Drying Gummi Bears Reduce Anti-Matter Lifetime

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Introduction

The exotic atom consisting of an electron and its antiparticle, the positron, is a bound state called positronium. Such positronium atoms can be formed by bombarding gummy bears with positrons. In our experiment, we could clearly observe an increased annihilation rate of positronium with increasing degree of drying of the used gelatin-glucose compound. We succeeded in not only measuring the reduced lifetime of positrons in dried jelly baby, but also in quantifying the mean size of the nanoscale pores in the biopolymer, where positronium annihilates.[2]

The Experiment

Gummy bears are an ideal model system for biopolymers which consist essentially of crosslinked gelatin and glucose. As sample material only red gummy bears[3] were used to exclude any color dependencies. Untreated red specimens were compared with pairwise equally prepared samples. One pair of gummy bears was saturation loaded with water for 24 hours. Two other couples were dried: one couple of gummy bears pair was dehydrated at 35^oC at a reduced pressure of $2 \cdot 10^4$ Pa for three days, while the other was stored with a sufficient quantity of silica gel desiccant at room temperature for more than two years. The photo in Figure 1 shows the set of gummy bears with different water content.

For the actual measurement of the positronium lifetime we chained each couple of identical samples around a radioactive positron source in a sandwich-like geometry in order to optimally exploit the solid angle and hence to implant almost all positrons in the jelly babies (see figure 2). The positron source ^{22}Na used here also emits a high-energy, nearly prompt gamma quantum, which is used to generate the *Start* signal required for the lifetime measurement. The *Stop* signal is provided by one of the gamma quanta released from the positron electron annihilation. Details of the required fast detectors with associated electronics for data readout can be found elsewhere (e.g. in CH2014).

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[2]Detailed information of this study –the positron lifetime spectrometer, variation of the lifetime in the biopolymer under axial pressure, complementary calorimetric measurements to determine the glass transition temperatures, further calculations and explanations as well as references to the specialist literature– can be found in the scientific original publication CH2014.

[3]For our experiments, the sample material (from Haribo GmbH& co. KG) was privately funded by the project leader. Since only red samples were used, the remaining material could be distributed among the experimenters to further increase their motivation.

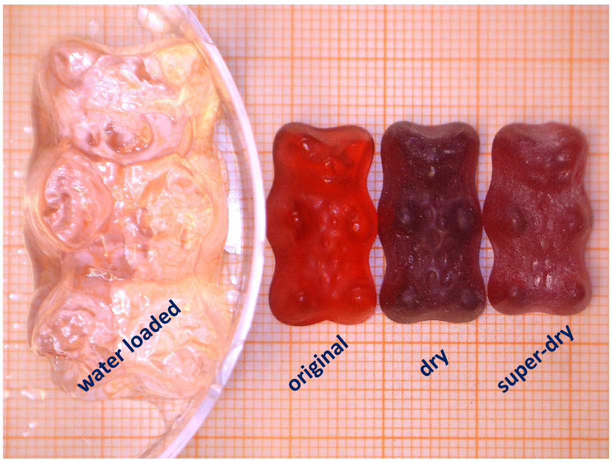

Figure 1: The sample family.

