Parity Conservation in Strong Interactions: Reaction $Li^7(p,p')Li^{7*}_{0.477}$†

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Unless parity conservation breaks down in strong interactions the radiations emitted from an isolated level cannot display odd powers of $\cos\theta$ in their angular distribution or correlation. A search for such powers is then an approach to the conservation problem. The $\frac{1}{2}$- first excited state of Li^7 at 477 kev has been excited by inelastic proton scattering. The expected angular distribution of the gamma rays of de-excitation relative to the bombarding proton beam is $1+\alpha\cos\theta$ where α is of order $\mathcal{R}\mathcal{F}^2$, $\mathcal{F}$ being the amplitude of the parity nonconserving part of the relevant wave functions and $\mathcal{R}$ is a matrix element factor. By comparison with the radiation following K capture in Be^7 it is shown that α is zero within a standard deviation of 6 parts in 10^4. This corresponds to $\mathcal{F}^2 \lesssim 1\times10^{-4}$.

INTRODUCTION

WE continue the investigations[1] of the conservation of parity in strong interactions with an experiment of the third class enumerated in I, namely those experiments in which we make use of interference effects due to parity-conserving and parity-nonconserving parts of the nuclear wave functions, but are sensitive only to $\mathcal{F}^2$, the *intensity* of the parity violation.

In II we sought for circularly-polarized gamma rays due to parity interference emitted from well-isolated bound nuclear states and were there sensitive to $\mathcal{F}$. In the present paper we exploit a feature of an isolated level of well-defined parity discussed in I, namely that the radiations emitted in its breakup show only even powers of $\cos\theta$ in their angular distributions relative to any preceding radiations which lead to that level. If, on the other hand, the parity of the state in question is mixed then odd powers of $\cos\theta$ can appear in the angular distribution. In particular if the emitting state is of $J=\frac{1}{2}$ then the angular distribution will be of the order $1+\mathcal{R}\mathcal{F}^2\cos\theta$ where $\mathcal{R}$ is a factor dependent on detailed matrix elements, the properties of the states preceding that in question and so on. The case of $J=\frac{1}{2}$ is particularly advantageous because, but for the parity interference, the emission would be rigorously isotropic in the center-of-mass system and it is very much easier to detect a small $\cos\theta$ term added to an isotropic distribution than a similar term added to a distribution containing even small amounts of $\cos^2\theta$ or higher terms. For the case $J=\frac{1}{2}$ the angles of observation can be very poorly defined; for higher J values which entrain the higher even powers of $\cos\theta$ the definition of the angles must be made with great precision. This is because we must compare emission at θ and $\pi-\theta$ to detect the odd powers of $\cos\theta$, and the pair of angles 0° and 180° is not available.

We therefore seek a well-isolated level of $J=\frac{1}{2}$ and since the isolation can be achieved to an adequate degree only if the level is bound it is clear that the radiation to be examined must be a gamma ray. This in turn means that we are experimentally involved in at least a three-stage process. In this we may either examine the correlation between the gamma ray and the radiation (gamma ray or heavy particle) which leads to the $J=\frac{1}{2}$ state or we may examine the distribution of the gamma ray relative to the incident particle (of a three-stage process). This second method of experimentation is much to be preferred since the counting-rates that can be achieved are much higher.

As in II we are helped by choosing if possible a transition where the radiation from the parity-nonconserving component is intrinsically stronger than that from the chief component. This means that we again look for a transition where the ordinary component is magnetic in character. (We obviously cannot use the trick of one of the experiments in II where we chose the ordinary transition to be an isotopic spin forbidden electric dipole since we must here use a state of $J=\frac{1}{2}$.)

Also in the interests of intensity we must choose a case where the second (unobserved) radiation which links the initial compound nucleus with the $J=\frac{1}{2}$ state is a heavy particle.

