from the velocity of the particles is taken thermodynamically into account, but not the energy contained in the rest mass of the particles. Therefore Eq. (3) would correspond to the statistics of an ensemble of particles which are lifted out of an unobservable reservoir without thermal energy being used for their creation, but their motion being described relativistically.

The subtraction of the rest energy of the particles representing the field may seem somewhat arbitrary. It is interesting to notice that a generalization of ordinary statistical mechanics effects the same result. In order to show this we have to go back to the very principles of statistical thermodynamics. The fundamental problem in that theory is to determine the distribution of an ensemble of a large number of identical systems over the possible states in which this ensemble can find itself, given that the energy of the ensemble is a constant. However, it has long been known that the distinguished role of the energy is simply that it is a constant of the motion. It is possible to generalize the formalism so as to refer to other constants of the motion as well. In this instance the partition function can be written

$$Z=\text{trace}\exp[-(1/k)\Sigma\alpha_i\mathbf{A}_i], \tag{4}$$

where the $\mathbf{A}_i$ are operators corresponding to arbitrary classical constants of the motion, and where the α_i are their respective inverse "temperatures."

With these notions it is possible to extend the thermodynamics of the Schrödinger-Gordon field. Let us take for $\mathbf{A}_1$ the ordinary Hamiltonian, for $\mathbf{A}_2$ the operator $\mathbf{N}$ which represents the number of particles "present" in the field (and corresponds thus to a classical constant of the motion). Then the partition function becomes

$$Z=\text{trace}\exp(-\vartheta\mathbf{H}-k^{-1}\alpha\mathbf{N}). \tag{5}$$

It is obvious that a suitable choice of the "number-temperature" $T_N=1/\alpha$ will reduce this partition function to that one which one obtains using the Hamiltonian given in (2). From a statistical standpoint, there is no *a priori* reason why the conventional partition function should be preferred over Eq. (5). If T_N in (5) is allowed to vary, different thermodynamic functions (with respect to the ordinary temperature $T=1/k\vartheta$) are found for every value of it. Again, there is no *a priori* reason for one set of such thermodynamic functions being preferred before another. The choice has to be made on physical grounds. Thus it seems that the set of formulas which were obtained in our earlier paper and the thermodynamic functions discussed here are both perfectly correct thermodynamic descriptions of the Schrödinger-Gordon field. Which set of formulas has to be used in a particular case depends solely upon the nature of the hypothetical interactions which are supposed to produce the canonical distribution of the fields.

In conclusion, one should perhaps remark that very similar facts apply when the Dirac field and its nonrelativistic form are studied. In this case the thermodynamic functions lead, after the subtraction of the rest mass of the particles, to a relativistic modification of Fermi statistics.

[1] A. E. Scheidegger and C. D. McKay, Phys. Rev. **83**, 125 (1951).

The Half-Life of Positrons in Condensed Materials*

S. DeBenedetti and H. J. Richings
Carnegie Institute of Technology, Pittsburgh, Pennsylvania
(Received November 28, 1951)

THE difference in the half-lives of positrons in several pairs of condensed materials was experimentally studied with the method of delayed coincidences between the nuclear γ-rays of Na^{22} and the annihilation radiation from the positrons of the same source.[1]

Two stilbene counters were pointed at the source, at about 90° from each other. The biases were so adjusted that a coincidence was recorded only if a 1.3-Mev γ was detected by one of the counters and an annihilation γ by the other.

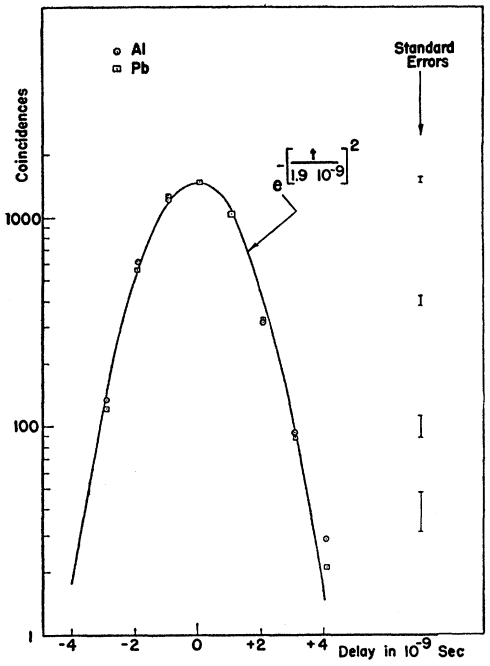

FIG. 1. Comparison of positron half-lives in Al and Pb.

