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ABSTRACT

A fast-slow coincidence system was constructed for the measurement of positron lifetimes in material. The time resolution of this system was 270 ps for the ^{60}Co γ rays. Positron lifetime spectra for 14 kinds of alkali halides were measured with this system. Two lifetime components and their intensities were derived from analyses of the lifetime spectra.

1. Introduction

When positrons shine in matter, the majority lose their energy of momentum in a short amount of time when inelastic dispersion is repeated and are annihilated when they bond with electrons. In order to maintain the amount of energy and momentum, 2 annihilation γ rays (energy $m_0c^2=511$ keV) are emitted in opposite directions at this time. The transmission power of the rays is large and therefore, information on the electronic structure, and in particular, on the amount of momentum and dispersion of electrons and electron density, in matter can be obtained with this annihilation γ ray measurement method. The positron is not very close to the nucleus because it has a positive charge and therefore, bonds with the outer electrons and is annihilated. Therefore, it is sensitive to lattice defects, etc. Consequently, the positron annihilation method is being used in fields such as materials science, radiation chemistry, etc. [1].

There are two types of positron annihilation methods, the method whereby the amount of momentum and dispersion of a pair of annihilation electrons are measured and the method whereby positron lifetime is measured. The first method is further divided into the angle correlation method and the γ ray

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** Numbers in margin indicate pagination of foreign text.

energy measurement method. In the angle correlation method, a simultaneous computation of the angle at which the 2 annihilation γ rays slip from 180° C (0-2 mrad) is carried out. Until now this method has been effective in research on film surfaces of metals, etc. However, in order to improve angle analysis and computation rates, a positron ray source with a strong $\mu\text{Ci-Ci}$ is necessary. Therefore, these are not simple methods. On the other hand, in the γ ray energy measurement method, the width of the energy of the annihilation γ ray (1-3 keV) is measured with the Doppler effect, which causes movement of the electrons. Theoretically, the same information obtained with the angle correlation method is obtained with this method. However, the angular decomposition ability is low at almost 1 line. Nevertheless, this is a simple method in that a weak positron ray source of 10 μCi is sufficient and a complex measurement cycle is unnecessary.

In the 2nd method, the measurement of positron lifetime, the timewise lag between the 1.27 MeV γ ray, which is emitted with ^{22}Na decay, and the 511 keV annihilation ray, which is emitted with positron annihilation, is measured using ^{22}Na as the positron ray source.

The speed at which positrons are annihilated in material is proportional to the probability that electrons are present at that position. The annihilation probability is as high and the lifetime of the positron is as short as the electron density is high. It is known that the positron lifetime spectrum in metals consists of 1 component with a lifetime of 200-400 ps and that in alkali halides it consists of 2 components with lifetimes of 200-250 ps and 500-650 ps.

Furthermore, lifetime is long when the positrons form quasistable positronium by bonding with electrons in the sample and are captured by the atomic air holes. Positron lifetime measurement is employed in many fields because the conventional fast-slow coincidence system, which is being used in nuclear spectroscopy, can be used, a positron ray source strength of several μCi is sufficient, differences in electronic structure and their thermal changes, etc. with regard to almost all types of materials can be detected with sensitivity, etc.

Time is measured in picoseconds in the positron lifetime measurement method and therefore, a fast coincidence system is necessary. The time decomposition ability of positron lifetime gauges reported thus far has been 250-350 ps. The measured lifetime spectrum can be analyzed with an electronic calculator.

We made a positron lifetime gauge using the most recent electronics. Measurements of the positron lifetime spectra with regard to 14 types of alkali halides were measured with this gauge and a method for analyzing the spectra was developed. The properties of this lifetime gauge, the method for analyzing the lifetime spectra, and the results of alkali halide analyses will be reported in this text.

2. Experiment

2.1 Positron Lifetime Gauge

2.1.1 Ray Source and Ray Detector

^{22}Na was employed as the positron ray source. After ^{22}Na was made to adhere to the top of a 10 mm x 10 mm x 2 mm alkali halide single crystal sample, it was sandwiched with the same sample and wrapped in aluminum foil. In order to prevent the sample from becoming dirty, it was placed in a 1 mm thick acrylic container, which was then tightly sealed. The ray source strength was about 2 μCi .

The decay scheme of ^{22}Na is shown in Figure 1A. ^{22}Na became ^{22}Ne by first going through transition to the 1st excitation state of ^{22}Ne with β^+ decay (90.5%) and electron capture (9.5%) and then emitting γ rays with an energy of 1.27 MeV. The lifetime of the first excitation state of ^{22}Ne (3.7 ps) is usually very short in comparison to the time resolution ability of

positron lifetime gauges (250–350 ps). Therefore, the time when the 1.27 MeV γ ray was detected can be regarded as the time when positrons were produced. The time when a 511 keV annihilation γ ray was detected is the time when positrons were annihilated. Therefore, the lifetime of positrons in the samples was determined from the difference between the two.

In addition, a γ ray from ^{60}Co was employed to determine the time resolution of this lifetime gauge. A ^{60}Co ray source of about 10 Ci was prepared and tightly sealed in an acrylic container. The decay scheme of ^{60}Co is shown in Figure 1B. ^{60}Co becomes ^{60}Ni by emitting the 2 main γ rays of 1.17 and 1.33 MeV with β^- decay.

