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POSITRON ANNIHILATION IN PERFECT AND IMPERFECT METALS: A BRIEF REVIEW*

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ABSTRACT

The current renaissance of investigations of positron annihilation in solids has its origins in the observation that positrons interact strongly with certain crystal-lattice defects. Three properties of the annihilation process are being measured to gain information about the defects or about the local environment of the positron at the instant of its annihilation: positron lifetime, angular correlation of the two annihilation quanta, and Doppler broadening of the 511-keV annihilation line. Until the physics of positron behavior in solids is fully understood, the phenomenon will continue to be useful in a manner analogous to electrical resistivity recovery for identifying the recovery stages in irradiated metals. Ultimately, it is destined to provide detailed quantitative information such as the formation volume of vacancies, vacancy-impurity binding energies and electron momentum distributions and densities at defect sites.

INTRODUCTION

About ten years ago evidence began to accumulate suggesting that positrons can become trapped at imperfections in solids. This conclusion was based upon observations that the characteristics of the annihilation process could be influenced by changes in the concentration of defects in the solid in which the annihilations occurred. For example, the shape of the two-photon angular-correlation curve changed as a function of sample deformation or temperature[1,2] as did the mean lifetime of the positrons.[3] Similarly, a parameter describing the lineshape of the Doppler-broadened annihilation photopeak at 511 keV

also exhibited this property.[4] To explain these results, several groups[5,6] proposed a phenomenological trapping model which actually had been introduced earlier by Brandt.[7]

The central assumption of the simple trapping model is that positrons annihilate in a solid from a free or a trapped state. Escape from traps is neglected, and the rate of trapping κ is assumed to be proportional to the concentration of traps, c. Thus,

$$\kappa = \mu c \quad , \tag{1}$$

where μ is a parameter characterizing a specific trap type in a given solid.

The total fraction of annihilations from each state j will be:

$$F_j = \int_0^\infty \lambda_j p_j(t) dt \quad , \tag{2}$$

where λ_j is the annihilation rate from state j, and $p_j(t)$ is the probability that the positron is in state j at time t. A consequence of this two-state trapping model is that

$$F_f = \frac{\lambda_f}{\lambda_f + \mu c} \quad \text{and} \quad F_t = \frac{\mu c}{\lambda_f + \mu c} \quad , \tag{3}$$

where the subscripts f and t refer to the free and trapped states, respectively.

As pointed out by West,[8] for example, if any characteristic of the annihilation process R is a linear function of the positron state such that

$$\bar{R} = \sum_j R_j F_j / \sum F_j \quad , \tag{4}$$

then measurement of $\bar{R}$ can provide information about state populations and the trap concentration. From Eq. (3) it follows that

$$\bar{R} = \frac{R_f F_f + R_t F_t}{F_f + F_t} \quad . \tag{5}$$

Since $F_f + F_t = 1$, it can be readily shown that,

$$\frac{R_f - \bar{R}}{\bar{R} - R_t} = \frac{\mu c}{\lambda_f} \quad , \tag{6}$$

In practice, R has been taken to be the positron lifetime, or a shape parameter derived from a two-photon angular-correlation curve or from a Doppler-broadened annihilation line spectrum. The fundamental assumptions in this simple model are that it is experimentally possible to determine R_f and R_t individually, and that only one defect species at a time acts as an effective trap during various portions of an experiment. Evidently, by analogy to electrical-resistivity measurements in radiation-damaged metals, positron experiments can be useful in studies of defect behavior even when the precise nature of the imperfections is not specifically known. However, were it not for the additional theoretical and experimental effort of recent years,[9-21] interest in the positron annihilation technique as a tool for studying defects might not have continued to grow so rapidly. Studies of positrons in perfect metals as well as in metals containing either equilibrium or nonequilibrium concentrations of defects are required in order to develop positron annihilation as a new technique for defect research.

Fortunately, one consequence of the experimental results has been to stimulate much-needed theoretical interest in developing a quantitative description of positron behavior in metals. For example, in recent years critical re-examinations of positron slowing down and subsequent motion before annihilation have been made by several investigators,[9,10] rate equations governing the trapping model have been rederived in a more fundamental fashion,[11] annihilation rates have been recalculated on the basis of several new theoretical approaches,[12-15] positron-vacancy binding energies have been calculated,[17-18] and the temperature dependence of the trapping probability has been investigated.[19-21] Many of these studies represent contributions to the general physics of positrons in solids irrespective of their relationship

to positron-defect interactions. Consequently, they also have had an impact upon other positron experiments such as Fermi-surface studies, and investigations of positron thermalization in metals.

