Polarization of Positrons from Ga^{66}, Ga^{68}, P^{29}, and Al^{25} †

R. S. PRESTON AND S. S. HANNA
Argonne National Laboratory, Lemont, Illinois
(Received February 19, 1958)

The longitudinal polarizations of thermalized positrons from Ga^{66}, Ga^{68}, P^{29}, and Al^{25} have been observed from measurements on annihilation with polarized electrons in a magnetic medium. When allowance is made for the depolarization suffered by the positrons in coming to rest, the observations are in qualitative agreement with the assumption that the initial polarizations are proportional to $+v/c$ with the same proportionality constant as for positrons from Cu^{64}.

THE polarization of the positrons emitted from a Ga^{66} source has been measured, with discordant results.[1–3] Since the spin of Ga^{66} is zero[4] it is fairly certain that the beta transition is of the type $0^+ \to 0^+$ and hence involves only the Fermi interaction. We have investigated the polarization with the method[5–7] used previously to determine the polarizations of positrons from Cu^{64} and N^{13}. The positrons come to rest and annihilate with electrons in a magnetized sample of iron. A change in the shape of the angular correlation of two-quantum radiation is observed when the direction of magnetization is reversed, and this change is then associated with the positron polarization. In the course of the experiment information was obtained also on the shorter-lived isotope Ga^{68}. The results on the gallium isotopes led to a study of the positrons from P^{29} and Al^{25}.

Each gallium source was prepared by bombarding a copper disk with about 40 μa hr of alpha particles (40 Mev) from the Argonne cyclotron. A typical disk was $\frac{3}{16}$ in. in diameter and 0.15 in. thick; the alpha-particle beam penetrated to a depth of about 0.007 in. A source was installed in the apparatus within one to two hours after preparation and at the start of a run approximately 50% of the positrons were from Ga^{68} with a half-life equal to 1.1 hr. In a few hours, however, the only effective activity remaining was due to Ga^{66} with a half-life of 9.4 hr. By inserting an appropriate absorber into the path of the positrons it was possible to study positrons emitted with high energies, thereby suppressing the positrons from Ga^{68}, since the end-point energies for Ga^{66} and Ga^{68} are 4.15 and 1.88 Mev, respectively. The initial source strength was, very roughly, 50 mC. The measurements, obtained in the same way as in the earlier work[5–7] with Cu^{64}, are given in Table I, together with some recent measurements on Cu^{64} which were taken for comparison. The data obtained with gallium are divided into an early part, in which positrons from both Ga^{66} and Ga^{68} were present, and a later part, in which the average contribution from Ga^{68} was less than 5%.

It appears in Table I that (1) the polarization effect for the gallium source is decidedly smaller than it is for Cu^{64}, (2) in the case of gallium, the result of an increase in the amount of absorber is a decrease, if anything, in the polarization effect—just the reverse of what happens with Cu^{64}, and (3) the Ga^{68} isotope produces a larger effect than does Ga^{66}. One explanation of these phenomena immediately suggests itself, namely, that the observed differences are due, not to a departure from the relation that the initial polarization is equal to v/c, but rather to a depolarization of the positrons in slowing down to thermal velocities. Both Coulomb and electron scattering contribute to the depolarization of the positrons during the process of slowing down, the Coulomb scattering being more important at high energies and the electron scattering more important at low energies.[8] Obviously positrons with high initial energies suffer more depolarization in coming to rest than those with low initial energies, since they must

TABLE I. Values of $(N_+ - N_-)/N_-$ in percent for Ga^{66}(E_{max} =4.15 Mev), Ga^{68}(E_{max}=1.99 Mev), and Cu^{64}(E_{max}=0.66 Mev), and for various thicknesses of absorber. The symbols N_+ and N_- represent the integral yield in the two-quantum angular correlation over angles greater than 8 milliradians, for field parallel (+) and antiparallel (−) to the direction of motion of the positrons. Thicker absorbers result in higher values for the average initial energy of the positrons whose annihilations in the iron sample are detected.

Source of positrons	Absorber (mg/cm²)	$(N_+ - N_-)/N_-$ (%)
$Ga^{66}+Ga^{68}$	280	4.1±1.4
Ga^{66}	280	2.9±1.3
$Ga^{66}+Ga^{68}$	750	2.6±4.4
Ga^{66}	750	0.9±1.9
Cu^{64}	55	4.5±1.6
Cu^{64}	110	7.0±1.9

† This work was performed under the auspices of the U. S. Atomic Energy Commission.

