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Study of the Emission of Low-Energy Positrons from MgO

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The mono-energetic beams of low-energy positrons have been developed for the study of positron-atom-interaction. The emission characteristics of the positrons from MgO have been investigated using the time-of-flight technique. The intensity of the slow positrons emitted from a ^{22}Na source-moderator system is about 0.7 per second in the measured range of the accelerating voltages from 1 V to 10 V. The mean energy is observed to be about 2 eV higher than the applied accelerating voltages in this range.

KEY WORDS: Low-energy positrons / Moderator / MgO / Time-of-flight technique /

INTRODUCTION

During the past decade a number of experimental efforts to increase the yield of mono-energetic slow positron beams, under the purpose of studying positron-atom-interaction, have been done. In those experiments a many kind of solid materials playing a role of a moderator of fast positrons from radioactive sources were investigated. The moderated positrons having well-defined energy near 1 eV are reemitted from the moderator. Among the rest the MgO coated metal-grid shows up to now the most prominent properties of the emission of the slow positrons with a mean energy $E \simeq 1.6$ eV and ~ 1.5 eV width at a rate of 10 per second using a 30-μCi ^{22}Na source.[1] It seems at present that no other good moderators exist. The aim here is to examine and discuss the general behavior of MgO as a positron moderator employing the time-of-flight (TOF) technique and to obtain more informations on the mechanism for the emission of the slow positrons which is still not revealed.

EXPERIMENTAL

The TOF spectrometer used for this experiment is shown schematically in Fig. 1. About one half of positrons from a $\sim$30-μCi ^{22}Na deposited as a 2-mm-diam spot at the center of one side on a 0.25-mm-thick and 20-mm-diam plastic-scintillation detector lose partly their energies inside the scintillator. The other side of the scintillator was covered with an aluminized Mylar of 0.5 mg/cm^2 thickness to reflect the light flashes due to energy transfer of positrons in the scintillator and to ground the accumulated charge caused by the positron bombardment. The start pulses to be fed into a time-to-amplitude converter (TAC) are derived from this scintillator coupled to 100-mm-

