NEUTRON INTERACTIONS

Neutrons can cause many different types of interactions. The neutron may simply scatter off the nucleus in two different ways, or it may actually be absorbed into the nucleus. If a neutron is absorbed into the nucleus, it may result in the emission of a gamma ray or a subatomic particle, or it may cause the nucleus to fission.

EO 3.1 DESCRIBE the following scattering interactions between a neutron and a nucleus:

a. Elastic scattering
b. Inelastic scattering

EO 3.2 STATE the conservation laws that apply to an elastic collision between a neutron and a nucleus.

EO 3.3 DESCRIBE the following reactions where a neutron is absorbed in a nucleus:

a. Radiative capture
b. Particle ejection

Scattering

A neutron *scattering* reaction occurs when a nucleus, after having been struck by a neutron, emits a single neutron. Despite the fact that the initial and final neutrons do not need to be (and often are not) the same, the net effect of the reaction is as if the projectile neutron had merely "bounced off," or scattered from, the nucleus. The two categories of scattering reactions, elastic and inelastic scattering, are described in the following paragraphs.

Elastic Scattering

In an *elastic scattering* reaction between a neutron and a target nucleus, there is no energy transferred into nuclear excitation. Momentum and kinetic energy of the "system" are conserved although there is usually some transfer of kinetic energy from the neutron to the target nucleus. The target nucleus gains the amount of kinetic energy that the neutron loses.

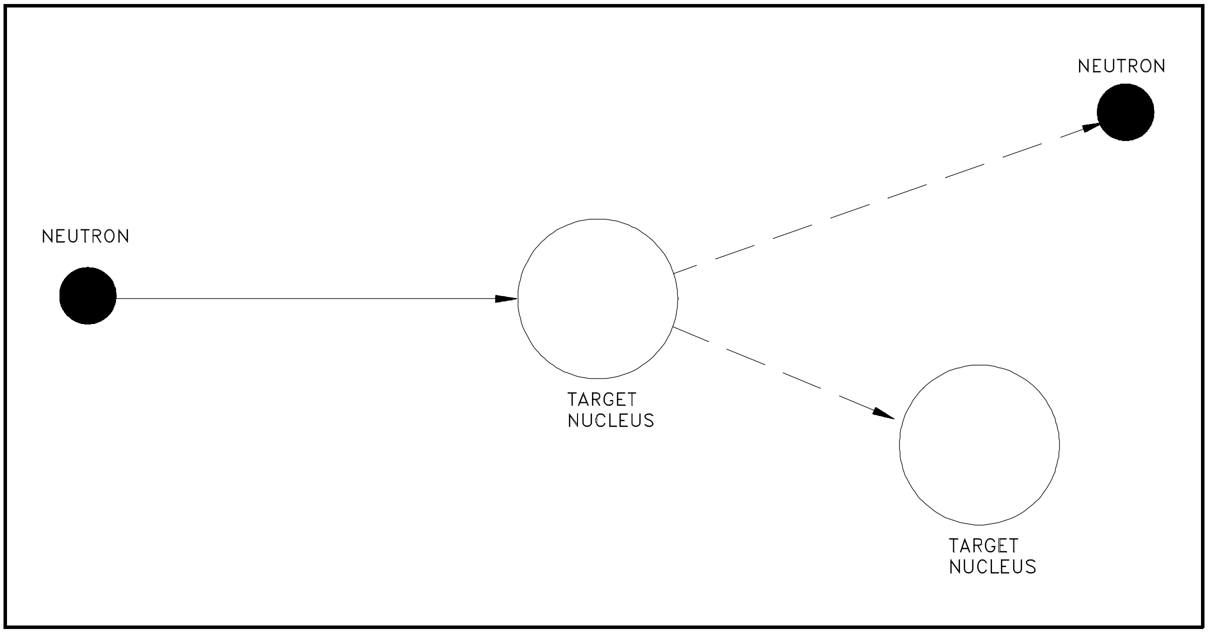

Figure 16 Elastic Scattering

Figure 16 illustrates the process of elastic scattering of a neutron off a target nucleus. In the elastic scattering reaction, the conservation of momentum and kinetic energy is represented by the equations below.

Conservation of momentum (mv)

$$\left(m_n\ v_{n,i}\right) + \left(m_T\ v_{T,i}\right) = \left(m_n\ v_{n,f}\right) + \left(m_T\ v_{T,f}\right)$$

Conservation of kinetic energy $\left(\frac{1}{2}\ m\ v^2\right)$

$$\left(\frac{1}{2}\ m_n\ v_{n,i}^2\right) + \left(\frac{1}{2}\ m_T\ v_{T,i}^2\right) = \left(\frac{1}{2}\ m_n\ v_{n,f}^2\right) + \left(\frac{1}{2}\ m_T\ v_{T,f}^2\right)$$

where:

m_n = mass of the neutron
m_T = mass of the target nucleus
$v_{n,i}$ = initial neutron velocity
$v_{n,f}$ = final neutron velocity
$v_{T,i}$ = initial target velocity
$v_{T,f}$ = final target velocity

Elastic scattering of neutrons by nuclei can occur in two ways. The more unusual of the two interactions is the absorption of the neutron, forming a compound nucleus, followed by the re-emission of a neutron in such a way that the total kinetic energy is conserved and the nucleus returns to its ground state. This is known as *resonance elastic scattering* and is very dependent upon the initial kinetic energy possessed by the neutron. Due to formation of the compound nucleus, it is also referred to as compound elastic scattering. The second, more usual method, is termed *potential elastic scattering* and can be understood by visualizing the neutrons and nuclei to be much like billiard balls with impenetrable surfaces. Potential scattering takes place with incident neutrons that have an energy of up to about 1 MeV. In potential scattering, the neutron does not actually touch the nucleus and a compound nucleus is not formed. Instead, the neutron is acted on and scattered by the short range nuclear forces when it approaches close enough to the nucleus.