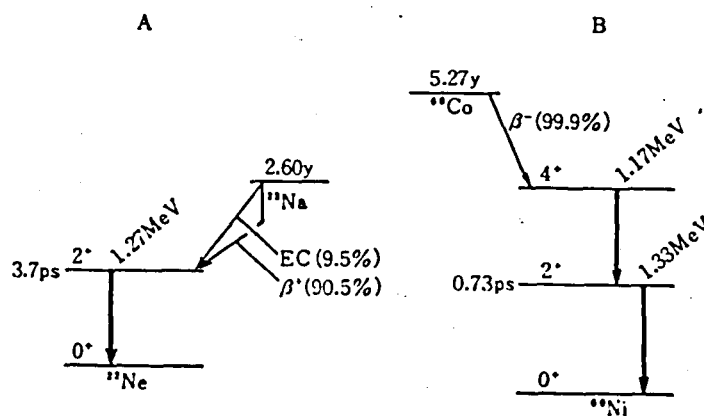


Fig. 1 Decay Schemes of ^{22}Na (A) and ^{60}Co (B).

At this time, the lifetime of the 1st excitation state of ^{60}Ni is very short at 0.73 ps. Therefore, these 2 γ rays can be regarded as rays that are simultaneously emitted. The time resolution ability of the lifetime gauge is generally expressed by the full width half maximum (FWHM) of the time resolution curve (prompt curve) when these 2 rays of ^{60}Co are measured.

A plastic scintillator was employed in detection of γ rays because time response is good. Moreover, it is necessary that the time for an increase in the output of the photo-multiplier which converts the light emitted by the scintillator to electronic signals, be short. Therefore, the Pilot-U (fluorescence reduction time of 1.36 ns) made by Nuclear Enterprise with a size of $\phi 25.4 \text{ mm} \times 25.4 \text{ mm}$ was

employed as the plastic scintillator in this gauge. The RCA 8850 (anode pulse increase time of 2.5 ns) was used as the photomultiplier. The applied voltage of the photomultiplier, which was determined by considering the wave height of the output pulse and the time resolution ability, was -2150 V on the start side and -2300 V on the stop side. The wave height value of the anode pulse of the photomultiplier at this time was 6 V with a load of 50 γ with regard to the γ ray of ^{60}Co .

2.1.2 Fast-Slow Coincidence System

A block diagram of the positron lifetime gauge is shown in Figure 2. The gauge was assembled using mainly the electronics module of the ORTEC company. Fast timing technology is essential for positron lifetime measurements and therefore, a fast-slow coincidence system, which consists of the 2 systems of a timing system (fast system) and energy discrimination system (slow system), was employed. In Figure 2, the path from the anodes of the right and left photomultiplier to the time to amplitude converter (TAC) through the constant fraction discriminator (CFD) is called the fast system and the path from the dynode of the photomultiplier through the single channel analyzer (SCA) to the coincidence device (COIN) is called the slow system. Furthermore, the system on the left is called the start system and the system on the right is called the stop system.

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Of the outputs from the photomultipliers, the anode output has good time response. Therefore, it is used in the timing of the fast system. The dynode output is proportional to the energy of the γ ray, which shines on the scintillator, and therefore, was used in wave height discrimination. If the CFD (ORTEC 473 A) has the same input pulse wave shape, timing signals with small fluctuations over time will be produced even though the amplitude varies. With this system the timewise fluctuations (walk) in the timing signals are ± 200 ps with regard to changes in the wave height of the output pulse from 50 mV to 5 V. Moreover, the timing signals of the stop system are connected to the TAC (ORTEC 467) through a delay circuit for time revisions. The TAC is a circuit which converts the time difference between the 2 timing signals to

voltage pulses. A time difference of 50 ns corresponds to a voltage pulse of 10 V.

The SCA of the slow system (ORTEC 20 A) is the differential type wave height discriminator. Discrimination output only with regard to input pulse within the ranges of the 2 top and bottom discrimination levels is produced. The SCA timing signals of the start and stop systems are input into the coincidence system and when the stop signal difference is within 20 ns, coincidence output is obtained.

Pulses pass from the TAC through the linear gate connected to the TAC when the gate opens when coincidence signals are produced. The signals that pass through the linear gate are analyzed with the 400 channel multichannel pulse height analyzer (Toshiba EDS-34802) and a positron lifetime spectrum is obtained. Time revisions in this gauge are carried out by determining the peak shift in the ^{60}Co prompt curve with the delay time of the delay circuit being varied. The time scale was 27 ps/channel. Moreover, the time resolution of only the fast system, which was measured by connecting the test pulser to the input of the CFD, was 31 ps (1.5 channel).

2.2 Measurement of Time Resolution

when γ rays are detected with the organic scintillator, such as a plastic scintillator, the atomic symbols of its structural elements are small and therefore, adsorption of γ ray energy is controlled by the Compton effect. Consequently, the energy spectrum obtained is dispersed with the Compton edge energy being close to the maximum, even with regard to the γ rays of single energy.

The changes in time resolution when the CFD discrimination level is varied up to 0-90% of the Compton edge energy using a ^{60}Co ray source are shown in Figure 3. As shown in the figure, the time resolution is almost constant at 27 ps (10 channel) with a discrimination level of 80% or more. This value is the time resolution obtained with this lifetime gauge.

