Positrons in gas filled traps and their transport in molecular gases

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Positrons in gas filled traps and their transport in molecular gases

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Abstract. In this paper we give a review of two recent developments in positron transport, calculation of transport coefficients for a relatively complete set of collision cross sections for water vapour and for application of they Monte Carlo technique to model gas filled subexcitation positron traps such as Penning Malmberg Surko (Surko) trap. Calculated transport coefficients, very much like those for argon and other molecular gases show several new kinetic phenomena. The most important is the negative differential conductivity (NDC) for the bulk drift velocity when the flux drift velocity shows no sign of NDC. These results in water vapour are similar to the results in argon or hydrogen. The same technique that has been used for positron (and previously electron) transport may be applied to model development of particles in a Surko trap. We have provided calculation of the ensemble of positrons in the trap from an initial beam like distribution to the fully thermalised distribution. This model, however, does not include plasma effects (interaction between charged particles) and may be applied for lower positron densities.

1. Introduction

It has recently become possible to model positron transport in gaseous media based on the measured scattering cross sections. The efforts of groups in San Diego [1-2], Trento [3], London [4], Detroit [5] Swansea [6] and recently Canberra [7,8] led to measurements of a wide range of data which cover all relevant momentum and energy transfer processes as well as the processes that change the number of particles (annihilation and positronium formation). Sometimes, however, one needs to complete the set with theoretical results which are also becoming reasonably abundant [9-11], preferably those results based on theories that were tested against experiments on other similar targets. In any case sufficiently detailed and complete sets are now available for argon, hydrogen, nitrogen and few more relevant gases.

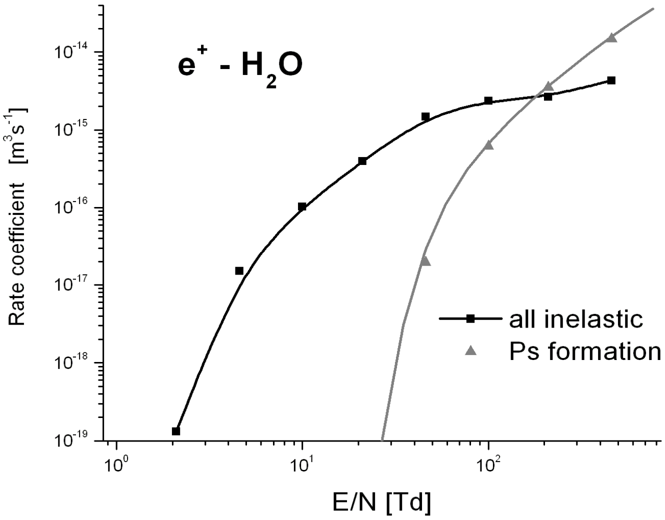

Figure 1. Rate coefficients for positrons in water vapour: Ps formation and inelastic losses.

Having in mind that the principal constituent of a human body is H_2O, we attempted to compile a set of cross sections that could be used to model behaviour of positrons in a human body. While a combination of experimental data and calculations was sufficient with some extrapolations to form the set, we have taken advantage of the recent measurements at the ANU in Canberra to provide two of the most important cross sections [8], the total scattering and the positronium formation cross section. It is important to note that all of the relevant processes, while providing a good balance and effective behaviour of the positron swarms, cannot be tested against the measured transport data yet as such experiments (with two exceptions [12,13]) are not available at the moment in a sufficiently wide range of normalized electric fields (E/N).

In our previous reviews of preliminary results we presented the first results for positron transport including the data for argon and some aspects of transport in molecular gases and in the crossed magnetic and electric fields [14]. Finally we have dealt with thermalization of positronium and transport in liquids which are associated with applications of positron transport [15]. Final results have been published for argon [16] and partly for nitrogen [18] with a special analysis of the negative differential conductivity (NDC) induced by positronium formation [16].

In this paper we present new developments with transport of positrons in water vapour and first attempts to model low density positron traps in gases.

2. Positron transport in water vapour

Before addressing the results we should perhaps discuss whether one has sufficient motivation for swarm (transport) studies of positrons and how those could be justified by applications.

The time scales of possible swarm experiments in gases that are at a high enough pressure are very short and yet positrons survive long enough to allow us determination of transport coefficients [12,13]. A review of past, existing and possible future swarm experiments with the discussion how to overcome formidable difficulties facing studies of positron swarms was given by Charlton [19]. It is important to note that a swarm system should not be viewed as a competition with traps in efficiency of storing swarms. Absence of multiplication (as compared to electrons) does not allow us to form stable ensembles of particles, so for any measurement the price is in the loss of particles. Such an experiment would thus provide transport data allowing us to adjust the desired properties by electric and magnetic fields- see accompanying paper [20], model some of the applications and also giving us a possibility to test and benchmark the calculations of the models of such applications. This is especially important as it would be very difficult to base all the comparisons on predicted trajectories and some averaged, accurately measured and calculated, data are needed. Finally such experiments would provide a natural occurrence of some of the predicted and yet to be predicted kinetic phenomena driven by non-conservative processes, Ps formation in this case.

