Pramāṇa - J. Phys., Vol. 27, No. 3, September 1986, pp. 401-408. © Printed in India.

Simulation of high frequency positron behaviour in argon gas

VIKRAM SINGH and P S GROVER*

Department of Physics and Astrophysics, *Department of Computer Science, University of Delhi, Delhi 110007, India

MS received 27 December 1985; revised 28 April 1986

Abstract. Positron annihilation and average energy in argon have been investigated in the presence of external high frequency electric and steady magnetic fields. The effect of temperature has also been studied. Two models of positron atom interaction have been employed and compared with experimental results wherever possible.

Keywords. Positron annihilation rate; average energy; argon gas; high frequency electric field.

PACS No. 34·90

1. Introduction

The interaction of low energy positrons with gaseous atoms and molecules has been studied by beam and lifetime measurement techniques. Review articles covering experimental and theoretical aspects of the subject have appeared (Charlton 1985; Ghosh and Grover 1985). When a swarm of positrons is introduced into a gaseous assembly, there are many processes by which the positrons can arrive at their eventual annihilation fate. At energies, less than the positronium formation threshold, E_{th} (E_{th} = 8·96 eV for Ar) only elastic scattering and annihilation processes are important in determining the behaviour of positrons. The annihilation can be influenced by external fields such as electric field, magnetic field and the temperature of the gas assembly (Grover 1977, 1982). Such studies provide tests of models of positron-atom interaction.

Recently, a different technique has been proposed (Grover 1980) to explore the positron behaviour in gases. The method involves investigating the diffusion and annihilation of positrons when high frequency electric and steady magnetic fields are applied to the assembly, consisting of positrons and gas atoms simultaneously. Using this technique, Grover (1980, 1981, 1982) investigated the annihilation decay rate of positrons in helium, neon and argon by studying the effect of electric field frequency. The analysis in helium and neon gases was based on McEachran's model for positron-atom interaction. However, argon was studied using the computer-based model of positron-atom interaction rates (Grover 1979). Recently, there has been more elaborate calculations of positron momentum transfer and annihilation rates in argon based on the polarized orbital approximation (McEachran *et al* 1979). Positron characteristics using this model have not been investigated so far. It is therefore of interest to compare the results of positron behaviour in argon based on the two models. In this paper, the calculations based on the data of McEachran are denoted by M_1 and those of Grover by M_2.

A comparative study is carried out of positron annihilation decay rate and the average energy under the influence of high frequency electric field based on the above two models. The effects of temperature and magnetic fields have also been studied. The electric and magnetic fields taken are 10, 25, 50 V cm^{-1} amagat^{-1} and 10, 30 and 50 kG respectively. The temperature of the gas assembly has been assumed to be 300, 1000 and 3000 K. The density of gas assembly has been taken as one amagat.

2. Method of study

We take the gas and positron system to be spatially homogeneous at temperature T to which a steady magnetic field H is applied. The assembly is further subjected to an alternating electric field, $E = E_0 \exp(i\omega t)$ ($i = \sqrt{-1}$, ω the frequency and t the time). The equilibrium distribution function, $F(v, \omega)$ of positrons with velocity v in such an assembly, can be obtained from the solution of the Boltzmann equation (Grover 1980).

$$\left(\frac{a_{\text{eff}}^2(\omega)}{3\nu_m(v)} + \frac{kT}{M}\right)\frac{\partial F(v,\omega)}{\partial v} + \frac{m}{M} v F(v,\omega)$$

$$= \frac{1}{\nu_m(v) v^2} \int_0^v [(\nu_a(v') - \lambda] v'^2 F(v', \omega)\, \mathrm{d}v', \tag{1}$$

where

$$a_{\text{eff}}^2(\omega) = \frac{1}{2}\left[a_p^2\left(1 + \frac{\omega^2}{\nu_m^2(v)}\right)^{-1} + \frac{a_t^2}{2}\left\{\left(1 + \frac{(\omega-\omega_c)^2}{\nu_m^2(v)}\right)^{-1} + \left(1 + \frac{(\omega+\omega_c)^2}{\nu_m^2(v)}\right)^{-1}\right\}\right]. \tag{2}$$

Here $\omega_c = eH/mc$ is the cyclotron frequency; e, m and v indicate the positron charge, mass and velocity respectively; $a_p = eE_{0p}/m$ and $a_t = eE_{0t}/m$, E_{0p} and E_{0t} are the electric field components, parallel and perpendicular to the direction of the magnetic field, c is the velocity of light; M is the mass of the gas atom and n is the gas density; k is the Boltzmann constant; $\nu_a(v)$ and $\nu_m(v)$ are the positron annihilation and momentum transfer rates respectively.

