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LETTER TO THE EDITOR

Isobaric analogue states in ^{6}Li and the solar neutrino anomaly

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Abstract A search is reported for the isobaric analogue state in ^{6}Li to the state in ^{6}Be proposed recently as a possible reason for the solar neutrino anomaly. Upper limits to the radiative probability of transition to such a state are obtained.

The suggestion has been made (Fetisov and Kopysov 1972) that the low observed solar neutrino flux may be due to a nuclear reaction which has escaped experimental observation until now. Indeed the formation of ^{7}Be in the sun by radiative capture of ^{3}He on α particles would be seriously diminished if the ^{3}He nuclei were involved in the reaction,

$$^3\mathrm{He} + {}^3\mathrm{He} \rightarrow {}^6\mathrm{Be}^* \rightarrow {}^4\mathrm{He} + 2\mathrm{p}. \tag{1}$$

Nonetheless the gap in our knowledge of the properties of ^{6}Be is quite small since the reactions between ^{3}He nuclei have been studied (Dwarakanath and Winkler 1971) down to within 80 keV of the threshold energy. A narrow level in ^{6}Be, which might exist in this interval, should be matched by an isobaric analogue state in ^{6}Li which, being a stable nucleus, is a suitable target for inelastic electron scattering experiments.

Because of the identity of the two ^{3}He particles and their Fermi–Dirac statistics, not all of the states in the $T = 0$ (^{6}Li) system can appear in the $T = 1$(^{6}Be) system. For the $T = 1$ system, formed by relative s-wave or p-wave respectively, the states are $^1S_0$ and $^3P_{0,1,2}$. For the $T = 0$ system additional $^3S_1$ and $^1P_1$ states can exist. Thus if a narrow level is found in ^{6}Li, it is further necessary to show that its spin and parity are 0^+ and not 1^+, before inferring the presence of a 0^+ state in ^{6}Be. As the ground state of ^{6}Li is 1^+, the electron scattering experiment must therefore be designed (Bishop 1964) to search for M1, E1 and E2 transitions.

Reported here are the results of two experiments, carried out on isotopically enriched targets of ^{6}Li, of the scattering of 100 MeV electrons through laboratory angles of 60° and 75°. These angles were chosen to give adequate sensitivity to E1 and E2 transitions, and to allow distinction between them by the dependence of the inelastic form factor on the momentum transfer q. In addition, since the total cross section for γ ray absorption by ^{6}Li is known in the relevant energy region, by subtracting the expected amount of E1 scattering from the observed electron cross section, some sensitivity to the M1 transition strength is expected from these experimental conditions.

The spectrum of electrons scattered at 75° (that at 60° is very similar), is shown in figure 1, on which is also plotted the radiative tails of the elastic and prior inelastic scattering peaks. The difference between the experimental points and the lower calculated curve is the inelastic scattering with excitation of the nucleus into the particle continuum, within energy intervals determined by the overall resolution, which in these experiments was 250 keV.

It is at once clear that no narrow peak exists in this spectrum within ± 2 MeV of the proposed analogue state to the threshold state of the ^{3}He + ^{3}He system, which is at an excitation energy of 14·577 MeV (Lauritsen and Ajzenberg-Selove 1966). Indeed if any structure is to be inferred from this spectrum it is of broad peaks with halfwidths in excess of 2 MeV, corresponding to the particle decays of possible states in ^{6}Li.

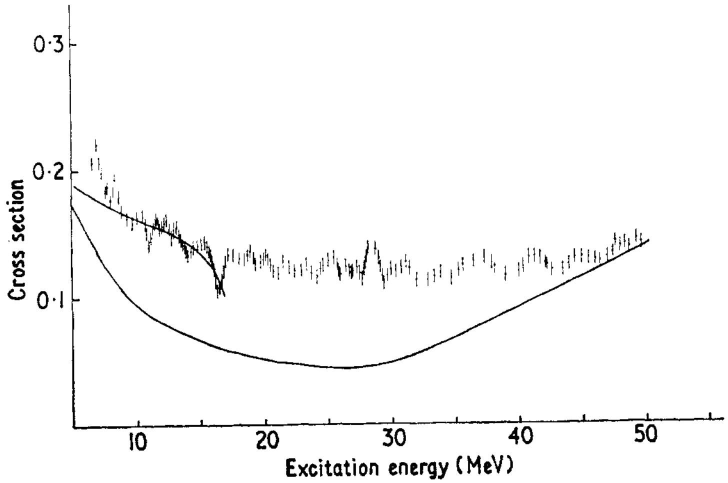

Figure 1. The spectrum of electrons inelastically scattered from ^{6}Li nuclei at $\theta = 75°$. The lower full curve is the radiative tail of the elastic and preceding inelastic peaks. The upper full curve is the cross section expected from virtual photon theory and the known photo-absorption cross section. To convert the ordinate into absolute cross section it must be multiplied by the factor $2{\cdot}53 \times 10^{-31}$ cm^2 sr^{-1} MeV^{-1}.