The Na^{22} source S was deposited on thin Al and sandwiched between the substances A and B for which the half-life was compared. With a source sandwich arranged in the order $BASAB$ the positrons stopped in A, while if the sandwich was arranged as $ABSBA$, the positrons stopped in B. However, the absorption of the 1.3-Mev γ-rays of Na^{22} and of the annihilation radiation was essentially the same in the two cases; in this way directly com-

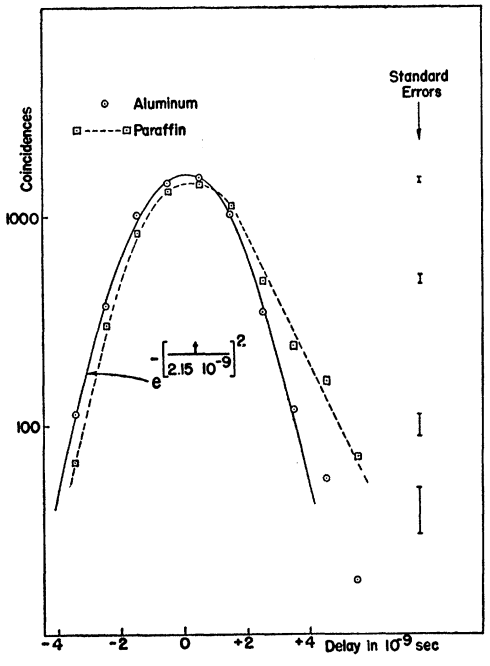

FIG. 2. Comparison of positron half-lives in Al and paraffin.

TABLE I. Difference in the positron half-life in the substance indicated and in aluminum.

Substance	Difference in 10^{-10} sec	Substance	Difference in 10^{-10} sec
Li	0±0.5	Al_2O_3	0±0.5
Na	0±0.5	SiO_2 (quartz)	2.5±1
K	0±0.5	Teflon	1.2±0.5
Ag	0±0.5	Polystyrene	2.5±1
Pb	0±0.5	Plexiglass	2.5±1
Cu	0±0.5	Paraffin	2.5±1
C (graphite)	0±0.5	Water	1.5±0.7
S	0±0.5	H_2O_2	0±0.5
NaCl	0±0.5	Benzene	2.6±1
AgCl	0±0.5	Alcohol (methyl)	2.3±1
PbO	0±0.5		

parable coincidence curves were obtained and spurious delays (possibly resulting from changes in pulse height connected with difference in energy degradation of the γ-rays) were avoided.

The coincidences were selected by means of a circuit of $\approx 2\times 10^{-9}$ sec resolving time, which had been previously tested with time-of-flight experiments[2] and which had been proved capable of detecting time differences of the order of 10^{-10} sec.

Typical coincidence curves obtained are shown in Figs. 1 and 2. Aluminum was used in most cases as one of the substances in the source sandwich.

By assuming that positron lives are exponentially distributed in time, one obtains from the shifts in the empirical curves the results shown in Table I. There is no apparent relation between the data of Table I and the density or atomic number, as might be expected if the delays were a result of slowing-down time. Thus, the results have probably to be interpreted in terms of differences in annihilation half-lives.

It is somewhat surprising that all metals tested exhibit the same half-life, for this is in contradiction with the simple view that positrons annihilate at low energy in free collision with the valence electrons.[3] From this viewpoint measurable differences should occur at least in the alkali series owing to the wide variation in atomic density. It is tempting to think that the positron and the conduction electrons form some kind of fast annihilating state, thus making the lifetime independent of the metal used.

In the case of insulators, one might be tempted to look for some connection between positron half-life and chemical properties. Substances whose molecules are very stable, like quartz, paraffin, and water, have longer half-life than substances which more readily enter into chemical reactions, such as sulfur or hydrogen peroxide. It is possible that this might be evidence for the formation of positron compounds in condensed materials.

Finally, one should consider the possibility that the time shifts observed were caused by different ratios of singlet to triplet annihilation in different materials. A greater percentage of three-quantum annihilation[4] could be accompanied by a longer positron life, but would also produce apparent time shifts as a result of the delayed response of our instrument to lower energy radiation. This point will be investigated experimentally in the near future.

