Chapter 5: Detailed Summary

The Atomic Nucleus

A common misconception is that radioactivity is new in the environment. Radioactivity, however, has been around far longer than the human race. It is as much a part of our environment as the sun and the rain. It has always occurred in the soil we walk on and in the air we breathe, and it warms the interior of Earth and makes it molten. The energy released by radioactive substances in Earth's interior heats the water that spurts from a geyser and the water that wells up from a natural hot spring. Radioactivity is a fully natural phenomenon.

Humans discovered radioactivity in the early 1900s. Three basic forms of radioactivity were then identified as *alpha*, *beta*, and *gamma* radiation. Alpha radiation consists of fast-moving helium nuclei, also known as alpha particles. Beta radiation consists of fast-moving electrons. Gamma radiation is energetic high-frequency electromagnetic radiation (light). All these forms of radiation result from processes occurring within the atomic nucleus.

Nuclear radiation has found many applications, especially in medicine and in the production and treatment of food. The ability of radiation to cause harm to living tissue is measured in *rems*. Over a year, we are each exposed, on average, to about 500 millirems (0.5 rem) of radiation from both natural and human-made sources.

So why are some atomic nuclei radioactive? In all atomic nuclei there are two major forces at play. The *strong nuclear force* is an attractive force that holds the nucleons together. The *electric force* occurs among all the protons of a nucleus and is always repulsive. In a stable nucleus, the attractive strong nuclear force wins out over the repulsive electric force. The key to making this happen is to have a sufficient number of neutrons, which exert only the strong nuclear force but not the electric force. In this way, the neutrons serve as a "glue" holding all the nucleons together.

Too many neutrons, however, is not a good thing. It turns out that neutrons need to have protons around them in order to remain neutrons. A lone neutron without any protons around it will spontaneously transform into a proton while spitting out an electron and other forms of energy. Thus, if a nucleus has too many neutrons, some of those neutrons (with not enough protons around them) will start transforming into protons while spitting out electrons, which we detect as beta radiation. As the nucleus gains more protons, it sheds those protons by emitting alpha particles, which we detect as alpha radiation.

Thus, as a radioactive element emits radiation, it is changing the count of its nucleons. This results in a transformation of the element's identity. As the element gains a proton (from the transformation of a neutron) its atomic number increases by 1 and it goes up by one in the periodic table. As the element loses an alpha particle, its atomic number goes down by 2 and so it moves down two steps in the periodic table. This process of one element transforming into another is called *transmutation*.

We measure the strength of an element's radioactivity by its *half-life*, which is the time it takes for half of the material (measured in grams) to transform. A material with a short half-life is undergoing rapid transformations and is most radioactive. A material with a longer half-life is correspondingly less radioactive. Archaeologists are able to date relics by measuring the level of radioactivity they emit. In general, the less radioactivity emitted, the older the relic.

This chapter culminates with in-depth discussions of nuclear fission and fusion. Briefly, nuclear fission is the splitting apart of the atomic nucleus. Only a few nuclei can undergo nuclear fission. The most notable examples are uranium-235 and plutonium-239, both of which are used for nuclear bombs and power plants. The massive release of energy from nuclear fission arises from the chain reaction that occurs when fissionable nuclei are concentrated within a macroscopic quantity. Nuclear fusion is the joining together of atomic nuclei. It occurs within our sun, where hydrogen nuclei are joined together (by gravitational pressures) to form helium nuclei.

An explosive fission chain reaction occurs when two subcritical masses (of about 1 kilogram each—depending upon the element) are brought together. This coming together of subcritical masses is not to be confused with nuclear fusion, which is the coming together of individual nuclei. Nuclear fission, by contrast, is the splitting of a relatively large nuclei into smaller pieces.

The source of energy arising from both nuclear fission and fusion is from the conversion of mass into energy. For example, when two protons and two neutrons combine to form a helium nucleus, the total mass that they have when together is less than the sum of the masses they had when apart. The difference in mass is that which was emitted to the environment as energy, as per Einstein's famous equation, $E = mc^2$. At present, all nuclear power plants obtain their energy from nuclear fission. The first net energy producing nuclear fusion power plant (ITER) is now underway in Caderache, France.

Summary of Terms

Alpha Particle A subatomic particle consisting of the combination of two protons and two neutrons ejected by a radioactive nucleus. The composition of an alpha particle is the same as that of the nucleus of a helium atom.

Beta Particle An electron emitted during the radioactive decay of a radioactive nucleus.

Carbon-14 Dating The process of estimating the age of once-living material by measuring the amount of radioactive carbon-14 present in the material.

Chain Reaction A self-sustaining reaction in which the products of one reaction event initiate further reaction events.

Critical mass The minimum mass of fissionable material needed for a sustainable chain reaction.

Gamma Rays High-frequency electromagnetic radiation emitted by radioactive nuclei.

Half-Life The time required for half the atoms in a sample of a radioactive isotope to decay.

Nuclear Fission The splitting of the atomic nucleus into two smaller halves.

Nuclear Fusion The combining of nuclei of light atoms to form heavier nuclei.

Radioactive Said of a material containing nuclei that are unstable because of a less than optimal balance in the number of neutrons and protons.

Radioactivity The high-energy particles and electromagnetic radiation emitted by a radioactive substance.

Rem A unit for measuring the ability of radiation to harm living tissue.

Strong Nuclear Force The attractive force between all nucleons, effective only at very short distances.

Thermonuclear Fusion Nuclear fusion brought about by high temperatures.

Transmutation The changing of an atomic nucleus of one element into an atomic nucleus of another element through a decrease or increase in the number of protons.