Our conditions are then clearly a reaction such as was considered in I, namely $X(h_1,h_2\gamma)Y$ where h_1 and h_2 are heavy particles. The gamma ray is to be a magnetic transition from a bound level of $J=\frac{1}{2}$. We then measure the angular distribution of the gamma ray relative to h_1, h_2 being unobserved. Many such cases are known. There are, however, other conditions of experimental importance. One of these is that the gamma ray should be uncontaminated, or should be accompanied only by gamma rays of a low enough energy for a complete separation to be effected, or that the other gamma rays follow it in a cascade, or that they be so weak as to be effectively negligible to the accuracy with which we perform the experiment or, if they are not negligible, then they must be both very weak and of a well-known angular distribution. These conditions severely limit our choice and, for example, eliminate most of the $X(d,h_2\gamma)Y$ reactions which would otherwise

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[1] D. H. Wilkinson, Phys. Rev. **109**, 1603, 1610 (1958), preceding papers. We refer to these as I and II, respectively.

be very useful. We are in effect almost completely limited to $X(h,h'\gamma)X$ reactions in which we can excite a low-lying state with great ease and suffer the competition only of the much weaker radiative capture.

ACCURACY OF THE EXPERIMENT

We have touched upon the accuracy of the experiment and a brief consideration of what is needed to be worthwhile is very discouraging. There is little point in the present type of investigation unless it is sensitive to a departure from isotropy of the order of 0.1% or better. Such accuracy is surely extremely difficult to achieve in a straightforward way and the author knows of no reliable measurement in which it has been even remotely approached. Even the problem of positioning the detector relative to the target spot to within the required 0.025% or so is very formidable. The achieving of the same absorption in the target material and housing to within this accuracy in both directions of observation is virtually impossible. Also, since the experiment is by its very nature asymmetrical, because of the use of h_1 to define $\theta=0°$, there will inevitably tend to be differences of scattering between the two directions and this is difficult to allow for completely.

To achieve the desired precision we must therefore resort to some indirect method. The problem would be solved if we had available another source of gamma rays of exactly the same energy as those which we study which we could put in exact geometrical coincidence with the target spot of the $X(h,h'\gamma)X$ reaction and in whose isotropy we had complete trust. This comparator source would then suffer exactly the same absorption and scattering of its gamma rays as those from the nucleus X. The problem of the positioning of the detector would vanish because we would simply have two quite independent and not necessarily similar detectors at the two angles to be compared and at distances from the target that need not even be known. The experiment would simply consist in comparing the ratios of counting rates in the two detectors for the $X(h,h'\gamma)X$ or reaction source and for the comparator source. Any difference between these ratios would indicate a departure from isotropy.

Generally speaking however, such suitable comparator sources are not available for the transitions which are satisfactory in the other respects that we have discussed. Even if they were, their exact positioning with respect to the target spot would be a severe problem. However, there exists one example where the energies of the reaction and the comparator sources are exactly the same and where the positioning can also be made exact. This is when we choose as our reaction source $Li^7(p,p'\gamma)Li^7$ with the gamma ray in question being that from the first excited state of Li^7 at 477 kev. Our comparator source is now Be^7 which K captures to the same state of Li^7 that we study in our reaction and so the comparator and reaction-source gamma rays are one and the same. The identity in position and spatial distribution between reaction and comparator sources is achieved by actually making the Be^7 from the same Li^7 target in the same target assembly as is used for the inelastic scattering. The lithium target is bombarded with protons of an energy above the $Li^7(p,n)Be^7$ threshold until enough Be^7 has been built up to act as the comparator. The proton energy is then simply lowered below the neutron threshold without touching anything and the gamma rays following inelastic scattering are excited. When the target current is zero we are observing the Li^7 gamma rays following the Be^7 decay. With current on the target we observe these gamma rays and also those from the same level following inelastic proton scattering so that a subtraction gives us the target yield by itself.

LIFETIME PROBLEM

We have, unfortunately, oversimplified the physical situation in describing the basis of the experiment. We have omitted the fact that the lifetime of the Li^7 state in question is shorter than the slowing-down time of the recoil nucleus in the target material. This brings two related difficulties. The first is that the isotropy of emission in the center-of-mass system in which we are interested is removed in the laboratory system in which we make our measurements because of the usual aberration of the gamma rays. In order to correct for this we must know the velocity-angular distribution of the emitting nuclei. Similarly the accompanying Doppler shift means that the energy of the observed gamma rays is a function of the angle of observation. This in turn means that our detectors will not have quite the same efficiency for the reaction source and comparator gamma rays. Also the absorption and scattering effects will be slightly different for the two sources. We may easily estimate that these effects are of the percentage order and so if we aim at an accuracy of ten times better than this we must understand them very well.