The experiments themselves have become more sophisticated, too. New detectors, faster electronics and inexpensive computers have made it possible to measure accurately the very short lifetimes characteristic of positrons in metals. High-efficiency, high-resolution Ge(Li) detectors permit rapid data collection in Doppler-broadening measurements. The small computer has become an integral part of most positron experiments where it performs many functions from data storage to electronic stabilization and preliminary data reduction.

POSITRON SOURCES

Out of the many beta emitters, only a handful are suitable as positron sources. Each satisfies some of the following criteria: reasonably long half-life, minimal gamma-ray background, ease of preparation, ability to withstand adverse environmental conditions, and moderate cost for a supply in the form of carrier-free radionuclide of adequate strength for experiments. In Table 1 are listed some useful or potentially useful sources. Others can be produced in targets bombarded by various particles from accelerators. However, except in special cases, the utility of such sources has been limited by other problems such as the high background from competing reactions or from nuclear decay.

The positron ranges corresponding to the endpoint energies can be as much as 20% greater than those for electrons of the same energies. However, a beta emitter produces a continuous energy spectrum, and the mean range of the positrons from a given source is much shorter than the maximum. The flux at some depth x is given by

$$I = I_o \exp(-\alpha x) \qquad (7)$$

Table 1. Possible Positron Sources

Source	Halflife	% β^+ Decay	Method of Preparation	End-point Energy (MeV)
*^{22}Na	2.58 y	89	^{27}Al(^{3}He,2α)	0.54
^{44}Ti/^{44}Sc	48 y	80	^{45}Sc(p,2n); ^{45}Sc(d,3n)	1.47
^{55}Co	18.2 h	60	^{58}Ni(p,α) ; ^{56}Fe(p,2n)	1.50
^{57}Ni	36.0 h	50	^{56}Fe(^{3}He,2n)	0.85
*^{58}Co	71.3 d	15	^{58}Ni(n,p) ; ^{55}Mn(α,n)	0.48
*^{64}Cu	12.9 h	19	^{63}Cu(n,γ)	0.65
*^{68}Ge/^{68}Ga	275 d	88	^{66}Zn(α,2n)	1.90
^{90}Nb	14.7 h	54	^{90}Zr(p,n) ; ^{90}Zr(d,2n)	1.50

* indicates commonly-used sources.

where the linear absorption coefficient, α, has been empirically determined.[22-23] Table 2 contains values of the depth α^{-1} in Al, Cu or Au at which the positron flux is e^{-1} (37%) of its value, I_o, at the surface for positrons from the four most commonly used sources. Also shown in parentheses are the ranges of positrons possessing the maximum energy.

Table 2, e-Folding Distance in Al, Cu and Au for Positrons from Four Common Sources

Source	Al	Cu	Au
^{58}Co	90.4 μm (7.86×10^{-2}cm)	27.4 μm (2.71×10^{-2}cm)	12.6 μm (1.6×10^{-2}cm)
^{22}Na	76.3 μm (9.23×10^{-2}cm)	23.1 μm (3.10×10^{-2}cm)	10.7 μm (1.86×10^{-2}cm)
^{64}Cu	118. μm (1.18×10^{-1}cm)	35.7 μm (4.05×10^{-2}cm)	16.4 μm (2.35×10^{-2}cm)
^{68}Ge/^{68}Ga	543. μm (4.25×10^{-1}cm)	165. μm (1.42×10^{-1}cm)	76.3 μm (7.68×10^{-2}cm)

It is evident from the values given in Table 2 that the majority of the positrons penetrate to a depth which is considerably smaller than the range of a positron with the maximum energy of the beta spectrum. Thus, the results of experiments in which nonuniform defect densities exist over depths comparable to α^{-1} have to be examined for evidence of this effect. For example, experiments involving quenching or irradiation plus quenching in particular must be analyzed with care for near-surface variations.