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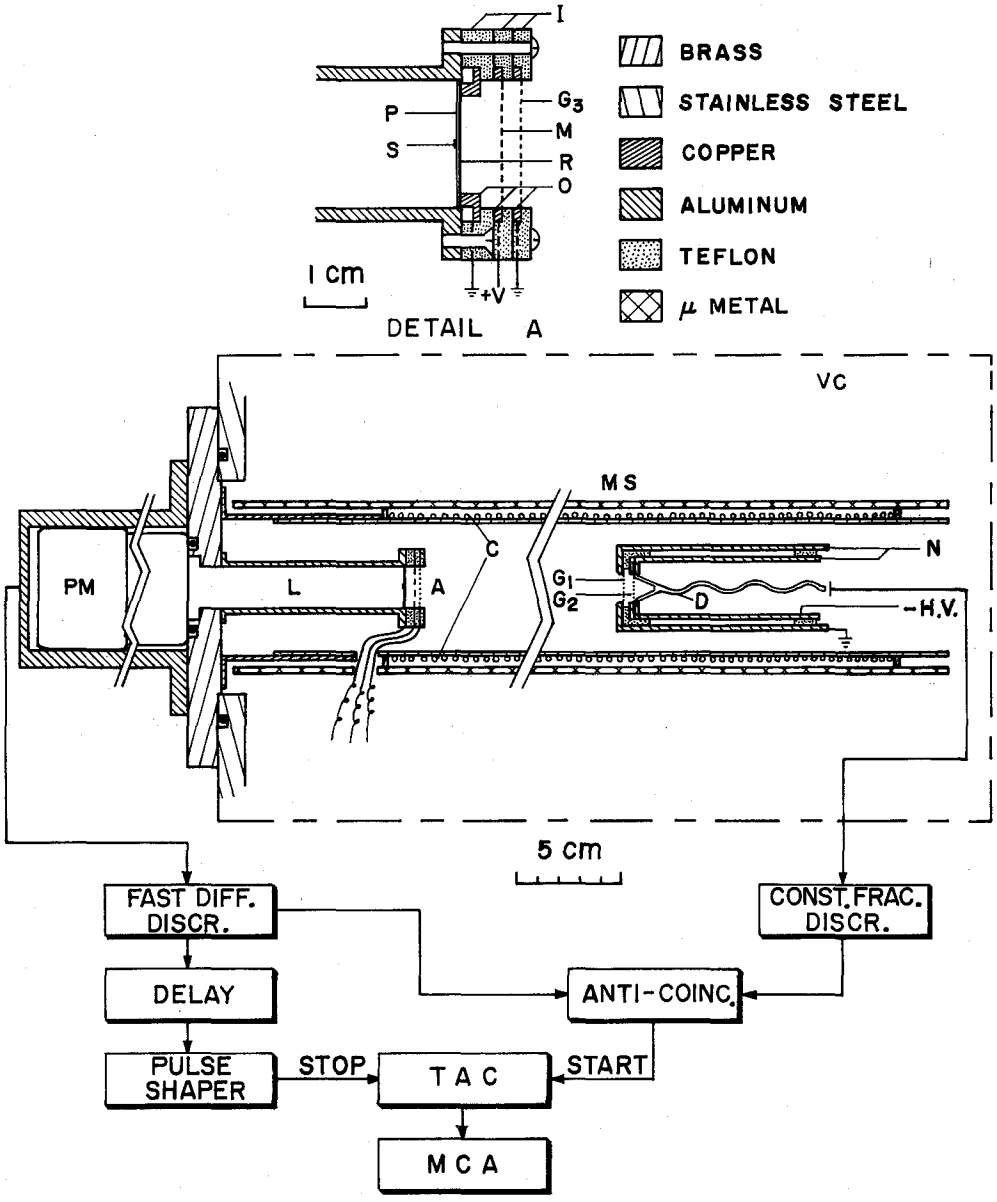

Fig. 1. Time-of-flight system including detail of the moderator and electronics. A) source-moderator assembly, L) Lucite light guide, D) Ceratron, N) outer and inner cylinders surrounded the Ceratron were grounded and applied the same negative potential as the Ceratron, respectively. PM) RCA 8575 photomultiplier, C) solenoid coil, MS) μ-metal shield, VC) vacuum chamber, G_1) grounded grid, G_2) grid at the Ceratron entrance with -4 kV, G_3) grounded grid, I) Teflon insulators, R) reflector, O) cupper rings, P) 0.25-mm-thick plastic scintillator, S) ^{22}Na source, M) MgO coated moderator.

long Lucite light guide with diameter 20 mm followed by a fast photomultiplier.

After giving the start pulses, the same positron which may have still energies of the order of keV strike MgO deposited on a micromesh grid by burning Mg ribbon in air. The moderator is positioned at just front of the scintillator. The slow positrons then are reemitted through an interaction of the fast positrons with the MgO grains. The positrons emitted to the forward direction are accelerated axially in the gap between the moderator applied a positive potential and a grounded 100 cells-per-inch tungsten grid to any desired energy and guided by an axial magnetic field which covers well beyond each end of the flight path, to confine them emitted at an angle to the axis in a helical path. The whole flight path of the positrons is surrounded by a single layer μ-metal magnetic shield on the outside of the solenoid coil against the earth magnetic field. After 300-mm flight in the straight path they are detected by the Murata EMW-1081B Ceratron (a channel electron multiplier made of ceramic) with the 10-mm-diam cone having two grids. The Ceratron has about 100% efficiency for the positrons and electrons, and inform the arrivals of the positrons as the stop pulses. The flight path is well shielded from the applied high voltage to the Ceratron. The detection efficiency of the Ceratron for the 0.511-MeV annihilation γ-rays and 1.28-MeV nuclear γ-rays emitted from the ^{22}Na source was measured to be less than 3% compared to that of positrons. The time resolution obtained by using the Ceratron was 5–6 ns width which was measured by detecting the fast positrons from the ^{22}Na source without the moderator.