The positron distribution function $F(v, \omega)$ can be obtained by solving equation (1). Knowing $F(v, \omega)$ the decay rate is computed from the relation (Grover 1980)

$$\lambda(\omega) = \left[\int_0^\infty \nu_a(v) v^2 F(v,\omega)\, \mathrm{d}v\right]\left[\int_0^\infty v^2 F(v,\omega)\, \mathrm{d}v\right]^{-1} \tag{3}$$

and the average energy, in units of 300 K, is given by

$$\bar{\varepsilon}(\omega) = \frac{m}{2}\left[\int_0^\infty v^4 F(v,\omega)\, \mathrm{d}v\right]\left[\int_0^\infty v^2 F(v,\omega)\, \mathrm{d}v\right]^{-1}. \tag{4}$$

For the known forms of annihilation and scattering rates, (1) cannot be solved analytically. We have to use a numerical method to obtain the distribution function. We have performed extensive computer calculations using realistic date on $\nu_a(v)$ and $\nu_m(v)$ based on the models of McEachran *et al* (1979) and Grover (1979) at different fields and temperatures.

3. Results and discussion

Figure 1 presents the variation of $\bar{Z}_{\text{eff}} = \lambda/\pi r_0^2 cn$ (r_0 = classical electron radius) with frequency at constant temperature, $T = 300$ K, and magnetic field, $H = 30$ kG, for different electric fields, $E_{0t} = E = 10, 25$ and $50\ \text{V cm}^{-1}\ \text{amagat}^{-1}$ and $E_{0p} = 0$. The cyclotron frequency, $\omega_c = 5{\cdot}22 \times 10^{11}\ \text{rad sec}^{-1}$ for $H = 30$ kG. It may be seen that the annihilation decay constant decreases with frequency, passes through a minimum at $\omega = \omega_c$ and then increases. This happens at $E = 10, 25$ and $50\ \text{V cm}^{-1}\ \text{amagat}^{-1}$ for model M_1. But for model M_2 this minimum occurs at higher fields $E = 25$ and $50\ \text{V cm}^{-1}\ \text{amagat}^{-1}$. At $E = 10\ \text{V cm}^{-1}\ \text{amagat}^{-1}$, variation of $\bar{Z}_{\text{eff}}$ with frequency is linear for model M_2. The presence of resonance effect implies that the positron lifetime increases suddenly at $\omega = \omega_c$. This is because the effective field ($= m\,a_{\text{eff}}/e$) 'seen' by the positrons enhances with frequency and becomes quite large at resonance thus causing a sudden 'dip' in the value of $\bar{Z}_{\text{eff}}$ or increase in the lifetime.