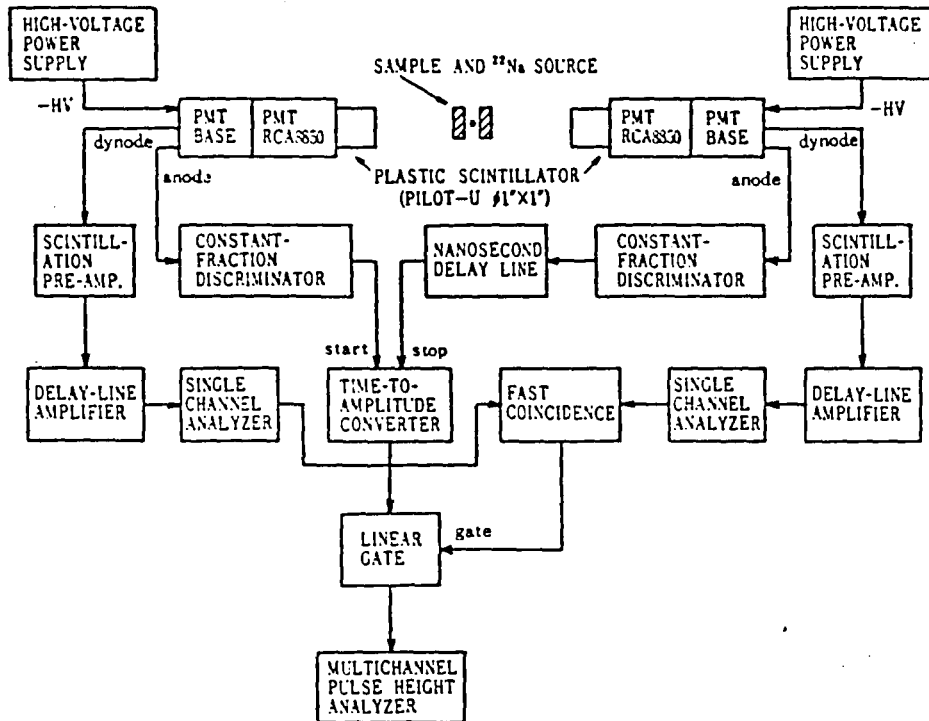


Fig. 2. Fast-slow coincidence system for the positron lifetime measurement.

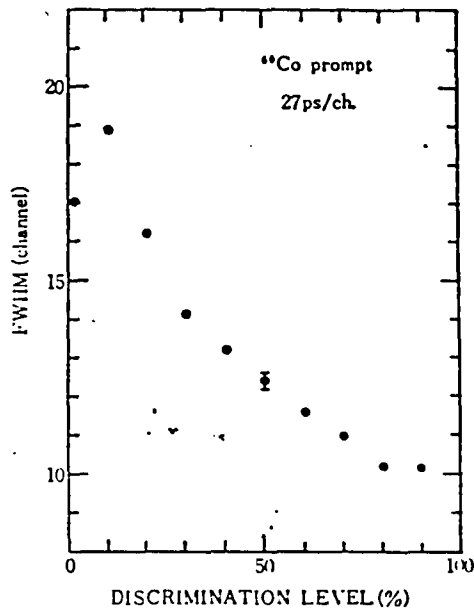


Fig. 3 Time resolution of the lifetime measurement system vs. the discrimination level of the constant fraction discriminator. FWHM means the full-width at half-maximum of the ^{60}Co prompt curve.

CFD walk is as small as the established discrimination level is high. On the other hand, the discrimination level must be established taking the time resolution and coincidence rate into consideration in actual measurements because the coincidence rate decreases when the discrimination level of the CFD is high. The ^{60}Co prompt curve when the discrimination level was set at 85% is shown in Figure 4A.

Next, the shape of the ^{60}Co prompt curve will be studied. As shown in Figure 4A, this curve has good symmetry and is shaped similar to the Gaussian function. However, it rounds out at about 1/5 below the peak value. An attempt to fit this curve to the Gaussian function was made. Figure 4B shows the results using 1 Gaussian function and Figure 4C shows the results using 2 Gaussian functions. The prompt curve can be accurately represented with the sum of 2 Gaussian functions. At this time, the Gaussian function in the narrow width direction is an FWHM of 8.0 channel and the surface area ratio with regard to the entire prompt curve is 44%. In addition, the FWHM of the wide Gaussian function is 17.0 channel.

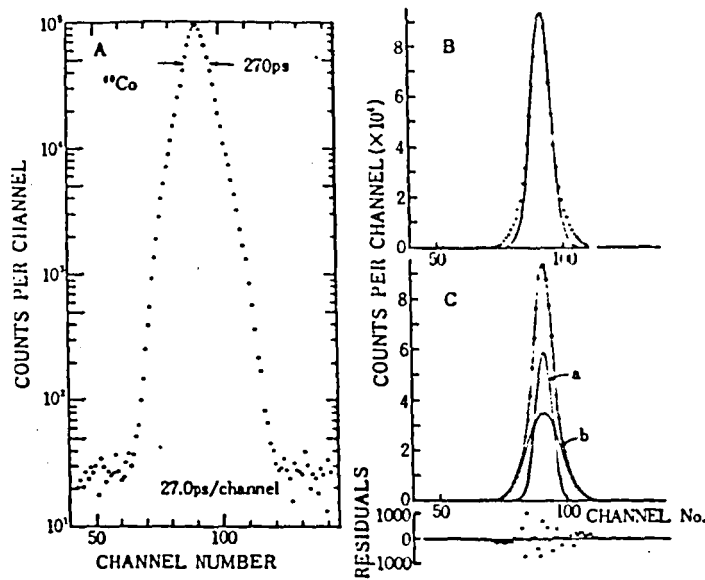


Fig. 4 (A) ^{60}Co prompt curve measured with the discrimination level (CFD level) at 85% of the Compton-edge energy in the γ -ray spectrum. The prompt curve was fitted to Gaussian functions; (B) Single Gaussian. (C) A sum of two Gaussian functions a and b.

