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THE POSITRONIUM INTERACTION WITH THE OXYGEN MOLECULES MEASURED BY POSITRONIUM ANNIHILATION SPECTROSCOPY

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Abstract
We have applied a conventional Time Differential Perturbed Angular Correlation (TDPAC) Method to observe the anisotropy oscillations in the 3γ annihilation decay of polarized Positronium in a weak magnetic field, predicted theoretically and experimentally demonstrated by Baryshevski et al. [1] and induced by the coherent admixture of m=0 states of ortho-Positronium and para-Positronium in interaction with the magnetic field.
The following experimental characteristics are to be considered:
i) oscillation frequency is proportional with B^2;
ii) privileged angles of the polarization vector- magnetic field- detector angles are required for optimizing the observed oscillation amplitude;
iii) in a fixed geometry the oscillation amplitude depends on mean polarization of Positronium states.
The R(t) functions measured in vacuum and different gases (Ar,H,N) are not damped and we conclude that the Ps atoms are not fully thermalised over a time interval of about 400 ns.
A damped R(t) function was observed for o-Ps annihilation in dry air and Ar O mixture, probably due to the paramagnetism of the Oxygen molecules.
Keywords: Positronium, Positron annihilation, Zeeman effect, thermalization, spin polarization, spin relaxation.

1. Introduction

The "quantum beat" oscillations predicted theoretically and experimentally demonstrated by Baryshevski et al. [1] are induced by the coherent admixture of m=0 states of ortho-Positronium and para-Positronium in interaction with the magnetic field. The basic idea of the experiment is that ortho-Positronium (o-Ps) and para-Positronium (p-Ps) atoms annihilation is influenced by a magnetic field. In an external magnetic field **B** the singlet state of positronium (p-Ps) and m=0 substate of o-Ps are perturbed to form two mixed states by the Zeeman effect, while other triplet substate m=± 1 of o-Ps are not perturbed (1 and 2). The two mixed states are:

$$\Psi_t^{'} = \frac{1}{\sqrt{1+y^2}}(\Psi_t(m=0) + y\Psi_s) \qquad (1)$$

and

$$\Psi_s^{t} = \frac{1}{\sqrt{1+y^2}}(\Psi_s - y\Psi_t(m=0)) \qquad (2)$$

where $y = \frac{x}{1+\sqrt{1+x^2}}$, and x=0.0276$\boldsymbol{B}$ (for B in kG) . These states, ψ_t' and ψ_s', are called an **ortho-like-Ps** and a **para-like-Ps**, respectively [2]. Due to the very short time (1 ps) elapsed between positron emission and Positronium formation we can consider that the **o-like-Ps** wave function is prepared as a "coherent" superposition of two states. If polarized e^+s are incident on a target located in an external magnetic field and capture unpolarized e^-s in the target to form Ps the time spectrum of Ps decays in the magnetic field ***B*** depends on ***P,*** the e^+ polarization, and φ the angle between the polarization direction and ***B.*** Barishewsky [1] calculated the annihilation amplitude for Ps in magnetic field and demonstrated that square of annihilation amplitude undergoes beating at three frequencies corresponding to the splitting energies of positronium levels in the magnetic field . The quantum coherence favours the interference which, in this case, is manifested by the modulation of the time distribution (3) of the intensity of 3γ - intrinsic annihilation or "quantum beats" :

$$N^{\pm}\ (t) = f + A * \exp^{(-\frac{(t-t_0)}{\tau_{annih}})} * (1 \pm a^{\pm} * \exp^{(-\frac{(t-t_0)}{\tau_{relax}})} * \sin(2 * \pi * \frac{(t-t_0)}{T}) \qquad (3)$$

2. Experimental arrangement

Baryshevski [1] shown that the intensity modulation can be observed only in a particular detection geometry having the **ortho-like-Positronium** atoms polarization vector (**P**) perpendicular on the detectors plane and on the magnetic field intensity (**B**). The maximum effect is obtained if the detectors axis are in the same plane as the magnetic field making 45^0 ($N^+(t)$) or 135^0($N^-(t)$) angles with **B**. The measurement can be done using only one STOP detector in correct position by changing with 180^0 the **P** direction . The changing of the magnetic field direction is without effect because the anisotropy is dependent on **B** square . Similar results were obtained by S. Fang [3].

A conventional Time Differential Perturbed Angular Correlation (TDPAC) Method [4] was applied to observe the anisotropy oscillations in the 3γ annihilation decay of polarized Positronium in a weak magnetic field.

In our experiment polarized Positronium atoms are produced in a porous alumina powder (Al_2O_3) placed in the front of a ^{22}Na $ß^+$ source deposited on Berillyum .
The source-sample sandwich was encapsulated in an Aluminium can and mounted in a vacuum chamber provided with gas filling accessories and placed between the poles of an electromagnet.