It is in fact possible to devise an experimental setup in which we could ignore them. Consider for illustration the two major effects implied by the moving source—the aberration or tendency of the moving Li^7 to throw the gamma rays forward in the laboratory system and the change in detector efficiency because of the Doppler effect. Within the accuracy of the immediate discussion, we may write the aberration effect nonrelativistically as $1+(2v/c)\cos\theta$, where v is the velocity of the recoil nucleus when the gamma ray is emitted. This means that the density of gamma rays emitted at the angle ϕ in the laboratory system is greater by this factor than it would be had the nucleus been stationary. The angle ϕ is now that between the direction of motion of the recoil nucleus and the direction of emission of the gamma ray; it approaches θ as we drop towards the threshold for inelastic scattering. But now to the same accuracy the Doppler shift is $\Delta E=E_0(v/c)\cos\phi$, where E_0 is the energy of the unshifted gamma ray. So we

may write the aberration as $1+2(\Delta E/E_0)$. Consider now the efficiency of the detectors. This, over the small range of energy (about 1%) involved may be written as $1+(\epsilon/\Delta E)$. If, therefore, we choose detectors such that $\epsilon=-2/E_0$, the Doppler and aberration effects cancel and so we need not concern ourselves with either the angular distribution of the recoiling nuclei, the lifetime, or any of the other complicating aspects of the moving source. In fact the other aspects of the situation such as the energy dependence of the absorption and scattering can also be written in this form and so can also be incorporated in the same correction.

In the present investigation we did not try to achieve this complete "tuning out" of the moving-source corrections but rather used available detectors of excellent characteristics and well-understood properties. In fact something like one-half to two-thirds of the effect was tuned out and the rest had to be allowed for. As will be seen, we know enough about the situation to do this with good accuracy.

DETECTORS AND THE CORRECTIONS

As detectors NaI(Tl) crystals were used. One of them was placed at $\theta=0°$ at about 15 cm from the target. It was a cylinder of approximately 2 inches in length and $1\frac{3}{4}$ inches in diameter. The other was placed at $\theta=145°$. It was a right cylinder of approximately $1\frac{1}{2}$ inches. It was positioned so that its counting rate was the same as that in the other crystal to within a few percent. This approximate equality of counting rate is of no fundamental importance for the method but was adopted to minimize certain small corrections to be reported later.

All the corrections that we shall discuss are well understood with the exception of that arising from the energy dependence of the scattering. However this effect is a very small one and is made negligible by counting only those pulses than lie in the peak of the crystal spectrum. This high-energy region of the spectrum was indistinguishable for the source in the experimental assembly and for a completely free thin source and, since we are concerned only with the change in the scattering for a 1% shift in energy it is clear that we may ignore this effect. This would perhaps not have been so had we counted all pulses from the crystal, as the effect of scattering in the experimental assembly was clearly manifest for small pulse heights and its energy dependence would have been difficult to discuss.

We now enumerate and discuss the various effects which lead to the ratio F/B being different for the reaction source (called Li) and comparator source (called Be). F and B are the respective counts registered in the forward ($\theta=0°$) and backward ($\theta=145°$) crystals.

There is first of all the aberration effect which we write neglecting quadratic terms as $1+(A\pm a)\Delta E$. The error a is small and is due only to the lack of precise knowledge of the level position.

