Equilibrium Positron Decay Rates in Helium

P. S. Grover
Department of Physics, University of Delhi, India

and M. S. A. Muhammed, and S. A. Sami
Department of Physics, College of Science, University of Sulaimaniyah, Iraq

Z. Naturforsch. **35a**, 1087 – 1089 (1980); received June 6, 1980

Equilibrium positron decay rates in helium gas have been computed over a wide range of temperatures and electric fields based on the model due to McEachran et al. [7]. Agreement between the theoretical and experimental values of the decay rate at room temperature and zero electric field is quite good.

Several authors have studied the behaviour of slow positrons (energies less than positronium formation threshold, $E_{\text{th}} = 17.8$, 14.7, 9.0 eV for helium, neon and argon gas, respectively) in noble gases and mixtures [1–8]. They have calculated the positron-atom momentum transfer rates, ν_{m}, annihilation rates, ν_{a}, positron life times, etc. Different models have been used for the positron-atom interaction to estimate ν_{m} and ν_{a}. This enables to calculate the positron annihilation decay rate, λ, the inverse of life time. It can also be measured [2–6]. λ depends on the temperature of the gas and external applied electric and magnetic fields. Comparison between the theoretical and experimental values provides information about the accuracy of the positron-atom interaction model.

The equilibrium decay rate, λ, is defined as

$$\lambda = \left[\int_0^\infty \nu_{\text{a}}(v)\, v^2 f(v)\,\mathrm{d}v\right]\left[\int_0^\infty v^2 f(v)\,\mathrm{d}v\right]^{-1}, \tag{1}$$

where $f(v)$ is the positron equilibrium distribution function and v the positron velocity. (Positrons reach equilibrium with the gas atoms at times sufficiently greater than their slowing down time). $f(v)$ can be obtained by solving the integro-differential Boltzmann diffusion equation [8]:

$$\left[\frac{e^2 E^2}{3\, m^2 \nu_{\text{m}}^2(v)} + \frac{k_{\text{B}} T}{M}\right]\frac{\partial f}{\partial v} + \frac{m\, v\, f(v)}{M} = \frac{1}{v^2 \nu_{\text{m}}(v)} \int_0^v [\nu_{\text{a}}(v) - \lambda]\, v^2 f(v)\,\mathrm{d}v\,. \tag{2}$$

Here E is the electric field; e and m are the positron charge and mass, respectively; T is the temperature of the gas assembly, M the gas atom mass and k_{B} the Boltzmann constant.

(2) can be solved by an iteration-perturbation technique [8] for the distribution function if the data on annihilation and momentum transfer rates are available. Then the annihilation decay constant can be computed from (1) and compared with the experimental results.

Recently, McEachran et al. [7] have calculated $\nu_{\text{a}}(v)$ and $\nu_{\text{m}}(v)$ in helium using the polarized orbital approximation. However, no study of positron lifetimes appears to have been performed using this model. We have done this and the results are being reported here.

We shall refer to the calculations of McEachran et al. [7] by model M_1 in the text. Using M_1 data on $\nu_{\text{a}}(v)$ and $\nu_{\text{m}}(v)$, we have solved Eq. (2) by a numerical algorithm described in [8]. We take helium gas at normal temperature and pressure with density equal to 1 amagat. The temperature range considered is 100–2000 K while the electric field values lie in the interval 0–50 V/cm/amagat.

We introduce the parameter $Z_{\text{eff}} = \lambda / \pi \gamma_0{}^2 c n$. Here r_0 is the classical electron radius, c the velocity of light and n the gas density. Z_{eff} also refers to the effective number of electrons per atom with which the positron can annihilate. By knowing $f(v)$, we can compute λ and hence Z_{eff}.

Z_{eff} has been investigated as a function of temperature and electric field. As a comparison, we have also made computations using the ν_{a} and ν_{m} data of Campeanu and Humberston [6] based on their H5 model. It will be referred to as M_2 in the manuscript.

