QUASISTABLE STATES WITH LARGE ISOTOPIC SPIN IN LIGHT NUCLEI

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We consider an odd nucleus A with one excess neutron, with a minimum value of isotopic spin $T = 1/2$ in the ground state, and with a neutron binding energy Q. The excited states of the nucleus A^* with excitation energy $E > Q$ have as a rule a rather large probability of neutron emission, i.e., a large width Γ_n of the process $A^* \to B + n$, where B is an even nucleus.

Let the ground state of the nucleus B have $T = 0$, and let the state B^* with $T = 1$ have an excitation energy Δ. We assume that the nucleus A has an excited state A_3^* with $T = 3/2$ and excitation energy E_3 such that $Q < E_3 < Q + \Delta$. The decay of A_3^* to $B^* + n$ is energetically impossible, while the decay of A_3^* into $B + n$ proceeds via a change in isotopic spin and should therefore have an anomalously small width Γ_n. The state A_3^* is quasistable and should appear in a unique manner in the scattering of neutrons by nuclei B, and also in the photoeffect $A + \gamma = B + n$.

When n is scattered by B the isotopic spin of the system in the initial state is $T = 1/2$, and it is usually assumed that states with $T = 3/2$ should make only a small contribution to the scattering cross section. However, if a quasistate exists, then sharp scattering resonance takes place at a neutron energy $E_n = E_3 - Q$, with a maximum cross section

$$4\pi\lambda^2(2J+1)/(2S+1).$$

The low probability of the process, connected with the disturbance of the isotopic spin, manifests itself not in a reduction in the scattering cross section, but in a reduction of the width of the resonance scattering. Therefore observation of resonance is quite possible if the neutrons are sufficiently monochromatic.

At resonance the increase in the scattered cross section will be accompanied by an increased probability of the process $B(n, \gamma)A$, since $\sigma_{n,\gamma}/\sigma_{sc} = \Gamma_\gamma/\Gamma_n$ and an anomalously small Γ_n should give* an anomalously large Γ_γ/Γ_n. Incidentally, the inequality $\Gamma_\gamma/\Gamma_n \ll 1$ remains in force, since $\Gamma_n \sim e^2$, when the isotopic spin is disturbed by the Coulomb interaction, like Γ_γ, which contains, however, other small factors, $(v/c)^u$, $(R/\lambda)^v$, and $(\hbar/Mc\lambda)^w$ in degrees that depend on the type of transition (for E1: $u = 2$, $v = 2$, and $w = 0$; for M1: $u = v = 0$, and $w = 2$, etc).

The existence of a quasistable A_3^* should lead to a narrow resonance in the reverse process† $A(\gamma, n)B$ and also to resonant scattering of γ by A. Incidentally, owing to the inequality $\Gamma_\gamma/\Gamma_n \ll 1$, the latter process can apparently not be observed.

The state A_3^* forms an isotopic multiplet with the ground state of the nucleus with three excess neutrons, and, by introducing a known Coulomb correction, it is possible to determine the expected position of the quasistable level. Thus, knowing the masses[1] of the boron isotopes B^{12} and B^{13}, it is possible to determine the energies of the corresponding states of C_2^{12*} $(T = 1)$ and C_3^{13*} $(T = 3/2)$. The result (in our notation) is $E_3 = 11.2$ Mev at $Q = 4.95$ Mev and $\Delta = 11.54$ Mev. Consequently, the level C_3^{13*} should be quasistable, since its energy is insufficient for decay into $C_2^{12*} + n$.

One should expect a narrow resonance in the scattering of n by C^{12} at $E_n = 11.2 - 4.95 = 6.25$ Mev, corresponding to a neutron energy of 7.20 Mev in the laboratory system.

From the similarity between C^{13} in the state with $T = 3/2$ and the ground state of B^{13} one expects C_3^{13*} to be in the state $3/2^-$, which leads to a scattering of neutrons in the state $P_{3/2}$ on C^{12}, with a cross section

$$4\pi\lambda^2(2J+1)/(2S+1) = 0.8 \text{ b}.$$

A relatively narrow resonance was observed experimentally[2] at $E_n = 6.30$ Mev, along with a superposition of two resonances at $E_n = 7.4$ and 8.7 Mev.