The source $^{44}Ti/^{44}Sc$ would appear to be ideal because of its long halflife, high-endpoint energy and large percentage of decays via positron emission. However, it is difficult and expensive to produce. At Brookhaven an attempt is being made to generate ^{44}Ti in a vanadium target exposed to 200-MeV protons in the Brookhaven Linac Isotope Producer (BLIP). It is anticipated that after several months of bombardment the target will contain the positron emitter in μCi amounts amenable to extraction in a form suitable for subsequent use as a positron source.

Positron experiments are usually performed with sources of μCi to mCi strength (1 μCi ≡ 3.7×10^4 disintegrations/sec). The annihilation rate of positrons in metals is of the order of 5×10^9 sec^{-1}. A simple calculation reveals that there is never more than one positron at a time in a sample. Positron-positron interactions are absent, and experiments consist of collecting data for a long series of independent events. In the later discussion of positron trapping by defects a set of rate equations will be introduced. In view of the foregoing, they should be regarded as statistical equations describing the probability that a positron is still present after spending a time, t, in a solid.

POSITRON SLOWING DOWN

Positrons enter a sample with relatively high velocities, and rapidly slow down to near thermal velocities in a metal. All theoretical treatments[24] arrive at the same conclusion that this slowing-down time is short relative to positron lifetimes provided the sample

temperature is not too low. The positron loses energy via ionizing collisions, plasmon creation, a minor amount of bremsstrahlung emission, electron-hole excitation and phonon creation. Until rather recently, the positron-phonon mechanism had been ignored by theorists. However, Mikeska[10] and Perkins and Carbotte[9] independently investigated this interaction and found that at low temperatures it can be the most important process by which positrons lose energy. The latter authors showed that in Na at 190 K, for example, the positron-phonon interaction begins to dominate the approach of the positron to thermal equilibrium with the lattice, if the positron effective mass $m^* = m$, the bare mass. The minimum temperature attained by the positrons in Na before annihilation in a sample at absolute zero is about 20 K. Recently, Kubica and Stewart[25] using a high-resolution angular-correlation apparatus have measured a thermalization temperature of 10 ± 10°K in a Mg crystal held at 4.2 K.

Upon entering the solid, the positron immediately becomes surrounded by its own polarization cloud which has the effect of screening it from the strong Coulomb interactions in the metal. The higher the electron density, the more strongly screened is the positron. In the final brief period before its annihilation, the positron slowly migrates through the lattice. The details of this diffusion process have been clarified in several recent theoretical publications,[26-29] stimulated largely by interest in positron-defect interactions. The topic of thermalized positron motion in solids will be deferred until we have discussed the mechanism of defect trapping and the experimental evidence which substantiates or has fostered current theories.

POSITRON TRAPPING BY DEFECTS

In order to understand why positrons are trapped at certain types of defects it is only necessary to introduce a few basic ideas. First, it has been shown[30] that the probability per unit time for annihilation into two photons whose total momentum lies between p and p + dp is given by the expression,

$$\sum_{\text{occ. } i} \lambda_i^{2\gamma}(\underline{p})d\underline{p} = \sum_{\text{occ. } i} \frac{2\, r_o^2 c}{(2\pi)^3} \left| \int \psi^i(\underline{r})\psi_+(r)\exp(i\underline{p}\cdot\underline{r}) \right|^2 d\underline{p} \quad . \tag{8}$$

In Eq. (8) the sum is to be taken over all occupied electron states, i. $\psi^i(\underline{r})$ is the electron wavefunction for state i, $\psi_+(\underline{r})$ is the positron wavefunction, r_o is the classical electron radius and c, the velocity of light. The total annihilation rate $\lambda^{2\gamma}$ is then found by integrating Eq. (8) over all electron momenta, and applying Parseval's theorem to obtain,

$$\lambda^{2\gamma} = 2\pi r_o^2 c \sum_{\text{occ. } i} \int \left|\psi_-^i(\underline{r})\right|^2 \left|\psi_+(\underline{r})\right|^2 d\underline{r} \quad . \tag{9}$$

If the annihilation rates are calculated without inclusion of positron-electron correlations in an electron gas, the resulting values are an order of magnitude less than the measured ones. To account for this discrepancy, an enhancement factor is included in the expression for the annihilation rate when an independent-particle model is used. This factor reflects the large increase in local electron density in the vicinity of the positron.

