were compared with that of electrons of identical energies. The comparison of their mass absorption coefficients (μ/ρ) indicates a small but finite difference, implying greater transmission of positrons than electrons, with the exception of 0.324-MeV particles in Be and Al. These measurements were performed at atmospheric pressure. The results obtained clarify the existing ambiguity in the literature and are in agreement with multiple-scattering theory.

In the literature on the transmission of positrons and electrons through thin metal foils, the results of Patrick and Rupaal[1] for 0.324-MeV positrons (^{65}Zn) and 0.312-MeV electrons (^{60}Co) and those of Takhar[2] for 1.88-MeV positrons (^{68}Ge-^{68}Ga) and 1.77-MeV electrons (^{86}Rb) are at variance. The μ/ρ ratio between electrons and positrons obtained by Patrick and Rupaal increased from 0.95 for Al to 1.19 for Pb, whereas the same ratio reported by Takhar was 1.12 for Al and 1.35 for Pb. Earlier, Seliger[3] studied the transmission of monoenergetic positrons and electrons using a 90° magnetic analyzer and an end-window proportional counter; these results, however, showed lesser penetration for positrons in low-Z and higher penetration in high-Z elements. Subsequently, using the relation between μ/ρ and E_{max} of Gleason *et al.*,[4] Cook[5] had pointed out that the discrepancy in the data of Takhar was due to the fact that the end-point energies of the positrons and electrons used were not equal, as they should be for a meaningful comparison of their transmission factors. The discrepancy in the results of Patrick and Rupaal can also be attributed to the difference in e^+, e^- end-point energies. In view of this, it was decided to redetermine the positron and electron transmission in low-Z and high-Z elements. Ideally, one needs a pair of radionuclides emitting either positrons or electrons of equal E_{max}. Since such a pair of sources cannot be obtained in practice, it was decided (a) to determine the electron mass absorption coefficients in Be, Al, Cu, Ag, and Pb for a set of β sources covering the desired energy range, (b) to establish empirical relations between μ/ρ and E_{max} for each element, and (c) to obtain the μ/ρ value for electrons of energy equal to that of a chosen positron energy from the empirical relation. Accordingly, the mass absorption coefficients of electrons having E_{max} of 0.167 MeV (^{35}S), 0.225 MeV (^{147}Pm), 0.425 MeV (^{185}W), 0.76 MeV (^{204}Tl), 1.71 MeV (^{32}P), 2.27 MeV (^{90}Y), and 3.60 MeV (^{42}K) were determined in Be, Al, Cu, Ag, and Pb. The empirical relations between μ/ρ and E_{max} were obtained, from which the mass absorption coefficients of electrons of energies 0.324 and 0.544 MeV were calculated. Similarly, the mass absorption coefficients of positrons of 0.324 MeV

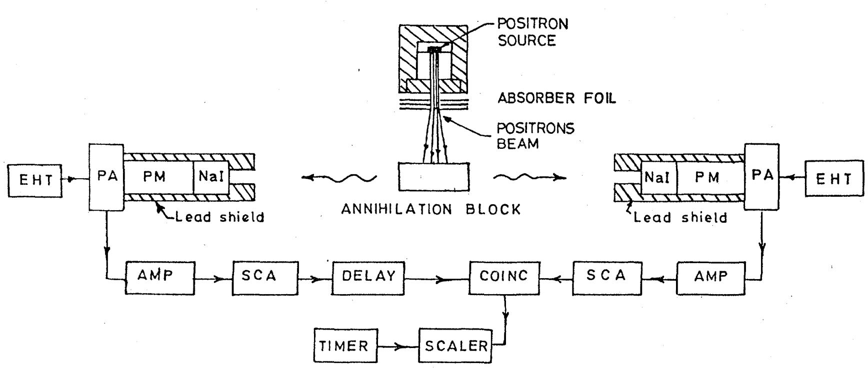

FIG. 1. Schematic diagram of γ-γ coincidence-counting system.

TABLE I. Comparison of mass absorption coefficient in g^{-1} cm^2 of positrons and electrons.