Reprint requests to Dr. P. S. Grover, Department of Physics, University of Delhi, Delhi-110007, Indien.

0340-4811 / 80 / 1000-1087 $ 01.00/0. — Please order a reprint rather than making your own copy.

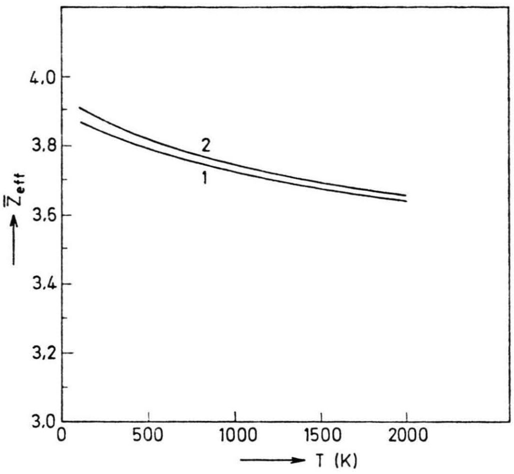

Fig. 1. Dependence of $\bar{Z}_{eff}$ on temperature. Curves 1 and 2 are for models M_1 and M_2, respectively.

Figure 1 shows the variations of $\bar{Z}_{eff}$ with temperature for the models M_1 and M_2. $\bar{Z}_{eff}$ decreases with increasing temperature. Model M_2 predicts higher values. The difference decreases with increase of temperature. Comparison with other calculations and experimental results at three temperatures: 77, 293, 1000 K and zero electric field is presented in Table I. The results of the present authors' model M_2 are based on the same numerical information as the computations of Campeanu and Humberston [6], and the agreement between these results to within 0.01 in $\bar{Z}_{eff}$ measures the consistency of two different computer routines. There are no other systematic experimental results over the temperature range investigated here.

The dependence of $\bar{Z}_{eff}$ on electric field is shown in Figure 2. The field values considered are 0, 1, 2, 3, 4, 5, 10, 15, 20, 30, 40, and 50 V/cm/amagat. A finer mesh has been chosen for lower fields because maximum variations in $\bar{Z}_{eff}$ occur in this region. Curves marked with numbers are for model M_1. For fields $\gtrsim 7$ V/cm amagat, $\bar{Z}_{eff}$ becomes almost independent of the electric field and temperature. Low electric field behaviour at various temperatures has been given separately in the inset of Fig. 2 for clarity. Curve A is for the model M_2 at $T = 300$ K. Both models predict a rapid fall in $\bar{Z}_{eff}$ at lower fields. However, at the higher fields, a gradual increase, though small, is present in $\bar{Z}_{eff}$ according to model M_2. When the electric field is changed from 10 to 50 V/cm/amagat, $\bar{Z}_{eff}$ varies from 3.239 to 3.330 at $T = 300$ K, and from 3.243 to 3.330 at $T = 2000$ K. It is obvious that this model also leads to almost constant $\bar{Z}_{eff}$ at higher temperatures and fields.

The effect of temperature is important only at low fields in both models. This is because the temperature term dominates over the electric field term in (2) at such fields [16].

Table 1. Comparison of experimental and theoretical values of $\bar{Z}_{eff}$ at $E = 0$.

Temperature (K)	77	293	1000
Experiment			
Lee et al. [9]		3.63 ± 0.04	
Roellig and Kelly [10]	3.96 ± 0.04		
Leung and Paul [11]	3.677 ± 0.025		
Fox et al. [12]	3.91 ± 0.02	3.89 ± 0.04	
Coleman et al. [13]		3.94 ± 0.02	
Theory			
Grover and Srivastava [14]	3.62	3.58	3.51 *
Campeanu and Humberston [6]	3.92	3.85	3.73
Farazdel and Epstein [15]	3.91 ± 0.03	3.87 ± 0.02	3.87 ± 0.02
Present work M_1	3.86	3.82	3.72
Present work M_2	3.91	3.85	3.74

* P. S. Grover, Unpublished calculations.

