7.656-Mev $E0$ TRANSITION IN C^{12}†

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The 7.656-Mev second excited state[1] of C^{12} is involved in theories[2,3] of helium burning and element synthesis in red giant stars. The cores of such stars are thought to consist mostly of helium which can combine into unstable Be^8 with an equilibrium ratio of Be^8 to He^4 of $\sim 10^{-9}$. As the next step in the process, Be^8 resonantly captures an alpha particle into the 7.656-Mev level in C^{12} whose spin-parity assignment is most probably 0+. Energy generation and element synthesis can occur if the 7.656-Mev level decays to the ground state of C^{12} rather than breaking up again into three He^4 nuclei.

Three modes of decay are open to the 7.656-Mev level, namely alpha-particle emission to Be^8, emission of a 3.2-Mev $E2$ gamma ray to the 2+ first excited state of C^{12} at 4.433 Mev, and the emission of nuclear pairs to the 0+ ground state. Assuming that the 7.656-Mev level is 0+, Cook et al.[3] suggested the following partial widths for these three modes of decay:

$$\Gamma_\alpha \sim 0.5 \text{ ev},$$

$$\Gamma_{3.2\gamma} \sim 0.0014 \text{ ev},$$

$$\Gamma_{e\pm} \sim 5\times10^{-5} \text{ ev}.$$

Γ_α is 1/10 of the upper limit of 5 ev according to Wigner, $\Gamma_{3.2\gamma}$ is a single-particle estimate, and $\Gamma_{e\pm}$ is calculated from a measurement[4] of $C^{12}(e, e')$. The spectrum of alpha particles from the 7.656-Mev level occurring in the beta decay of B^{12} was observed by Cook et al.,[3] thus proving that the state can be formed in the manner suggested in the astrophysical theories. Neither of the other two decay paths has been firmly established heretofore and the width Γ_α is not known. For astrophysical calculations the ratios of the various widths are required.

By means of an intermediate-image pair spectrometer[5] the 7.656-Mev nuclear pair line has been observed in the $Be^9(\alpha, n)C^{12}$ reaction. For these measurements the instrument was moved to Oak Ridge where it was set up at the large Van de Graaff accelerator. Singly-ionized helium was accelerated and then gas-stripped before entering the 90° deflecting magnet. Runs were made with beams of ~4 μa of He^{++} at energies of 5.38 and 5.81 Mev on thick targets (6-mg/cm^2 Be foil) and with a beam of ~1 μa of He^{++} at 5.81 Mev on a thin target (0.2-mil Be, ~0.7 Mev thick for alpha particles). In all of the runs the 7.656-Mev nuclear pair line was observed with approximately the same intensity relative to the 4.433-Mev internal pair conversion line associated with the 2+ first excited state of C^{12}.

The observed ratio of 7.656- to 4.433-Mev pair line intensities when using the thin Be target and $E_\alpha = 5.81$ Mev is $(5\pm1.5)\times10^{-4}$. By applying a factor[6] of 1.26 for the ratio of spectrometer efficiencies for $E2$ to $E0$ pairs and by making use of the theoretical internal pair conversion coefficient[7] of 1.3×10^{-3} for the 4.433-Mev $E2$ transition, the derived ratio of pair to alpha widths for the 7.656-Mev level is

$$\Gamma_{e\pm}/\Gamma_\alpha = 8.2\times10^{-7}\times R,$$

where R is the ratio of neutron populations, $R = N_{4.433}/N_{7.656}$. A precise number for R under the conditions of the thin target run cited in the present work is not available, and in fact the only information on the relative neutron populations is from a photographic plate measurement at 0° by Guier et al.[8] using 5.3-Mev alpha particles on a thin Be target. Their observed ratio of 4.433- to 7.656-Mev neutron group intensities was 8. As a rough estimate we assume R~8 in the present experiment, which gives

$$\Gamma_{e\pm}/\Gamma_\alpha \sim 7\times10^{-6}.$$

An accurate value of R would be highly desirable in view of the astrophysical importance of this level. Time-of-flight techniques might be one possible approach to this problem.