From Eq. (9) it is clear that the annihilation rate in a solid depends upon the electron density at the positron. Thus, if a positron migrates to a site of low electron density relative to the average value, the probability per unit time that it will annihilate is reduced. In practice, this will manifest itself as an increase in the lifetime of the positron. As a matter of fact, a solid can contain many regions of lower than average electron density, the most obvious type being a vacant lattice site. However, under appropriate conditions, clusters of vacancies, vacancy-impurity complexes, voids and dislocations may also be present.

The second point to be made is that it has been shown theoretically that vacancies are in fact favorable trapping sites. Hodges,[17] Arponen et al.,[31] Hodges and Stott,[18] Seeger,[32] Bergersen and Taylor,[33] and Brandt and Fahs[34] have all investigated the trapping of positrons

at a vacancy. Hodges represented the vacancy by a potential well centered at r = 0 and a Wigner-Seitz sphere of radius R_a surrounding it. This positron potential exhibits strong Coulomb repulsion near ion centers and screening of the Coulomb interaction in the interstitial and vacancy regions. Positron-electron correlations were neglected by Hodges although his effective potential was calculated by treating the positron and its polarization cloud as a neutral pseudo-atom interacting with the lattice atoms through a pairwise potential. More recently, Brandt and Fahs[34] have considered the problem using a statistical model of the electron distribution around a vacancy. The positron wavefunction and the redistribution of the electrons around a vacancy were initially calculated in a self-consistent manner. A new self-consistent potential for the system composed of a positron occupying a vacant site was then determined, and used to deduce new electron and positron distributions. Brandt and Fahs deduced values of the positron-vacancy binding energy from their theory for a number of metals. Their values are considerably larger than those obtained by Hodges, ranging from 4 to 8 eV. They point out that this arises because they took into consideration the electron redistribution around the positron in the vacancy, a process neglected by Hodges. In any case, it appears that positrons are trapped at vacancies in most metals with binding energies sufficient to make detrapping unlikely.

Hodges and Stott[18] extended their theory of the positron work function[35] to a discussion of positron behavior near voids or external surfaces of metals. Treating the void as an internal surface they concluded that for large voids the positron states of lowest energy are probably localized in a potential "trough" at the void-metal interface. Unless the positron work function, ϕ_p, is greater than about 0.39 Ryd., these positron bound states, localized at the surface, can exist. The binding energy depends upon ϕ_p and ranges in value from about 0.03 Ryd. for Li to $\sim$ 0.25 Ryd. for Al. Within their approximate one-dimensional model Hodges and Stott reached the conclusion that positronium (Ps) formation in voids was less probable than the formation of bound surface states. If Ps does form, there will be states which extend over

the entire void volume.

We conclude that in a metal containing nonequilibrium concentrations of defects several types of positron traps may be present. If vacancies and voids can act as trapping centers, then vacancy complexes can be expected to trap positrons, also. On the other hand, calculations by Stott and Kubica[36] indicate that single interstitial atoms of the host metal or of an impurity are repulsive centers for the positron.

The simple trapping model can be extended to allow for the simultaneous presence of several types of traps. Assuming that a positron in trap type j has an annihilation rate λ_j, we write the rate equations for $p_L(t)$, the probability that a positron is free in the metal at time t, and $p_j(t)$, the corresponding probability for a trapped positron in the form,

$$dp_L(t)/dt = -\lambda_L p_L(t) - \sum_{j=1}^{m} \kappa_j(T) p_L(t) \quad , \tag{10}$$

$$dp_j(t)/dt = -\lambda_j p_j(t) + \kappa_j(T) p_L(t) \quad . \tag{11}$$

The trapping rate for each type of trap is $\kappa_j(T)$. Equations (10) and (11) have been discussed by Seeger[32] and Hall et al.[37] They presuppose no escape from traps, and allow for the possibility that the trapping rate is temperature dependent. Frank and Seeger[11] have given a more extensive theoretical treatment of the trapping model on the basis of Waite's theory of diffusion-limited reactions. Their equations reduce to Eqs. (10) and (11) when escape from traps is neglected.

All of the theories mentioned treat in a cursory way annihilations with core electrons. They proceed from an electron gas model including electron-positron and electron-electron correlations as well as sophisticated screening models. They strive to match measured annihilation rates for the alkali metals and are generally in rather poor agreement, although a recent approach for perfect metals by Lowy and Jackson[16] seems to yield somewhat better results. Nevertheless, experimental

results for metals in other columns of the periodic table suggest that the fraction of annihilations with electrons in higher momentum states is appreciable. While these events may not be attributable solely to core states, it is plausible to assume that a large percentage of them can be so identified. Collaborative experiments in progress at Brookhaven[38,39] and Bell Labs.[40] will shortly provide additional quantitative information about core electron-positron annihilations, and the positron wavefunction. The method of separating experimental data into core and valence electron contributions may then require revision. The significance of this statement will become evident as the methods of annihilation detection and data analysis are considered in the next section.