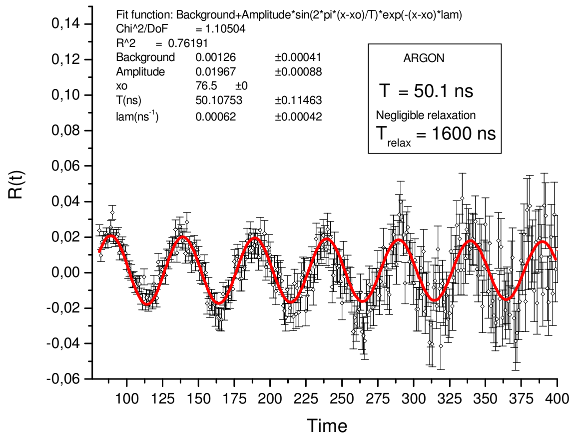
3. Results

In the last experiment a spectrometer with one START and four STOP detectors, was used and so four time spectra were simultaneously registered.
The data were analyzed with the Difference **(t)** and **R(t)** functions defined as :

$$Difference\ (t) = N^{+}(t) - N^{-}(t) = A * \exp^{(-\frac{(t-t_0)}{\tau_{annih}})} \exp^{(-\frac{(t-t_0)}{\tau_{relax}})} * 2 * a^{\pm} * \sin(2 * \pi * \frac{(t-t_0)}{T})$$

$$R(t) = \frac{N^{+}(t) - N^{-}(t)}{N^{+}(t) + N^{-}(t)} = \exp^{(-\frac{(t-t_0)}{\tau_{relax}})} * (a^{+} - a^{-}) * \sin(2 * \pi * \frac{(t-t_0)}{T})$$

The **R(t)** functions (fig 1-2) measured in vacuum and different gases (Ar,H,N) are not damped and we conclude that the Ps atoms are not fully thermalised over a time interval of about 400 ns.



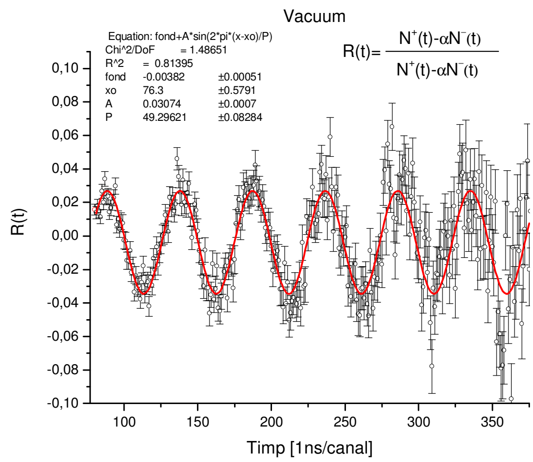


Fig. 1. R(t) functions for vacuum and Argon.

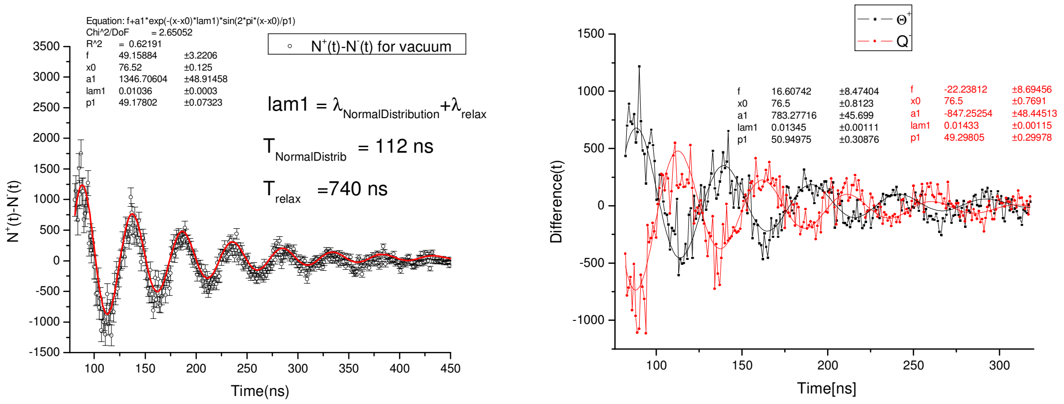


Fig. 2. Difference (t) functions measured for vacuum and Argon.

A damped **R(t)** function (fig.3) was observed for o-Ps annihilation in dry air and $Ar_x O_{1-x}$ mixture, probably due to the para magnetism of the Oxygen molecules. All R(t) parameters, except the oscillations frequency, are influenced by Oxygen presence. The effect of the paramagnetic molecules influences the polarization degree of the positrons.

