The decay processes

A nucleus emitting an alpha particle ($^{4}_{2}He$) loses two protons and two neutrons. Therefore, the atomic number Z decreases by 2, the mass number A decreases by 4, and the neutron number decreases by 2. The decay can be written

$$^{A}_{Z}X \rightarrow \, ^{A-4}_{Z-2}Y + \, ^{4}_{2}He$$

-where *X is called the parent nucleus and Y the daughter nucleus*.

As a general rule in any decay expression such as this one, (1) *the sum of the mass numbers A must be the same on both sides of the decay* and (2) *the sum of the atomic numbers Z must be the same on both sides of the decay*. As examples, ^{238}U and ^{226}Ra are both alpha emitters and decay according to the schemes

$$^{238}_{92}U \rightarrow \, ^{234}_{90}Th + \, ^{4}_{2}He$$

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

B) Beta Decay

When a radioactive nucleus undergoes beta decay, the daughter nucleus contains the same number of nucleons as the parent nucleus but the atomic number is changed by 1, which means that the number of protons changes:

$$^{A}_{Z}X \rightarrow \, _{Z+1}^{A}Y + e^{-}$$

$$^{A}_{Z}X \rightarrow \, _{Z-1}^{A}Y + e^{+}$$

(Incomplete expression)

As with alpha decay, the nucleon number and total charge are both conserved in beta decays. Because A does not change but Z does, we conclude that in beta decay, *either a neutron changes to a proton or a proton change to a neutron*.

$$ {}^{A}_{Z}X \rightarrow {}_{Z+1}{}^{A}Y + e^{-} + \bar{\nu} \qquad \text{(complete expression)} $$

$$ {}^{A}_{Z}X \rightarrow {}_{Z-1}{}^{A}Y + e^{+} + \nu \qquad \text{(complete expression)} $$

where the symbol $\bar{\nu}$ represents the antineutrino, the antiparticle to the neutrino

Note:

- Neutrino is emitted in positron decay and an antineutrino is emitted in electron decay.
- **The neutrino has the following properties**

- It has zero electric charge.
- Its mass is either zero (in which case it travels at the speed of light) or very small
- It interacts very weakly with matter and is therefore very difficult to detect.
- In Equation one of the complete expression, the number of protons has increased by one and the number of neutrons has decreased by one. We can write the fundamental process of e^{-} decay in terms of a neutron changing into a proton as follows:

$$ n \rightarrow p + e^{-} + \bar{\nu} $$

- The electron and the antineutrino are ejected from the nucleus, with the net result that there is one more proton and one fewer neutron, consistent with the changes in Z and A - Z.

- A similar process occurs in e^+ decay, with a proton changing into a neutron, a positron, and a neutrino.
- This latter process can only occur within the nucleus, with the result that the nuclear mass decreases.
- It cannot occur for an isolated proton because its mass is less than that of the neutron.
- A process that competes with e^- decay is **electron capture**, which occurs when a parent nucleus captures one of its own orbital electrons and emits a neutrino. The final product after decay is a nucleus whose charge is Z - 1:

$${}^{A}_{Z}X + {}^{0}_{-1}e \rightarrow {}^{A}_{Z-1}Y + \nu$$

(electron capture)

In most cases, it is a K-shell electron that is captured and the process is therefore referred to as K capture. One example is the capture of an electron by ${}^{7}_{4}Be$:

$${}^{7}_{4}Be + {}^{0}_{-1}e \rightarrow {}^{7}_{3}Li + {}^{0}_{0}\nu$$

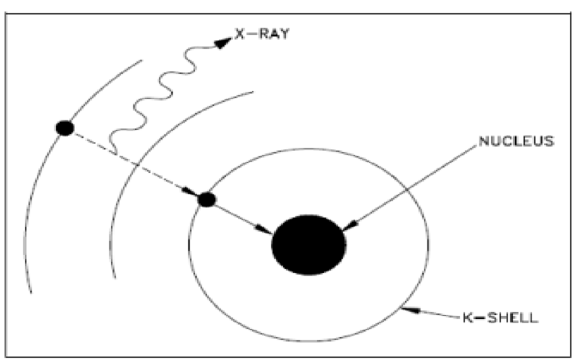

Figure orbital electron capture

3) Gamma Decay

- Very often, a nucleus that *undergoes radioactive decay is left in an excited energy state*. The nucleus can then undergo a second decay to a lower-energy state, perhaps to the ground state, by emitting a high-energy photon:
- where X* indicates a nucleus in an excited state.

