NEUTRONS AND NEUTRON INTERACTIONS

OBJECTIVES

At the conclusion of this lesson the trainee will be able to:

1. Write equations for:
   a) Transmutation
   b) Radiative capture
   c) Photoneutron reaction with deuterium.
2. Describe elastic and inelastic scattering of neutrons.

NEUTRONS AND NEUTRON INTERACTIONS

A nuclear reactor will not operate without neutrons. It is important to have a thorough knowledge of those reactions which produce neutrons and those interactions which neutrons undergo.

NEUTRON PRODUCTION

Most of the neutrons in a CANDU reactor come directly from fission. In addition, about ½% of the neutrons in a reactor at power are emitted by the fission products. These two important types of neutrons (known as prompt and delayed neutrons respectively) are discussed in Module 6. The only other important neutron source in an operating CANDU is the photoneutron reaction.

THE PHOTONEUTRON REACTION

A gamma ray with an energy of 2.2 MeV or greater can interact with a deuterium nucleus removing a neutron. The deuterium nucleus becomes a normal hydrogen nucleus and the neutron is free to move around.

$$^{2}_{1}H + \gamma \longrightarrow ^{1}_{1}H + ^{1}_{0}n$$

NEUTRON INTERACTIONS

1. Elastic Scattering

   This resembles a billiard ball collision. A neutron collides with a nucleus, transfers some energy to it and bounces off in a different direction. The fraction of its initial energy lost depends on whether it hits the target nucleus dead-on or at an angle - exactly like the cue ball striking a ball on the billiard table. The energy lost by the neutron is gained by the target nucleus which then moves at an increased speed. Light nuclei are the most effective for slowing down neutrons.

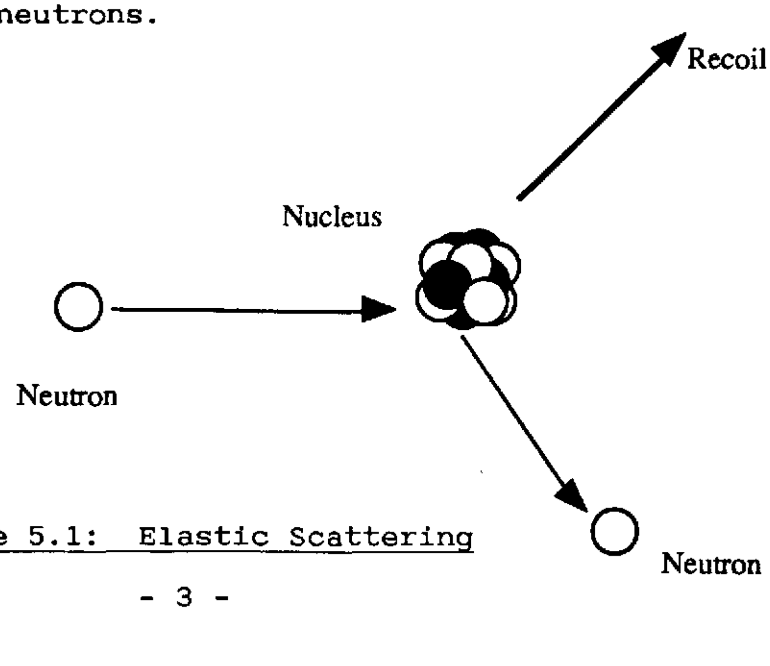


Figure 5.1: Elastic Scattering

A neutron colliding with a heavy nucleus rebounds with little loss of speed and transfers very little energy - rather like firing the cue ball at a cannon ball.

On the other hand neutrons will not be scattered by the light electron clouds surrounding the nucleus, but will travel straight on - much like baseballs through a fog.

2. Inelastic Scattering

A neutron may strike a nucleus and, instead of bouncing off, be temporarily absorbed, forming a "compound nucleus". This will be in an excited state. It de-excites by emitting another neutron of lower energy, together with a gamma photon which will take the remaining energy. This process is known as INELASTIC SCATTERING. It generally happens only when high energy neutrons interact with heavy nuclei and has little practical importance for reactor operation.