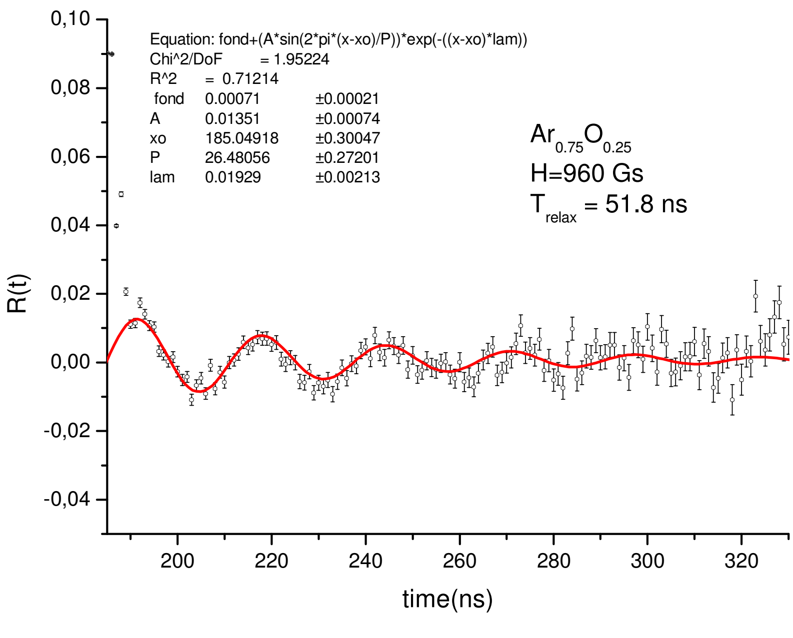


Fig. 3. Damped R(t) function for a mixture $Ar_{0,875}O_{0,125}$

The effect is observed in fig. 4 were the modulation depth dependence on Oxygen partial pressure is show.

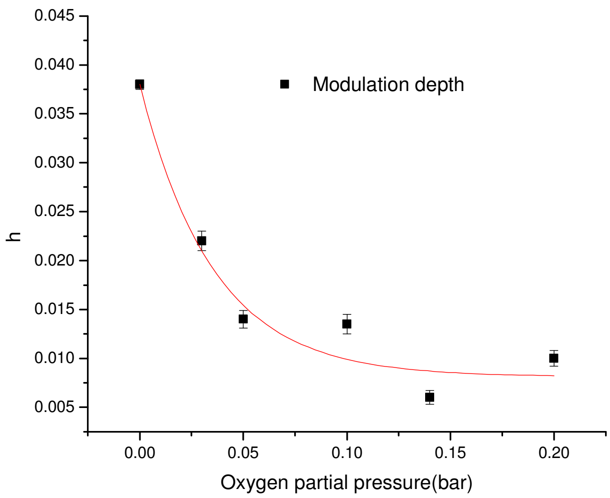


Fig. 4. The dependence of modulation depth on the Oxygen partial pressure

Another, observed, effect of the Ps- Oxygen paramagnetic interaction is the relaxation of the R(t) functions (fig.3) and the decreasing of life time of Ps atoms with Oxygen partial pressure increasing (fig.5).

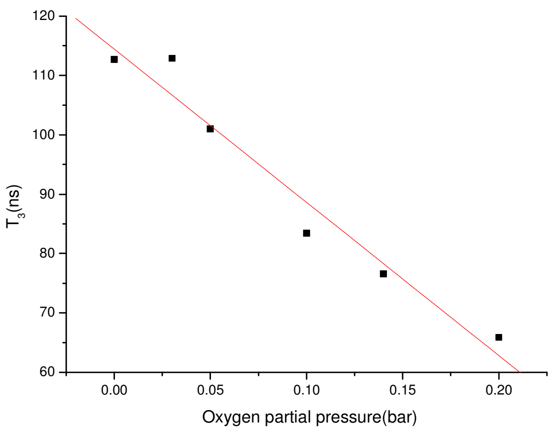


Fig. 5. The dependence of intrinsic lifetime o-Ps annihilation on the Oxygen partial pressure

The experimental data permit the calculation of the cross section, $\sigma_{\beta^+\text{-}O2}$ for positron-Oxygen interaction:

$$\lambda_{\beta^+-O_2} = n * v * \sigma_{\beta^+-O_2} \qquad \Rightarrow \qquad \sigma_{\beta^+-O_2} = 2.5 * 10^{-19} cm^2$$

were n is the Oxygen density and v is the positron velocity.

Similar value for Ps- O_2 interaction obtained is : $\sigma_{Ps-O_2} = 2.8 * 10^{-19} cm^2$

4. Conclusion

The experiment confirms the "quantum beats" oscillation existence in **o-Ps** decaying in weak magnetic field.

The coherence of **o-like Ps** is conserved for very long times (more than 400 ns).

The paramagnetic molecules influence the polarization degree of the positrons and produce a relaxation effect on **R(t)** functions.

Acknowledgements

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