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[6] S. S. Hanna and R. S. Preston, Phys. Rev. **108**, 160 (1957).
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undergo more scatterings. In single scattering, the greatest depolarization occurs for the largest scattering angles.[8] Unfortunately, positrons which undergo large-angle single scatterings are not always lost from the beam in this experiment because of the focusing action of the magnetic field. Hence positrons whose annihilation radiations are eventually detected may be appreciably depolarized, those initially of high energy more so than those of low energy. This latter property would account for the fact that the observed polarization effect becomes progressively larger in the sequence, Ga^{66}(E_{max}=4.15 Mev), Ga^{68}(E_{max}=1.88 Mev), and Cu^{64}(E_{max}=0.66 Mev). It accounts also for the decrease in the effect when absorber is added to the gallium source, thereby eliminating positrons which are emitted with low energies and therefore suffer less depolarization. There is, of course, some positron energy below which this decrease in depolarization is offset by the lower initial polarization resulting from a lower value of v/c at emission. Hence, in the case of Cu^{64} the empirical evidence is that the size of the effect is increased when absorber is added.

In view of these considerations, measurements were made on two other sources, Al^{25} and P^{29}, with large end-point energies of 3.24 and 3.94 Mev, respectively. In both these cases the transitions are between mirror nuclei and presumably of a mixed type. The sources were prepared by (d,n) reactions in the Van de Graaff generator, using the technique[5] developed for N^{13}. Because of the short lifetimes of Al^{25} and P^{29} (7.3 and 4.7 sec, respectively), an automatic sequence of operations was provided for taking the data. The source was irradiated with a fixed integrated current for about 10 sec. The beam was interrupted and the annihilations were detected for a period of 5.0 sec; after a deadtime of 0.83 sec the counting was continued for another 5.0 sec. During the first period of counting, the collimating plug which restricts the observed yield to the wings of the angular correlation was in place. During the deadtime this collimator was removed and in the second period the "total" coincidence yield was recorded. Following this first cycle the source was irradiated again and a second cycle was carried out with the same time intervals. This time, the "total" coincidence yield was measured during both periods of counting. The complete program was automatic and repeated itself until it was interrupted in order to reverse the direction of the magnetic field. To obtain the result for a given source, the cumulative yield with the collimator in place was normalized to that with the collimator removed as obtained during the first cycles. The result was then corrected for the decay of the source by normalizing it to the ratio of the counting rates obtained without the collimator in the second cycles. This latter correction was made because of the possibility of the presence of small amounts of impurities in the sources which could have affected the observed rate of decay. The results in Table II then give a comparison of the final normalized yields for the two directions of the magnetic field. Although the statistical uncertainties in the results are large, it appears that there is a positive polarization for both P^{29} and Al^{25} and that the observations fall between those for Ga^{66} and Cu^{64}.

TABLE II. Values of $(N_+-N_-)/N_-$ in percent for the short-lived positron sources P^{29} and Al^{25} produced by Van de Graaff irradiation.

Source of positrons	E_{max} (Mev)	Absorber (mg/cm²)	$(N_+-N_-)/N_-$ (%)
P^{29}	3.94	400	4.7±3.1
Al^{25}	3.24	400	3.2±3.1

In order to examine further the influence of depolarization, the thick sample in which the annihilations took place (in reality an extension of a pole face of the magnet) was replaced with a thin sample, suspended in the magnetic field, which preferentially stopped only the positrons of low energy. With such a sample there were no significant differences among the results obtained for Ga^{66}, Ga^{68}, and Cu^{64}, as tabulated in Table III. The values (2–3%) are, however, markedly smaller than the values (4–7%) obtained with Cu^{64} and a thick annihilation sample. This diminution of the effect can be attributed chiefly to the unavoidable reduction of the magnetic field (~50%) in the suspended sample. The two final runs in Table III were obtained with a Cu^{64} source using a thick annihilation sample. In one, the field was maintained at its usual value and a 7% effect was observed, as expected. In the other run, the field in the sample was reduced to a value comparable to that measured for the thin samples. In this case, a greatly reduced effect was observed.

TABLE III. Values of $(N_+-N_-)/N_-$ in percent for positrons from Ga^{66}(E_{max}=4.15 Mev), Ga^{68}(E_{max}=1.88 Mev), and Cu^{64} (E_{max}=0.66 Mev), and for various thicknesses of the absorber and of the annihilation sample. A thin annihilating sample preferentially stops positrons that have low energies when they reach it.

Source of positrons	Sample thickness (inches)	Absorber (mg/cm²)	$(N_+-N_-)/N_-$ (%)
$Ga^{66}+Ga^{68}$	0.037	80	3.0±1.7
Ga^{66}	0.037	80	3.6±1.7
$Ga^{66}+Ga^{68}$	0.027	200[a]	2.0±2.3
Ga^{66}	0.027	200[a]	2.5±1.8
Cu^{64}	0.027	55	2.6±1.0
Cu^{64}	0.027	110	2.6±1.2
Cu^{64}	∞[b]	105	7.1±2.5
Cu^{64}	∞[c]	105	3.7±2.5

[a] Plastic absorber.
[b] Full magnetic field.
[c] Reduced magnetic field.

