

## Nuclear Decay

### Nuclear Reactions

The standard nuclear reactions are

$$\alpha\text{-Decay: } (Z,N) \rightarrow (Z-2,N-2) + \alpha$$

$$\beta^-\text{-Decay: } (Z,N) \rightarrow (Z+1,N-1) + e^- + \bar{\nu}$$

$$\beta^+\text{-Decay: } (Z,N) \rightarrow (Z-1,N+1) + e^+ + \nu$$

$$e^-\text{ Capture: } (Z,N) + e^- \rightarrow (Z-1,N+1) + \nu$$

For them to happen spontaneously, they must release energy. That is, the rest masses of the daughter nucleus and any products must be less than that of the parent nucleus.

$$K = \Delta Mc^2 = \left\{ m_{\text{nucleus}}(Z,N) - [m_{\text{daughter}} + m_{\text{product}}] \right\} c^2$$

where the daughter nucleus and product depend on the decay process. Appendix D in TZDII gives atomic masses, not nuclear masses. We can convert the masses of nuclei to those of atoms by adding and subtracting  $Zm_e$  and associating them with the appropriate nuclei (see TZDII §16.7). thus, the energy equations of the reactions are:

$$K_{\alpha} = \Delta Mc^2 = \left\{ m_{\text{atom}}(Z,N) - [m_{\text{atom}}(Z-2,N-2) + m_{\text{He}}] \right\} c^2$$

$$K_{\beta^+} = \Delta Mc^2 = \left\{ m_{\text{atom}}(Z,N) - [m_{\text{atom}}(Z-1,N+1) + 2m_e] \right\} c^2$$

The original atom has an extra electron when  $p^+ \rightarrow n^0$  and the emitted mass of the  $e^+$  ( $= m_e$ ), gives  $2m_e$  as products in  $\beta^+$  decay.

$$K_{\beta^-} = \Delta Mc^2 = \left\{ m_{\text{atom}}(Z,N) - [m_{\text{atom}}(Z+1,N-1)] \right\} c^2$$

If a different reaction occurs, say the emission of a neutron, a proton, or a  $^{12}\text{C}$  atom, the energy will have to take into account the atomic mass of the product (i.e. TZDII Pr. 17.27).

$$K_{n^0} = \Delta Mc^2 = \left\{ m_{\text{atom}}(Z,N) - [m_{\text{atom}}(Z,N-1) + m_n] \right\} c^2$$

$$K_{p^+} = \Delta Mc^2 = \left\{ m_{\text{atom}}(Z,N) - [m_{\text{atom}}(Z-1,N) + m_H] \right\} c^2$$

$$K_{^{12}\text{C}} = \Delta Mc^2 = \left\{ m_{\text{atom}}(Z,N) - [m_{\text{atom}}(Z-6,N-6) + m_{^{12}\text{C}}] \right\} c^2$$

All of these ultimately require the conversion from  $uc^2$  to MeV using the conversion factor:

$$1 \text{ u} = 931.5 \frac{\text{MeV}}{c^2}.$$