POSITRON ANNIHILATION:
A TOOL IN INTERDISCIPLINARY INVESTIGATIONS*

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After a review on the applications of positron annihilation methods an example is presented of recent results as they apply to studying structural imperfections in the glassy phase. It is concluded that positron trapping is caused in the amorphous phase by the substantial amount of free volume; furthermore, a correlation is indicated between the positron-trapping and the quenching rate used in producing the amorphous metallic glass samples.

Introduction

The basic discoveries made in natural sciences during the early thirties mean that we now have occasion to celebrate their 50th anniversary. Certainly some of these discoveries were milestones in physics. One such milestone was the theoretical prediction — followed by the experimental demonstration — of the existence of positrons.

Dirac’s theoretical prediction [1] was verified by Anderson [2], who discovered positrons, antiparticles of electrons. After a long dormant period they have enjoyed very active interest in the last twenty years. Initially, the positron and the annihilation of the electron-positron pair found favour in quantum electrodynamics research and in theoretical physics, the reason being that this was the first possibility of testing the validity of the then developing new theoretical ideas.

This development took several years during which time experimental physics was already able to provide suitable methods of observing the annihilation phenomenon. The advent of scintillation detectors and fast nuclear electronics in the fifties and sixties established world-wide access to modern experimental facilities enabling the extensive study of the positron annihilation field, too. The active work started in several laboratories at about the same time subsequently led to several important discoveries being made within the same time span. Investigations into annihilation radiation yielded (by means of the determination of the cross sections of $2\gamma$- and $3\gamma$-annihilation) the discovery of the positron-electron bound states. These bound states, whose lifetime was also determined, became known as positronium.

* Dedicated to Prof. I. Kovács on his 70th birthday
A clear sign of the world-wide interest of the physicists in these questions was the organization of the first Positron Annihilation Conference in Detroit in 1965; since then a series of such meetings has followed, the last being held in Fort Worth, Texas, in 1982.

Positrons currently represent a very important research topic in high energy and particle physics but we limit ourselves here to the application of positron annihilation methods for investigating problems rooted, for example, in solid state physics.

Our aim — after a brief description of the positron annihilation (PA) methods generally used — is to demonstrate the power of these methods. In describing the fruitful research going on in Hungary in this field, we present results on the structural imperfections of disordered condensed materials.

### Positron annihilation methods

The main techniques in PA applications are:

a) measurement of the lifetime of positrons (LT);

b) measurement of the 2γ-angular correlation of the annihilation radiation (ACAR);

c) measurement of the Doppler broadening of the annihilation radiation (DBAR);

Positrons employed in these three techniques are generally obtained from the decay of neutron-deficient nuclides, where positron emission competes with electron capture. Stability considerations give the reason why positron emission is confined almost exclusively to elements with low Z-value. The most commonly used positron-emitting isotopes are: \(^{22}\text{Na}\), \(^{58}\text{Co}\), \(^{64}\text{Cu}\), \(^{68}\text{Ge}\). The high-energy (0.4—1.8 MeV, depending on the isotopes considered) positrons injected into a sample are thermalized in a very short time compared with their lifetime.

A new type of PA measurement is being developed that utilizes slow positron beams; by varying the penetration depth of positrons surface studies are also possible. Slow-positron guns operate by taking advantage of the enrichment of the positron spectrum by low energy positrons after reflection from or penetration into high Z materials. An appropriate electromagnetic or electrostatic guiding and focusing system enables these positrons — monochromatized by an electrostatic accelerating system — to reach the target-end of a curved high-vacuum tube.

LT measurements give the mean lifetime of positrons in the media studied. The method takes advantage of the fact that the \(^{22}\text{Na}\) positron source emits a 1.28 MeV γ-quanta simultaneously with the emission of a positron, this radiation initiates a time-to-pulse height converter (TPHC); the stop signal is one of the 0.5 MeV energy annihilation γ-quanta. Annihilation of positrons takes place through different annihilation channels each with a characteristic lifetime value which can generally be distinguished experimentally. Annihilation itself depends on the presence of different