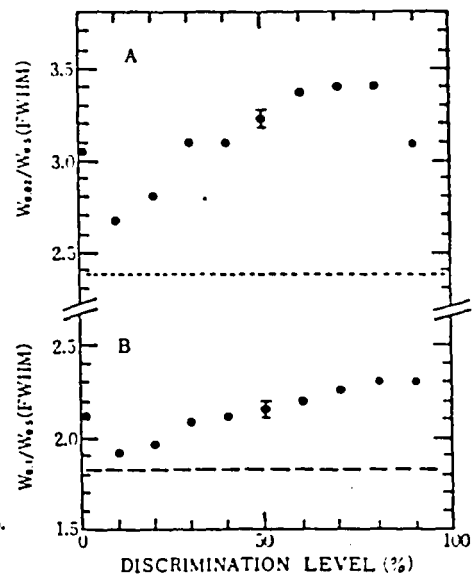


Fig. 5 CFD level dependence of the ^{60}Co prompt curve. (A) The ordinate indicates the ratio of the full-width at fiftieth maximum of the prompt curve ($W_{0.02}$) to the FWHM. (B) The ordinate indicates the ratio of the full-width at tenth maximum of the prompt curve ($W_{0.1}$) to the FWHM. Dotted and broken lines are those of 3 Gaussian function.

The results of studying the lags in the prompt curve from /153
the Gaussian function when the discrimination level of the CFD was varied are shown in Figure 5. The ordinate in Figure 5A shows the ratio of the full width at fiftieth maximum of the prompt curve ($W_{0.02}$) to the FMWH. The ordinate in Figure 5B shows the ratio of the full width at tenth maximum of the prompt curve ($W_{0.1}$) to the FMWH. The dotted lines and broken lines are the values for the Gaussian functions, 2.38 and 1.82. When the discrimination level is low, the shape of the prompt curve is close to the Gaussian function. However, time resolution deteriorates a great deal, as shown in Figure 3. When the discrimination level is high, time resolution ability is good, but it is clear that the shape of the curve slips from the Gaussian function.

2.3 Measurement of Positron Lifetime in Alkali Halides

The positron lifetime spectra in 14 types of alkali halides was measured using this lifetime gauge. Those samples used in measurements of the positron annihilation γ ray energy spectrum [2] were remeasured.

Measurements were carried out for 12 consecutive hours on each sample. Room temperature during the measurements was held constant with air conditioning to about 24° C. Measurements were carried out in 1,000 second intervals with the ray source being replaced with ^{60}Co during each measurement. There were no changes in the time resolution of the device. The lifetime spectra of the alkali halides measured are shown in Figure 6.

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The CFD discrimination levels of the stop and start systems were each set at 85% of the Compton edge energy of the ray. Consequently, the CFD discrimination level of the stop system was less than 1/2 of the start system in order to detect the 511 keV γ ray. In order to determine the response function of the equipment with regard to this type of measurement, the ^{60}Co prompt curve was measured with the CFD discrimination level being set the same as during the lifetime measurements. In Figure 7, A is the prompt curve in the case where the discrimination level was set at 85%, as mentioned in 2.2, and B is the prompt curve in the case where the discrimination level of the stop system was set at the same value as during lifetime measurements. The latter has an FWHM of 11.4 channel (308 ps), which is somewhat wider than the former. However, the latter is more suitable with regard to the response function corresponding to the lifetime spectra.