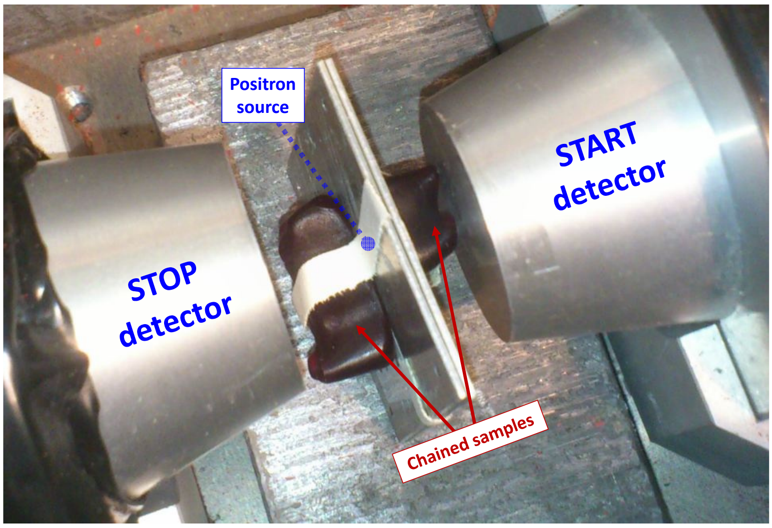

Figure 2: Set-up for the lifetime measurement of positronium in gummy bears. The positron source is mounted inside thin foils hold by the alumimium frame.

The Results

The analysis of the recorded time spectra was carried out by a two-component decomposition in exponential functions of the form

$$I(t) = I_1 \exp^{-t/\tau_1} + I_2 \exp^{-t/\tau_2} + c_{bgr}$$

with the characteristic lifetimes τ_1 and τ_2 with the corresponding intensities I_1 and I_2; the constant background is accounted for by c_{bgr}. The short lifetime component, which corresponds to the short-lived para-positronium (positronium with antiparallel orientation of electron and positron spin, τ =125 ps) and the direct positron electron annihilation without formation of positronium, is not relevant for further evaluation. The long lifetime τ_2 is directly related with the size of the nano-pores, wherein the positronium[4] annihilates.

Figure 3 shows exemplarily the raw data of the time spectra for the dried and water-loaded sample. Even by the naked eye we can clearly assess that drier gummy bears shorten the positronium lifetime considerably, and the associated intensity is decreased as well. The red

[4]In fact, we consider here the long-lived *otho-positronium* with parallel alignment of electron and positron spin, which is briefly called *positronium*

lines demonstrate the excellent agreement of the fitted exponential functions to the measured data for the long lifetime component.

The data analysis of all spectra allows the quantitative comparison of the measured positronium lifetime τ_2 with the degree of dryness and the associated density change of the biopolymers (see Figure 4). The duplicate values of the dried samples demonstrate the excellent reproducibility of the results obtained by repeated measurements. The decrease in positronium lifetime can clearly be observed with increasing degree of dryness of the gummy bears In the water-loaded state, the positronium lifetime amounts to about 1860 ps while in super dry gummy bears this value decreases by more than a third to 1200 ps. Also the intensity I_2, which is a measure of the total free volume, decreases significantly by drying the biopolymers.

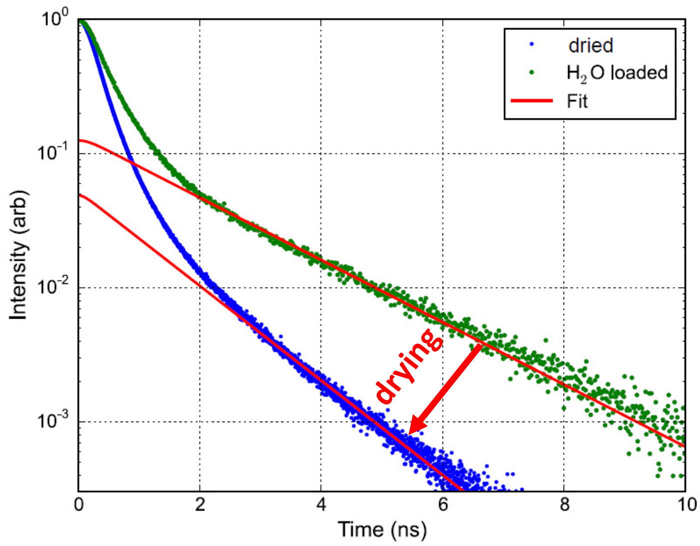

Figure 3: Raw data of the lifetime spectra: The considerably shorter positronium lifetime in the dried gummy bears can clearly be observed.

