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Positron annihilation in Kapton source-supporting foils

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Abstract. The fraction of positrons annihilated in the Kapton support of a positron source has been measured as a function of the atomic number, Z, of the sample studied. The data have been filtered by both exponential and logarithmic laws obtained from a backscattering model. Two formulas are given to correct the source contribution in a positron lifetime experiment. The results shown that the exponential fit is satisfactory for low atomic numbers while a logarithmic fit is better for $Z > 30$.

1. Introduction

Nowadays, positron annihilation techniques are common tools in the study of defects in solids [1, 2]. Positrons for annihilation experiments are obtained from active sources such as ^{22}Na, ^{64}Cu or ^{68}Ge. Usually, the sources are made by depositing the radioactive substance between two identical thin foils of Al, Ni or plastic materials and mounted between two identical samples in a sandwich configuration. Therefore the foils must insulate the samples from the radioactive substance and their thickness must be very small to be sure that only a small fraction of the positrons is absorbed by them. In this respect the polyamide Kapton is very interesting. This material has the physical and chemical properties desirable in a source support in a wide temperature range and its positron lifetime spectrum has only one component with a value of 382 ps [3], not dependent on the temperature [4].

It is well known that in the above-mentioned source arrangement, the number of positrons annihilated (i.e. the intensity of the exponential component) in the source itself plays an important role in the analysis of the positron lifetime spectra. In the case of ^{22}Na the source is usually made by evaporating a water solution of ^{22}NaCl onto the support, giving rise to an intense source component produced by the positrons annihilated in the salt crystals. In addition, an extra component due to positrons annihilated in the support foils must be taken into account. In the case of a Kapton support, the salt component can be included in the Kapton characteristic positron lifetime, $\tau = 382$ ps. Then, the source spectrum is reduced to one component, simplifying the data analysis.

In both cases, metal support or Kapton support, the thickness of the foils drastically increases the intensity of this component and introduces a complex backscattering process. The main interest is to obtain a relation between the source intensity and the atomic number of the sample measured.

In this paper, we report results on positron annihilation intensities in Kapton sources obtained from lifetime measurements. The results are fitted by two empirical equations as a function of the atomic number of the sample.

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2. Experimental details

All measurements have been carried out with high-purity samples (see table 1), ranging from Mg ($Z = 12$) to Bi ($Z = 83$). Every specimen was mechanically polished, vacuum annealed close to the melting point and slowly cooled down to room temperature. In some cases, after this treatment, a chemical polish was done.

Positron lifetime spectra were recorded at room temperature using a fast–fast coincidence system with a resolution of 218 ps (FWHM). The positron source was made by evaporating a water solution of ^{22}NaCl onto a standard Kapton foil (7 μm thickness and 1.065 mg cm^{-2}) and sealed with another one. The data were analysed with the classical computer program POSITRONFIT. The spectra were fitted by two components and without subtraction of any source component. In all cases the variance of the fit was good.

In order to find the influence of the source activity on the intensity of the source component several samples were measured with a lower-activity source. The results show the independence of the source intensity from its activity.

3. Results and discussion

The results obtained from the analysis of the spectra showed the presence of two components, a component with a long lifetime ranging between 372 ps and 385 ps, close to the positron lifetime in Kapton, and a component with a short lifetime which was always in agreement with the characteristic positron lifetime in the defect-free sample [5]. The intensity of the long-lifetime component has been assigned to the positron fraction annihilated in the source.

Table 1. Experimental results for the annihilation fraction of positrons in a ^{22}Na source sandwiched between two Kapton foils. The data correspond to a two-component free analysis. The long-lifetime component ranges between 372 ps and 385 ps.

Element	Z	Bulk lifetime (ps)	Source intensity (%)	Purity (%)
Mg	12	225	9.9	99.9999
Al	13	166	10.5	99.999
Si	14	223	11.0	99.99
Ti	22	154	14.2	99.8
Zn	30	154	15.6	99.999
Ge	32	228	14.6	99.99
Zr	40	163	14.6	99.99
Ag	47	130	15.8	99.9999
Cd	48	184	14.7	99.9999
Sn	50	199	15.2	99.999
Pb	82	204	16.5	99.9999
Bi	83	241	17.5	99.99

Table 1 presents the experimental results obtained as well as the purity of the samples used in this work. The values obtained for the lower-activity source have been omitted from the table because there were no differences when compared with the higher-activity source, indicating that the source intensity is independent of the amount of ^{22}Na deposited between the foils in the activity range studied.