Secondly there are the effects coming from the energy dependence of the crystal sensitivity. These depend partly on the nature of the detector and partly on the way of using it. The actual probability of interaction of a gamma ray with the crystal depends on the gamma-ray energy and is written $1+(B\pm b)\Delta E$. The quantities B were computed from the extensive tables[2] available. The error b comes chiefly from our uncertainty in knowledge of the exact crystal dimensions. Now comes the way in which the crystals were used. This was to measure the counting rate by using a single-channel kicksorter whose lower limit was adjusted with great care to coincide with the trough of the pulse spectrum (for the Be^7 source). The upper limit was comfortably above the upper tail of the spectrum but no higher than was needed to give confidence that only a negligible number of 477-kev pulses were being lost. We now define the "peak-to-total ratio" of our detectors to be the ratio of counts in this channel to the number of all interacting gamma rays for a scatter-free source. This peak-to-total ratio is a function of gamma-ray energy and so introduces the correction $1+(C\pm c)\Delta E$. C was measured for the crystals used and for the source position used by careful measurements on the "peak-to-total ratio" for gamma rays of energy 411, 477, and 511 kev deriving from Au^{198}, Be^7 and annihilation radiation, respectively. For this purpose a 100-channel kicksorter was used. This correction is by far the most troublesome to determine and involves by far the greatest error, but it was considered that the advantages of a narrow channel and avoidance of worries about scattering more than made up for the difficulty and error. A further correction is due to the fact that our measurements were not of the peak itself except for the Be^7 source but were rather taken in a fixed channel with a constant lower bias corresponding to the trough of the Be^7 spectrum. So in the forward direction we count a little more than the peak and in the backward direction a little less. This correction, $1+(D\pm d)\Delta E$ is easily determined by examination of the detailed 100-channel spectra for the three calibrating gamma rays. Note that we must use several gamma rays to determine this correction also because we are concerned not with the shift of the *peak* of the spectrum with gamma-ray energy but rather with the shift of the *trough*; this is a little more rapid, relatively speaking, because the relative width of the peak increases as the gamma-ray energy decreases. These three corrections complete the discussion of the energy dependence of our detector sensitivity.

A final correction is due to the energy dependence of the absorption of the gamma rays in escaping from the target assembly. The main absorption itself is accurately allowed for by our comparator procedure of course and need not even be evaluated but its energy dependence concerns us and introduces the correction $1+(E\pm e)\Delta E$.

[2] Wolicki, Jastrow, and Brooks, Naval Research Laboratory Report NRL-4833, 1956 (unpublished).

This correction was calculated. In the forward direction we have absorption by the end of the target tube: 1.0 mm of brass. The target material proper is negligible in its effect. In the backward direction there is cosec $35°\times\frac{1}{32}$ inch of brass.

In Table I we summarize these corrections, measured or calculated. The units used are $(100\text{ kev})^{-1}$. The subscripts F and B are used for the forward and backward detectors, respectively, where the corrections are not the same for the two.

Although these are all the corrections which are due to the Doppler shift and allied effects and so which are proportional to that shift, there is one more correction that we must consider before writing down the expected F/B ratio for the reaction source with isotropic distribution in the center-of-mass system in terms of that for the comparator source. This final correction is one that could have been avoided but to do so would have made the experiment more tedious. The reaction source was confined to the immediate surface layers of the LiOH target, since the proton bombarding energy was 1.3 Mev and the process has an effective threshold of about 1 Mev. However, in order to build up sufficient Be^7 activity in a reasonable time, a proton energy of 3.0 Mev was used for the $Li^7(p,n)Be^7$ reaction. This means that although the lateral distributions of the reaction and comparator sources were identical, they had a slightly different depth distribution. These depth distributions were computed knowing the energy dependence of the cross sections for the neutron-producing reaction[3] and for the inelastic scattering.[4] The correction has two components of the same sign. The first is because the comparator source is closer to the forward counter and further from the backward one than the reaction source; the second is because the gamma rays from the comparator source suffer relatively less absorption in the source material in reaching the forward counter and more in reaching the backward counter than those from the reaction source. These two components are of roughly equal importance, 0.073% for the geometrical correction and 0.079% for the absorption correction. They combine to give a correction factor of 1.00152 ± 0.00010 where the stated error amply covers all uncertainties due to cross-section variation with proton energy, range-energy relations, and allowance for the small fraction of gamma rays that suffer Compton scattering and yet are counted in the peak of the NaI(Tl) spectrum.

