Radiative Capture (n, γ)

The ejected particle is a photon so that instead of p^2/v the quantity $h^2\nu^2/c^3$ must be considered, see equation (2-10). If the neutron hits a nucleus and is captured there is generally an excess of energy – that energy associated with the binding of the neutron to the nucleus. Neutron capture is almost always exothermic, one notable exception being helium. The energy available for photon emission will be $\mu v_1^2/2 + W$ where W is the binding energy of the neutron. If the first photon corresponds to a drop to a level L (not necessarily ground) then it will have an energy $h\nu = \mu v_1^2/2 + W_L$. Now as v_1 approaches zero the quantity $h\nu$ approaches a fixed number W_L so that $h^2\nu^2/c^3$ becomes constant. The other factor in the cross section is $1/v_1$ which increases rapidly. As a consequence (n, γ) processes should have cross sections which increase as 1/v for slow neutrons ($v \sim 0$), provided M' itself is constant.

(n, α) Processes

These reactions, in which the capture of a neutron results in the emission of an alpha particle, can be endothermic or exothermic (Q positive or negative). As in the previous example of an absorption process the energy equation in the center of gravity system is

$$\mu_e v_e^2/2 = \mu_1 v_1^2/2 + Q$$

with μ_e the reduced mass of the ejected alpha particle and μ_1 the reduced mass of the incident neutron. If Q is positive then v_e^2 is at least $(2Q/\mu_e)$ so that the cross section which from equation (2-11) is $M'\mu_e^2 v_e/v_1$ is going to obey the $1/v_1$ law, at least for small v_1. Thus slow neutrons in an (n, α) process for which $Q > 0$ should be absorbed according to a 1/v law. However, for $Q < 0$ the situation is different. Denoting the threshold energy by $Q = -\mu_1 v_o^2/2$ the energy equation can be reduced to $(\mu_e/\mu_1)v_e^2 = (v_1^2 - v_o^2)$ with v_o the threshold velocity. As discussed in the inlastic scattering process the velocity of the emitted alphas should increase in proportion to the square root of the excess velocity at the threshold, Figure 7. Actually, see Figure 8, the rise in σ is not parabolic. This is due to the variation of M' in this case. Being a charged particle the alpha has to escape through an electrostatic potential barrier ("Gamow" barrier). This effectively decreases the cross section as shown in the figure.

2.5 EXAMPLES FROM EXPERIMENT

The absorption of neutrons by boron in the reaction B^{10} (n, α) Li^7 illustrates the type process discussed at the end of the preceding section. Q is positive, about 3 Mev (although since Li^7 is normally left in an excited state only about 2.5 Mev are available for kinetic energy). For slow neutrons this reaction should go as 1/v. Experiment confirms this. In unseparated boron (B^{10} and B^{11}) the cross section has been measured over a wide range of energies with the results shown in Figure 9. For room temperature neutrons the total cross section is 737 barns; since this temperature* (15°C) corresponds to a neutron velocity of 2200 m/sec the cross section is thus $737 \times 2200/v = 1.62 \times 10^6/v$ in barns (v in meters per second). For pure B^{10} the room temperature cross section is 3525 barns. This high cross section and the ionizing ability of both products (He^4 and Li^7) as well as the fact that functional dependence of σ on neutron energy E is relatively simple ($\sigma = 116/\sqrt{E}$ for σ in barns E in ev) make boron extremely useful in neutron detectors, particularly in the form of the gas BF_3. If boron trifluoride is prepared with boron enriched in the isotope B^{10} the detector sensitivity for slow neutrons can be increased, as is apparent from the cross section values, by as much as a factor of five.

*Figure 11 shows the relation between neutron velocities, energies, and temperatures.

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