If the first resonance peak occurs on the average for, say, nuclei of medium weight at $E_p \sim E$, then it would be anticipated that the energy level spacing of medium weight nuclei (in the region of excitation corresponding to the binding energy of the incident particle) is of the order of magnitude of E. For medium weight nuclei such "first capture resonances" occur at ~10 electron volts, so that the energy level spacing at compound nucleus energies ($W_A + W_p \sim 8$ Mev) is of the order of 10 electron volts. Experiments with such nuclei that are near their ground states (e.g., excitation by gammas) indicate that the spacing between energy levels is of order of 10^5 or 10^6 electron volts at low energies.

4.3 TWO NUCLEAR MODELS

The fact that the level spacing decreases very rapidly with excitation energy for medium (or large) weight nuclei needs explanation. Qualitatively this fact can be appreciated by considering two models of the compound nucleus: (1) a mechanical system with many degrees of freedom (2) a neutron-proton gas.

In the first model the nucleus is represented by a mechanical system with A members (A = mass number), each member having three degrees of freedom. Since the total number of degrees of freedom is 3A the system will sustain vibrations with 3A characteristic frequencies. With a vibration frequency ν there is associated an energy $h\nu$. If the system is vibrating with frequencies ν_1 and ν_5 at once it has an energy $h\nu_1 + h\nu_5$. In general it will have an energy:

$$a_1 h\nu_1 + a_2 h\nu_2 + a_3 h\nu_3 + \ldots\ldots a_{3A} h\nu_{3A}$$

where the a's are integers. If $\nu_1 = \nu_2 = \nu_3$, etc., it is easy to see that at high energies there will be more levels per unit energy. This is strictly an inexact qualitative argument but the basic idea, that a system of many degrees of freedom will pack its energy levels at high energy, is correct.

This type of consideration can be refined by depicting the nucleus as a liquid drop (Bohr and Kalckar proposal: Kgl. Dansk Acad. Vol. 14, No. 10, (1937)). The liquid drop is held together by the attraction of each part of the drop to the nearest neighboring part of the drop, that is by short range forces (short compared to droplet dimensions). Drop volume is proportional to drop mass. Similarly nuclear forces are short range forces with each proton attracted to the very few neighboring neutrons or protons and the nuclear volume is proportional to the total number of neutrons and protons in the nucleus. Considering a spherical drop there are a number of possible modes of vibration. Higher modes will be characterized by a relatively "wrinkled" surface, that is many nodal lines; the energies corresponding to these higher modes will be relatively closer together than those for lower and fundamental modes. This liquid drop model will be discussed later in the chapter on fission.

The second nuclear model is a Fermi gas of neutrons and protons in a potential well. The temperature of the gas is T. When T = 0 the nucleus is in the ground state with some particles moving rather fast nonetheless because of the Pauli exclusion principle. If energy is fed into the gas some particles move faster and T increases. It can be shown that for a degenerate gas of the type here considered the energy is proportional to the T^2 rather than T. In fact,

$$\text{Energy} = U = (\pi^2/4)(A/\zeta)\tau^2$$

A = number of particles

$\tau = kT$

ζ = energy of ground state

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