The start and stop pulses thus obtained are fed via constant fraction discriminators into the start and stop inputs of the TAC, but in practice they are reversed each other because of the high pulse rate being 6×10^5 s^{-1} at the scintillator in contrast to the rate about 5 s^{-1} at the Ceratron. The pulses out of the TAC, whose amplitudes are proportional to the time intervals between the start and stop pulses, are fed to a multichannel analyzer (MCA), in which the TOF spectrum is accumulated for proper duration.

A very important requirement for the TOF spectrometer is to maximize the peak-to-random background ratio on the measured time spectrum because of the small rate of real events. This is performed in three ways. The first is to set the distance between the plastic detector and the Ceratron as short as possible. The second is to use a fast differential discriminator direct after the plastic detector instead of the constant fraction discriminator. By selecting the appropriate energy region of the energy loss spectrum in the plastic detector on the fast differential discriminator the peak-to-random background ratio can be reduced by about 30%. The third is to employ an anti-coincidence channel in the electronics as presented in Fig. 1. Prompt pulses due to unmoderated fast positrons, nuclear γ-rays, and annihilation γ-rays which contribute to the random background can be removed by this channel.

A vacuum chamber housed the source-moderator assembly including the light guide, the solenoid coil, and the Ceratron was pumped to a pressure of 1×10^{-6} Torr by means of an oil diffusion pump, and oil backstreaming was reduced by liquid nitrogen-cooled trap.

RESULTS AND DISCUSSIONS

Typical time spectra with two different accelerating voltages of 2 V and 20 V applied to the MgO coated stainless-steel grid are shown in Fig. 2 with corresponding restored and energy spectra (for 2 V). Real time scale on the spectra should be read from right to left because of the reversal of the timing sequence described in previous section. True time zero was defined at the centroid of the prompt peak caused by fast positrons and γ-rays measured without the anti-coincidence channel. A correction to the centroid resulting from finite flight time of these fast events was not applied in the present assignment of the time zero. Since the time spectrum dN/dt is proportional to $E^{1.5}\ dN/dE$, where E is a positron energy, at 20 eV (or higher energies) the observed spectrum has a sharp peak dominated mostly by the instrumental time resolution of the system, while at 2 eV (or lower energies) the peak width becomes wider over the background component.