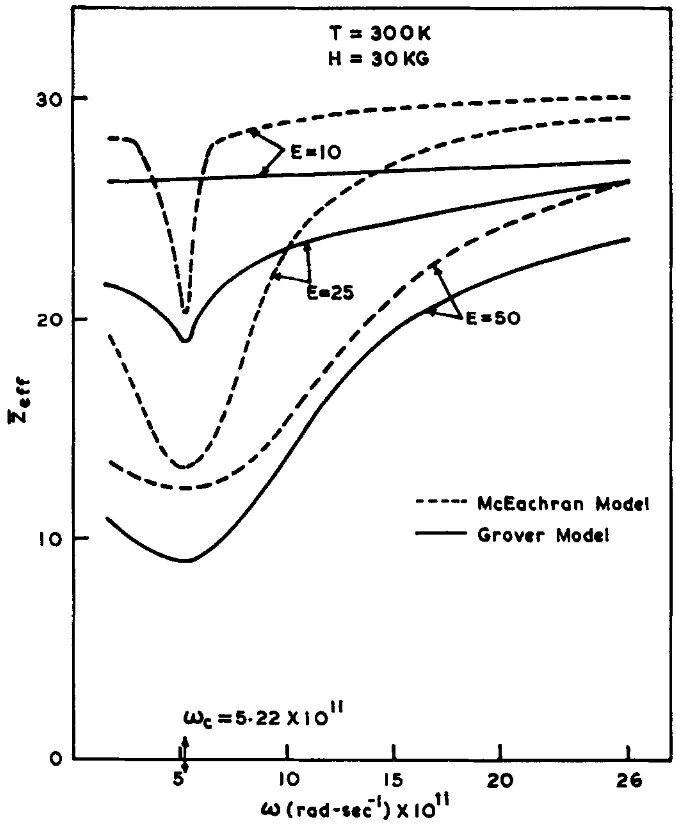

Figure 1. Variation of annihilation decay constant with frequency at different electric fields.

As the strength of the electric field is increased, the resonance dip becomes broader and the minimum decreases. The value of $\bar{Z}_{\text{eff}}(\omega_c) = 20{\cdot}39,\ 14{\cdot}35,\ 12{\cdot}30$ at $E = 10$, 25 V cm^{-1} amagat^{-1} for model M_1, while for model M_2, these values are 19·00 and 9·12 at $E = 25$ and 50 V cm^{-1} amagat^{-1} (at $E = 10$ V cm^{-1} amagat^{-1} there is no resonance for model M_2). We have estimated the relative variation in $\bar{Z}_{\text{eff}}$ as

$$\Delta \bar{Z}_{\text{eff}} = \frac{\bar{Z}_{\text{eff}}(\omega_0) - \bar{Z}_{\text{eff}}(\omega_c)}{\bar{Z}_{\text{eff}}(\omega_0)}$$

where ω_0 is the highest frequency considered $= 2{\cdot}61 \times 10^{12}$ radian/sec. The value of $\Delta \bar{Z}_{\text{eff}}$ comes out to be 32%, 54% and 53% for model M_1 at $E = 10$, 25 and 50 V cm^{-1} amagat^{-1}, 28% and 61% for model M_2 at $E = 25$ and 50 V cm^{-1} amagat^{-1}. This implies that variations in the lifetime of positrons are greater as predicted by model M_1 as compared to those brought out by model M_2. This fact can be examined experimentally and the validity of the model checked. We expect this observation to serve as quite a sensitive test of any e^+-atom interaction model.

Figure 2 shows the dependence of $\bar{Z}_{\text{eff}}$ on frequency at three temperatures, 300, 1000 and 3000 K as well as at constant electric ($E = 25$ V cm^{-1} amagat^{-1}) and magnetic ($H = 30$ kG) fields. As the temperature of the gas assembly is increased, the resonance becomes broader. The relative variation in $\bar{Z}_{\text{eff}}$ over the frequency range $5{\cdot}22 \times 10^{11}$ (resonance) to $2{\cdot}61 \times 10^{12}$ rad sec^{-1} is 54%, 45% and 28% for model M_1 and 28%, 30% and 26% for model M_2 at temperatures $T = 300$, 1000 and 3000 K respectively. The value of $\bar{Z}_{\text{eff}}$ at resonance is 13·35, 13·09, 12·78 for model M_1 whereas for model M_2 the values are 19·00, 14·41 and 10·56 at these temperatures. Thus, it is observed that at