The state of interest to us can be investigated by studying the angular distribution and polarization of the scattered neutrons. On the other hand, at least in principle, there is a possibility of ascertaining the existence of the unknown isobars by resonance in the scattering of neutrons by stable nuclei. Thus, narrow resonance in neutron scattering on Be^{10} or C^{14} could denote the existence of stable (with respect to emission of neutrons) nuclei Li^{11} or B^{15}.

I take this opportunity to express my gratitude to V. I. Gol'danskiĭ for a discussion.

*$A_3 \to A + \gamma$ is allowed, Γ_γ has a normal value.

†It is possible that the best method of observing the quasi-stable level is to let the reaction proceed against the continuous spectrum of bremsstrahlung and to determine the maxima in the spectrum of the emitted neutrons from the time of flight, using a pulsed γ source.

[1] F. Ajzenberg-Selove and T. Lauritsen, Nucl. Phys. 11, 5 (1959).

[2] Bondelid, Dunning, and Talbott, Phys. Rev. **105**, 193 (1957).

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(d, t) REACTIONS ON MEDIUM AND HEAVY NUCLEI

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THE study of triton spectra from (d, t) reactions on light nuclei[1,2] has shown that mainly hole levels, corresponding to the ripping out of a neutron from the nucleus, are excited in this reaction. It is of interest to investigate the hole levels of medium and heavy nuclei, which differ in that they have a complex structure and a large number of filled shells. The neutron would be expected to be ripped out of various shells, with the excitation of hole levels with differing excitation energies, corresponding to the binding energies of the neutron in these shells.

In the present work, the spectra of tritons from (d, t) reactions in Fe, Zr, In, Au, and Bi were measured. Deuterons were accelerated in the cyclotron up to an energy of 20 Mev. The triton spectra were measured as previously[1-3] from the activity of tritium collected in stacks of foil.

Since the energies of tritons emitted from heavy nuclei depend only weakly on angle, tritons were collected in stacks of foil subtending a rather wide angular interval. There was one angular interval, 15 — 40°, for the targets of iron and indium, and two angular intervals, 8.5 — 23° and 24.5 — 39° for zirconium and gold. The maxima of distributions corresponding to practically all angular momenta l of the removed neutron lie within these angular intervals, with the exception of $l = 0$. The angular distribution of the tritons was measured for the bismuth target.

The measured triton spectra are given in Fig. 1. Along the abscissa are marked the excitation energies of the residual nucleus formed as a result of the reaction on the main isotope (Fe^{56} — 92%, Zr^{90} — 51%, In^{115} — 96%, Au^{179} — 100%, Bi^{209} — 100%). The magnitude of the energy resolution for each of the spectra is shown as a horizontal dash in the region of the main group. The magnitudes of the cross sections for Fe^{56}, Zr^{90}, and In^{115} were calculated from the atoms in a naturally occurring mixture of isotopes.

In all spectra, an intense group of tritons, which usually had two peaks, was observed corresponding to an excitation energy of 0 — 2 Mev. Excitation of states of the residual nucleus of energy higher than 2 Mev proceeds with substantially smaller probability. This means that in all of the nuclei studied, the main process is removal of the most weakly bound neutron, apparently out of the same outer (filled or unfilled) shell. The width of the group (1.5 — 2 Mev) is characterized by the spread in binding energies of the removed neutrons.

The character of the angular distributions, following from comparison of intensities of groups in the two angular intervals, agrees with known data on the character of that from outer shells.[4] In Zr^{90}, the outer neutrons are in $1g_{9/2}$ states; therefore the angular momentum of the removed neutron should be $l = 4$. The intensities of the first maxima in the Zr^{90}(d, t) spectrum are almost the same for the angular intervals 8.5 — 23° and 24.5 — 39°, in complete agreement with what one would expect for a large value of l.

On the other hand, the intensity of the group of tritons from reactions in the isotopes $Zr^{91,92,94}$ drops by a factor of 4 or 5 in going from the first to the second angular interval, in agreement with neutrons filling the $2d_{5/2}$ state above the closed shell.

In the spectrum of Au^{197}, both lines are more intense in the angular interval 24.5 — 39° than in the interval 8.5 — 23°. According to shell theory, the state of outer neutrons, $1i_{13/2}$, corresponds to a large value of the angular momentum $l = 6$. It should be noted that a reliable determination of angular momenta for medium and heavy nuclei cannot be made, since there is, up to now, no possibility of reliably calculating the effect of the Coulomb interaction on the angular distribution.

In Fig. 2 are shown angular distributions of three groups of tritons from the reaction