1)

a) $m_e = \dfrac{9.1\times10^{-31}}{1.6\times10^{-19}}\times9\times10^{16} = 51.1\times10^{-31+16+19}$ $= 511\ \text{keV/c}^2$

b) $m_p = \dfrac{1.67\times10^{-27}}{1.6\times10^{-19}}\times9\times10^{16} = 59.39\times10^{-27+16+19}$ $= 939\ \text{MeV/c}^2$

c) $E^2 = p^2c^2 + m^2c^4 = (1)^2 + (0.511)^2 \quad \rightarrow E$ $= 1.12\ \text{MeV}$

d) $E^2 = p^2c^2 + m^2c^4 = (1)^2 + (0939)^2 \quad \rightarrow E = 939.00053$

$K = E - mc^2 = 0.00053\ \text{MeV}$ $= 530\ \text{eV}$

e) $K = \dfrac{p^2}{2m} = \dfrac{(1)^2}{2\times939} = 0.00053\ \text{MeV}$ $= 530\ \text{eV}$

f) $\dfrac{v}{c} = \dfrac{pc}{E} = \dfrac{1}{2} \quad E^2 = p^2c^2 + m^2c^4 = \dfrac{E^2}{4} + m^2c^4$

so $\dfrac{3E^2}{4} = m^2c^4 \quad \rightarrow \quad E = \dfrac{2}{\sqrt{3}}mc^2$

$K = E - mc^2 \quad \rightarrow \quad \left(\dfrac{2}{\sqrt{3}} - 1\right)mc^2$ $= 145\ \text{MeV}$

2) To make an α - particle we need process [3] once, process [2] twice and process [1] twice. So the energy released $= (2\times0.41 + 2\times5.51 + 12.98)$ MeV .

In addition two e^+ annihilate with two e^-, giving $E = 4m_ec^2 = (4\times0.511)$ MeV

Total energy released $= (24.82 + 2.04)$ $= 26.86\ \text{MeV}$

3) $\pi_0 \rightarrow \gamma + \gamma$. Decay at rest so $p_\pi = 0$

Momentum conservation: $\rightarrow \quad p_1 + p_2 = 0$ equal and opposite

Energy conservation: $\rightarrow \quad E_1 + E_2 = m_\pi c^2$

But $E_1 = E_2 = pc$ (photons are massless)

(a) So $E_1 = \dfrac{m_\pi c^2}{2} = \dfrac{135}{2}$ $= 67.5\ \text{MeV}$

(b) and $p = \dfrac{E}{c}$ $= 67.5\ \text{MeV/c}$

4) $K^0 \rightarrow \pi^0 + \pi^0$ Decay at rest so $p_K = 0$

Momentum conservation: $\rightarrow \quad p_1 + p_2 = 0$ equal and opposite

Energy conservation: $\rightarrow \quad E_1 + E_2 = m_K c^2$

But $E_1 = E_2 = \sqrt{p^2c^2 + m_\pi^2c^4}$

(a) So $E_1 = \dfrac{m_K c^2}{2} = \dfrac{498}{2}$ $= 294\ \text{MeV}$

(b) and $p_\pi^2 = E_\pi^2 - m_\pi^2c^4 = (249)^2 - (135)^2$

and $p = \sqrt{62000 - 18225} \quad \rightarrow$ $= 209\ \text{MeV/c}$