Inelastic Scattering

In *inelastic scattering*, the incident neutron is absorbed by the target nucleus, forming a compound nucleus. The compound nucleus will then emit a neutron of lower kinetic energy which leaves the original nucleus in an excited state. The nucleus will usually, by one or more gamma emissions, emit this excess energy to reach its ground state. Figure 17 shows the process of inelastic scattering.

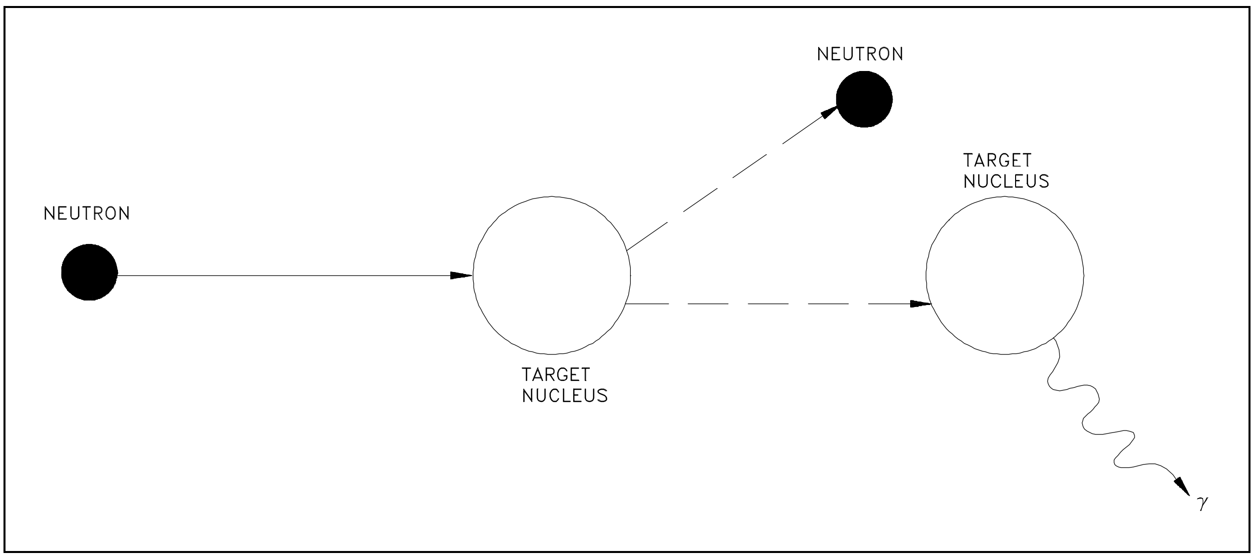

Figure 17 Inelastic Scattering

For the nucleus that has reached its ground state, the sum of the kinetic energy of the exit neutron, the target nucleus, and the total gamma energy emitted is equal to the initial kinetic energy of the incident neutron.

Absorption Reactions

Most *absorption reactions* result in the loss of a neutron coupled with the production of a charged particle or gamma ray. When the product nucleus is radioactive, additional radiation is emitted at some later time. Radiative capture, particle ejection, and fission are all categorized as absorption reactions and are briefly described below.

Radiative Capture

In *radiative capture* the incident neutron enters the target nucleus forming a compound nucleus. The compound nucleus then decays to its ground state by gamma emission. An example of a radiative capture reaction is shown below.

$$ {}^{1}_{0}n + {}^{238}_{92}U \rightarrow \left({}^{239}_{92}U\right)^{*} \rightarrow {}^{239}_{92}U + {}^{0}_{0}\gamma $$

Particle Ejection

In a *particle ejection* reaction the incident particle enters the target nucleus forming a compound nucleus. The newly formed compound nucleus has been excited to a high enough energy level to cause it to eject a new particle while the incident neutron remains in the nucleus. After the new particle is ejected, the remaining nucleus may or may not exist in an excited state depending upon the mass-energy balance of the reaction. An example of a particle ejection reaction is shown below.

$$ {}^{1}_{0}n + {}^{10}_{5}B \rightarrow \left({}^{11}_{5}B\right)^{*} \rightarrow {}^{7}_{3}Li + {}^{4}_{2}\alpha $$

Fission

One of the most important interactions that neutrons can cause is fission, in which the nucleus that absorbs the neutron actually splits into two similarly sized parts. Fission will be discussed in detail in the next chapter.

Summary

The important information in this chapter is summarized below.

Neutron Interactions Summary

- Interactions where a neutron scatters off a target nucleus are either elastic or inelastic. In elastic scattering, kinetic energy and momentum are conserved and no energy is transferred into excitation energy of the target nucleus. In inelastic scattering, some amount of kinetic energy is transferred into excitation energy of the target nucleus.

- The conservation principles that apply to an elastic collision are conservation of kinetic energy and conservation of momentum.

- Radiative capture is the absorption of a neutron by the target nucleus, resulting in an excited nucleus which subsequently (typically within a small fraction of a second) releases its excitation energy in the form of a gamma ray.

- Particle ejection occurs when a neutron is absorbed by a target nucleus, resulting in the formation of a compound nucleus. The compound nucleus immediately ejects a particle (for example, alpha or proton).