TABLE I. Table of correction terms and errors for the two crystal positions—see text for explanation of the symbols. The units are $(100\text{ kev})^{-1}$.

Correction		Error	
A	+0.419	a	0.001
B_F	−0.080	b_F	0.002
B_B	−0.099	b_B	0.002
C_F	−0.221	c_F	0.015
C_B	−0.261	c_B	0.015
D_F	+0.082	d_F	0.004
D_B	+0.082	d_B	0.004
E_F	+0.008	e_F	0.001
E_B	+0.011	e_B	0.001

A combination of all these corrections and errors leads to a predicted $(F/B)_{\text{Li}}$ ratio for the reaction source with isotropic distribution relative to the $(F/B)_{\text{Be}}$ ratio for the comparator source of:

$$X_{\text{computed}}=\left[\frac{(F/B)_{\text{Li}}}{(F/B)_{\text{Be}}}\right]_{\text{computed}}$$
$$=\frac{1+(0.208\pm0.016)\Delta E_F+(0.152\pm0.016)\Delta E_B}{1.00152\pm0.00010}$$
$$+\text{quadratic terms},$$

where ΔE_F and ΔE_B are the Doppler shifts seen by the forward and backward counters, respectively, in units of 100 kev. (The terms quadratic in the corrections are small but are taken into account later.)

We must now determine the Doppler shifts ΔE.

DOPPLER SHIFTS

The above correction factor is not correct because we do not have a unique recoil velocity and so no unique Doppler shift. However we may easily convince ourselves that the second-order correction due to the difference in behavior of the actual gamma-ray spectrum at a given angle and the substitute monochromatic line whose effective shift is just the appropriately-weighted mean of the shift over the actual spectrum is quite negligible. We therefore use the above formula where the ΔE are these mean weighted shifts at each angle of observation.

In order to compute the initial velocity-angle distribution of the recoiling excited Li^7 nuclei, we must know not only the excitation function for the inelastic scattering[4] but also the angular distribution of the inelastically-scattered protons. It was because this latter distribution is known up to a proton bombarding energy of 1.3 Mev[5] that this energy was chosen for this experiment. These two pieces of information[4,5] then permit the computation of the initial distributions. To compute the Doppler shifts, we must now consider the finite mean lifetime of the state[6] of $\tau=(7.7\pm0.8)\times10^{-14}$ sec in relation to the rate of energy loss of the Li^7 ions in moving through the target material. This latter is a complicated matter but fortunately there have been recent measurements[7] on the rate of energy loss of lithium ions in the energy range of interest here for

[3] R. Taschek and A. Hemmendinger, Phys. Rev. **74**, 373 (1948); also Bair, Willard, Snyder, Hahn, Kington, and Green, Phys. Rev. **85**, 946 (1952).
[4] A. A. Kraus, Phys. Rev. **93**, 1308 (1954).
[5] Mozer, Fowler, and Lauritsen, Phys. Rev. **93**, 829 (1954).
[6] Bunbury, Devons, Manning, and Towle, Proc. Phys. Soc. (London) **A69**, 165 (1956).
[7] S. K. Allison and C. S. Littlejohn, Phys. Rev. **104**, 959 (1956).

several gases. Data exist for stopping in hydrogen, air, and argon and we are able to make accurate interpolations for stopping in oxygen and lithium for our LiOH target.

If now we have a situation such as the present one where most of the nuclei decay before having lost much speed, we may easily show that the full Doppler shift is simply multiplied by the factor $1-\xi\tau$, where

$$\xi=(1/mv)(dE/dx).$$

Here v is the initial speed of the recoiling nucleus, m is the mass of that nucleus, and dE/dx is the rate of energy loss in the moderating material. From the stopping data we find, for the mean lithium recoil energy of 153 kev, $\xi=(7.8\pm1.6)\times10^{11}$ sec^{-1}. In making this computation we have decreased the stopping power by 20% below the quoted figures for gases[7] because solids at this energy region seem to be so much less efficient, mass for mass, than the corresponding gases. The error that we place on ξ covers this and other uncertainties such as the use of a mean effective recoil energy.

