IL NUOVO CIMENTO VOL. LII B, N. 2 11 Dicembre 1967

Source-Supporting Foil Effect on the Shape of Positron Time Annihilation Spectra.

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(ricevuto il 27 Luglio 1967)

Summary. — The fraction k of positrons annihilating in source-supporting foils (mica or polyester film) was measured as a function of the foil thickness and of the atomic number of the surrounding material in which positrons are absorbed. It was found that k attains considerable values when the positron absorber has a high atomic number; at very low Z the fraction k is smaller for mica than for the polyester film. On the basis of the obtained results a procedure is indicated for correcting the time spectra. This procedure when applied to analyse time annihilation spectra in some metals, has shown that metals are characterized by a single exponential decay, in agreement with the results of recent investigations.

1. – Introduction.

Recent experiments have put in evidence that sample-preparation techniques appreciably affect the shape of the time spectrum of positrons annihilating in metals where a single lifetime component is to be expected according to present knowledge ([1-4]). It was recognized that the longer lifetime component observed in some metals with several percent intensity ([4]) arises from the fact that, with the usual sample preparation techniques, some positrons annihilate in regions other than the homogeneous interior of the metal. An-

([1]) T. KOHONEN: *Ann. Acad. Sci. Fennicae*, A 6, 130 (1963).
([2]) H. WEISBERG: *Bull. Am. Phys. Soc.*, **10**, 21 (1965).
([3]) H. W. KUGEL, E. G. FUNK and J. W. MIHELICH: *Phys. Lett.*, **20**, 364 (1966).
([4]) H. WEISBERG and S. BERKO: *Phys. Rev.*, **154**, 249 (1967).

nihilations in the source itself, in the oxide layer and in lattice defects on the metal's surface have been put forward as an explanation. Furthermore if the active sample is deposited from the solution directly on the metal surface, a « tail » appears, which depends to some extent upon the normality of the acid solution containing the positron emitter ^{22}Na [3].

Frequently a thin supporting foil (~ 1 mg/cm^2) is used for source deposition. The effect due to this foil can be made evident when positronium formation occurs in it; in this case in fact the time annihilation spectrum contains a tail displaying the lifetime (of the order of $(1 \div 2) \cdot 10^{-9}$ s) characteristic of the foil material. When this situation does not occur (for instance mica or metallic foil) it is not possible to decompose the time spectrum and to establish which component is due to the metal and which to the foil. This way of preparing the active sample is unavoidable when the same source assembly must be used for different materials or when a point source is required for investigating powders or liquids. In order to interpret correctly the time annihilation spectra one is then faced with the problem of establishing the effect of the foil, *i.e.* the annihilation-spectrum shape of the foil and the fraction of positrons annihilating in it. The answer to the first part of the problem can be easily given, while the same is not true for the second. In fact accurate theoretical treatment of positron absorption in the foil is made impracticable by the combination of multiple scattering and energy loss in the foil itself and in the surrounding material. For that reason one is forced to an empirical approach in which the main difficulty to overcome arises from the necessity of working with the same geometrical arrangement used in positron annihilation experiments.

In the present paper we report the results of such an approach; the fraction of positrons annihilating in the foil was studied as a function of the foil thickness and of the atomic number of the surrounding material. The correctness of our conclusions was checked by analysing the annihilation spectrum shape in some metals. After correcting for foil effect, a single lifetime component appeared, in agreement with present theoretical knowledge.

2. – Experimental procedure.

As support of the positron source, we have studied:

a) Commercially available polyester foild, montivel (polyglicol ethylene terephthalate). These foils are insoluble in acids and alkalies and have the advantage of being easily welded together. In this organic compound positronium formation occurs and the ortho-state decays with a mean life of $1.80 \cdot 10^{-9}$ s. However this is an unfavourable circumstance which limits the use of polyester foils.

b) Thin layers of mica removed from large crystals by a thin needle. They are insoluble in acids with the exception of HF and have the further advantage of being fit for use, even at high temperature. Our measurements indicate that in mica positrons decay through two competitive processes characterized by mean lives of $2.43 \cdot 10^{-10}$ s and $4.23 \cdot 10^{-10}$ s; there is no trace of tails in the time spectrum.

All data obtained by us on positron annihilation in montivel and mica are collected in Table I. Figure 1 shows the time annihilation spec trum in mica.

