that they appreciably distort this one-level formula. It can be applied, for example, to $(n,\gamma)$ processes. For resonance capture in indium, it is observed* that $E_r = 1.44$ ev, $\sigma(n,\gamma)$ at resonance $\simeq 26{,}000$ barns, $\Gamma \cong 0.09$ ev. In addition, the experimental measurements show that only neutrons and gammas are observed to be emitted (thus $\Gamma = \Gamma_n + \Gamma_\gamma$), and more gammas are emitted than neutrons ($\Gamma_\gamma > \Gamma_n$). With these experimental data, it is desired to find *the number of neutrons emitted for each gamma emitted*. The solution follows from equation (5-1):

$$\sigma(n,\gamma) \text{ at resonance } = 4\pi \lambda\!\!\!^{-}{}_n^2 \, \Gamma_n \Gamma_\gamma / \Gamma^2$$

$$\lambda\!\!\!^{-}{}_n = \hbar / \sqrt{2mE_r}; \quad m = \text{Neutron mass}$$

Substituting the experimental values of $\sigma$ and $E_r$ gives the value

$$\Gamma_n \Gamma_\gamma / \Gamma^2 = 0.015$$

Since $\Gamma_n < \Gamma_\gamma$, then $\Gamma_\gamma \simeq \Gamma = 0.09$ ev. Also $\Gamma_n\Gamma_\gamma/\Gamma^2 \cong \Gamma_n/\Gamma = 0.015$, from which $\Gamma_n = 0.015\Gamma = 0.015 \times 0.09 = 0.0013$ ev. Thus the ratio of widths is $\Gamma_n/\Gamma_\gamma = 0.015$, or for each thousand gammas emitted, approximately 15 neutrons will be emitted.

The same reasoning for gold and silver† shows that:

Au: $E_r = 4.8$ ev, $\sigma_{res} \simeq 60{,}000$ barns, $\Gamma \simeq 0.1$ ev (experimental)

$\Gamma_n \simeq 0.01$ ev, $\Gamma_\gamma \simeq 0.1$ ev, $\Gamma_n/\Gamma \cong 0.11$ (calculated)

Ag: $E_r = 5.1$ ev, $\sigma_{res} = 7200$ barns, $\Gamma = 0.19$ ev (experimental)

$\Gamma_n = 0.0027$ ev, $\Gamma = 0.19$ ev, $\Gamma_n/\Gamma = 0.014$ (calculated)

The capture reactions for indium, gold, and silver are very useful in methods of slow neutron detection.††

## 5.2 SOME GENERAL CONSIDERATIONS ON NEUTRON SCATTERING

For the elastic scattering of low-energy neutrons, formula (5-1), by virtue of the relations $a = b = n$ and $E_n \cong 0$, reduces to

$$\sigma(n,n) = \pi \lambda\!\!\!^{-}{}_n^2 \Gamma_n^2 / E_r^2 \qquad (5\text{-}5)$$

$$[E_n \simeq 0, \ \Gamma \ll E_r]$$

The inequality is assumed and limits the applicability to neutrons whose energy is less than the first resonance energy and to cases where the width of the first resonance energy level is much less than the energy itself. Now since $\lambda_n$ is proportional to $1/\mu v_n$ and $\Gamma_n$ is proportional to $p_e^2/v_e$ or $\mu^2 v_e$ where $p_e$ and $v_e$ are momentum and velocity of the neutron, and since $v_n = v_e$ (elastic collision), then it follows that $\lambda_n^2 \Gamma_n$ is proportional to $\mu^2$ and should be fairly constant for scattering of neutrons with energies less than the first resonance energy.

*Physical Review 71:165 (1947).

†Phys. Review 70:166 (1946); 71:165 (1947); 71:757 (1947).

††For a summary of activation cross sections for thermal neutrons, see L. Seren, H. N. Friedlander, S. H. Turkel in Phys. Rev. 72:888 (1947).

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