Thus we finally find $\xi\tau=0.060\pm0.013$ and so the Doppler shift is 0.940 ± 0.013 of that computed without regard for the slowing down.

This correction, applied to the initial shifts computed from the cross-section data,[4,5] gives $\Delta E_F=0.0310$ and $\Delta E_B=0.0255$ in units of 100 kev. These shifts have been calculated with allowance for the finite size of the crystal detectors. The relativistic shift is here only a few parts in 10^5 different from the classical. These effective mean Doppler shifts are subject to errors of $\pm1.4\%$ from the slowing down correction just discussed and $\pm1.6\%$ from the errors in the angular distribution of the inelastically-scattered protons.[5] These combine to give an error in the Doppler shift of $\pm2.1\%$.

COMPUTED FORWARD-BACKWARD RATIO

When we insert these shifts into the above formula for the computed value of $(F/B)_{\mathrm{Li}}/(F/B)_{\mathrm{Be}}$ for an isotropic distribution in the center-of-mass system of the reaction source and take account of the error in the Doppler shift and of the small quadratic terms including those in the full aberration formula, we find

$$X_{\mathrm{computed}}=1.00876\pm0.00069.$$

EXPERIMENT AND RESULTS

The experimental set up has already been sketched from the point of view of the detecting apparatus. The target was a thin layer of LiOH, thick to 3-Mev protons, which was fused into a small depression in a thin brass plate. The thickness of brass behind the LiOH was 1.0 mm and this and the fact that the target tube was of brass of wall thickness $\frac{1}{32}$ inch have already been used in discussing the differential absorption corrections. Approximately $10\frac{1}{2}$ inches "upstream" from the target the incident proton beam was defined by a tantalum stop which was carefully surface-ground and cleaned. The defining aperture was of diameter $\frac{1}{10}$ inch. In both irradiations, that at 3.0 Mev to build up the Be^7 activity and that at 1.3 Mev for the inelastic scattering, it was arranged that the proton beam was rather poorly focused (following the initial careful centering with a well-focused spot) so that the greater part was collected by the stop and only a small fraction passed to the LiOH target. In this way effectively uniform distribution of current over the target spot was assured. This was confirmed by the very uniform appearance of the light carbon deposit where the beam had struck the target which was seen after the final dismantling at the end of the experiment.

This uniformity precluded as much as a 10% difference in current between the two halves of the target spot. Such a difference would have introduced a spurious anisotropy of less than $1+10^{-4}\cos\theta$. It was therefore felt that no possible nonuniformity of the beam distribution across the target spot could make any significant contribution to the errors in this experiment.

The 3.0-Mev irradiation was carried out using currents of a few microamperes on the target. The region of the tantalum stop was cooled by air-blast and a removable water jacket was clamped to the back of the thin brass plate which bore the target. For the 1.3-Mev irradiation, currents of a few hundredths of a microampere were used and no cooling was necessary. The water jacket was removed.

Approximately 6 cm of lead shielding was placed between the backward (145°) crystal and the tantalum stop. This was completely effective in removing any radiations which the 1.3-Mev protons, intercepted on this stop in large quantity, might have produced. Careful tests were made by placing a further 7 cm of lead between the target spot and each counter and comparing the counting rates in the counting channels with the beam on and off the target (and so the stop also). This lead diminishes the intensity of the 477-kev radiation by more than a factor of 10^5. In this way it was established that the counting rate in the backward counter due to radiation from the stop was less than 1 part in 2×10^4 of that due to the target. Even with no shielding present between the stop and the counter the contribution from the stop was less than 1 part in 10^3 of that from the target so the possible effect on the forward (0°) counter, which of course could not be shielded, was quite negligible because it was approximately 3 times farther away.