The above ratio deduced for $\Gamma_{e\pm}/\Gamma_\alpha$ is a factor of ~15 smaller than the estimates given by Cook et al.[3] This could arise from (a) an underestimate of the magnitude of Γ_α, (b) incorrectly assuming that R~8, or (c) an incorrect calculation of $\Gamma_{e\pm}$ from the $C^{12}(e,e')$ measurement. It would seem that (a) is the most likely possibility. This would allow $\Gamma_{3.2\gamma}$, which is probably the dominant path to the ground state, to be in agreement with the single-particle estimate, and it would also explain why attempts to detect the 3.2-Mev gamma ray have not yet met with success.

Full details of these experiments will be published later. The author is greatly indebted to the staff of the Oak Ridge National Laboratory for their hospitality and to Dr. Paul H. Stelson for his invaluable assistance.

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POSSIBILITY OF STUDYING THE Λ-HYPERON–NUCLEON FORCE BY LOW-ENERGY SCATTERING

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Currently our ideas concerning the Λ-hyperon–nucleon force derive primarily from (a) meson-theoretic static models, together with restrictions imposed by isotopic spin conservation,[1-3] and (b) analysis of the binding energies and decay mode branching ratios of hyperfragments.[2-6] Such considerations have led to the following characterization of the Λ-hyperon–nucleon force: (1) it is of shorter range than the nucleon-nucleon force, most likely having a characterisitc range $a \approx \hbar/2m_\pi c$, corresponding to a 2-pion exchange process; (2) it is "weaker" than the nucleon-nucleon force, being of insufficient strength to bind a Λ hyperon to a single nucleon; (3) it is spin dependent; and (4) the singlet force is somewhat stronger than the triplet force.[7]

We wish to note that the polarization which arises in the production of Λ hyperons may be used in a simple way to explore the spin dependence of the s-state Λ-hyperon–nucleon force. Let us for the moment assume that there is available a beam of low-energy (≲25-30 Mev, center of mass)[8] Λ hyperons which are polarized in some direction (specified by the unit vector $\vec{n}$) by an amount $\langle \vec{\sigma}_\Lambda \cdot \vec{n} \rangle = P_\Lambda$, and which are allowed to scatter from unpolarized (free) protons; let us further suppose that the scattering is in fact observed to be isotropic (in the center-of-mass system) so that we are observing the effects of the s-state Λ-hyperon–nucleon force. It is straightforward to show that the polarization $P_{\Lambda(\text{final})}$ of the Λ hyperon after the scattering is related to its initial polarization in the following way:

$$D = \frac{P_{\Lambda(\text{final})}}{P_{\Lambda(\text{initial})}} = \frac{2[\sin^2\delta_t + \sin\delta_t \sin\delta_s \cos(\delta_t - \delta_s)]}{3\sin^2\delta_t + \sin^2\delta_s} . \qquad (1)$$

δ_t and δ_s are, respectively, the triplet and singlet state scattering phase shifts. The direction of polarization is, of course, unchanged if the scattering is s-state scattering. One notes that for a spin-independent force ($\delta_t = \delta_s$), $D = 1$, i.e., the polarization is unchanged. If $\delta_t \gg \delta_s$, $D \simeq \frac{2}{3}$; conversely, if $\delta_s \gg \delta_t$, $D \simeq 0$, i.e., the Λ hyperon is strongly depolarized. Hence, one can say that any reduction in polarization of the Λ hyperon is evidence for spin dependence of Λ-hyperon–nucleon force; a reduction by a factor greater than $\frac{2}{3}$ is evidence that the singlet force is "stronger" than the triplet force.

In order to estimate the magnitude of D as a function of the relative strengths of the singlet and triplet forces, we suppose the Λ-hyperon–nucleon s-state potential to be of the following