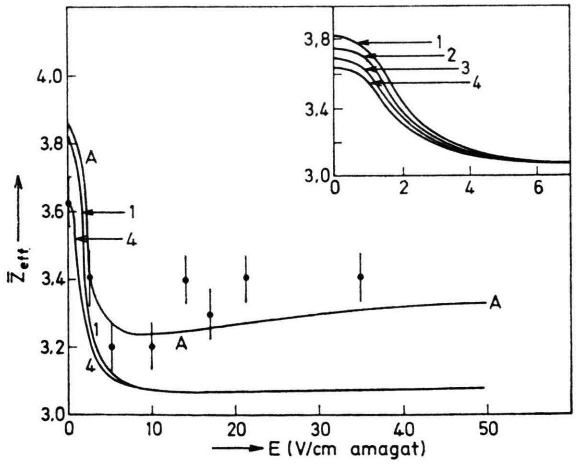

Fig. 2. Variation of $\bar{Z}_{eff}$ with electric field. Curves 1 and 4 are for model M_1 at $T = 300$ and 2000 K, respectively. The inset shows the low electric field behaviour. (Note the change in scale). Curves 1, 2, 3, 4 are for $T = 300$, 800, 1500, 2000 K, respectively. Curve A is for model M_2 at $T = 300$ K. Dots are the experimental points of Lee et al. [9].

Lee et al. [9] have measured the dependence of Z_{eff} on electric field. Their results have been indicated by dots in Figure 2. The sharp fall in the values of Z_{eff} also occurs for electric fields $\lesssim 7$ V/cm amagat. This feature is present in the experimental studies of Leung and Paul [11] as well. It is found that the calculations based on model M_2 yield better agreement with experiment at non-zero values of the electric field. However, the experimental value of Lee et al. [9] at $E = 0$ is too low as compared with other workers and also less accurate [13].

Agreement of Z_{eff} based on model M_1 with the existing experimental data for $E > 0$ is quite poor. As there are no accurate measurements of the variation of Z_{eff} with electric field and temperature, it would be premature to comment on the relative accuracy of the two models as regards their explaining the equilibrium decay rates at higher temperatures and electric fields. However, at zero electric field and room temperature, both models yield good agreement with the recent experimental measurements.

[1] R. J. Drachman, Phys. Rev. **144**, 25 (1966); **173**, 190 (1968).
[2] P. H. R. Orth and J. G. Jones, Phys. Rev. **183**, 1 (1969).
[3] R. E. Montogomery and R. W. La Bahn, Can. J. Phys. **48**, 457 (1972).
[4] S. Hara and P. A. Frazer, J. Phys. **B8**, 219 (1975).
[5] P. S. Grover, Appl. Phys. **18**, 109 (1979).
[6] R. I. Campeanu and J. W. Humberston, J. Phys. **B10**, 239 (1977).
[7] R. P. McEachran, A. G. Ryman, and A. D. Stauffer, J. Phys. (B) **10**, 663 (1977).
[8] P. S. Grover, J. Phys. (B) **10**, 2269 (1977).
[9] G. F. Lee, P. H. R. Orth, and G. Jones, Phys. Lett. (A) **28**, 674 (1969).
[10] R. A. Fox, K. F. Canter, and M. Fiscbein, Phys. Rev. A **15**, 1340 (1977).
[11] C. Y. Leung and D. A. L. Paul, J. Phys. (B) **2**, 1278 (1969).
[12] L. O. Roellig and T. M. Kelly, quoted by P. A. Frazer in Adv. Atomic Mol. Physics **4**, 63 (1968).
[13] P. G. Coleman, T. C. Griffith, G. R. Heyland, and T. L. Killen, J. Phys. (B) 8, 1734 (1975).
[14] P. S. Grover and M. P. Srivastava, J. Phys. (B) **5**, 609 (1975).
[15] A. Farazdel and I. R. Epstein, Phys. Rev. A **16**, 518 (1977).
[16] P. S. Grover, Z. Naturforsch. **35 a**, 350 (1980).