PHYS3002 - NUCLEI AND PARTICLES

Problem Sheet 3 - Due March 9, 2014

$$
\begin{aligned}
m_p &= 938.27\ \mathrm{MeV/c^2} \\
m_n &= 939.57\ \mathrm{MeV/c^2} \\
m_D &= 1875.61\ \mathrm{MeV/c^2} \\
m_{^4He} &= 3727.37\ \mathrm{MeV/c^2} \\
m_e &= 0.511\ \mathrm{MeV/c^2} \\
1\mathrm{Mev/c^2} &= 1.78 \times 10^{-30}\,\mathrm{kg} \\
1\mathrm{yr} &= 3.2 \times 10^7 \mathrm{secs.} \\
\text{Luminosity of the sun} &= 4 \times 10^{26}\,\mathrm{W} \\
\text{Distance of Earth to sun} &= 1.5 \times 10^{11}\,\mathrm{m}
\end{aligned}
$$

1. A de-excitation transition in a nucleus with mass M has energy E_0. Compute the shift from E_0 in the energy of the emitted photon (you may assume that $E_0 \ll Mc^2$). The nuclei can not re-absorb a photon of this energy - why? [3]

2. In the fusion reaction
$$ {}^1_1\mathrm{H} + {}^1_1\mathrm{H} \rightarrow {}^2_1\mathrm{H} + e^+ + \nu, $$
what is the maximum energy of the emitted neutrino. [2]

3. What are the dominant multipolarities of the following electromagnetic transitions (state whether they are electric or magnetic transitions)
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\begin{aligned}
\frac{1^+}{2} &\rightarrow \frac{1^+}{2} \\
\frac{7^-}{2} &\rightarrow \frac{1^+}{2} \\
\frac{7^+}{2} &\rightarrow \frac{3^-}{2} \\
\frac{3^+}{2} &\rightarrow \frac{1^-}{2} \\
\frac{3^+}{2} &\rightarrow \frac{1^+}{2} \\
\frac{5^+}{2} &\rightarrow \frac{1^+}{2}
\end{aligned}
\qquad [3]
$$

4. Assuming that the dominant source of energy of the sun is from the proton cycle, calculate the mass (in kg) of ${}^4_2\mathrm{He}$ produced in the sun per second. How many neutrinos are produced per second?
   Calculate the solar neutrino flux (no. of neutrinos per unit area per second) on Earth. [4]

5. Ordinary water contains two molecules of DHO for every 10,000 molecules of H_2O (D stands for a deuteron). What mass of water is required to supply a lifetime of energy for a single person (500 W for 80 years) from the fusion process

$$\mathrm{D} + \mathrm{D} \rightarrow {}^4_2\mathrm{He} \; ? \quad [4]$$

6. Using the Semi-empirical Mass Formula calculate how much energy is released when one gram of ${}^{235}_{92}\mathrm{U}$ undergoes the induced fission process

$$ {}^{235}_{92}\mathrm{U} + n \rightarrow {}^{148}_{57}\mathrm{La} + {}^{87}_{35}\mathrm{Br} + n.$$

   (neglect the energy of the incident neutron). [3]

7. There are no known bound states of two protons or of two neutrons, but deuterium has a binding energy of 2.2 MeV. What is the isospin of deuterium? What is the spin of a deuteron in its ground state (the proton and neutron are in the ${}^1s$ state)? [3]

8. What are the third components of isospin of the nuclides

$$ {}^6_2\mathrm{He}, \quad {}^6_3\mathrm{Li}, \quad {}^6_4\mathrm{Be} \; ? \quad [3]$$

Non-Assessed Questions

1. Explain why it is not usually possible for a nucleus to absorb a photon emitted when an identical nucleus makes a transition from a higher state to a lower state.
   Describe the Mössbauer effect and explain how it can be used to measure the widths of very narrow spectral lines.

2. Describe the process of nuclear fission. Explain why spontaneous fission, although energetically allowed, is very rare. For fission induced by neutron scattering explain why incident neutrons must have a kinetic energy of more than $\approx$ 1 MeV to induce fission in ${}^{238}_{92}\mathrm{U}$, whereas neutrons of any energy can induce fission in ${}^{235}_{92}\mathrm{U}$.

3. Explain the terms "proton cycle" and "carbon cycle" in the sun and explain why neutrinos are produced in solar activity.

4. What is meant by a chain reaction? Why does a chain reaction not occur in ${}^{238}_{92}\mathrm{U}$, but it can occur if the uranium ore is enriched with a higher concentration of ${}^{235}_{92}\mathrm{U}$.

5. What is meant by mirror nuclei? What can be deduced about the strong interactions from the fact that mirror nuclei have almost the same energy levels?

6. Explain what is meant by isospin. For nucleons what is the relation between the third component of isospin and the electric charge of the nucleon.