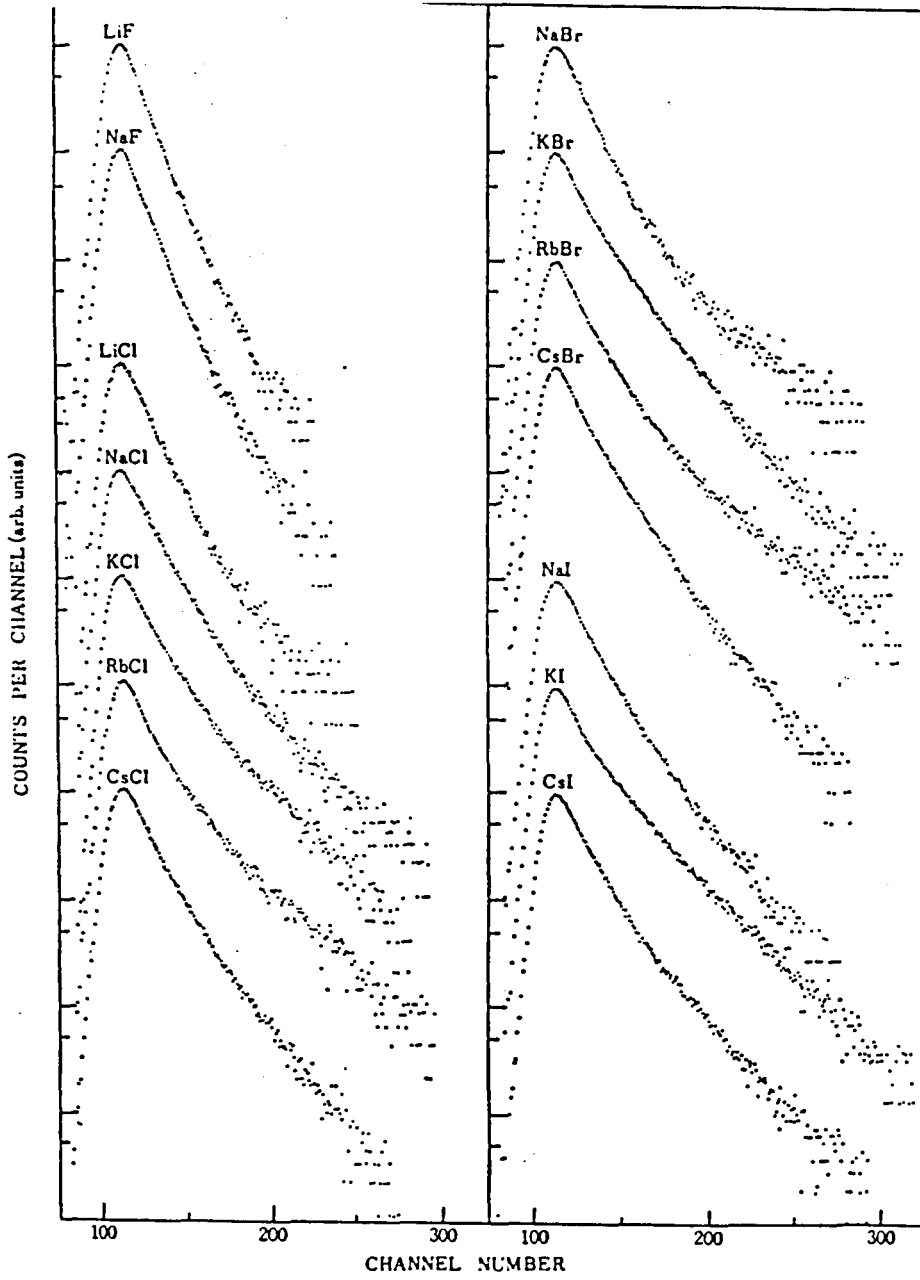


Fig. 6 Positron lifetime spectra for 14 kinds of alkali halides.

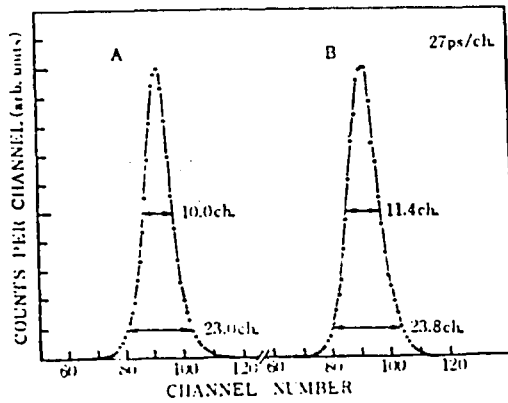


Fig. 7 ⁶⁰Co prompt curves at CFD level of 85% for start and stop CFD (A) and at the level similar to the positron lifetime measurement (B).

3. Analysis of Positron Lifetime Spectra

3.1 Analytical Method

In general, the spectra obtained with various gauges are displayed by convolution of the response function of the device and the true spectrum. When the effects of the response function of the true spectrum cannot be disregarded, deconvolution of the resolution of the device must be carried out with regard to the spectrum measured. This method has been carried out for many years in many fields [3]. Deconvolution is also necessary in analysis of the positron lifetime spectrum.

When the measured lifetime spectrum is $F(x)$ (x is time and corresponds to the channel number.), the true lifetime spectrum is $f(x)$, and the response function is $g(x)$,

$$F(x) = \int_{-\infty}^{\infty} f(t)g(x-t)dt, \quad (1)$$

provided that

$$\int_{-\infty}^{\infty} g(x)dx = 1$$

In the case of lifetime spectra, $f(x)$ is expressed as the sum of several exponential functions. Therefore,

$$f(x) = \sum_m A_m \exp(-\lambda_m x), \quad (2)$$

$$\lambda_m = 1/\tau_m$$

Here, λ_m shows the annihilation probability and τ_m shows the lifetime. Moreover, the strength of the lifetime τ_m component becomes $I_m = A_m / \lambda_m$. Consequently, A_m and λ_m in equation (2) should be found to determine the lifetime and strength.

These are determined with the nonlinear minimum square method as follows.

$F(x)$ is Taylor developed by the initial value $p_k^0 (k=1 \sim l)$ of the l parameter $p_k (k=1 \sim l)$ and taken up to the primary item. That is, when $p_k \approx p_k^0 + \Delta p_k$

$$\begin{aligned} F(x; p_1 \sim p_l) &\approx \bar{F}(x; \Delta p_1 \sim \Delta p_l) \\ &= F(x; p_1^0 \sim p_l^0) + \sum_{k=1}^l \left(\frac{\partial F}{\partial p_k} \right)_0 \Delta p_k \quad (3) \end{aligned}$$

$\bar{F}(x)$ becomes the linear function of $\Delta p_1 \sim \Delta p_l$. Thereupon, the residual sum becomes

$$\chi^2 = \sum_{i=1}^n w_i (C_i - \bar{F}_i)^2 \quad (4)$$

when $\bar{F}(x=i) = \bar{F}_i$. Here, n_i is the total number of channels used in the fitting and c_i is the coincidence value in channel number i . Moreover, w_i is the weight of i . ($w_i = 1/c_i$).