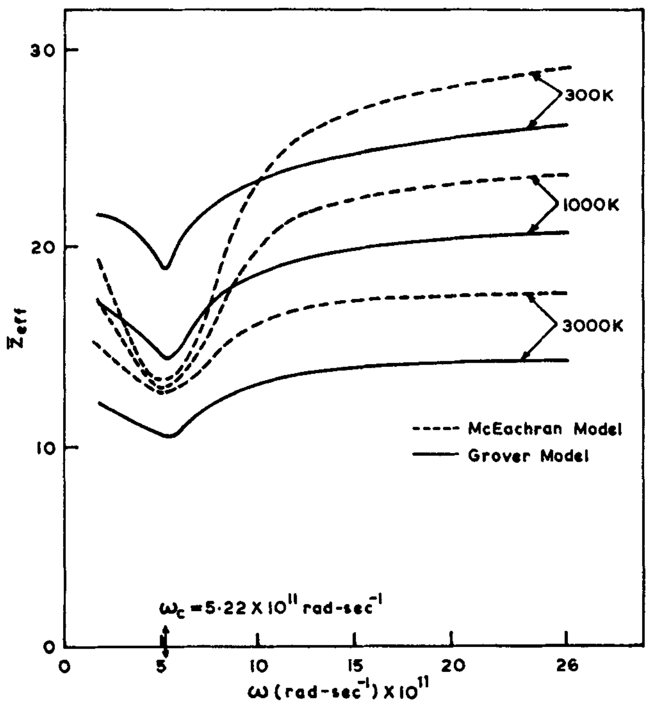

Figure 2. Dependence of $\bar{Z}_{\text{eff}}$ on frequency at different temperatures.

resonance, the temperature effect is greater according to model M_2 as compared to model M_1.

Figure 3 presents the variation of $\bar{Z}_{eff}$ with frequency at different magnetic fields for both models. It is seen that at $H = 10$ kG, the resonance is very weak as predicted by either model. However, as the magnetic field is increased, resonance becomes sharper. Moreover, the resonance shifts towards higher frequencies as the magnetic field is increased. Resonance occurs at frequencies $1{\cdot}74 \times 10^{11}$, $5{\cdot}22 \times 10^{11}$ and $8{\cdot}70 \times 10^{11}$ rad sec^{-1} for $H = 10$, 30 and 50 kG respectively.

We have also computed the average energy of positrons (equation (4)) for models M_1 and M_2 at different fields and frequencies. The dependence of average energy on frequency is presented in figure 4 for $E = 10, 25$ and 50 V cm^{-1} amagat^{-1} at $T = 300$ K and $H = 30$ kG. The average energy increases, attains a maximum at $\omega = \omega_c$ and then decreases. This behaviour is present for model M_1 at the above fields. However, for model M_2, $\bar{\varepsilon}$ varies almost linearly with frequency at $E = 10$ V cm^{-1} amagat^{-1}, though resonance is present at higher fields. We define the relative variation in average energy as

$$\Delta\bar{\varepsilon} = \frac{\bar{\varepsilon}(\omega_0) - \bar{\varepsilon}(\omega_c)}{\bar{\varepsilon}(\omega_0)}.$$

The value of $\Delta\bar{\varepsilon}$ over the frequency range $5{\cdot}22 \times 10^{11}$ to $2{\cdot}61 \times 10^{12}$ rad sec^{-1} is 12·92, 27·92 and 18·82 (in units of 300 K) for model M_1 at $E = 10, 25, 50$ V cm^{-1} amagat^{-1}; while $\Delta\bar{\varepsilon}$ is 6·66 and 17·17 (in units of 300 K) for model M_2 at $E = 25$ and 50 V cm^{-1} amagat^{-1} respectively. It may be observed that $\bar{\varepsilon}$ shows a maxima at the same frequency where $\bar{Z}_{eff}$ attains a minima.

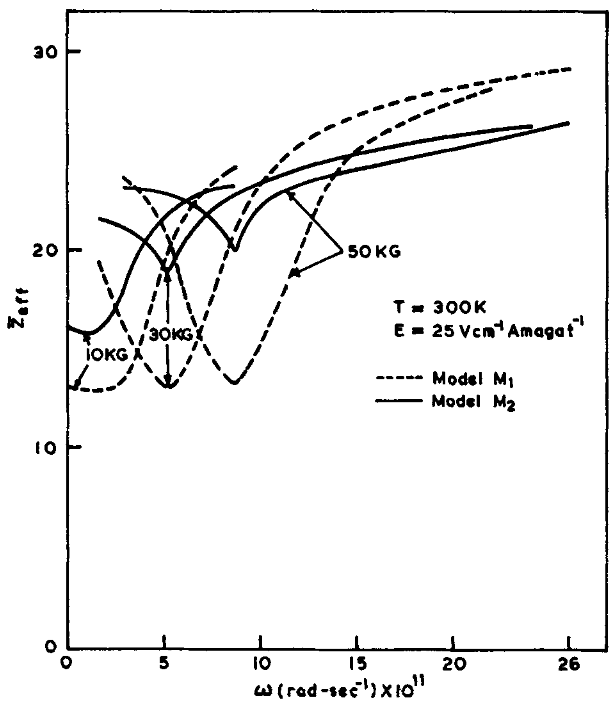

Figure 3. Variation of $\bar{Z}_{eff}$ with frequency at $H = 10, 30, 50$ kG.

