# CHAPTER V

# THE SCATTERING OF NEUTRONS

## 5.1 THE BREIT-WIGNER FORMULA

For certain special cases, the matrix elements occurring in the general formula for the cross section, that is, the factor M discussed briefly in section 2.4, can be reduced to relatively simple formulas. In particular, if the resonance levels of a compound nucleus are far apart and we are interested in the cross section in the neighborhood of one of the resonance levels, the expression for the cross section of an (a,b) process can be shown to take the form:

$$\sigma(a,b) = \pi \lambda\!\!\!^{-}_a{}^2 \frac{\Gamma_a \Gamma_b}{(E_a - E_r)^2 + (\Gamma^2/4)} \tag{5-1}$$

$$\lambda\!\!\!^{-}_a = \lambda_a/2 = \hbar/\sqrt{2\mu E_a}; \quad \mu = mM/(m+M)$$

$E_a$ is the kinetic energy of the incident particle, $\lambda_a$ its deBroglie wavelength, m the mass of the incident particle, M the mass of the target nucleus, $E_r$ is the resonance level energy ($E_{Pr}$ in Section 4.2) of the compound nucleus, and $\Gamma$ the width of the resonance peak at half its maximum value. Actually equation (5-1), known as the Breit-Wigner formula, should be multiplied by factors depending on the spins of the initial particles and the compound nucleus. For simplicity, consider these factors to be incorporated in the $\Gamma_a$ and $\Gamma_b$. $\Gamma_a$ and $\Gamma_b$ are the partial widths of the resonance peak and are associated with the probability of emitting "a" and "b" particles, respectively. Their exact form is rather complicated, but since the probability of emission of a particle "b" of momentum $p_e$ [see equation (2-11)] is proportional to $p_e^2/v_e$, then so is $\Gamma_b$. The relative probability that the outgoing particle will be an "a" particle is $\Gamma_a/\Gamma$, relative probability that it will be a "b" particle, $\Gamma_b/\Gamma$, etc., so that the sum of all $\Gamma_i$ is $\Gamma$:

$$\Sigma \Gamma_i = \Gamma \tag{5-2}$$

$$i = a, b, \ldots$$

If $\tau_i$ is the average time of emission of a particle i after the formation of the compound nucleus, then

$$\Gamma_i \tau_i \cong \hbar. \tag{5-3}$$

This is a restatement of the uncertainty relation discussed in section 4.1 and expressed in equation (4-4). The probability that no particle i has been emitted from the nucleus up to a time $t$ is $\prod_{i=a,b\ldots} \exp(-t/\tau_i) = \exp(t\sum_i 1/\tau) = e^{-t/\tau}$

where t is the average life of the compound nucleus:

$$\tau = [\sum_i 1/\tau_i]^{-1} \tag{5-4}$$

If one describes the emission in terms of the disintegration constant $\lambda = 1/\tau$ the exponential relation is seen to be the familiar $\exp(-\lambda t)$. The average life $\tau$ is seen to satisfy the Heisenberg relation in the same manner as the $\tau_i$, that is, $\Gamma_\tau \cong \hbar$.

The Breit-Wigner formula of equation (5-1) can be applied to any nuclear collision involving the formation of a compound nucleus , provided that the resonance levels are not so close together



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