## Positron Annihilation in Noble Gas Mixtures

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The annihilation decay constant of positrons in (He + Ne + Ar) mixtures has been computed and its dependence on concentration and electric field investigated. This constant is found to depend quite sensitively on the nature of the gas mixture and the applied electric field.

Hara and Massey [1] have investigated the annihilation of positrons in Ar-CO mixtures while the present author studied the behaviour of positrons in the noble gas mixtures (Ne + Ar) [2] and (He + Ar) [3]. It has been found that the annihilation decay constant, $\lambda$, depends quite sensitively on the nature of the gas mixture. Our calculations [3] indicate that it will be quite interesting to explore gaseous mixtures experimentally. We have now extended our previous work to the three component system (He + Ne + Ar).

The annihilation decay constant, $\lambda$, is the quantity which is determined experimentally. Theoretically, it is calculated from the relation

$$\lambda = \left(\int_0^\infty \nu_a(v)\, v^2 f(v)\, dv\right)\left(\int_0^\infty v^2 f(v)\, dv\right)^{-1}, \qquad (1)$$

where $f(v)$ is the positron velocity distribution function and is determined by solving the Boltzmann equation [2]

$$\left[\frac{E^2 e^2 v^2}{3 m^2 \nu_m(v)} + \frac{kT\, v^2 \nu_m(v)}{M}\right] \frac{\partial f(v)}{\partial v} + \mu\, \nu_m v^3 f(v) = \int_0^v (\nu_a(v) - \lambda)\, v^2 f(v)\, dv\,. \qquad (2)$$

Here $e, m, v$ are the positron charge, mass, and velocity, respectively; $M$ = gas atom mass; $T$ = temperature of the gas; $k$ = Boltzmann constant; $E$ = electric field; $\nu_a$ = annihilation rate and $\nu_m$ = momentum transfer rate of positrons at velocity $v$. Equation (2) is an integro-differential equation, and because of the complicated velocity dependence of $\nu_a$ and $\nu_m$ it cannot be solved analytically. A numerical algorithm to solve this equation has been described in detail in [2].

Equation (2) can be solved if data of annihilation and momentum transfer rates are available. There exist calculations of $\nu_a(v)$ and $\nu_m(v)$ for pure gases, but none for mixtures. To study mixtures, we have to make some plausible assumptions about these rates. Assuming that the positron interacts with one gas atom at a time, we approximate the annihilation and momentum transfer rates of gas mixtures by the prescription [2]

$$\begin{aligned}\bar{\nu}_a(v) &= C_1\, \nu_a^{(1)}(v) + C_2\, \nu_a^{(2)}(v) + C_3\, \nu_a^{(3)}(v)\,,\\ \bar{\nu}_m(v) &= C_1\, \nu_m^{(1)}(v) + C_2\, \nu_m^{(2)}(v) + C_3\, \nu_m^{(3)}(v)\,, \end{aligned} \qquad (3)$$

where bar indicates that the quantity refers to the mixture. $C_1$, $C_2$, $C_3$ are the atomic concentrations of gas 1, gas 2 and gas 3, respectively, in the mixture, such that $C_1 + C_2 + C_3 = 1$.

In our systems, we take gas 1 to be helium, gas 2 to be neon and gas 3 to be argon. Thus, $C_1$, $C_2$, $C_3$ are concentrations of He, Ne and Argon, respectively. To estimate $\bar{\nu}_a(v)$ and $\bar{\nu}_m(v)$, we need the data on $(\nu_a^{(1)}, \nu_m^{(2)})$, $(\nu_a^{(2)}, \nu_m^{(2)})$ and $(\nu_a^{(3)}, \nu_m^{(3)})$. In the present calculations, we use the same data for the three gases as used in [2, 3]. The advantage of using the same data is that comparison between the two- and three-component systems becomes more relevant.

We assume the gas mixture to be at room temperature and normal pressure and vary the electric field. The range of electric field considered is zero to 40 V cm$^{-1}$ in steps of 5 V cm$^{-1}$. The concentrations taken are: $(C_1, C_2, C_3)$ = (0.1, 0.4, 0.5), (0.2, 0.4, 0.4), (1/3, 1/3, 1/3) and their permutations.

The dependence of the reduced annihilation decay constant, $Z_{eff} = \lambda/\pi r_0^2 c n$ (where $c$ = velocity of light, $n$ = density of gas, $r_0 = e^2/mc^2$) on the electric field in all systems considered is presented in Figures 1–3. It is found that $Z_{eff}$ shows greater variations with electric field in systems which contain more argon. This is so because $\nu_a$ and $\nu_m$ of argon have large velocity variations. In every case, $Z_{eff}$ reduces with electric field. Another interesting finding of the present calculations is that in each system, except $C_1 = C_2 = C_3 = 1/3$, there exist electric field values at which $Z_{eff}$ is the same for two different systems. Such fields are shown in the figures by small thick arrows (↑). We refer to such fields by $E_c$. $E_c$ is different in different systems. In some cases there is a range of values.