$$ {}^{A}_{Z}X^{*} \rightarrow {}^{A}_{Z}X + \gamma $$

- The typical half-life of an excited nuclear state is 10^{-10} s.
- Photons emitted in such a de-excitation process are called **gamma rays**. Such photons have very high energy (1 MeV to 1 GeV) relative to the energy of visible light (approximately 1 eV).
- Since the energy of a photon emitted or absorbed by an atom equals the difference in energy between the two electronic states involved in the transition. *Similarly, a gamma-ray photon has an energy hf that equals the energy difference ΔE between two nuclear energy levels*.
- When a nucleus decays by emitting a gamma ray, the only change in the nucleus is that it ends up in a lower-energy state. **There are no changes in *Z*, *N*, or *A*.**
- A nucleus may reach an excited state as the result of a violent collision with another particle.
- More common, however, is for a nucleus to be in an excited state after it has undergone alpha or beta decay.

The following sequence of events represents a typical situation in which gamma decay occurs:

- Figure below shows the decay scheme for ^{12}B, which undergoes beta decay to either of two levels of ^{12}C. It can either (1) decay directly to the ground state of ^{12}C by emitting a 13.4-MeV electron or (2) undergo beta decay to an excited state of ^{12}C* followed by gamma decay to the ground state. The latter process results in the emission of a 9.0-MeV electron and a 4.4-MeV photon. The various pathways by which a radioactive nucleus can undergo decay are summarized in Table 44.3.

$$^{12}_{5}\mathrm{B} \rightarrow {}^{12}_{6}\mathrm{C}^* + e^- + \bar{\nu}$$

$$^{12}_{6}\mathrm{C}^* \rightarrow {}^{12}_{6}\mathrm{C} + \gamma$$

TABLE 44.3 *Various Decay Pathways*

Alpha decay	$^{A}_{Z}X \rightarrow {}^{A-4}_{Z-2}Y + {}^{4}_{2}He$
Beta decay (e^-)	$^{A}_{Z}X \rightarrow {}_{Z+1}{}^{A}Y + e^- + \bar{\nu}$
Beta decay (e^+)	$^{A}_{Z}X \rightarrow {}_{Z-1}{}^{A}Y + e^+ + \nu$
Electron capture	$^{A}_{Z}X + e^- \rightarrow {}_{Z-1}{}^{A}Y + \nu$
Gamma decay	$^{A}_{Z}X^* \rightarrow {}^{A}_{Z}X + \gamma$

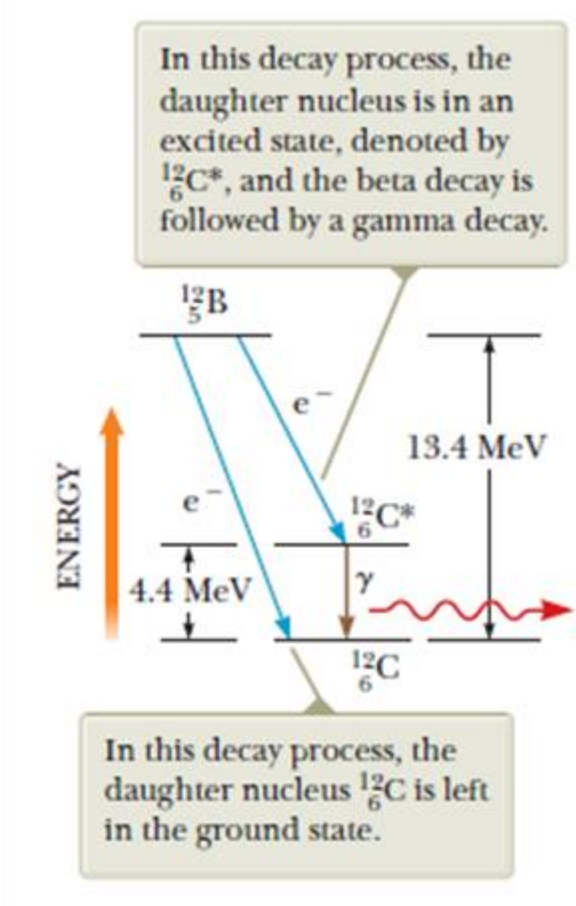

Figure 5 An energy-level diagram showing the initial nuclear state of a ^{12}B nucleus and two possible lower-energy states of the ^{12}C nucleus.