30–5 Beta Decay

β^- Decay

Transmutation of elements also occurs when a nucleus decays by β decay—that is, with the emission of an electron or β^- particle. The nucleus $^{14}_{6}\mathrm{C}$, for example, emits an electron when it decays:

$$^{14}_{6}\mathrm{C} \rightarrow {}^{14}_{7}\mathrm{N} + \mathrm{e}^- + \text{a neutrino},$$

where e^- is the symbol for the electron. (The symbol $^{\;0}_{-1}\mathrm{e}$ is sometimes used for the electron whose charge corresponds to $Z = -1$ and, since it is not a nucleon and has very small mass, then $A = 0$.) The particle known as the neutrino, whose charge $q = 0$ and whose rest mass is very small or zero, was not initially detected and was only later hypothesized to exist, as we shall discuss later in this Section. No nucleons are lost when an electron is emitted, and the total number of nucleons, A, is the same in the daughter nucleus as in the parent. But because an electron has been emitted from the nucleus itself, the charge on the daughter nucleus is $+1e$ greater than that on the parent. The parent nucleus in the decay written above had $Z = +6$, so from charge conservation the nucleus remaining behind must have a charge of $+7e$. So the daughter nucleus has $Z = 7$, which is nitrogen.

It must be carefully noted that the electron emitted in β decay is *not* an orbital electron. Instead, the electron is created *within the nucleus itself.* What happens is that one of the neutrons changes to a proton and in the process (to conserve charge) emits an electron. Indeed, free neutrons actually do decay in this fashion:

CAUTION
β-decay e^- comes from nucleus (not an orbital electron)

$$\mathrm{n} \rightarrow \mathrm{p} + \mathrm{e}^- + \text{a neutrino}.$$

Because of their origin in the nucleus, the electrons emitted in β decay are often referred to as "β particles," rather than as electrons, to remind us of their origin. They are, nonetheless, indistinguishable from orbital electrons.

EXAMPLE 30–8 **Energy release in $^{14}_{6}\mathrm{C}$ decay.** How much energy is released when $^{14}_{6}\mathrm{C}$ decays to $^{14}_{7}\mathrm{N}$ by β emission?

APPROACH We find the mass difference before and after decay, Δm. The energy released is $E = (\Delta m)c^2$. The masses given in Appendix B are those of the neutral atom, and we have to keep track of the electrons involved. Assume the parent nucleus has six orbiting electrons so it is neutral; its mass is 14.003242 u. The daughter in this decay, $^{14}_{7}\mathrm{N}$, is not neutral since it has the same six orbital electrons circling it but the nucleus has a charge of $+7e$. However, the mass of this daughter with its six electrons, plus the mass of the emitted electron (which makes a total of seven electrons), is just the mass of a neutral nitrogen atom.

CAUTION
Be careful with atomic and electron masses in β decay

SOLUTION The total mass in the final state is

$$(\text{mass of } ^{14}_{7}\mathrm{N} \text{ nucleus} + 6 \text{ electrons}) + (\text{mass of 1 electron}),$$

and this is equal to

$$\text{mass of neutral } ^{14}_{7}\mathrm{N} \text{ (includes 7 electrons)},$$

which, from Appendix B is a mass of 14.003074 u. So the mass difference is $14.003242\,\mathrm{u} - 14.003074\,\mathrm{u} = 0.000168\,\mathrm{u}$, which is equivalent to an energy change $\Delta m\, c^2 = (0.000168\,\mathrm{u})(931.5\,\mathrm{MeV/u}) = 0.156\,\mathrm{MeV}$ or 156 keV.

NOTE The neutrino doesn't contribute to either the mass or charge balance since it has $q = 0$ and $m \approx 0$.