Modes of Radioactive Decay

Henri Becquerel’s discovery of natural radioactivity in 1896 opened a whole new world of physics and introduced new and exciting opportunities for physics research that eventually developed into important branches of modern physics such as nuclear physics and particle physics. While the early investigators explained the macroscopic kinetics of radioactive decay soon after 1896 starting with the work of Marie and Pierre Curie, Ernest Rutherford and Frederick Soddy, it took several decades until the various radioactive decay modes were fully understood on a microscopic scale.
In this chapter the various radioactive decay modes are presented with a special emphasis on specific aspects of radioactive decay that are of importance to medical physics. In addition to standard modes of radioactive decay, such as alpha, beta and gamma decay, the chapter also includes proton and neutron decay as well as spontaneous fission as interesting examples of spontaneous decay despite their limited importance to medical physics. The chapter concludes with a discussion of the Segrè chart of the nuclides which presents an orderly catalog of all known stable as well as radioactive nuclear species, provides useful basic data for all known nuclides, and indicates the possible decay paths for radionuclides.

11.1 Introduction to Radioactive Decay Processes

Radioactive nuclides, either naturally occurring or artificially produced by nuclear reactions, are unstable and strive to reach more stable nuclear configurations through various processes of spontaneous radioactive decay that involve transformation to a more stable nuclide and emission of energetic particles. General aspects of spontaneous radioactive decay may be discussed using the formalism based on the definitions of activity $A$ and decay constant $\lambda$ without regard for the actual microscopic processes that underlie the radioactive disintegrations. A closer look at radioactive decay processes shows that they are divided into six main categories:

1. Alpha ($\alpha$) decay
2. Beta ($\beta$) decay
3. Gamma ($\gamma$) decay
4. Spontaneous fission (SF)
5. Proton emission decay
6. Neutron emission decay

$\beta$ decay actually encompasses three decay processes ($\beta^-$, $\beta^+$, and electron capture) and $\gamma$ decay encompasses two ($\gamma$ decay and internal conversion).

There are many spontaneous radioactive decay modes that an unstable nucleus may undergo in its quest for reaching a more stable nuclear configuration. On a microscopic scale the nine most important modes are:

1. $\alpha$ decay
2. $\beta^-$ decay
3. $\beta^+$ decay
4. Electron capture (EC)
5. $\gamma$ decay
6. Internal conversion (IC)
7. Spontaneous fission (SF)
8. Proton emission decay
9. Neutron emission decay