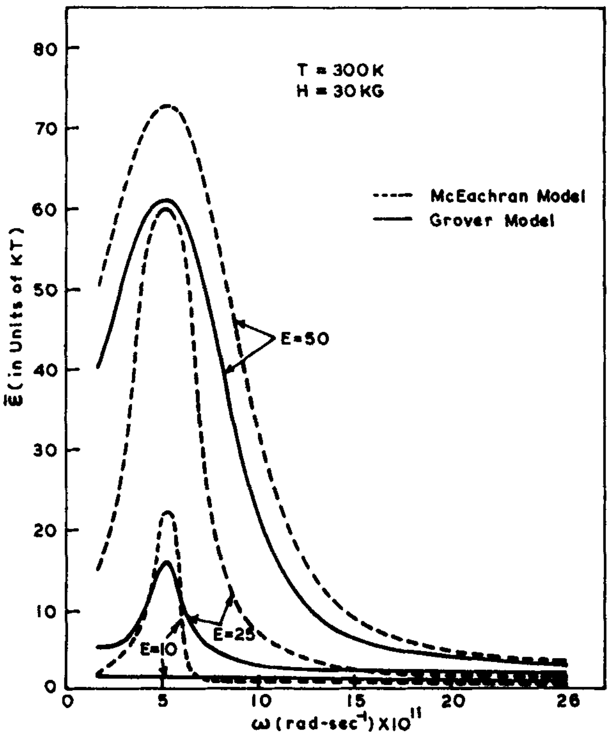

Figure 4. Effect of frequency variation on average energy at $E = 10, 25, 50\,\mathrm{V\,cm^{-1}}$ amagat^{-1} for both models.

The dependence of average energy on frequency at constant electric ($E = 25\,\mathrm{V\,cm^{-1}}$ amagat^{-1}) and magnetic ($H = 30$ kG) fields for different temperatures $T = 300, 1000, 3000$ K is brought out in figure 5. The average energy attains a maximum at resonance. The maximum goes up as the temperature of the gas assembly is increased. The relative variation of average energy from resonance frequency ($\omega_c = 5{\cdot}22 \times 10^{11}$ rad sec^{-1}) to highest frequency edge (considered here as $\omega_0 = 2{\cdot}61 \times 10^{12}$ rad sec^{-1}) viz $\Delta\bar{\varepsilon}$ is equal to 27·92, 9·46 and 2·57 (in units of 300 K) for model M_1, while for model M_2 the values are 6·96, 2·94 and 1·66 (in units of 300 K) at temperatures 300, 1000 and 3000 K respectively. At resonance, the values of $\bar{\varepsilon}$ are: 60·10, 61·45 and 63·71 (in units of 300 K) for model M_1 and 15·82, 27·35 and 43·73 (in units of 300 K) for model M_2 corresponding to the above temperatures. It is found that at resonance, the temperature effect on average energy is much greater for model M_2 as compared to model M_1.

Our calculated values of average energy for zero electric and magnetic fields at room temperature, 300 K, are 456·0 K for model M_1 and 453·0 K for model M_2, whereas the theoretical value at this temperature is 450·0 K. The agreement between calculated and actual values of average energy is quite good confirming our computer codes and calculations.

