LOW-ENERGY NUCLEAR PHYSICS TEST FOR A POSSIBLE ISOTENSOR COMPONENT OF THE ELECTROMAGNETIC INTERACTION

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It is shown how a comparison of the γ widths for corresponding $T=\frac{3}{2}\rightarrow T=\frac{1}{2}$ transitions in mirror nuclei can give information about a possible isotensor component of the electromagnetic interaction. From data available at present it is concluded that the isotensor γ transition amplitude in the decays considered is less than about 10% of the isovector amplitude.

During the last few years the usually accepted symmetry properties of the electromagnetic interaction have been raised in question, and experimental tests for investigating these properties have been suggested.[1-8] In particular, interest has centered on the isospin nature of the interaction and whether, in addition to the isoscalar ($T=0$) and isovector ($T=1$), the electromagnetic current has an isotensor ($T=2$) component. The object of this note is to suggest a test in the field of low-energy nuclear physics sensitive to the presence of such a component.

In previous discussions of nuclear-physics tests two methods have been suggested. The first[5-7] is to look for deviations from the quadratic mass formula $M=M_0(1+aT_z+bT_z^2)$ which should hold for members of a nuclear isospin multiplet assuming only isoscalar and isovector properties for the electromagnetic interaction. The second[2,7] is to look for the presence of $\Delta T=2$ γ transitions. As with all nuclear-physics tests the effects searched for are suppressed since matrix elements of a $T=2$ current with respect to single-nucleon states vanish. With the first test any two-nucleon interaction stemming from a $T=2$ component (i) will be short range since, as just stated, there can be no $T=2$ coupling of a photon to a single nucleon and (ii) can lead at most in first order to quadratic terms in the mass formula[5,9]. Thus for the test to be effective either theoretical and experimental values of a and b have to be compared thereby bringing into play uncertainties about nuclear wave functions and the charge dependence of nuclear forces, or the T_z^3 term stemming from a three-body charge-dependent force has to be searched for. In the latter case this means that very accurate measurements have to be made of the energies of all the $2T+1$ members of a $T\geq\frac{3}{2}$ isospin multiplet. The second test is difficult since there are not many examples of established states in the same nucleus differing by $\Delta T=2$. Furthermore, direct γ transitions between such states are difficult to observe. Nevertheless, one such case has recently been reported in the literature[10] in which a limit has been set on the γ width ($\Gamma_{\gamma 1}$) for the decay from the 0^+, $T=2$ state at 15.2 MeV to the 2^+, $T=0$ state at 1.78 MeV in ^{28}Si. An upper limit $\Gamma_{\gamma 1}\lesssim 0.03\Gamma_\gamma$ was obtained, where Γ_γ is the total γ width of the 15.2-MeV state. This result implies that the $T=2$ γ decay amplitude for the 15.2-MeV state is less than about 20% of the $T=1$ amplitude.

We now propose a test in which comparisons are made between the decay widths for $T=\frac{3}{2}\rightarrow T=\frac{1}{2}$ transitions in mirror nuclei ($T_z=\pm\frac{1}{2}$). The matrix element for such a transition has the isospin form

$$M_\gamma(T_z)=\langle\tfrac{1}{2},T_z|\sum_{t=0,1,2}\boldsymbol{H}_\gamma^{(t)}|\tfrac{3}{2},T_z\rangle,$$

where the electromagnetic interaction H_γ has been decomposed into its isoscalar ($t=0$), isovector ($t=1$), and isotensor ($t=2$) parts.[11] Application of the Wigner-Eckart theorem gives at once

$$M_\gamma(\tfrac{1}{2})=-3^{-1/2}A_1-5^{-1/2}A_2;\quad M_\gamma(-\tfrac{1}{2})=-3^{-1/2}A_1+5^{-1/2}A_2,$$

where A_1 and A_2 are reduced amplitudes for the isovector and isotensor parts of H_γ, respectively.

Assuming that $A_2\ll A_1$ it then follows that the γ decay widths for the two decays [$\Gamma_\gamma(+\frac{1}{2})$ and $\Gamma_\gamma(-\frac{1}{2})$] are related by

$$R=\frac{\Gamma_\gamma(-\frac{1}{2})}{\Gamma_\gamma(+\frac{1}{2})}=\left[1-4\left(\frac{3}{5}\right)^{1/2}\frac{A_2}{A_1}\right]\frac{\rho(E_{-1/2})}{\rho(E_{+1/2})},$$

where $\rho(E)$ is an energy-dependent factor relevant to a decay of the multipolarity and energy considered.

