Other radioactive elements were soon discovered as well. The radioactivity was found in every case to be unaffected by the strongest physical and chemical treatments, including strong heating or cooling and the action of strong chemical reagents. It was clear that the source of radioactivity must be deep within the atom, that it must emanate from the nucleus. And it became apparent that radioactivity is the result of the *disintegration* or *decay* of an unstable nucleus. Certain isotopes are not stable, and they decay with the emission of some type of radiation or "rays."

Many unstable isotopes occur in nature, and such radioactivity is called "natural radioactivity." Other unstable isotopes can be produced in the laboratory by nuclear reactions (Section 31–1); these are said to be produced "artificially" and to have "artificial radioactivity."

Rutherford and others began studying the nature of the rays emitted in radioactivity about 1898. They found that the rays could be classified into three distinct types according to their penetrating power. One type of radiation could barely penetrate a piece of paper. The second type could pass through as much as 3 mm of aluminum. The third was extremely penetrating: it could pass through several centimeters of lead and still be detected on the other side. They named these three types of radiation alpha ($\alpha$), beta ($\beta$), and gamma ($\gamma$), respectively, after the first three letters of the Greek alphabet.

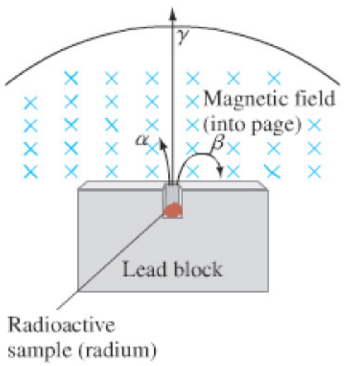


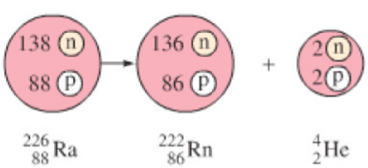

**FIGURE 30–4** Alpha and beta rays are bent in opposite directions by a magnetic field, whereas gamma rays are not bent at all.

Each type of ray was found to have a different charge and hence is bent differently in a magnetic field, Fig. 30–4; $\alpha$ rays are positively charged, $\beta$ rays are negatively charged, and $\gamma$ rays are neutral. It was soon found that all three types of radiation consisted of familiar kinds of particles. Gamma rays are very high-energy photons whose energy is even higher than that of X-rays. Beta rays are electrons, identical to those that orbit the nucleus, but they are created within the nucleus itself. Alpha rays (or $\alpha$ particles) are simply the nuclei of helium atoms, ${}^{4}_{2}\text{He}$; that is, an $\alpha$ ray consists of two protons and two neutrons bound together.

We now discuss each of these three types of radioactivity, or decay, in more detail.

## 30–4 Alpha Decay

**FIGURE 30–5** Radioactive decay of radium to radon with emission of an alpha particle.




When a nucleus emits an $\alpha$ particle $\left({}^{4}_{2}\text{He}\right)$, it is clear that the remaining nucleus will be different from the original: it has lost two protons and two neutrons. Radium 226 $\left({}^{226}_{88}\text{Ra}\right)$, for example, is an $\alpha$ emitter. It decays to a nucleus with $Z = 88 - 2 = 86$ and $A = 226 - 4 = 222$. The nucleus with $Z = 86$ is radon (Rn)—see Appendix B or the periodic table. Thus the radium decays to radon with the emission of an $\alpha$ particle. This is written

*$\alpha$ decay*

$${}^{226}_{88}\text{Ra} \rightarrow {}^{222}_{86}\text{Rn} + {}^{4}_{2}\text{He}.$$

See Fig. 30–5.

*Daughter nucleus*
*Parent nucleus*
*Transmutation*

It is clear that when $\alpha$ decay occurs, a new element is formed. The **daughter** nucleus (${}^{222}_{86}\text{Rn}$ in this case) is different from the **parent** nucleus (${}^{226}_{88}\text{Ra}$ in this case). This changing of one element into another is called **transmutation**.

Alpha decay can be written

$${}^{A}_{Z}\text{N} \rightarrow {}^{A-4}_{Z-2}\text{N}' + {}^{4}_{2}\text{He} \qquad [\alpha \text{ decay}]$$

where $N$ is the parent, $N'$ the daughter, and $Z$ and $A$ are the atomic number and atomic mass number, respectively, of the parent.