The positron emitter (^{22}Na from a carrier-free, neutral, aqueous solution) was deposited on the foil under investigation; a second identical foil was placed over the source. The source so assembled was then sandwiched between two sheets of the material in which the annihilation was to take place.

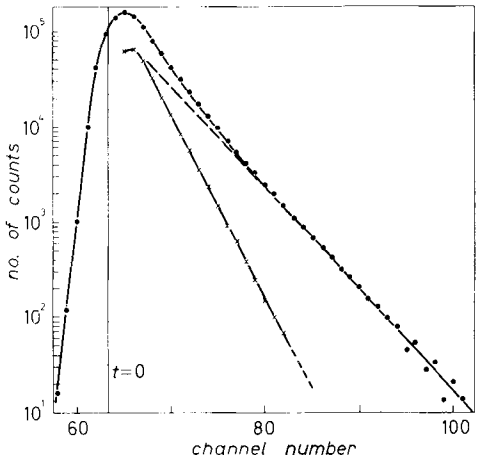

Fig. 1. – Time spectrum of positrons annihilating in mica. 1 channel = $1.03 \cdot 10^{-10}$ s, • $\tau_2 = 4.23 \cdot 10^{-10}$ s, × $\tau_1 = 2.43 \cdot 10^{-10}$ s.

The measurements of the time annihilation spectra were performed in a conventional way; the experimental set-up has been previously described [5]. We shall mention here only that the prompt time resolution curve for the conditions of the present experiment has a full width at half maximum of

TABLE I. – *Positrons annihilating in montivel and mica: lifetimes and intensities.*

Material	τ_1 (10^{-10} s)	I_1 (%)	τ_2 (10^{-10} s)	I_2 (%)	τ_3 (10^{-10} s)	I_3 (%)	τ_4 (10^{-10} s)	I_4 (%)
Montivel	1.1 ±0.2	10±3	3.5 ±0.1	68±4	7.1±0.3	8±1	18.0±0.4	15±2
Mica	2.43±0.08	48±5	4.23±0.08	51±5	—	—	—	—

$3.4 \cdot 10^{-10}$ s and that the sides simulate a single exponential decay through at least four decades. The logarithmic slope of the sides corresponds to a half-life of $0.40 \cdot 10^{-10}$ s.

The fraction k of positrons annihilating in the supporting foils was measured by means of the following procedure.

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[5] C. BUSSOLATI, S. COVA and L. ZAPPA: *Nuovo Cimento*, **50** B, 256 (1967).

a) Montivel foils. Firstly the montivel itself is chosen as annihilating material surrounding the source and a measure was made of the fraction f_0 of the annihilation events from those positronium atoms which have survived a time longer than t_1 and less then t_2. The instant t_1 ($2.0 \cdot 10^{-9}$ s) was selected as that for which any other-time-component contributions due to montivel itself or to the other investigated materials are quite negligible. The instant t_2 ($12 \cdot 10^{-9}$ s) was chosen so as to have a counting rate statistically still significant. Then, when the source assembly was surrounded by the metals

TABLE II. – *Fraction k of positrons annihilating in source-supporting foils.*

Foil material	Positron absorber	Foil thickness (mg/cm²)	k
Montivel	Al	1.19	0.118 ± 0.004
Montivel	Al	2.38	0.194 ± 0.002
Montivel	Al	3.57	0.258 ± 0.003
Montivel	Ni	1.19	0.142 ± 0.002
Montivel	Ni	2.38	0.233 ± 0.003
Montivel	Ni	3.57	0.306 ± 0.005
Montivel	Au	1.19	0.211 ± 0.003
Montivel	Au	2.38	0.318 ± 0.004
Montivel	Au	3.57	0.409 ± 0.006
Mica	Polyethylene	0.92	0.007 ± 0.008
Mica	Polyethylene	2.25	0.056 ± 0.008
Mica	Polyethylene	3.00	0.116 ± 0.008
Mica	Teflon	1.00	0.023 ± 0.009
Mica	Teflon	2.25	0.080 ± 0.008
Mica	Teflon	3.00	0.124 ± 0.006
Mica	Pt	0.93	0.177 ± 0.010
Mica	Au	0.93	0.178 ± 0.010
Mica	Au	2.19	0.320 ± 0.022
Mica	Au	2.24	0.317 ± 0.020
Mica	Au	2.97	0.349 ± 0.022
Mica	Au	3.13	0.328 ± 0.024

indicated in Table II, the fraction of annihilation events occurring between t_1 and t_2 is reduced to $f < f_0$. The ratio

$$k = f/f_0$$

gives directly the required fraction of positrons annihilating in montivel foils. The metals, employed *i.e.* Al, Ni and Au, were selected because a preliminary investigation (made without supporting foils and with a source from a neutral solution) showed that no tail extending up to t_1 was present in their time annihilation spectra.