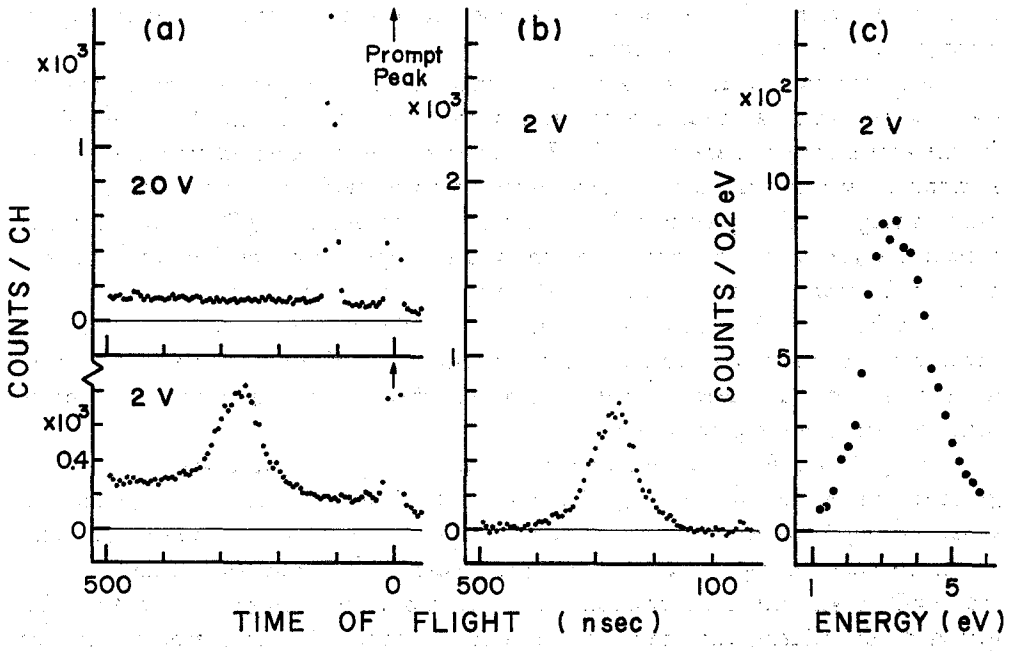

Fig. 2. (a) Obtained time spectra, upper and lower spectra are measured with the accelerating voltages of 20 V and 2 V, respectively. (b) Restored time spectrum for 2 V. (c) Energy spectrum transformed from spectrum (b), with no corrections for the instrumental time resolution.

In TAC–MCA system, the time spectrum is generally distorted by unrelated events, especially when a large number of unrelated pulses are contained in either start or stop pulses, or both, hence the time spectrum has to be restored by analyzing the measured data. A general treatment of this analyzing procedure was fully described by Coleman *et al.*[2] Figure 2b shows the restored spectrum with 2 V acceler-

ating voltage. The restored time spectrum was then transformed into energy spectrum by usual manner, which is shown in Fig. 2c. In this procedure, the corrections for the angular distribution of the emitted slow positrons, increase in path length by spiralling of flight path caused by the magnetic field, its energy dependency, and the time required in energy moderation process, are not included.

Following the procedure above mentioned various characteristics of the MgO moderator were examined. Firstly, the electrochemically prepared micromesh grid of Cu with 400 and 1500 cells per inch and of Ni with 500 cells per inch, and a woven stainless-steel grid with 200 cells per inch, on which MgO was coated with thickness of about 1 mg/cm^2 in average for all grids (for Cu–400, without MgO), have been attempted. A Cu foil (coated only on the forward side with MgO) with a thickness 0.01 mm was also attempted. The peaked spectrum was obtained as well as the micromesh grid, but the yield fell to about 20% compared to the MgO-coated Ni grid. Although it seems that the micromesh grids or foil serve only as a supporter for MgO and an electric plate for the accelerating voltage, and the grid and foil itself did not contribute to enhance the emission of the slow positron because the positrons having such low energies will be absorbed inside the MgO layer, further systematic experiments should be made in this regard.

Next, the axial magnetic field dependency of the slow positron yield with the stainless-steel grid was measured by varying coil currents from zero A to 6 A (45 G) for the accelerating voltage of 10 V. The observed yields decreased from 1 A to zero A in this measuring condition. The decreasing feature was found not to be monotonous but swinging. This implies that the emitted positrons from the MgO having inherently a certain angle to the axis may be off the sensitive opening of the Ceratron with decreasing the magnetic field. Above 2 A the yields show a flat dependency.

It is felt from the measurement with and without a liquid nitrogen trap in a vacuum pump that a clean and ultra-high vacuum is not of vital importance, or rather the presence of some gases adsorbed and/or absorbed on the MgO surface might be useful to facilitate the positron emission.

The yield was found to be high with the newly deposited MgO moderator but it gradually decreased with elapsing of time and then it became almost stable, after that when the MgO was exposed to air (with no accelerating voltage), it again increased. When the accelerating voltage on the MgO moderator was retained during exposing the MgO to air, the peak position shifted toward lower energies, the peak width spreaded very widely, and the yield increased to about twice, compared to the case with no voltage on the MgO. This behavior was consistently reproducible. This could be speculated as follows. The electrons and/or the negative ions in air caused by the positrons and γ-rays from the ^{22}Na source would be attracted by the applied potential on the MgO. This would result charging of MgO negatively. Here, when a measurement with the vacuum chamber evacuated is commenced again, the negatively charged MgO would contributed to shift the peak position toward lower energies, and inhomogeneity of the negative charge at the MgO surface would broaden the peak. The enhancement of the yield could be explain as a result of adsorption and/or absorption of the air molecules on the MgO surface. This fact may lead to an understanding

of the emission mechanism of the slow positrons.

