1 amu = 931.50 MeV/c^2	Particle rest masses:	Electron	5.486 x 10^{-4} u
		Proton	1.007276 u
		Neutron	1.008665 u

1. Which of the following reactions is forbidden because it would involve the non-conservation of charge?

   (a) $p + p \rightarrow p + p + \pi^0$
   (b) $p + p \rightarrow p + p + \pi^+ + \pi^-$
   (c) $p + p \rightarrow p + p + \pi^+ + \pi^- + \pi^+$

2. Which of the following reactions is forbidden because baryon number is not conserved?

   (a) $p + p \rightarrow \pi^+ + p + n$
   (b) $p + p \rightarrow \pi^+ + p + n + n$
   (c) $p + p \rightarrow p + p + \pi^0 + \pi^0$

3. Why is the decay $\Lambda^0 \rightarrow p + \pi^- + \pi^0$ forbidden?

4. The strong interaction conserves quark flavour. Analyse each of the following strong interactions in terms of their constituent quarks and confirm that quark flavour is conserved.

   (a) $\pi^- + p \rightarrow \mathrm{K}^0 + \Lambda^0$
   (b) $\pi^+ + p \rightarrow \mathrm{K}^+ + \Sigma^+$

5. An electron-positron pair bound by their Coulomb attraction is called *positronium*. Show that when positronium decays from rest to two photons, the photons have equal energy. What is the wavelength of each photon?

   [2.42 x 10^{-12} m]

6. Find:
   (a) An *approximate* expression for the mass of a nucleus of mass number A.
   (b) An expression for the volume of the nucleus in terms of A.
   (c) An estimate of the nuclear density (in kg m^{-3}).

   [3 x 10^{17} kg m^{-3}]

7. The compressed core of a star formed in the wake of a supernova explosion can consist of pure nuclear material (neutrons) and is called a pulsar or neutron star. Use the result from 6(c) to calculate the mass of a sugar lump sized piece of neutron star.

8. ${}^{60}_{28}Ni$ has an atomic mass of 59.930789u.

   (a) What is its nuclear mass?
   (b) What is the binding energy per nucleon?

   [59.9154u; 8.78MeV]

9. Which of the pair of nuclei, ${}^{41}_{20}Ca$ and ${}^{41}_{19}K$ is unstable with respect to the other (atomic masses 40.962278u and 40.961825u)? What decay mode/modes are possible and how much energy is released in each allowed mode?

10. (a) Show that ${}^{8}_{4}Be$ can decay into two α particles with an energy release of 0.1 MeV, but that ${}^{12}_{6}C$ cannot decay into three α particles.

(b) Find the energy released in the following reaction (including the energy of the photon):

$$ {}^{2}_{1}H + {}^{4}_{2}He \rightarrow {}^{6}_{3}Li + \gamma \ . $$

Binding energies: ${}^{8}_{4}Be$ = 56.50MeV; ${}^{12}_{6}C$ = 92.16MeV; ${}^{2}_{1}H$ = 2.22MeV; ${}^{4}_{2}He$ = 28.30MeV and ${}^{6}_{3}Li$ = 31.99MeV.

[1.47MeV]

11. Two Th isotopes, ${}^{224}_{90}Th$ and ${}^{230}_{90}Th$, decay by emitting α particles with energies of 7.31 MeV and 4.77MeV respectively. For each isotope calculate the range r_c at which the α particle leaves the Coulomb potential barrier. Estimate the ratio of the half lives for these two isotopes.

(this last question is optional, but a good practice of what we saw in the lectures)