So as to place an upper limit on the transition probabilities to hypothetical narrow levels in this energy region the cross section expected from virtual photon densities and the photo-absorption cross sections has been calculated. The cross section for inelastic electon scattering is given (Bishop 1964) by

$$\frac{\mathrm{d}\sigma}{\mathrm{d}\Omega} = \left(\frac{\mathrm{d}N_\mathrm{l}}{\mathrm{d}\Omega} + \frac{\mathrm{d}N_\mathrm{t}}{\mathrm{d}\Omega}\right) \int \frac{\sigma(k)}{k} \mathrm{d}k. \tag{2}$$

To evaluate this equation the bremsstrahlung weighted cross section for the photo-absorption process must be inserted. Fortunately, for the excitation energy region between the (γ, n) threshold and 17 MeV, there exist several independent and concordant measurements as summarized by Kurdyumov *et al* (1970). Between 17 MeV and 35 MeV there are several conflicting measurements of the photoreactions leading to charged particle final states. Detailed comparison of this information with the corresponding cross section of the present experiment is reserved for a paper in preparation.

The densities of longitudinal $(\mathrm{d}N_\mathrm{l}/\mathrm{d}\Omega)$, and transverse $(\mathrm{d}N_\mathrm{t}/\mathrm{d}\Omega)$ photons are given in table 1, for a nucleus considered as a point charge. Since the nucleus has a finite extent a form factor correction must be applied (Bishop 1964), which depends on the size of the region within the nucleus that is absorbing the photon. For the excitation energy region of interest here, a value (Bishop and Bernheim 1963) of $\langle r^2 \rangle = (4 \pm 0{\cdot}8)\mathrm{fm}^2$, was used to give the calculated upper line of figure 1. This

Table 1. Densities of longitudinal and transverse photons

Transition	$\mathrm{d}N_\mathrm{l}/\mathrm{d}\Omega$	$\mathrm{d}N_\mathrm{t}/\mathrm{d}\Omega$
E1	$\dfrac{\alpha}{2\pi^2}\dfrac{p^2(1+\cos\theta)}{q^2}\dfrac{1-\frac{1}{5}q^2\langle r^2\rangle}{1-\frac{2}{5}k^2\langle r^2\rangle}$	$\dfrac{\alpha}{4\pi^2}\dfrac{p^2+p'^2+pp'(1-\cos\theta)}{p^2(1-\cos\theta)}\dfrac{k^2}{q^2}\dfrac{1-\frac{2}{5}q^2\langle r^2\rangle}{1-\frac{2}{5}k^2\langle r^2\rangle}$
E2	$\dfrac{2\alpha}{3\pi^2}\dfrac{p^2(1+\cos\theta)}{k^2}\dfrac{1-(1/7)q^2\langle r^2\rangle}{1-(5/21)k^2\langle r^2\rangle}$	$\dfrac{\alpha}{4\pi^2}\dfrac{p^2+p'^2+pp'(1-\cos\theta)}{p^2(1+\cos\theta)}\dfrac{1-(5/21)q^2\langle r^2\rangle}{1-(5/21)k^2\langle r^2\rangle}$
M1	0	$\dfrac{\alpha}{4\pi^2}\dfrac{p^2+p'^2+pp'(1-\cos\theta)}{p^2(1-\cos\theta)}\dfrac{1-(5/21)q^2\langle r^2\rangle}{1-(5/21)k^2\langle r^2\rangle}$

calculation renders good account of the observed inelastic cross section so that any scattering from a narrow level, if it exists, can be considered as hidden within the statistical inaccuracy of the data. From table 1 it can be seen that the ratio of the longitudinal densities for E1 and E2 transitions is practically k^2/q^2, or 1/55 for $E_\gamma = 15$ MeV and $\theta = 75^\circ$. Thus, as distinct from the real photon case, E2 transitions in electron scattering are here emphasized by a factor of 55 times relative to E1 transitions. The M1 virtual photon density is about 1·7 times the E1 longitudinal density at $\theta = 75^\circ$. Analysis of the data then shows that any peaks with a width less than 250 keV, the resolution of this experiment, would be unobserved within the statistical imprecision of this experiment provided that the radiative widths for E1, E2 and M1 transitions do not exceed 15 eV, 0·27 eV and 8·8 eV respectively. Similar upper limits were derived from the data of the experiment at $\theta = 60^\circ$.

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