Energy (MeV)	Particle	Absorption coefficients in Beryllium	Aluminum	Copper	Silver	Lead
0.324	Positrons	78.2 ±1.8	92.0 ±2.2	108.2 ±2.2	114.0 ±2.5	119.0 ±2.5
	Electrons	74.7 ±1.5	90.7 ±1.8	110.0 ±2.6	121.0 ±3.3	129.0 ±3.9
	μ_{e^-}/μ_{e^+}	0.96±0.02	0.99±0.03	1.02±0.03	1.06±0.04	1.08±0.04
0.544	Positrons	26.8 ±0.5	41.1 ±0.7	43.9 ±0.8	44.4 ±0.8	47.6 ±0.9
	Electrons	32.9 ±0.7	42.7 ±1.3	51.0 ±1.3	57.9 ±1.7	62.9 ±1.8
	μ_{e^-}/μ_{e^+}	1.22±0.03	1.04±0.04	1.12±0.04	1.30±0.04	1.31±0.04

(^{65}Zn) and 0.544 MeV (^{22}Na) were determined in these materials and compared with those for same-energy electrons.

The electron-transmission measurements were performed using an end-window gas-flow proportional counter placed at a distance of 10 cm from the source. The details of these measurements are described elsewhere.[6] The positron transmission was studied with a γ-γ coincidence-counting system as shown in Fig. 1, in which a collimated beam of positrons was allowed to illuminate on a Perspex block kept in place of the end-window counter. The source-absorber geometry was kept the same as for the electron measurements. The resulting 0.511-MeV annihilation photons from the block were detected by a pair of collimated 2-in. $\times 1\frac{3}{4}$-in. NaI(Tl) scintillation detectors placed equidistantly from the center of the Perspex block and operated in coincidence. The electron and positron transmission was studied in pure metal foils (99.9%) of Be, Al, Cu, Ag, and Pb up to a thickness yielding <0.5% transmission. The total activity of each positron emitter was $\simeq$500 μCi and that of each electron emitter was around 5 μCi, prepared by evaporation of the liquid source on Perspex planchettes. The values of mass absorption coefficients were determined from the corresponding linear transmission on a semilog graph. From the electron transmission data, the empirical relation between μ/ρ and E_{max} was fitted for each element. The μ/ρ values for 0.324- and 0.544-MeV electrons for each element were determined from the empirical relation of that particular element. A comparison of electron μ/ρ values thus obtained, with the experimentally determined value of positron μ/ρ for the same energy, is presented in Table I. The results indicate greater transmission of positrons than of electrons in Be, Al, Cu, Ag, and Pb, with the exception of 0.324-MeV positrons in Be and Al. The present result is consistent with theoretical multiple-scattering prediction of Rohrlich and Carlson[7] as well as the experimental evidence of Takhar for 0.544-MeV positrons. However, the results for 0.324-MeV positron transmission in Be and Al show completely the opposite effect, which cannot be ascribed to multiple-scattering differences alone.

The various sources of uncertainties in the experimental determination of electron and positron absorption coefficients in pure metal absorbers are (a) gravimetric determination of surface density of absorbers, (b) uniformity of the absorber surface density, (c) counting statistics, and (d) graphical determination of the absorption coefficient from a least-squares fit of the experimental data. The overall uncertainty in the final result has been estimated to be around ±3% and the maximum uncertainty is not likely to exceed ±5%. The magnitude of deviations is shown in Table I along with the experimental results.

The results of the present investigation confirm that there is a difference between the transmission behavior of positrons and electrons of the same energy and indicate that the difference observed by Takhar is not entirely due to the difference in energies of the two types of particles. The calculation based on the multiple-scattering theory of Rohrlich and Carlson also indicates effects which are consistent with experimental results for higher energy (0.544 MeV). Whatever the lower-energy transmission through lighter elements such as Be and Al, the present work as well as that of Patrick and Rupaal indicate finite difference in the opposite direction, which is not consistent with multiple-scattering theory.

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