Transport coefficients in water vapour calculated by a standard Monte Carlo procedure [16] show similar features as in argon and hydrogen. In other words, while mean energy is similar to what was observed for electrons, the drift velocity shows the duality of drift velocities, with NDC unlike anything seen for electrons (although the effect was predicted for electrons [21] in a model gas). The ***flux*** drift velocity increases gradually throughout the range of electric fields covered and at the same time the ***bulk*** drift velocity shows a very pronounced NDC with a maximum difference between the two that is greater than an order of magnitude. With the exception of hydrogen there are no experiments confirming such drift velocities. Our good experience with electron swarms teaches us that our predictions are quite accurate but one would prefer to have the transport data to normalize the entire sets of cross sections.

One example of the data shown here in Fig. 1 is the rate for Ps formation compared to other elastic and inelastic processes.

3. Monte Carlo modelling of a Penning Malmberg Surko trap

The initial development and analysis of a Surko trap was done on the basis of assumed beam like properties of particles in the trap. Yet particles in such traps start from a beam like distribution and thermalize to an isotropic Maxwellian distribution at room temperature. In that respect the Surko trap is similar to the Frank Hertz experiment that will have its 100th anniversary in 2014. Very much like in the case of the Frank Hertz experiment [22] we believe that proper modeling of the Surko trap may be performed by swarm techniques that may provide description of a non-hydrodynamic particle kinetics (when the swarm is not in equilibrium with the local field but may depend on the spatial or temporal history).

In Figure 2 we show temporal development of the mean energy of positrons in trap. At the same time we show energy distributions at several times after the particles have been introduced to the trap. Unlike the real trap where particles are fed into the trap continuously here we introduce the whole batch together in order to follow the temporal development.

While providing the qualitative physical picture of the trap that is already available, the modeling also does so in a quantitative manner thus allowing comparisons between

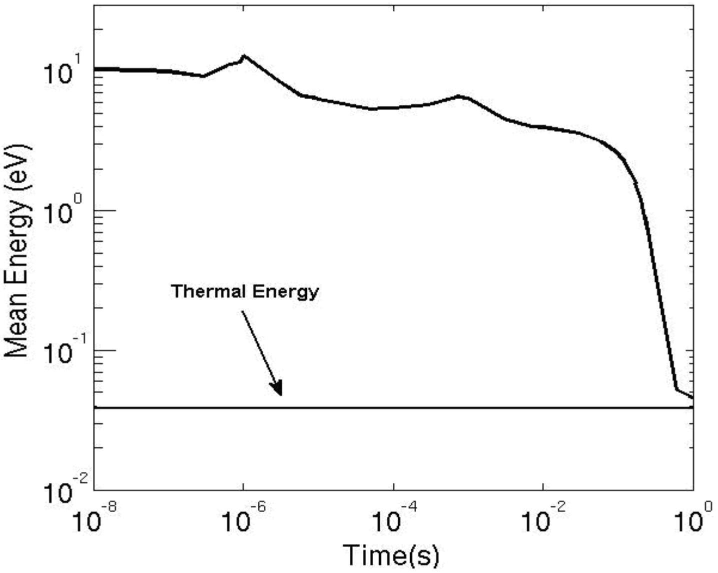

Figure 2. Temporal development of the mean kinetic energy of positrons in Surko trap.

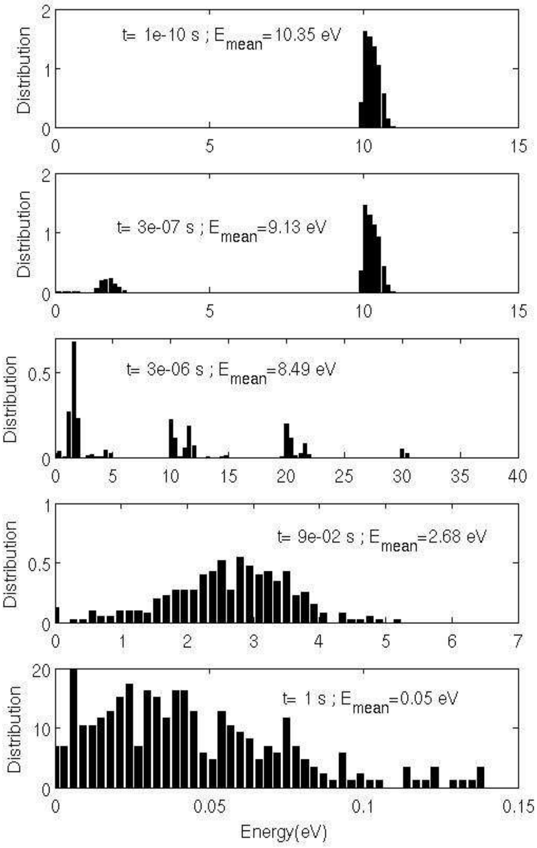

Figure 3. Temporal development of the energy distribution function (probability of finding particles in a given energy bin) of positrons in a trap.

different gases, different fields, analysis of a possible benefit of added axial or radial electric fields.

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