$\Delta p_1 \sim \Delta p_l$ is determined by solving the following simultaneous equation in order to obtain the minimum of χ^2 .

$$\frac{\partial \chi^2}{\partial (\Delta p_k)} = 0, \quad (k=1 \sim l) \quad (5)$$

The refixed $p_k^1 = p_k^0 + \Delta p_k (k=1 \sim l)$ of the 1st cycle is determined by adding these values to the initial values. By repeating this process, the optimum value of each parameter can be obtained. If χ^2/ν ($\nu = n-l$, degree of freedom) is determined with every repetition, a good fit is obtained. That is, χ^2/ν becomes the simple χ^2 distribution of an average of 1, variance of $\sqrt{2/\nu}$ and is near 1 when the fit is good.

Here when $g(x)$ in equation (1) can be expressed with the Gaussian function

$$g(x) = a \exp \left\{ - \left(\frac{x - x_0}{\sigma} \right)^2 \right\} \quad (6)$$

$$\begin{aligned} F(x) &= \sum_{i=1}^n \frac{a}{2} \exp \left\{ - \lambda_m (x - x_0) + \frac{\lambda_m^2 \sigma^2}{4} \right\} \\ &\quad \left\{ 1 - \operatorname{erf} \left(\frac{\lambda_m \sigma}{2} - \frac{x - x_0}{2} \right) \right\} \quad (7) \end{aligned}$$

Here, $a=1/\sigma\sqrt{\pi}$, σ is the variance of the Gaussian function and I_0 shows the channels corresponding to a delay time of zero in the lifetime spectrum. After $F(x)$ is computed as shown here, the nonlinear minimum square method is used in the POSITRONFIT [4] well known as a lifetime spectrum analysis program. Nevertheless, the ^{60}Co prompt curve obtained in our lifetime measurements was beyond the single Gaussian function, as mentioned in 2.3. Thereupon, in this analysis, convolution was carried out on $F(x)$ in accordance with equation (1) to develop an analytical program.

F and $\partial F/\partial p_k$ in equation (3) were computed as follows.

$$F(x; p_1 \sim p_l) = F_i(p_1 \sim p_{l-1}, x_0) = \sum_{j=1}^n f_j(p_1 \sim p_{l-1}) g_{i-j}(x_0) \quad (8)$$

$$\left\{ \frac{\partial F_i}{\partial p_k} = \sum_{j=1}^n \left(\frac{\partial f_j}{\partial p_k} \right) g_{i-j} \right. \quad (k=1 \sim l-1) \quad (9)$$

$$\left. \frac{\partial F_i}{\partial x_0} = \sum_{j=1}^n f_j \left(\frac{\partial g_{i-j}}{\partial x_0} \right) \right\} \quad (10)$$

This method is suitable even when the response function is expressed with any curve.

3.2 Effects of the Analysis Series and Response functions.

This analysis method was used with regard to the lifetime spectrum of KCl. According to past studies, KCl lifetime spectrum consists of 2 components. We also carried out 2 component lifetime analysis. The lifetime spectrum of KCl is shown in Figure 8A. Moreover, in Figure 8B, the ^{60}Co prompt curve shown in Figure 7B is shown with 2 Gaussian functions.

The residual $C_i - \bar{F}_i$, ($i=1 \sim n$) is shown when the KCl lifetime spectrum was analyzed using this as the response function. As is clear from the figure, the fit is not good within a range of 85-110 channels. Therefore, the prompt curve shown in Figure 7B does not display optimum sensitivity with regard to the response function.

