Nuclear Excitation of Indium with Alpha-Particles

It has been found that indium bombarded with neutrons,[1] protons,[2] or x-rays[3] becomes beta-radioactive and that this activity is due to In^{115*} which forms a metastable state and decays with a half-life period of 4.1 hours.

Barnes and Aradine[2] also tried to produce this excitation with 8.5 Mev alpha-particles but did not observe the 4.1-hour period.

Since we have 16 Mev alpha-particles available from our cyclotron, we have investigated this process again. After bombardment with about $0.03\mu\text{A}$ for periods of 30 to 90 minutes the 4-hour period was found with either the multiple counter[4] described recently, or a Dow metal counter of 0.004-inch wall thickness.[5] By exposing two identical layers of indium, one behind the other, it was found that the activity is not due to neutrons or x-rays, since only the piece in front directly exposed to the beam becomes active. Traces of antimony and tin were added to a a solution of activated indium and after chemical separation the 4-hour period was found with the indium precipitate. The number of counts is comparable with the intensity reported by other observers for the nuclear excitation process. Samples of indium obtained from Hilger and from the Indium Corporation of America gave the same results: we conclude therefore that impurities cannot be responsible for this activity.

In the Wilson chamber six hours after exposure only soft electrons can be observed. These electrons are absorbed in aluminum of approximately the thickness as reported by others.[6]

Besides the 4-hour period other weak activities of about one hour and a half day have been found which are being investigated now. Also a short period of about 5 minutes (due to a positron-emitter as shown by cloud chamber experiments) has been found. This period goes with the antimony-tin precipitate, and since only stable tin isotopes can be formed, it should be due to antimony.

It seems, therefore, that the nuclear excitation of In^{115} can also be produced by an (α, α) process.

K. Lark-Horovitz
J. R. Risser
R. N. Smith

Purdue University,
Lafayette, Indiana,
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[1] Goldhaber, Hill, Szilard, Phys. Rev. **55**, 47 (1939).
[2] Barnes and Aradine, Phys. Rev. **55**, 50 (1939).
[3] Collins, Waldman, Stubblefield, and Goldhaber, Phys. Rev. **55**, 506 (1939).
[4] How and Lark-Horovitz, Phys. Rev. **53**, 334 (1938).
[5] Risser, Phys. Rev. **52**, 768 (1937).
[6] See reference 1, p. 49.

Vibration-Rotation Energies in the Tetrahedrally Symmetric XY_4 Type of Molecule

The complete quantum-mechanical Hamiltonian for the oscillating-rotating XY_4 type molecule has been derived perfectly generally to second order of approximation and may be written $H=H_0+H_1+H_2$. In H_0 are contained the energy of a spherical top, $P/2A_0$, P being the total angular momentum operator and A_0 the equilibrium value of the moment of inertia, and the energies

$$\tfrac{1}{2}\left[\sum_{i=1}^{3}(p_i^2+4\pi^2\nu_3q_i^2)+\sum_{k=4}^{6}(p_k^2+4\pi^2\nu_4^2q_k^2)\right.$$
$$\left.+\sum_{j=7}^{8}(p_j^2+4\pi^2\nu_2^2q_j^2)+(p_9^2+4\pi^2\nu_1^2q_9^2)\right]$$

of the molecule oscillating in its nine modes. H_1 contains the first-order centrifugal expansion terms, the potential energy terms cubic in the coordinates, and in particular the Coriolis interaction terms $(p_xP_x+p_yP_y+p_zP_z)/A_0$; the p_α are components along the axes of the molecule of the angular momentum arising from the oscillations and consist essentially of a sum of terms of the type

$$\zeta_{ij}\left[\left(\frac{\nu_i}{\nu_j}\right)^{\frac{1}{2}}q_i\frac{\partial}{\partial q_j}-\left(\frac{\nu_j}{\nu_i}\right)^{\frac{1}{2}}q_j\frac{\partial}{\partial q_i}\right],$$

ζ_{ij} being the modulus of the internal angular momentum vector. For the frequency ν_2, $\zeta_2=0$ and for ν_3 and ν_4 the relation $\zeta_3+\zeta_4=\frac{1}{2}$ is known to hold. H_2 contains the second-order centrifugal expansion terms, second-order Coriolis terms, terms quadratic in p_α and quartic terms of the potential energy. The zeroth-order wave equation is at once soluble and of the terms in H_1 only the Coriolis interaction terms where $\nu_i=\nu_j$ give first-order contributions to the energy. It is therefore convenient to transform H by a contact transformation, SHS^{-1} into $H_0+H_1'+H_2'$, so that to second approximation H_1' contains only the Coriolis interaction terms where $\nu_i=\nu_j$. This transformation facilitates the determination of the second-order energy corrections.

It has been possible to find linear combinations of the zeroth-order eigenfunctions such that the matrix of H_1' will be diagonal, for the states ν_1, ν_2, ν_3, ν_4, $2\nu_3$, $2\nu_4$, $\nu_1+\nu_3$, $\nu_1+\nu_4$, $\nu_2+\nu_3$, $\nu_2+\nu_4$, and $\nu_3+\nu_4$. For the state ν_3 (and ν_4) these combinations were found to be identical with those of Jahn[1] which lead to the eigenvalues of H_1': $-(J-1)\zeta_3\hbar^2/A_0$, $-\zeta_3\hbar^2/A_0$ and $J\zeta_3\hbar^2/A_0$. For the states $\nu_2+\nu_{3,4}$ and $\nu_1+\nu_{3,4}$ the eigenfunctions are respectively products of the functions

$$\left(\frac{1}{2}\right)^{\frac{1}{2}}\chi_{v_8=0}^{v_7=1}\pm\chi_{v_8=1}^{v_7=0}$$

and $\varphi(v_9=1)$ times the eigenfunctions of ν_3 and ν_4 and lead to the same eigenvalues of H_1'. The selection rules for J are the same as those found by earlier investigators.

For $\nu_3+\nu_4$ wave functions have been derived which give the matrix of H_1' as a step matrix, consisting of two single steps, two double steps and one triple step. The eigenvalues for this case are

$$J(\zeta_3+\zeta_4)(\hbar^2/A_0),\quad -(J-1)(\zeta_3+\zeta_4)(\hbar^2/A_0),$$
$$\tfrac{1}{2}\{(J-1)(\zeta_3+\zeta_4)\pm[(J+1)^2(\zeta_3-\zeta_4)^2+4\zeta_3\zeta_4]^{\frac{1}{2}}\}\hbar^2/A_0,$$
$$-\tfrac{1}{2}\{(J-2)(\zeta_3+\zeta_4)\pm[J^2(\zeta_3-\zeta_4)^2+4\zeta_3\zeta_4]^{\frac{1}{2}}\}\hbar^2/A_0$$

and those given by the cubic equation

$$0=\epsilon^3+2(\zeta_3+\zeta_4)\epsilon^2+[\tfrac{3}{4}(\zeta_3+\zeta_4)^2-(J^2-J-\tfrac{1}{4})(\zeta_3-\zeta_4)^2]$$
$$\times\epsilon-J(J+1)(\zeta_3+\zeta_4)(\zeta_3-\zeta_4)^2$$

where $E^1=\epsilon\hbar^2/A_0$ and $\hbar=h/2\pi$. The selection rules are