DETECTION AND ANALYSIS OF ANNIHILATION IN METALS

Those interested in the experimental details of annihilation detection and subsequent data analysis can refer to a large number of excellent summaries;[8,41] only the salient features and some critical comments will be offered here.

Statistics and the selection rules governing positron annihilation state that the most probable event is annihilation accompanied by the emission of two photons. The total energy of the photons equals the rest mass of the two particles ($2 mc^2$) minus the binding energy of the electron. Momentum must be conserved also, and because the positron is assumed to be thermalized, the final momentum is taken to be that of the electron. Three-photon decay is less likely than two-photon decay by the factor 1/372, while decay from a bound Ps state in bulk metals has not been positively observed.

Three kinds of experiments have been devised to detect the two-photon annihilation process: the lifetime spectrum is measured, the angular correlation between the two nearly collinear gamma rays is determined or the width of the Doppler-broadened annihilation photopeak is measured. The latter two properties can yield information about the

electron momentum distribution in a solid, whereas the lifetime is related to the local electron density as pointed out earlier.

From the previous discussions of positron trapping at defects, it is evident that phenomenological models using empirically-defined parameters can be used to study defects systematically. The parameters are different for each type of measurement.

Lifetime Method

The standard coincidence techniques are used to record a time spectrum which is the distribution of positron lifetimes in a sample. The usual parameter is the mean lifetime $\bar{\tau}$ which can be extracted as the centroid of the time spectrum. Electronic techniques have been devised for accurately detecting shifts in the centroid brought about by trapping of positrons in vacancies, for example, where the electron density is low. However, the centroid-shift measurement is a relative one, and does not furnish values for the lifetimes of free and trapped positrons, τ_f and τ_t, respectively. These must be deduced from analysis of the spectrum, taking care to accurately determine the time resolution of the system. It is not always obvious where trapping is involved that saturation of the effect has occurred, or that no trapping is taking place. The mean lifetime is then the weighted average of the two extreme values. In any case, the lifetimes in metals can be within a factor of two or so of the instrumental resolution, and a computer analysis of the data is necessary even if only one lifetime is important. Accurate lifetime values can only be deduced from accumulation of many counts. With a standard fast-slow coincidence system this can take several days during which drift and stability of the electronics must remain at a minimum. However, new developments in fast-fast coincidence systems such as that reported by Hardy and Lynn[42] can reduce data-collection times to minutes without a sacrifice of resolution. Since lifetime measurements provide unique information regarding electron densities at defects it seems likely that they will be employed increasingly once these new techniques become generally known.

Angular-Correlation Method

Measurements of the angular correlation between the two annihilation quanta can, in principle, be performed as accurately as desired by increasing the distance between the source and the detectors. However, because the positrons are distributed nonuniformly throughout the sample (which is in effect the source), great care must be taken to calculate the optical resolution function of the instrument. As applied to radiation-induced defects there is an increasing tendency to use the ratio of peak counting rate to tail counting rate as the parameter R, defined in the Introduction. The basis for this is the assumption that core annihilations are less probable at a vacant site, and consequently valence electron annihilations are more probable. Thus, the angular distribution becomes narrower as trapping increases, and this is reflected in an increase in the peak counting rate at the expense of the counting rate in the tails of the distribution. Good statistics can be achieved by counting at only a few angular positions along the distribution.

Arbitrary decomposition of the angular distribution into "valence" and "core" components is often carried out. However, this procedure is not on completely solid ground. High momentum state valence electrons can be included as core states, for example. Moreover, surprisingly large core state fractions seem to be required to explain some experimental results.[43] That core states are involved is evident from several kinds of experiments and calculations. Kubica,[44] for example, has shown that the effects of lattice expansion on annihilation rates at low temperatures can be explained in terms of increased overlap of the positron wavefunction with core states.