When the accelerating voltage was varied, both the position of the slow-positron peak and the FWHM did not follow immediately to the newly applied voltage. This feature is prominent after a change of more than 10 V. This fact strongly suggests, as postulated by Jacobs,[3] the persisting effect of the charging at the surface of MgO caused by secondary electron emission due to the positron bombardment. Griffith *et al.*[4] have also noted the same behavior of the MgO moderator.

Fixing the coil current to 2 A with shortening the distance between the plastic detector and the moderator 2 mm apart, the slow-positron yields with varying the accelerating voltage from 1 V to 10 V were measured as shown in Fig. 3 with the corresponding FWHM and difference between the measured mean energy of the positrons E_{av} and the accelerating voltage V, for the MgO-coated stainless-steel grid. Owing to the unstable properties of MgO as a positron moderator as described above, the present measurements, hence, have been always commenced after holding the moderator 6–10 hours without measurement when the accelerating voltage was changed. The moderator used here was well aged for 20 days in the vacuum chamber with different voltages on the moderator and sometimes without the voltage.

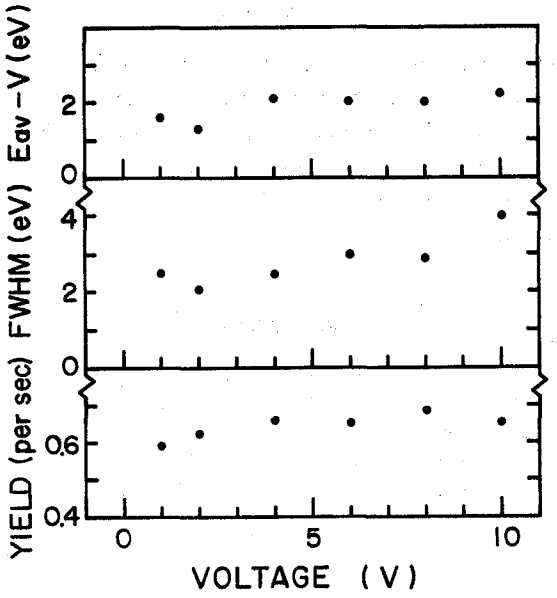

Fig. 3. Main characteristics of the MgO moderator obtained by varying the accelerating voltages V at low energy region.

The yield fluctuates from 0.6 s^{-1} to 0.7 s^{-1} in the measured energy region. It may be reasonable to accept that the yield is almost constant with the voltage. As the correction for the instrumental time resolution for the FWHM was not applied it is not easy to derive exact informations from the middle bin in Fig. 3. It, however, appears that there is no evidence of the remarkable broadening in the peak width and the feature of the variation of FWHM with the voltage based predominently on the

energy spread of the emitted positrons suggested by Coleman *et al.*[5] Although the reason for the different picture in the FWHM is not clear, there is a fact that the μ-metal magnetic shield is employed in the present system, whereas they do not install it. A very interesting feature in Fig. 3 is the difference $(E_{av}-V)$ shown in the most upper bin with almost constant dependency. It is reasonable to speculate that the MgO is left with a positive charge due to the secondary electron emission under fast positron bombardment. This charge retained at the surface of the MgO may give an additional positive accelerating voltage being about 2 V as seen in Fig. 3. All positrons with any energies in the present system may be subject to about 2 eV pedestal.

It can be concluded that the MgO moderator definitely shows a high yield of the slow positrons compared to any other materials examined so far, but the behavior is not so stable. The mechanism for the emission process of the positrons may at least be connected with the charge layer formed at the MgO surface. A complete analysis of the moderator characteristics would be lead to the optimum use of the MgO and understanding the emission mechanism. More detailed investigation with improved system is now in progress and will be published elsewhere.

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