b) Mica foils. An analogous procedure as that reported above could be used here only with Au and Pt whose time annihilation spectra are not at all contaminated by tails. Obviously different values of t_1 and t_2 were chosen ($t_1 = 2.5 \cdot 10^{-9}$ s, $t_2 = 3.5 \cdot 10^{-9}$ s). At lower atomic numbers no metal convenient for this type of measure was found; so we were forced to utilize as absorbers only polyethylene and teflon. In these cases the fraction k was obtained by measuring the decrease of the intensity of a convenient portion of the orthopositronium time spectrum.

3. – Results.

All the results obtained are collected in Table II and Fig. 2. It can be easily seen that even with thin foils (1 mg/cm^2) the fraction k attains considerable values ($\sim 20\,\%$) when the positron absorber has a high atomic number. If one takes into account that the positron back-scattering coefficient p increases linearly with Z ([6]), it is possible to explain qualitatively the amount of the observed effect. The positron before annihilating suffers a great number of back-scattering processes that force it to go many times through the foils. It is obvious that in the case of an ideal absorber with back-scattering coefficient equal to 1, all the positrons annihilate in the supporting foils independent of their thickness and nature. Indeed for gold ($p = 0.53$) it is very hard to note a different behaviour between mica and montivel foils.

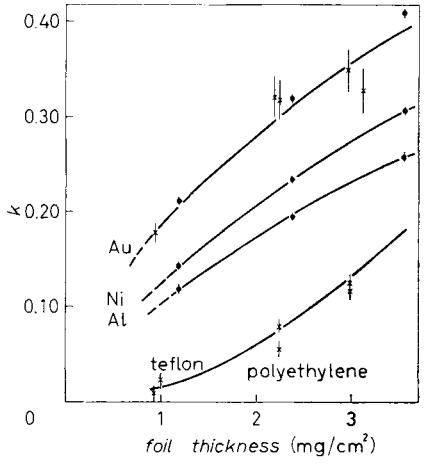

Fig. 2. – Fraction k of positrons annihilating in source-supporting foil as a function of the foil thickness. • Montivel, × Mica.

At very low Z it can be noted that the fraction k is smaller for mica than for montivel. Owing to the fact that in these cases the backscattering processes give a small contribution to the annihilation in the foils, the observed effect

([6]) A. Bisi and L. Braicovich: *Nucl. Phys.*, **58**, 171 (1964).

has to be ascribed to intrinsically different properties of the materials used. This observation is in qualitative agreement with the results of SAXON (7) on the transmission factor for beta particles through G.M. counter windows: the transmission factor in mica is higher than that of an organic material (cellophane) and this difference increases with decreasing beta-particle energy. A quantitative comparison is prevented because the transmission factor is strictly connected with the geometry used in the experiment.

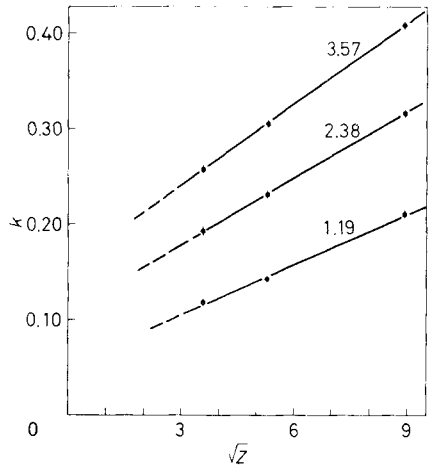

Fig. 3. – Fraction k of positrons annihilating in montivel foil as a function of $\sqrt{Z}$. The numbers on the curves indicate the foil thickness in mg/cm².

The fraction k of the positrons annihilating in the supporting foils, at different thicknesses and atomic numbers of the absorber, can be obtained by interpolation of the data of Table II. In this connection it shall be noted that for montivel foils the interpolation procedure is made easier because of the existence of a linear relationship between k and $\sqrt{Z}$, for each foil thickness (see Fig. 3). Unfortunately a similar situation does not occur for mica foils. For these, interpolation through a graph in a doubly logarithmic scale was found convenient. Equivalently the following empirical formula can be used:

$$k = 3.24 \cdot 10^{-3} \cdot Z^{0.93} \cdot s^{3.45/Z^{0.41}},$$

where s is the foil thickness in mg/cm².