All values of $Z_{eff}$ for the different mixtures considered lie between the values of He, Ne and Ar,

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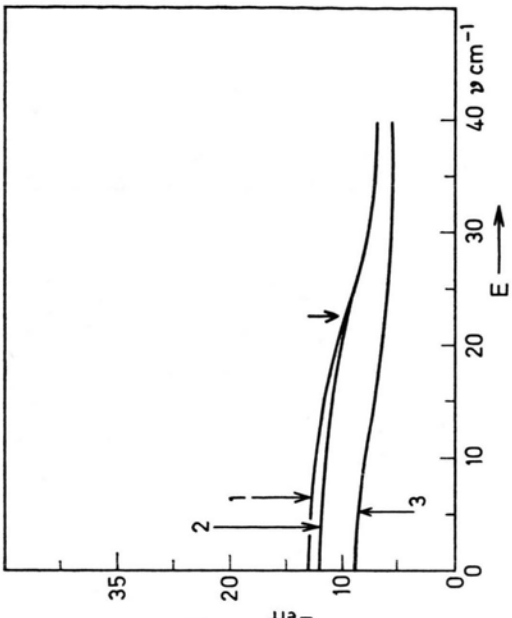


Fig. 2

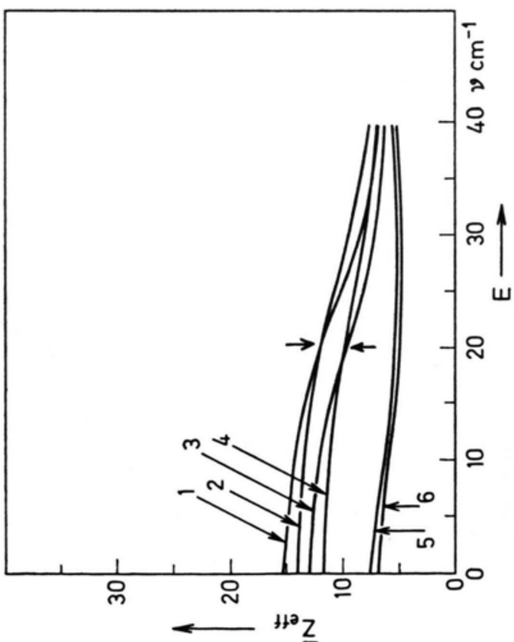


Fig. 1

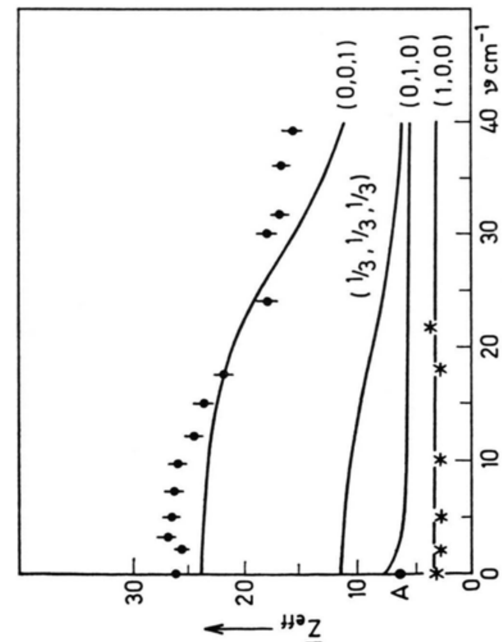


Fig. 3

Fig. 1. Variation of $\bar{Z}_{eff}$ with electric field. The concentrations corresponding to the various curves are: 1 = (0.1, 0.4, 0.5); (2 = (0.4, 0.1, 0.5); 3 = (0.1, 0.5, 0.4); 4 = (0.5, 0.1, 0.4); 5 = (0.4, 0.5, 0.1); 6 = (0.5, 0.4, 0.1).

Fig. 2. Dependence of reduced annihilation decay constant on electric field. Curve 1: (0.2, 0.4, 0.4); 2: (0.4, 0.2, 0.4); 3: (0.4, 0.4, 0.2).

Fig. 3. Electric field variation of $\bar{Z}_{eff}$ for pure gases and the (1/3, 1/3, 1/3) system. Concentrations are shown on the curves. ⫶ experimental points for argon (ref. [4]); ● experimental point for neon (ref. [6]); * experimental points for helium (ref. [5]).

as expected. To avoid repetition and for clarity, we have plotted $\bar{Z}_{eff}$ for He, Ne and Ar only in Figure 3. Also shown in Fig. 3 are the experimental data for pure gases. Agreement is good for heliun but not for neon and argon. There are no experimental studies on mixtures, so no comparison is possible.

The appearance of $E_c$ in these systems appears to be interesting as it was not there in two component systems [2, 3]. Moreover, the rate of variation of $\bar{Z}_{eff}$ with respect to the electric field can be better "controlled" in the present case than is possible with systems consisting of two gases only. Gases like neon, where $Z_{eff}$ depends weakly on the electric field, can be studied more accurately if mixed with other gases, like argon [2].

Conclusions about the value of $E_c$ and the rate of variation of $Z_{eff}$ with the electric field are model dependent. If data of annihilation and momentum transfer rates of some other model are used, their values may differ. However, the overall features are expected to be similar [2]. Experimental studies of three component systems may prove to be equally interesting as those of two component systems. The experimental results could also be used to estimate the validity of Eq. (3) or formulate some new prescription to compute the annihilation and momentum transfer rates of gaseous mixtures.

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