Consider as an example the following mirror decays in ^{13}C and ^{13}N for which[12,13]

$$\Gamma_\gamma(+\tfrac{1}{2}) \equiv \Gamma_\gamma(^{13}\mathrm{C}{:}T=\tfrac{3}{2},\tfrac{3}{2}^-,\ 15.11\ \mathrm{MeV} \to T=\tfrac{1}{2},\tfrac{1}{2}^-,\ 0.00\ \mathrm{MeV}) = 25\pm 7\ \mathrm{eV}$$

and[13,14]

$$\Gamma_\gamma(-\tfrac{1}{2}) \equiv \Gamma_\gamma(^{13}\mathrm{N}{:}T=\tfrac{3}{2},\tfrac{3}{2}^-,\ 15.07\ \mathrm{MeV} \to T=\tfrac{1}{2},\tfrac{1}{2}^-,\ 0.00\ \mathrm{MeV}) = 27\pm 5\ \mathrm{eV}.$$

Since the decays have essentially the same energy we have at once $R = 1.08 \pm 0.36$ and $A_2/A_1 = -0.026 \pm 0.116$, setting an upper limit of the order 15% on the relative isotensor amplitude. Similarly, consider the more complicated case of γ decay from the same two $T=\frac{3}{2}$ states to the 3.51- and 3.56-MeV states in ^{13}N and the 3.68 and 3.85-MeV states in ^{13}C for which[13]

$$\frac{\Gamma_\gamma(\frac{1}{2})}{\Gamma_{\gamma 0}(\frac{1}{2})} = \frac{\Gamma_\gamma(^{13}\mathrm{C}{:}15.11 \to 3.68+3.85)}{\Gamma_{\gamma 0}(\frac{1}{2})} = 0.79 \pm 0.10,$$

$$\frac{\Gamma_\gamma(-\frac{1}{2})}{\Gamma_{\gamma 0}(-\frac{1}{2})} = \frac{\Gamma_\gamma(^{13}\mathrm{N}{:}15.07 \to 3.51+3.56)}{\Gamma_{\gamma 0}(-\frac{1}{2})} = 0.81 \pm 0.10,$$

where $\Gamma_{\gamma 0}$ refers to the widths for the ground-state decays just discussed. Here $R = 1.025 \pm 0.181$ and $(A_2/A_1)' = 0.008 \pm 0.058$, where the prime indicates that the value of $(A_2/A_1)'$ refers to a combination of the amplitudes A_1 and A_2 for the three γ transitions involved.[15] Thus an upper limit of the order 7% is set on this composite isotensor amplitude.

The following comments can be made:

(i) Choice of inhibited decays (i.e., A_1 small) could lead to appreciable amplification of the effects of an isotensor component. This is not the case with the example given here since the γ widths are of the order of the single-particle Weisskopf estimate.[16]

(ii) The analysis could be complicated by appreciable isospin mixing—this, of course, is true of any test for an isotensor component. In the case in point this would mean replacing A_2/A_1 in the foregoing results by $A_2/A_1 + \xi$, where the isospin-impurity term ξ has the form

$$\xi = (5/3)^{1/2} \sum\nolimits_\nu C_\nu \alpha_\nu B_\nu / A_1.$$

C_ν is a geometrical factor (Clebsch-Gordan coefficient) $\lesssim 1$. α_ν is the amplitude with which some isospin-impurity state $|\nu\rangle$ is admixed into either the parent or daughter state. B_ν is the γ transition amplitude between the admixed state $|\nu\rangle$ and either the parent or daughter state.