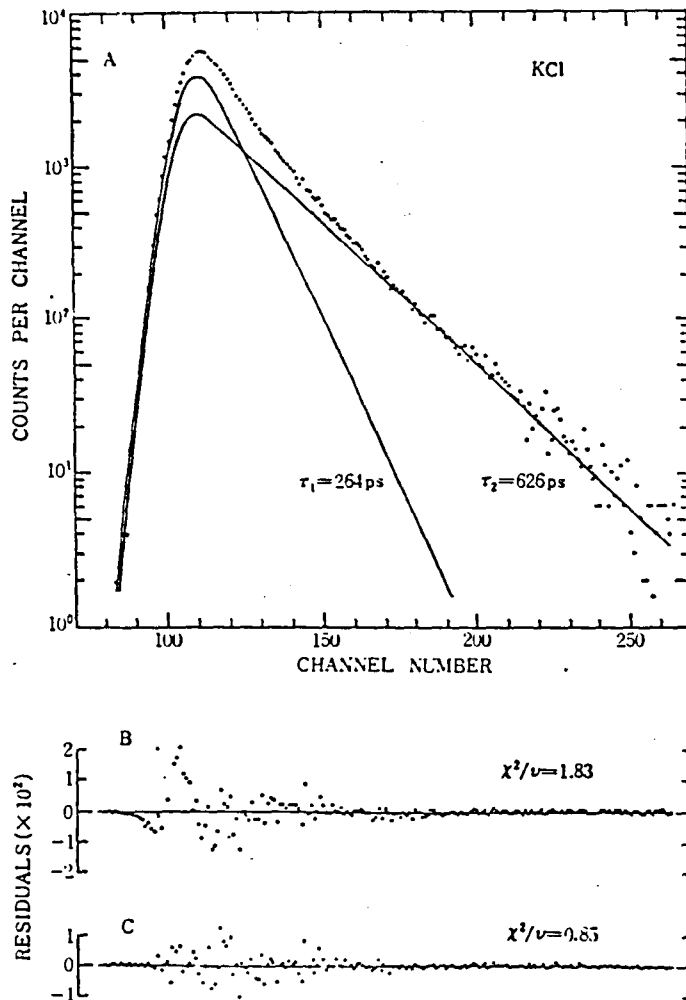


Fig. 8 Positron lifetime spectrum for KCl (A) and residuals in the analyses with two different response functions; ^{60}Co prompt curve (B) and a sum of two Gaussians having FWHM of 10 and 15 channels (C). Solid lines in figure A indicate the result of the analysis with latter response function.

The optimum response function for lifetime spectra analysis was determined as follows. With the response function being expressed by 2 Gaussian functions, the KCL lifetime spectrum was analyzed by varying the FWHM W_1 , W_2 and the ratio of strength, χ^2 and changes in lifetime in this case are shown in Figure 9. According to these results, optimum analysis is obtained when the FWHM is made 10.0 channels and the strength 53% with regard to a narrow Gaussian function and the FWHM is made 15.0 channels with regard to a broad Gaussian function. The FWHM was 11.5 channels for the response function determined in this way and the 1/10 width was 22.0 channels. The width is somewhat narrower in comparison to the results shown in Figure 7B. The residual in the case of analysis with the response function is shown in Figure 8C. The fluctuations are the statistical deviation in each value and a good fit is obtained. In addition, the solid line in Figure 8A shows the 2 components obtained with this analysis. This response functions may also be used in analysis of other alkali halides.

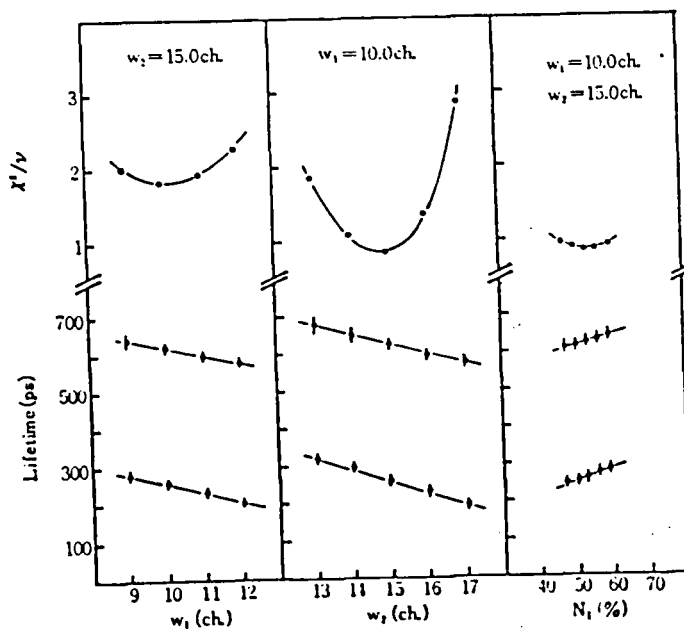


Fig. 9 Results in the analysis of the positron lifetime spectrum for KCl with various response functions. The response function was represented as a sum of a narrow Gaussian (FWHM = W_1) and a broad Gaussian (FWHM = W_2). N_1 means the intensity of the narrow Gaussian.

3.3 Positron Lifetime in Alkali Halides

The positron lifetime spectrum with regard to the 14 alkali halides shown in Figure 6 was broken down into 2 components to determine the lifetime and their strength. These results are shown in Table 1. In this table, $\bar{\lambda}$ is the mean annihilation rate and was determined with the following equation.

$$\bar{\lambda} = \lambda_1 I_1 + \lambda_2 I_2$$

Moreover, n^* is introduced by Bertolaccini, et al. [6] and signifies the number of anions per unit area, as expressed in the following equation.

$$n^* = \frac{nv_-}{1 - \frac{4}{3}\pi R_+^3 nv_+}$$

This is provided that

$$n = \frac{\rho N_0}{M}$$

Here, ρ is the density, N_0 is the avogadro number, M is molecular weight, R_+ is the cation radius, and v_- and v_+ are respectively, the number of anions and cations in 1 molecule. Bertolaccini, et al. experimentally showed that the mean annihilation rate of positrons in ionic crystals was proportional to n^* . This is due to the fact that positrons have a positive charge, and therefore, they are attracted by the cations in the crystal and are thereby annihilated. Figure 10 shows the correlation between the mean annihilation rate obtained from these experiments and n^* . The solid line and dotted line were obtained, respectively, from the test results of Kerr, et al., [6] and Bertolaccini, et al. [5]. Our results agree well with the other test results. They are particularly close to the results of Kerr, et al. with regard to samples with a large n^* .

Table 1. Positron lifetimes decomposed in two components and their intensities. $\bar{\lambda}$ and n^* indicate the mean annihilation rate and the number of negative ions per unit volume, respectively.

