CHAPTER IV

MODELS OF NUCLEI AND OF NUCLEAR REACTIONS

4.1 THE COMPOUND NUCLEUS

In section 2.4 it was shown that for (n,γ) processes the cross section for low energies is:

$$\sigma = M'(h^2 \nu^2/c^3)\frac{1}{v_i} \tag{4-1}$$

where ν = frequency of emitted gamma, v_i = velocity of incident neutron. Of the more than one hundred (n,γ) reactions known the $1/v$ law holds for most only very close to $v_i = 0$. This is due to the sharp variations of M' associated with resonance phenomena.

An explanation of the nature of these resonances can be made in terms of the so-called "compound nucleus" model of reactions first proposed by Niels Bohr in Nature: 137: 344(1936). In this model a nuclear reaction is a three-step scheme:

$$\begin{pmatrix}\text{Initial}\\ \text{Nucleus}\end{pmatrix} + \begin{pmatrix}\text{Incident}\\ \text{Particle}\end{pmatrix} \rightarrow \begin{pmatrix}\text{Compound}\\ \text{Nucleus}\end{pmatrix} \rightarrow \begin{pmatrix}\text{Final}\\ \text{Nucleus}\end{pmatrix} + \begin{pmatrix}\text{Outgoing}\\ \text{Particle}\end{pmatrix} \tag{4-2}$$

This means that when a neutron hits a nucleus it does not knock out the first particle it hits. Instead it distributes its energy among the various members of the nucleus and for some time exists in combination with the original nucleus in a system called the compound nucleus.* Whether a particle is emitted by the compound nucleus depends upon the probability of concentrating the necessary escape energy on one particle in the course of the many-body interactions within the compound nucleus. An (n,γ) process may be represented as:

$$A + N \rightarrow (A + n)^* \rightarrow (A + n) + h\nu \tag{4-3}$$

The compound nucleus $(A + n)^*$ is in this instance the excited state of the final nucleus, the asterisk being used to denote excitation.

The compound nucleus is relatively stable, that is to say the compound nucleus exists for a time long compared to the time it would take a nuclear particle to cross the nucleus. This latter time is of the order of 10^{-12} cm divided by the neutron velocity (see Figure 11, page 21), or for slow neutrons about $10^{-12}/10^7 = 10^{-19}$ second. The time of existence can be inferred from the uncertainty principle which states that the product of the energy uncertainty in a system (ΔE) and the time uncertainty (Δt), in this case the time during which the system can be said to exist, is of the order of Planck's constant:

$$\Delta E \cdot \Delta t \sim h \tag{4-4}$$

It is possible to determine the magnitude of the energy uncertainty to be discussed later, so that Δt can be inferred. Sometimes Δt is of the order of 10^{-14} second or 10^5 times the crossing time. In terms of the physical picture this means that the incident particle hits the nucleus, distributes its energy among the nuclear particles, and very many "transit times" later the necessary energy is concentrated in a constituent particle so that it can escape.

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* The distribution of energy among all nuclear particles arises from the fact that the nuclear particles interact with forces comparable to the force exerted upon any nuclear particle by the incident neutron. This is different from the case in atomic collisions when, say, an electron hits an atom. In this latter case the interaction between the colliding electron and the electron being struck is large compared to the interaction between the struck electron and the other electrons of the atom. Put another way, collisions between neutrons and nuclei must be considered "many-body" problems whereas electron-atom collisions can generally be reduced to a two-body (or one body in a field) problem. For an excellent discussion of these differences and a general introduction to nuclear processes see H. A. Bethe in Reviews of Modern Physics 9: 71 to 74 (1937).

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