Theoretical estimates for light nuclei using shell-model calculations (e.g., MacDonald[17]) suggest $\sum_\nu |\alpha_\nu|^2 \lesssim 2\times 10^{-3}$ for nuclei in the region of $A=12$. More recently Bohr, Damgård, and Mottelson[18] have given convincing reasons which suggest that $\sum_\nu |\alpha_\nu|^2$ may be up to an order of magnitude smaller than the above shell-model estimate. Cocke, Adloff, and Chevallier[13] give experimental arguments and comparisons which suggest that $\sum_\nu |\alpha_\nu|^2 \approx 10^{-3}$ and accordingly we adopt this value in order to estimate an upper limit on the size of ξ. There is little information about the B_ν but since for the transitions considered in ^{13}C and ^{13}N, A_1 is of the order of the Weisskopf amplitude, it is reasonable to assume that $B_\nu/A_1 \lesssim 1$. Thus, finally, it follows that $\xi \lesssim 3\times 10^{-2}$ is a generous upper limit on ξ; so isospin impurities are estimated to lead to an additional uncertainty of at most 3% in the determination of A_2/A_1.

(iii) We feel that it is reasonably safe to conclude from the various $A=13$ data that $A_2/A_1 \lesssim 10\%$. Obviously this figure could be improved with better experimental accuracy and by choice of mirror transitions for which A_1 is inhibited. Further and deeper analysis is also needed from the point of view of relating the amplitude A_2 (which derives from the nuclear matrix element of a two-nucleon electromagnetic operator) to the actual isotensor component of the fundamental electromagnetic interaction.

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where a and b refer to the two transitions considered and where, again, the small energy-dependent factors have been neglected.
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J-DEPENDENCE STUDIES IN (α,p) REACTIONS AT 30 MeV

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Proton angular distributions have been measured for the reactions ^{58}Ni$(\alpha,p)^{61}$Cu, ^{60}Ni$(\alpha,p)^{63}$Cu, and ^{28}Si$(\alpha,p)^{31}$P at $E_\alpha = 30$ MeV. Strong J dependence is observed for the $l=1$ transfer distributions to the ground and first excited states of ^{61}Cu and ^{63}Cu, whereas essentially no J dependence is observed for the $l=2$ transfer distributions to the first and second excited states of ^{31}P. Distorted-wave Born-approximation calculations are also discussed.

In recent years numerous direct reactions have been shown to be J dependent,[1] i.e., the relative shapes of the angular distributions of the emerging particles for a given l transfer are dependent upon the total angular momenta of the final states involved in the reactions. This previous work has shown that the (α,p) reaction (along with its inverse) exhibits the most pronounced J dependence. The marked J dependence observed in the (α,p) work strongly suggests that this reaction could be employed as a useful spectroscopic tool in nuclear-structure studies. Some qualitative success in interpreting J dependence in (α,p) reactions with distorted-wave Born-approximation (DWBA) calculations support this argument. There has been no extensive systematic study to establish the range in atomic number, incident energy, and excitation energy over which J dependence might serve as a reliable technique for extracting spectroscopic information. Such a program of study has been initiated at the Naval Research Laboratory (NRL), and the present Letter reports on the three reactions ^{58}Ni$(\alpha,p)^{61}$Cu, ^{60}Ni$(\alpha,p)^{63}$Cu, and ^{28}Si$(\alpha,p)^{31}$P at an incident alpha energy of 30 MeV. States of well-established spins and parities were chosen for study. J dependence has not been studied previously at as high an incident energy in (α,p) reactions. The marked difference between the results on Ni and Si indicates some possible limitation on the range of applicability of J dependence as a spectroscopic tool.

The 30-MeV alpha beam was produced by the NRL sector-focusing cyclotron, and beam currents ranged from 0.2 to 0.8 μA. The isotopically enriched Ni targets and the natural SiO targets were self-supporting foils with a nominal areal density of 0.5 mg/cm^2. The protons were detected with a counter telescope consisting of a 1-mm Si passing counter and a 4-mm Si stopping counter. Digital particle identification was made using the NRL on-line computer facility. The observed energy resolution was generally about 150 keV full width at half-maximum, and this was quite adequate for resolving the proton groups of interest.

On the left of Fig. 1 are shown the measured proton angular distributions for the ground and first excited states of ^{61}Cu and ^{63}Cu from the reactions ^{58}Ni$(\alpha,p)^{61}$Cu and ^{60}Ni$(\alpha,p)^{63}$Cu. These distributions for $l=1$ transfer exhibit a very marked J dependence at $E_\alpha = 30$ MeV. Comparison of these results with those of Lee et al.[2] for the same states at $E_\alpha = 18$ MeV indicates that the effect is enhanced at 30 MeV over what is observed at the lower energy. The data of Fig. 1 also reveal that the pairs of distributions with the same J^π are nearly identical.