4. – Time annihilation spectra in metals.

By using a positron source deposited on a mica foil and assembled as previously described, time annihilation spectra in some metals were investigated. The results are collected in Table III. The lifetimes and intensities were obtained after subtraction of the mica contribution and the analysis of the spectral shape was performed with a maximum-likelihood method which was described in a previous paper (8). It appears that metals are characterized mainly by a single exponential decay in agreement with the results of other

(7) D. SAXON: *Phys. Rev.*, **81**, 639 (1951).
(8) M. BERTOLACCINI, A. BISI and L. ZAPPA: *Nuovo Cimento*, **46** B, 237 (1967).

TABLE III. – *Positrons annihilating in metals: lifetimes and intensities after mica correction.*

Metal	τ (10^{-10} s)	I (%)	τ_{tail} (10^{-10} s)	I_{tail} (%)	Note
Ni	1.65 ± 0.04	98 ± 3	—	—	—
Ni	1.77 ± 0.06	95 ± 5	5.2	1.1	Source directly deposited from a neutral solution
Cu	1.81 ± 0.05	95 ± 5	4.1	5.0	—
Ag	2.01 ± 0.05	101 ± 5	12	0.3	—
Cd	1.90 ± 0.05	96 ± 5	13	0.3	—
W	1.45 ± 0.04	97 ± 5	24	0.1	—
Pt	1.73 ± 0.03	105 ± 5	—	—	—
Pt	1.78 ± 0.05	93 ± 5	5.0	3.7	Source directly deposited from a neutral solution
Au	1.91 ± 0.03	100 ± 3	—	—	—
Au	2.00 ± 0.05	95 ± 5	17	0.05	Source directly deposited from a neutral solution
Hg	2.19 ± 0.03	103 ± 5	22	0.3	—

observers ([3,4]). In many cases a tail accompanied the main component, which if interpreted as arising from an exponential decay, indicated the existence of a longer lifetime component of faint intensity (a few per cent or a few per thousand), perhaps attributable to some of the spurious effects quoted in the first Section.

The τ values after mica correction are in strict agreement with the corresponding values obtained for some metals (Ni, Pt, Au) where a source from a neutral solution was directly deposited. Moreover these values strictly agree with those given by WEISBERG and BERKO ([4]).

Two conclusions can be drawn from the above discussion. First, mica appears to be a good material for supporting foils, better than polyester compounds. Second, the procedure adopted for mica correction proves to be a reliable one, thus indicating that its extension to those cases where powders or liquids are used as annihilating materials may be helpful.

RIASSUNTO

La frazione k di positoni che annichilano in lamine sottili (mica o film poliesteri) usate come supporto per la sorgente attiva è stata misurata in funzione dello spessore della lamina e del numero atomico del mezzo circostante in istudio. Si è constatato

che k raggiunge valori considerevoli quando il numero atomico dell'assorbitore è alto; a bassi Z la frazione k relativa alla mica è più piccola di quella relativa al film poliestere. Sulla base dei risultati ottenuti si indica un procedimento per correggere gli spettri temporali. Questo procedimento applicato all'analisi degli spettri temporali di annichilazione in alcuni metalli, ha mostrato che i metalli sono caratterizzati da un singolo decadimento esponenziale, in accordo con i risultati di recenti ricerche.

Влияние источника, поддерживающего фольгу, на форму временного спектра аннигиляции позитронов.

Резюме (*). — Измерялась доля k позитронов, аннигилирующих в источнике, поддерживающем фольги (слюда или полистироловая пленка), как функция толщины фольги и атомного номера окружающего материала, в котором поглощаются позитроны. Было обнаружено, что k достигает значительных величин, когда поглотитель позитронов имеет высокий атомный номер; при низких Z доля k меньше для слюды, чем для полистироловой пленки. На основе полученных результатов указывается процедура для исправления временного спектра. При анализе временного аннигиляционного спектра в некоторых металлах эта процедура показала, что эти металлы характеризуются единственным экспоненциальным распадом, что согласуется с результатами недавних исследований.

(*) *Переведено редакцией.*