PH20016 – Particles, Stars and Nuclei **Mock test**

Name:

24 November 2022

Tutor:

Mark: /18

<u>This test is a mock test:</u> it is informal and does not contribute to the unit mark at all. The aims of this test are to show you what typical examination questions look like, to indicate how these questions may be assessed, and to identify any areas that should be more particularly targeted in your revisions.

1. For each of the following reactions, check whether it violates any conservation law (and state which one(s) are violated):

(a) $p + p \rightarrow p + p + \pi^0$

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

(c) $p \rightarrow e^+ + \gamma$

[3 marks]

2. The lowest few energy levels in the shell model are:

$1s_{1/2}$ $1p_{3/2}$ $1p_{1/2}$ $1d_{5/2}$ $2s_{1/2}$ $1d_{3/2}$

Predict the spins of the following nuclei: ${}^{4}_{2}He$ ${}^{9}_{4}Be$ ${}^{9}_{4}Be^{*}$ (show all reasoning)

[3 marks]

3. An atom of ${}^{238}_{92}U$ passing through matter interacts mainly with the neutrons in the nuclei, and has a total cross-section of 1.45 barns. Assuming that half of the mass of a typical piece of matter is due to neutrons and that all of the neutrons in a nucleus act independently, work out the probability that the uranium atom will interact as it passes through your finger.

Mean human density: 325.58 kg/m^3

Mean diameter of a human finger: 1 cm

[6 marks]

4. Light stellar nucleosynthesis can use carbon present in stars as a catalyst, through the CNO chain:

$$p + {}^{12}_{6}C \rightarrow {}^{13}_{7}N + \gamma \qquad (1)$$

$${}^{13}_{7}N \rightarrow {}^{13}_{6}C + e^{+} + \nu_e \qquad (2)$$

$$p + {}^{13}_{6}C \rightarrow {}^{14}_{7}N + \gamma \qquad (3)$$

$$p + {}^{14}_{7}N \rightarrow {}^{15}_{8}O + \gamma \qquad (4)$$

$${}^{15}_{8}O \rightarrow {}^{15}_{7}N + e^{+} + \nu_e \qquad (5)$$

$$p + {}^{15}_{7}N \rightarrow {}^{12}_{6}C + {}^{4}_{2}He \qquad (6)$$

Binding energies:

B($^{4}_{2}He$) = 28.3 MeV B($^{12}_{6}C$) = 92.2 MeV B($^{13}_{6}C$) = 97.1 MeV

B($^{13}_{7}N$) = 94.1 MeV B($^{14}_{7}N$) = 104.7 MeV B($^{15}_{7}N$) = 115.5 MeV

B($^{15}_{8}O$) = 112.0 MeV

The two decays (2) and (5), taken together, release a total energy of 2.9 MeV. Assuming that positrons annihilate with electrons in the stellar plasma, calculate the energy released in the other reactions of the CNO chain and hence the overall energy released by this chain. **[6 marks]**