Sample	τ_1 (ps)	τ_2 (ps)	I_1 (%)	I_2 (%)	χ^2/ν	$\bar{\lambda}$ (ns ⁻¹)	n^* (10 ²² cm ⁻³)
LiF	184 ± 9	341 ± 9	49 ± 3	51 ± 6	1.21	4.17	7.77
NaF	245 ± 7	404 ± 23	79 ± 4	21 ± 7	1.27	3.74	4.87
LiCl	259 ± 19	462 ± 34	63 ± 7	37 ± 14	1.14	3.22	3.27
NaCl	287 ± 6	574 ± 13	66 ± 2	34 ± 4	1.14	2.89	2.63
KCl	264 ± 7	626 ± 10	54 ± 1	46 ± 3	0.85	2.78	2.06
RbCl	253 ± 7	698 ± 13	57 ± 1	43 ± 3	1.62	2.87	1.87
CsCl	259 ± 9	540 ± 10	50 ± 2	50 ± 4	1.37	2.85	2.32
NaBr	296 ± 4	694 ± 29	87 ± 1	13 ± 2	1.07	3.12	2.15
KBr	269 ± 6	558 ± 6	44 ± 1	56 ± 2	1.68	2.63	1.73
RbBr	303 ± 4	758 ± 15	74 ± 1	26 ± 2	1.53	2.78	1.46
CsBr	253 ± 6	539 ± 6	46 ± 1	54 ± 2	1.31	2.82	1.90
NaI	318 ± 11	547 ± 17	59 ± 4	41 ± 7	1.33	2.60	1.64
KI	274 ± 5	692 ± 5	48 ± 1	52 ± 2	1.10	2.50	1.35
CsI	309 ± 7	608 ± 12	62 ± 1	38 ± 1	1.18	2.63	1.46

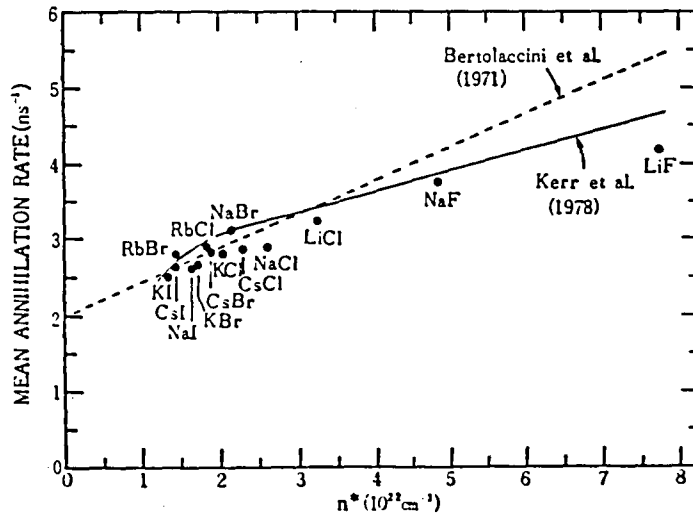


Fig. 10 Mean annihilation rate ($\bar{\lambda}$) as a function of the number of the negative ions per unit volume (n^*). Solid and broken lines indicate the experimental results obtained by Kerr et al.¹⁰ and by Bertolaccini et al.¹¹, respectively.

The fact that the positron lifetime spectrum with regard to alkali halides is made from 2 components shows that the annihilation process of positrons in these substances is complex. Of these 2 lifetime components, the short lifetime component seems to be the free annihilation of positrons and halogen ions (annihilation when bonding does not occur). Moreover, in the case of annihilation when the positrons are captured by the atomic air holes in regard to the long lifetime component, electrons and protons seem to form a quasistable state, just as positronium, and are annihilated. /158

4. Considerations

McKee and McMullen [7] and Fluss, et al. [8] report on the point that the ^{60}Co prompt curve is wider than the Gaussian function in the case where the plastic scintillator Pilot U was employed. Moreover, Eldrup, et al. [9] point out that the response function is important in determining the precise positron lifetime components. The ^{60}Co prompt curve obtained with our lifetime gauge was also wider in comparison to the Gaussian function. Moreover, its shape could be expressed as the sum of 2 Gaussian functions. The reason for this wide prompt curve is still unknown. Experiments where scintillators with different materials sizes and shapes are employed are necessary in order to determine the reason for the shape of the prompt curve with the Pilot U.

The optimum response function for analyzing the positron lifetime spectra was determined from computations where the KCl lifetime spectrum consisted of 2 components. The x^2/v values of other alkali halide lifetime measurements using this response function were sufficiently close to 1 and had a good fit.

In the analysis of the positron lifetime spectra in alkali halides, Kerr [6] divided the lifetime components into 3-4 components. Moreover, Bertolaccini, et al. also divided the components into 3 components with regard to CsBr, etc. Fitting may be carried out by increasing the number of components. However, it seems that analysis up to components with a weak strength lacks accuracy. We were able to break the spectra down

into 2 components as a result of lifetime spectra analysis with sufficient consideration given to the response function. In order to carry out decomposition of the spectra from alkali halides into more than 2 components, it is necessary to consider the response function and to improve the time resolution of the equipment.

5. Conclusions

Measurements of the positron lifetime spectra in alkali halides were carried out using a positron lifetime gauge. A time resolution of 270 ps was obtained. When compared to the Gaussian function, the ^{60}Co prompt curve obtained by using the plastic scintillator Pilot U was partially wider. Moreover, a method for analyzing the lifetime spectra was developed and 2 lifetime components were determined by breaking down the positron annihilation lifetime spectra of 14 types of alkali halides. This positron lifetime measurement method may play a role in physics research in the future.

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