A further type of background which must be discussed is that due to the capture radiation: $Li^7(p,\gamma)Be^8$. This, as we have remarked, is asymmetric in its distribution relative to the proton beam and so, being detected in our counting channel, could possibly give a spurious $\cos\theta$ term. The capture radiation is, however, very much weaker than that following inelastic scattering. Its possible importance was estimated in the

following way. The known yield[8] of the capture reaction, which is due chiefly to the well-known resonance at a proton energy of 440 kev, was used together with the computed efficiency of the crystals[2] for detecting the radiation and the measured probability that a pulse due to the 15–18 Mev complex would fall in the relatively very narrow counting channel around 477 kev, to calculate the counting rate under our conditions. This was 0.002% of the observed counting rate due to inelastic scattering. The strengths of other capture radiation for example in the Li^6, deuterium or oxygen of the target or in the carbon deposit is very much less than that in the lithium.

No other intense gamma rays are to be expected from the target materials. The possible reactions are: $Li^7(p,\alpha)\alpha$, $Li^6(p,He^3)\alpha$, $O^{18}(p,\alpha)N^{15}$, $O^{17}(p,p')O^{17*}{}_{0.870}$. Of these only the last is accompanied by a gamma ray and it is wholly negligible because of the very low (0.04%) relative abundance of O^{17} and because we are barely above threshold and faced by a formidable Coulomb barrier.

The experimental sequence was a long series of interleaved runs alternately with and without a beam of 1.3-Mev protons incident on the target. The current was adjusted so that the counting rate with the beam (the combined sources) was about four times that without the beam (the comparator source alone). The electronic stability was good but the effects of possible small drifts are eliminated by the interleaving procedure. Occasional background measurements were made by interposing lead blocks between the counters and the target in the manner described above. A total of some 120 runs was made and analyzed.

Two problems are raised by the change in counting rate between the comparator and combined-source runs. The first is the question of the loss of counts due to deadtime of the detecting equipment. At the maximum counting rates this amounted to 0.2%. The deadtimes of the forward and backward systems were the same to within better than 15% and the counting rates were the same to within 3%. The corrections were therefore not only very small but also very nearly the same for the two detectors, and so the error introduced into the ratio of the counting rates, which is all that matters, is negligible. The second problem is that of the rate-dependent gain[9] of the photomultipliers which were of the type DuMont 6292. Both tubes were selected for their small dependence of gain on rate. One of them had an increase of gain of 0.03% for a factor of two in counting rate and the other had an increase of 0.02%. The correction on this score would have been less than 1 part in 10^4 and was ignored.

On the basis of approximately 11 300 000 counts, the value for the comparator source was found to be

$$(F/B)_{\mathrm{Be}}=0.96688\pm0.00056.$$

On this basis of approximately 27 900 000 counts, the reaction source gave

$$(F/B)_{\mathrm{Li}}=0.97484\pm0.00065.$$

These now combine to give the ratio

$$X_{\mathrm{experimental}}=\left[\frac{(F/B)_{\mathrm{Li}}}{(F/B)_{\mathrm{Be}}}\right]_{\mathrm{experimental}}=1.00823\pm0.00089.$$

This value is to be compared with X_{computed}, the value theoretically expected for this ratio for isotropic emission in the center-of-mass space of the Li^7 and which we quoted above. If we write the angular distribution as $1+\alpha\cos\theta$ we have, since the backward angle is 145°,

$$1+1.82\alpha=X_{\mathrm{experimental}}/X_{\mathrm{computed}}=0.99947\pm0.00112,$$

or

$$\alpha=-0.00029\pm0.00062.$$

DISCUSSION

The experiment establishes isotropy within a standard deviation of 6 parts in 10^4. As has been remarked in I, we may interpret this number as being of the order $\mathfrak{R}\mathfrak{F}^2$, where $\mathfrak{R}$ is the *a priori* ratio between the matrix element of electric and magnetic transitions. We have also argued in I that

$$\mathfrak{R}\sim McR/3\hbar,$$

which in this case is about 5.

We therefore conclude that

$$\mathfrak{F}^2\lesssim 1\times10^{-4}.$$

As we noticed in I, this general method is likely to be less sensitive than experiments in the first two classes and has been performed to complete the possible methods of examining the problem. Its result is of course consistent with the much sharper figures obtained in I and II.

[8] F. Ajzenberg and T. Lauritsen, Revs. Modern Phys. **27**, 77 (1955).

[9] Bell, Davis, and Bernstein, Rev. Sci. Instr. **26**, 726 (1955).