* Supported in part by the AEC.

[1] J. W. Shearer and M. Deutsch, Phys. Rev. **76**, 462 (1949).

[2] S. DeBenedetti and H. J. Richings, Phys. Rev. **82**, 771 (1951); and Rev. Sci. Instr. (to be published).

[3] DeBenedetti, Cowan, Konneker, and Primakoff, Phys. Rev. **77**, 205 (1950).

[4] A. Ore and J. L. Powell, Phys. Rev. **75**, 1696 (1949).

A New Method of Obtaining Focused Images with X-Rays

G. N. RAMACHANDRAN
Department of Physics, Indian Institute of Science, Bangalore, India
(Received October 1, 1951)

ATTEMPTS at constructing an x-ray microscope have been made utilizing the total reflection of x-rays at glancing angles less than about 30 minutes of arc.[1-3] Since the images are highly astigmatic, a combination of two concave mirrors with their planes of reflection at right angles is necessary. Magnifications of 15 to 30 have been reported with an object of dimensions of approximately 0.4 mm square.

It occurred to the author that under certain conditions, focused images could be obtained using crystal reflections. The use of Bragg reflection in various types of cameras for focusing a particular wavelength to a linear focus is familiar to the x-ray crystallographer. In the method to be described below, the wavelength of the x-rays may vary, but rays diverging from a particular point are again brought to a focus at another point.

Crystal reflection has the property that the angle of incidence is equal to the angle of reflection for a particular set of lattice planes, but for a given value of this angle θ only a narrow range of wavelengths on either side of a wavelength λ satisfying the Bragg relation $\lambda = 2d\sin\theta$ is reflected. Thus those rays which are reflected, are reflected according to the same law as ordinary light, incident at the same angle on a plane mirror placed in the same orientation as the lattice plane of the crystal under consideration.

Now in the optical case, a concave mirror would give a focused image (either reduced or magnified) of an object placed in front of it at a suitable distance. If the mirror were now replaced by a thin cleavage plate of the crystal, curved to the same surface as the mirror, and if white x-rays were allowed to illuminate the object, then according to the argument of the preceding paragraph one should get a focused image with x-rays of the same size and at the same place as that produced in the optical case. It is important to realize that of all the rays which originate from a point on the object, those which are reflected must converge to the corresponding point of the image, if the mirror has no aberrations. The others are just transmitted. Thus the only background would be that resulting from x-rays incoherently scattered by the mirror.

This very simple possibility does not appear to have been pointed out before. Experiments have been undertaken by the author in collaboration with Mr. Y. T. Thathachari in this laboratory to test the preceding ideas, and it is found that they are workable. Although details of the experiment will be published elsewhere, the possible methods of constructing such an x-ray focusing arrangement may be mentioned here. One method would be to fix a cleavage flake of mica on a flange attached to a circular tube and to partially evacuate the inside of the tube, thereby obtaining a concave surface. Another method would be to bend a circular plate of quartz, cut perpendicular to the c-axis, by means of two concentric rings, where the region inside the smaller ring should have nearly constant curvature.[4] A third method would be to deform a plastic crystal like rocksalt to take the shape of a truly spherical surface. In all these cases, one would expect the lattice planes to take up the requisite curvature (at least on a macroscopic scale).

The geometry of the arrangement would be as follows. The object, kept inside an aperture on a lead screen, is placed close to the window of an x-ray tube and the diverging beam of x-rays is allowed to fall on the "mirror" situated at a suitable distance from it. The mirror is slightly tilted so as to throw the reflected beam on one side of the object, and a photographic plate is kept at the correct distance from the mirror, judged optically. The x-ray image also would occur at the same place and could thus be recorded.

This technique has interesting possibilities in connection with constructing an x-ray microscope. Although the image would be astigmatic in the aforementioned arrangement, it would be possible to get an axial arrangement by combining two mirrors (with central holes) similar to the arrangement in an optical reflection microscope. But, unlike the optical case, the wavelength of a ray reflected by the first mirror is dependent on its angle of incidence, and very special conditions have to be satisfied by the second mirror if each ray is again to be incident at the Bragg angle on it. These conditions have been worked out, and