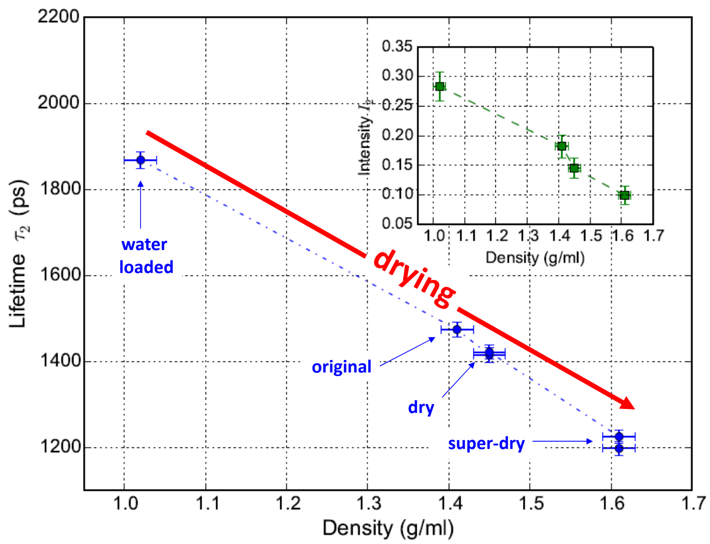

Figure 4: The positronium lifetime τ_2 and the associated intensity I_2 (insert) in gummy bears depending on their density and thus at different water contents.

The Free Volume

The application of a semi-empirical quantum mechanical model allows us to determine the average size of the nano-pores from the measured lifetime τ_2. If we solve the radial Schrödinger equation using the single-particle wave function of positronium in a spherical cavity, we obtain the correlation between positronium lifetime and cavity radius R

$$\tau_{\mathrm{o-Ps}} = \frac{1}{2}\Big(\frac{\Delta R}{R} + \frac{\sin[2\pi(1-\Delta R/R)]}{2\pi}\Big)^{-1}\mathrm{ns}$$

with the empirically determined parameter ΔR=1.656 $\mathring{A}$.[5]

The deduced values for the mean size V of the nano-pores, the relative change of the free volume with respect to unharmed gummy bears $\Delta V_{tot}/V_{tot,0}$ and their mass density ρ are summarized in the table. For the calculation of the total free volume both is required, the mean size of the nano-pores and their number, which can be estimated from the variation of I_2. In comparison to the water-loaded sample, the approximately 2.5 times lower mean volume of the nano-pores of only 33.5 $A^mathring$ in super-dried gummy bears leads to a a significantly lower positronium lifetime. Together with the much lower I_2 values it can be concluded that the free volume in the super-dry sample is six times smaller compared to the water-loaded bear.

sample	ρ [g/cm^3]	V [$\mathring{A}^3$]	$\Delta V_{tot}/V_{tot,0}$
H_2O loaded	1.02(2)	84.3(1.9)	2.54(23)
original	**1.41(2)**	**51.6(1.3)**	**1.00(11)**
dry	1.45(2)	47.1(1.3)	0.48(10)
super-dry	1.62(2)	33.5(1.0)	0.41(5)

Table 1: The microscopic values of the biopolymers determined by PALS: mean radius r and mean volume V of the nano-voids; change of the total free volume $\Delta V_{tot}/V_{tot,0}$.

Upshot

The lifetime reduction of positronium, i.e. of a bound system of an particle and its anti-particle, has been clearly observed in dried gummy bears. This observation is attributed to the size reduction of the nano-pores by dehydration of the biopolymers.

In fact, the method of positron annihilation lifetime spectroscopy is applied for the non-destructive characterization not only of biopolymers but also of the free volume in any amorphous substances –polymers and inorganic glasses. By now, specifically for this purpose an international conference was organized for the eleventh time.[6]

Literature

CH2014: Christoph Hugenschmidt and Hubert Ceeh. *The free volume in dried and H_2O loaded biopolymers studied by positron lifetime measurements.* The Journal of Physical Chemistry B, 118 (2014) 9356

[5] The mathematical derivation according to the so-called Tao-Eldrup model can be found in the Appendix of CH2014; details and extensions to the model can be found in the references given there too.

[6] 11^{th} International Workshop on Positron and Positronium Chemistry (PPC-11), 2014