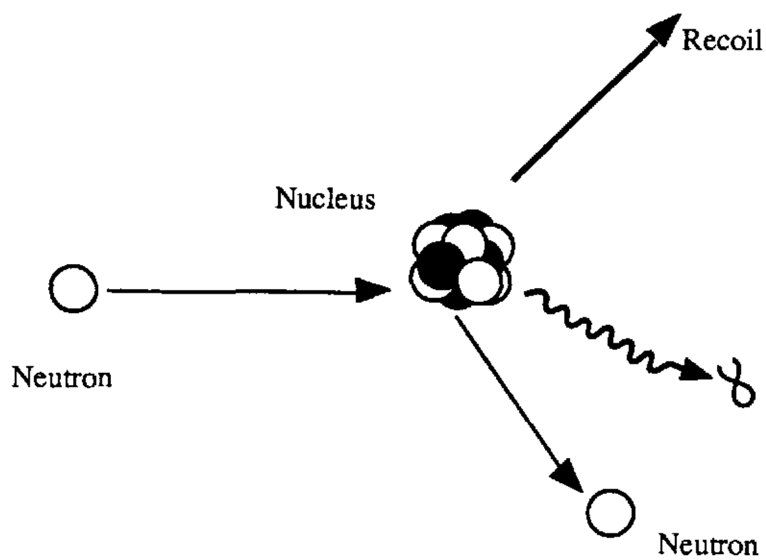


Figure 5.2: Inelastic Scattering

3. Transmutation

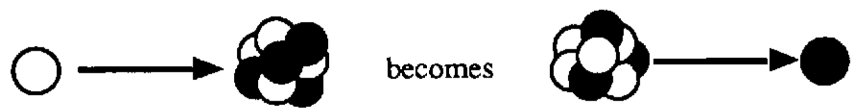
A neutron may be captured by a nucleus forming a compound nucleus which then de-energizes by emitting a charged particle, either a proton or an alpha particle. This produces a new nucleus of a different element. Such a nuclear reaction is called a TRANSMUTATION.

TRANSMUTATION is the transformation of one element into another by a nuclear reaction.

Examples:

a) Neutron-Proton Reaction (n,p)

Oxygen-16 captures a neutron and emits a proton to form nitrogen-16:

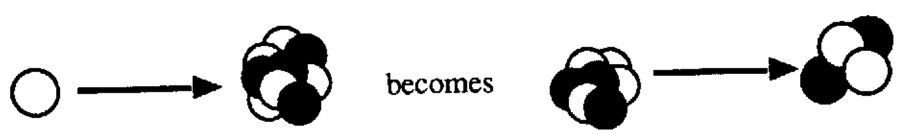


$^{1}_{0}$ Neutron + $^{16}_{8}$ 0 Nucleus $^{16}_{7}$ Nucleus + $^{1}_{1}$ proton

The product, nitrogen-16, is radioactive with a half-life of 7.1 seconds; it is a beta emitter, but more important, it also emits very high energy gammas.

b) Neutron-Alpha Reaction (n,α)

Neutrons captured by boron-10 cause the following reaction:



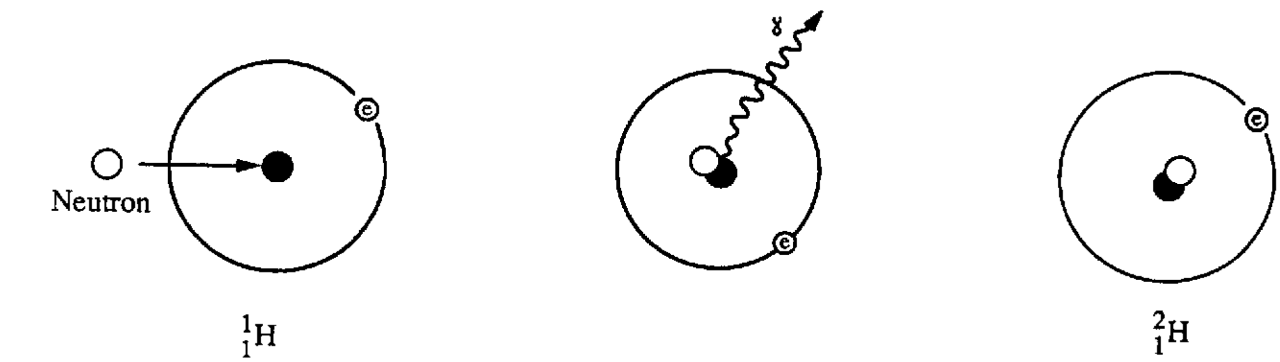
$^{1}_{0}$ Neutron + $^{10}_{5}$ B Nucleus $^{7}_{3}$ Li nucleus + $^{4}_{2}$ He