It is clear that for all the sources investigated the positrons are polarized, and the sense of the polarization is the same in all cases. There is evidence that in coming to rest the positrons suffer an appreciable depolarization, making it difficult to compare the polarizations of different sources if the initial energies of the positrons are markedly different. Hence, the effect observed for Ga^{66} is invariably smaller than for Cu^{64}, unless positrons of approximately the same initial energies are compared in the two cases. When this is done (Table III) the evidence supports the assumption of full polarization $(+v/c)$ for Ga^{66} (if that is the value for Cu^{64}) and hence is in agreement with the results of Deutsch *et al.*[2] and of Frankel *et al.*[3]

ACKNOWLEDGMENTS

We are grateful to A. E. Everett for his valuable assistance during the early stages of the investigation. We have profited from stimulating discussions with our colleagues J. P. Schiffer and T. B. Novey.

PHYSICAL REVIEW VOLUME 110, NUMBER 6 JUNE 15, 1958

Radiative Capture of Alpha Particles to States of O^{18} and F^{18}†

W. R. PHILLIPS
University of Wisconsin, Madison, Wisconsin
(Received February 28, 1958)

The radiative capture of alpha particles in N^{14} and C^{14} has been studied for bombarding energies between 1.3 and 3.0 Mev. Four narrow resonances were observed in the reaction $N^{14}(\alpha,\gamma)F^{18}$, corresponding to levels in F^{18} at 5.60, 5.67, 6.24, and 6.65 Mev. Two narrow resonances were observed in the reaction $C^{14}(\alpha,\gamma)O^{18}$, corresponding to levels in O^{18} at 7.63 and 8.05 Mev. These two are 1^- states.

The decay schemes of some of these levels were partly elucidated, and several partial radiative widths were measured. The decays studied gave information on the low-lying levels in F^{18} and O^{18}.

INTRODUCTION

THE radiative capture of alpha particles can be a very useful means of obtaining information on the low-lying levels in the light nuclei. It is a method which so far has been little exploited for bombarding energies greater than 1.5 Mev. The study of the decay scheme and of the angular properties of the gamma rays emitted at an isolated resonance will yield information on all of the levels involved in the compound nucleus. If the elastic alpha scattering data in the region of the resonance under examination can put limits on the spin of the level formed, then this can be of great help in interpreting what is seen in its radiative decay.

Much theoretical and experimental work has recently been done on the nuclei above O^{16} in the $1d$ shell. The positions of the positive-parity levels in F^{19} and many dynamic characteristics of the mass-19 nuclei agree very well with the prediction of the intermediate coupling shell-model theory,[1] and also with a rotational interpretation.[2] Similar success has been obtained with the first few O^{18} levels.[3] In the present work N^{14} and C^{14} were bombarded with alpha particles of energies between 1.3 and 3.0 Mev to try to find out more about the levels in F^{18} and O^{18}.

† Work supported by the U. S. Atomic Energy Commission and by the Graduate School from funds supplied by the Wisconsin Alumni Research Foundation.

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EXPERIMENTAL RESULTS

Cylindrical NaI crystals, 2 in. and $1\frac{1}{2}$ in. in diameter, 2 in. and 1 in. thick, were used as gamma-ray detectors, together with DuMont type 6292 phototubes. After amplification, pulses were fed into a multichannel pulse-height analyzer, and into conventional coincidence and gate circuitry as required. The gamma-ray energies were determined by comparison with six standard sources: annihilation radiation (0.511 Mev); Cs^{137} (0.661 Mev); Na^{22} (1.277 Mev); ThC″ (2.62 Mev); the $N^{15}(p,\alpha\gamma)$ reaction (4.43 Mev); and the $F^{19}(p,\alpha\gamma)$ reaction (6.14 Mev).

The investigation of (α,γ) reactions is rendered difficult by their low yield and by several sources of background, the most important being the neutrons formed in the reaction $C^{13}(\alpha,n)O^{16}$. The pulse-height spectrum produced in a NaI crystal by 3-4 Mev neutrons has a roughly exponential distribution. The upper "cutoff" moves up with increasing neutron energy. In addition the yield of the $C^{13}(\alpha,n)$ reaction increases rapidly above 2 Mev.[4] These two factors make the study of gamma rays of energies below 3-4 Mev increasingly difficult for bombarding energies greater than 2 Mev. To minimize this background stringent precautions were taken to make the buildup of natural carbon on the targets as slow as possible. The most effective experimental arrangement employed an activated charcoal pump maintained at liquid air temperature and surrounding the path of the beam. All gaskets used on the target side of this pump were of Teflon, and the target was kept at a temperature of

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