Figure 1 shows the evolution of the source intensity with the atomic number of the sample. For low atomic numbers, $Z < 30$, the intensity increases very quickly from 10% to

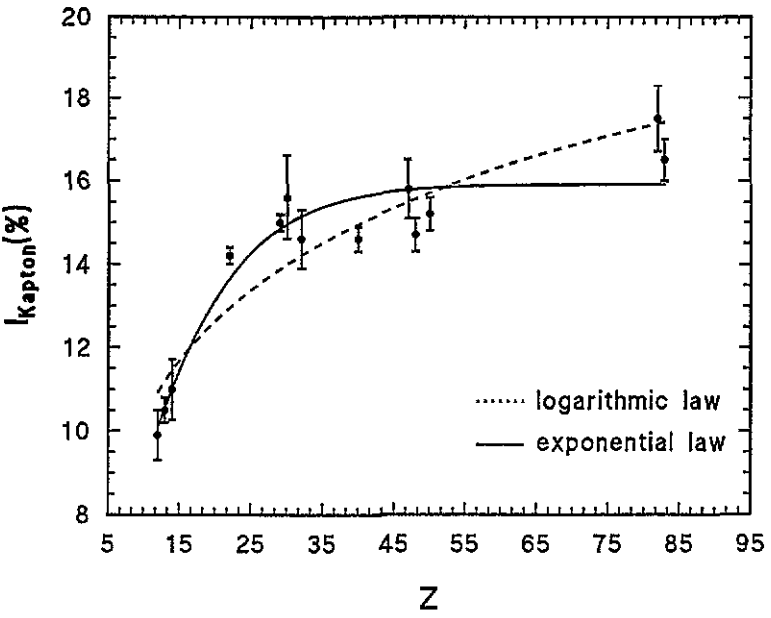

Figure 1. The fraction of positrons annihilated in the source-supporting Kapton foils as a function of the atomic number, Z, of the sample. The lines represent the data fitted by equation (4) (– – –) and by equation (5) (——).

approximately 15%. Between $Z = 30$ and $Z = 50$ the value achieved for I_{Kapton} could be considered constant at an average value of 15%. However, the values obtained for Pb and Bi show a slow increase in the source intensity for samples with an atomic number higher than 30.

The number of positrons transmitted through the foils can be described by the following law:

$$I_T(s) = I_0 e^{-\alpha s} \tag{1}$$

where s is the thickness in mg cm^{-2} of the absorber, I_0 the incident intensity of positrons and α the positron absorption coefficient. We will consider the absorption in the salt as negligible in comparison with the absorption in the supporting foils. With this simplification, a fraction $(I_0 - I_T)/I_0$ of emitted positrons is annihilated in the foil thickness s_f. The remaining fraction of positrons reaches the interface between foil and sample, where the positrons can be backscattered into the supporting foils with a probability given by the backscattering coefficient.

The positrons backscattered in the first interaction with the sample return to the source, where they can be again backscattered into the sample or annihilated in it. This process could be repeated an infinite number of times. Then the relative number of positrons annihilated in the foils is given by

$$I_f(Z) = (1 - e^{-\alpha_f s_f}) + \sum_{n=1}^{\infty} R^n(Z) e^{-\alpha_f s_f (1+2n)} (1 - e^{-2\alpha_f s_f}) \tag{2}$$

where α_f is the foil absorption coefficient, s_f is the thickness of the supporting foil and $R(Z)$ is the backscattering coefficient. The most important terms of the latter series are

those with low power n, which have the highest contribution to the intensity of the source component. The latter equation is a simple geometrical series, which sums to

$$I_f(Z) = (1 - e^{-\alpha_f s_f}) + e^{-\alpha_f s_f} R(Z)(1 - e^{-2\alpha_f s_f})/[1 - R(Z)e^{-2\alpha_f s_f}]. \tag{3}$$

To solve the latter equation it is necessary to know the dependence of $R(Z)$ on the atomic number. MacKenzie *et al* have reported two kinds of dependence of $R(Z)$ [6]. Their results show that at both low and high Z the data are satisfactorily fitted by an exponential law with saturation. However, in the region $30 < Z < 70$ the results are overestimated. A much better fit over the entire region is afforded by a logarithmic law.

In accordance with this result we have used two dependences for $R(Z)$, a logarithmic law ($R(Z) = A\ln(Z) + B$) and a exponential law ($R(Z) = A(1 - e^{-BZ})$) in order to obtain two empirical equations for the dependence of I_f on the atomic number. The results obtained from a least-squares fit are

$$I_{\text{Kapton}} = 88.1 + \frac{11.7(0.35\ln Z - 8.11)}{1 - 0.014(0.35\ln Z - 8.11)} \tag{4}$$

for a logarithmic fit and

$$I_{\text{Kapton}} = 3.5 + \frac{4/21(1 - e^{-0.117Z})}{1 - 0.68(1 - e^{-0.117Z})} \tag{5}$$

for an exponential fit.

In figure 1 we show the fit of the data in both cases. As can be seen in the low-Z region, $Z < 30$, the data are satisfactorily fitted by an exponential-type equation. However, for higher atomic numbers the logarithmic approximation is better. This result is in agreement with the behaviour of $R(Z)$ proposed by MacKenzie *et al*, indicating that positrons annihilated in the source originate from a backscattering process in the sample–source interface.

4. Conclusion

The value for the positron fraction annihilated in a Kapton supporting foil has been measured for a wide atomic number range. The data have been fitted by both exponential and logarithmic laws. The results show that for atomic numbers lower than 30 an exponential fit is the best, while for higher Z a logarithmic law gives a better fit.

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