4. Radiative Capture (n,γ)

This is the most common nuclear reaction. The compound nucleus formed emits only a gamma photon; in other words the product nucleus is an isotope of the same element as the original nucleus (its mass number will have increased by one).

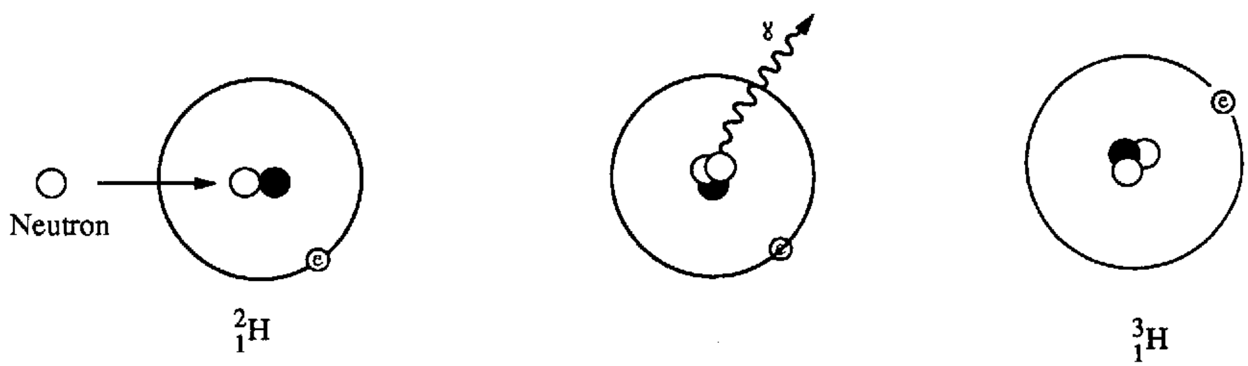
Examples

a) The simplest neutron-gamma reaction occurs with hydrogen to produce deuterium (heavy Hydrogen);



The deuterium formed is a stable nuclide. However, many radiative capture products are radioactive and are beta-gamma emitters.

b) Deuterium itself undergoes a radiative capture reaction to form tritium;



The tritium isotope is unstable and is one of our major radiation hazards.

c) Cobalt-59 undergoes radiative capture to form highly radioactive Co-60:

$$^{59}_{27}Co + ^{1}_{0}n \longrightarrow ^{60}_{27}Co + \gamma$$

Cobalt-60 has a long half-life (5¼ years) and very penetrating gamma radiation, making it a serious hazard among activated corrosion products. The concentration of cobalt in reactor grade materials is limited to trace amounts.

Cobalt-60 is also the isotope most commonly used in radiation treatment of cancer.

5. Fission

This most important reaction is the subject of the next lesson.

ASSIGNMENT

1. Write the equation for the photo-neutron reaction with H-2.

2. Describe elastic and inelastic scattering of neutrons.

3. Identify the following reactions:

   a) $^{40}_{18}Ar + ^{1}_{0}n \longrightarrow ^{41}_{18}Ar + \gamma$

   b) $^{16}_{8}O + ^{1}_{0}n \longrightarrow ^{16}_{7}N + ^{1}_{1}p$

4. List the examples of neutron reactions is this chapter which are also activations.