We have also checked the accuracy of our calculations by computing $\bar{Z}_{\mathrm{eff}}$ in the absence of the electric and magnetic fields at room temperature. Table 1 presents the

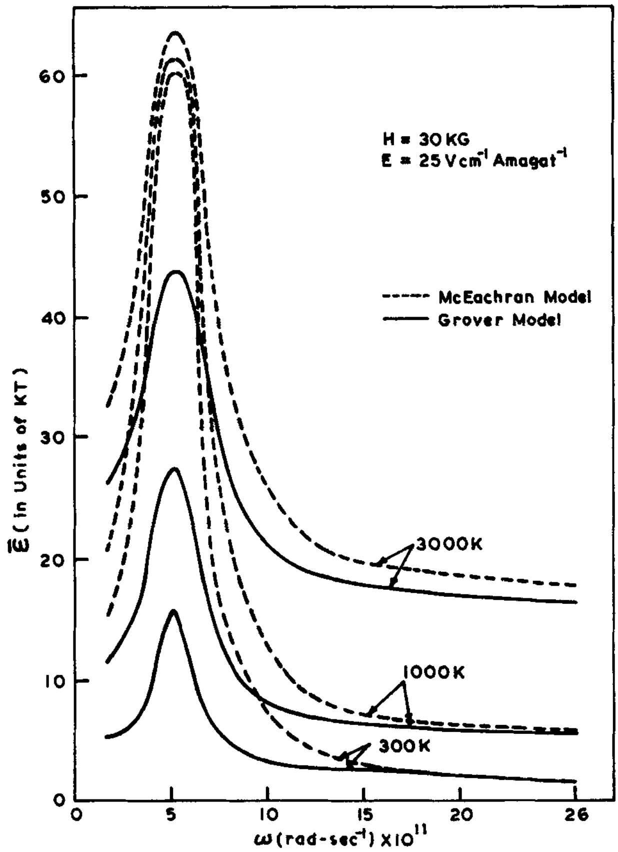

Figure 5. Dependence of $\bar{\varepsilon}$ on frequency at constant electric and magnetic fields at different temperatures.

Table 1. Annihilation decay constant, $\bar{Z}_{\text{eff}}$, at $T = 300$ K and at $E = H = 0$.

Experimental	Present calculations
27·3 ± 1·3 (Lee and Jones 1974)	30·13 (model M_1)
26·6 ± 0·51 (Orth and Jones 1969)	27·33 (Model M_2)
26·77 ± 0·09 (Coleman *et al* 1975)	

values as obtained by various workers. It is observed that as far as the equilibrium values of $\bar{Z}_{\text{eff}}$ are concerned, model M_2 gives better agreement with experiment.

4. Conclusions

The present study brings out clearly the influence of the electric field frequency and other fields on positron lifetime. An interesting observation is the resonance effect in the lifetime of positrons. This effect is quite sensitive to the e^+-atom interaction model. The numerical results obtained from the various quantities are model-dependent. If data from some other model were used, these values may differ. However, the general conclusions arrived at in this paper are expected to be similar. By performing an experiment, when high frequency electric and steady magnetic fields are applied, it would be possible to study the positron lifetime and other characteristics. This will be a new experiment. All the experimental studies performed so far have been concerned with the constant electric field. The present technique is expected to provide an impetus in studies concerning positron behaviour. Interestingly, high frequency effects are more important in lighter gases as compared to heavier one (Grover 1982). We expect that the present technique could prove useful for determining the positron lifetime and other characteristics.

References

Charlton M 1985 *Rep. Prog. Phys.* **48** 737
Coleman P G, Griffith T C, Heyland G R and Killeen T L 1975 *J. Phys.* **B8** 1734
Ghosh A S and Grover P S 1985 *Positron Annihilation* (eds) P C Jain, R M Singru and K P Gopinathan (Singapore: World Sci. Pub. Co.) p. 307
Grover P S 1977 *J. Phys.* **B10** 2269
Grover P S 1979 *Appl. Phys.* **18** 109
Grover P S 1980 *Z. Naturforsch.* **A35** 1118
Grover P S 1981 *Phys. Lett.* **A81** 37
Grover P S 1982 *Positron annihilation* (eds) P G Coleman, S C Sharma and L M Diana (Amsterdam: North Holland)
Lee G F and Jones G 1974 *Can. J. Phys.* **52** 17
McEachran R P, Ryaman A G and Stauffer A D 1979 *J. Phys.* **B12** 1031
Orth P M R and Jones G 1969 *Phys. Rev.* **A183** 7