While annihilation rates are increased by the enhanced local electron density, it has been shown that the positron is only weakly coupled to its surroundings by virtue of the screening that arises from this enhancement. Therefore, it does not perturb the electron momentum distribution characteristic of the solid. However, if the screening changes, as it will at a defect, the momentum distribution may be

influenced more strongly by the positron. These matters must be clarified through careful experiments on equilibrium concentrations of defects.

Doppler-Broadening Method

Owing to the poor energy resolution of scintillator-photomultiplier combinations, Doppler-broadening measurements were for a long time considered too insensitive to be gainfully employed in annihilation studies. The advent of the high efficiency, high resolution Ge(Li, has altered this picture.[45] Measurements of the annihilation photopeak require only one detector. Hence the counting rate can be high, and experiments performed relatively rapidly with good statistics. MacKenzie and his colleagues[46] have led the way in demonstrating that changes in the lineshape of the photopeak correspond to variations in the defect structure of metals. Using the ratio of counts in channels around the peak to total counts in two symmetrically-placed groups in the wings as a lineshape parameter, they have investigated equilibrium and nonequilibrium defect concentrations in numerous metals. In fact, more studies of defects in irradiated metals have been performed by this means than any other.

Doppler-broadening measurements are still not regarded seriously as a technique for determining electron momentum distributions. Nevertheless, it should be remarked that a broadening of 1.6 keV is associated with an electron of only 10 eV corresponding to an angle of 6.25 mrad in an angular-correlation experiment. As a good Ge(Li) detector will have a resolution of $\sim$ 1.2 - 1.3 keV at 514 keV, structure in the high-momentum components of the angular distribution can be detected. Recent modifications in the Doppler-broadening method have further enhanced the capabilities of this technique.[38-40]

TEMPERATURE DEPENDENCE OF TRAPPING RATES

Investigations of annihilations at defects as a function of temperature have stimulated interest in the dynamics of positron motion after thermalization. Specifically, the temperature dependence of the specific trapping rate, μ (see Eq. (1)), has been in question. Several theories[26,33,47,48] and a few experimental results[19-21] have been published. The conclusions are not in accord. It may be that in the case of the experiments, conditions were sufficiently different that agreement should not have been expected. The most comprehensive theoretical development is that recently published by Brandt.[26] He divides the problem into two regimes, one in which μ is diffusion-limited and the positron behaves in a particle-like manner, and a second in which the positrons propagate as extended wave packets and trapping is limited by the transition rate into the localized bound state of a defect. Defining an apparent diffusion constant for a positron, Brandt has been able to represent μ for a vacancy to a first approximation by the expression,

$$\mu \simeq \frac{4\pi r_d \phi}{1 + Bc_{sc}(300\ K/T_+)^b} \quad . \tag{12}$$

Here r_d is the radius of the square-well potential of the defect. The parameter ϕ has the dimensions of a diffusion constant and is characteristic of the transition rate of thermalized positrons into vacancies. B equals $1.6 \times 10^4 n a_o^3$ with n, the atomic density and a_o, the Bohr radius. The concentration of scattering centers is c_{sc} and the thermalized positron temperature is T_+. The exponent, b, takes on values such that $1/2 \leq b \leq 3/2$ depending upon the imperfection. Equation (12) indicates the existence of temperature regimes and defect concentrations over which a temperature dependence T^b might be observed.

A recent addition to this subject has been proposed by Seeger.[48] He has adapted the concept of "self-trapping" of positive particles to positrons in metals. Self-trapping occurs when a positive particle

creates its own distorted region by virtue of repulsive interactions with its surroundings. The resulting trapped state may be metastable relative to the ground state, and the phenomenon will be temperature dependent. Seeger has suggested that recent observations by Lichtenberger et al.[49] of an anomalous temperature dependence of the annihilation lineshape at intermediate temperatures (200-400 K) in Cd can be explained by self-trapping. Additional experimental evidence is required in this area of the field, and other subleties such as the temperature dependence of the vacancy formation energy must be taken into consideration in the analysis of data.

CONCLUDING REMARKS

It seems clear now that after a somewhat prolonged nucleation period,[50-52] the growth of positron physics as applied to radiation-effects research has begun in earnest. Major new efforts are starting throughout the world, and several reports from established research groups are evident in these proceedings. Therefore, the purpose of this brief review has been to introduce the basic theoretical and experimental concepts currently in use by those in the field. Hopefully, this will have the beneficial effect of making the subsequent shorter and more specific positron papers understandable to the uninitiated.

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