

END OF TERM TEST

6 DECEMBER 2019

TIME AVAILABLE: 1 HOUR 30 MINUTES

Answer the questions in the spaces provided on these question sheets. If you run out of room for an answer, continue on the back of the page or at the end of the book.

Only non-programmable calculators may be used during this test.

This test has 13 pages of questions.

There are 60 marks available. FULL MARKS 50 = 100%

Name: _____

Student number: _____

Signature: _____

Do not write below this line

Question	Points	Score
1	5	
2	5	
3	5	
4	5	
5	5	
6	5	
7	5	
8	5	
9	5	
10	5	
11	5	
12	5	
Total:	60	

USEFUL INFORMATION

The radius of a nuclei may be approximated by $R \approx 1.2A^{1/3}$ fm.

The semi-empirical mass formula (SEMF) for the binding energy of a nucleon is

$$B(Z, A) = a_V A - a_S A^{2/3} - a_C \frac{Z(Z-1)}{A^{1/3}} - a_A \frac{(A-2Z)^2}{A} + \delta(Z, A).$$

Constants in the SEMF: $a_V = 15.56$, $a_S = 17.23$, $a_C = 0.697$, $a_A = 23.28$, $a_P = 12.0$ where each number is in MeV.

Nuclear Shells: Protons

$$1s_{\frac{1}{2}} \downarrow_2 \quad 1p_{\frac{3}{2}} \mid 1p_{\frac{1}{2}} \downarrow_8 \quad 1d_{\frac{5}{2}} \mid 2s_{\frac{1}{2}} \mid 1d_{\frac{3}{2}} \downarrow_{20} \quad 1f_{\frac{7}{2}} \downarrow_{28} \quad 2p_{\frac{3}{2}} \mid 1f_{\frac{5}{2}} \mid 2p_{\frac{1}{2}} \mid 1g_{\frac{9}{2}} \downarrow_{50} \quad 1g_{\frac{7}{2}} \mid 2d_{\frac{5}{2}} \mid 1h_{\frac{11}{2}} \mid 2d_{\frac{3}{2}} \mid 3s_{\frac{1}{2}} \downarrow_{82} \quad 1h_{\frac{9}{2}} \mid 2f_{\frac{7}{2}}$$

Shells: Neutrons

$$1s_{\frac{1}{2}} \downarrow_2 \quad 1p_{\frac{3}{2}} \mid 1p_{\frac{1}{2}} \downarrow_8 \quad 1d_{\frac{5}{2}} \mid 2s_{\frac{1}{2}} \mid 1d_{\frac{3}{2}} \downarrow_{20} \quad 1f_{\frac{7}{2}} \downarrow_{28} \quad 2p_{\frac{3}{2}} \mid 1f_{\frac{5}{2}} \mid 2p_{\frac{1}{2}} \mid 1g_{\frac{9}{2}} \downarrow_{50} \quad 2d_{\frac{5}{2}} \mid 1g_{\frac{7}{2}} \mid 1h_{\frac{11}{2}} \mid 2d_{\frac{3}{2}} \mid 3s_{\frac{1}{2}} \downarrow_{82} \quad 2f_{\frac{7}{2}} \mid 1h_{\frac{9}{2}}$$

$\frac{e^2}{4\pi\epsilon_0}$	= 1.439965 MeV fm
Boltzmann's constant	$k_B = 8.6173303 \times 10^{-5}$ eV/K
Planck's constant	$h = 4.135668 \times 10^{-15}$ eV s
Speed of light	$c = 2.99792 \times 10^8$ m/s
Neutron mean lifetime	881 s
Atomic mass unit	$1 u = 931.4940954 \text{ MeV}/c^2 = 1.66054 \times 10^{-27}$ kg
Mass of electron	$m_e = 5.4858 \times 10^{-4} u = 0.51099895 \text{ MeV}/c^2$
Mass of proton	$m_p = 1.00727646688 u = 938.27208 \text{ MeV}/c^2$
Mass of neutron	$m_n = 1.00866491578 u = 939.56541 \text{ MeV}/c^2$
Mass of ${}^1_1\text{H}$	= 1.00782503 u
Mass of ${}^2_1\text{H}$	= 2.01410178 u
Mass of ${}^3_1\text{H}$	= 3.01604927 u
Mass of ${}^3_2\text{He}$	= 3.01602932 u
Mass of ${}^4_2\text{He}$	= 4.00260325 u
Mass of ${}^{232}_{90}\text{Th}$	= 232.038055 u
Mass of ${}^{234}_{90}\text{Th}$	= 234.043601 u
Mass of ${}^{235}_{92}\text{U}$	= 235.043930 u
Mass of ${}^{236}_{92}\text{U}$	= 236.045568 u
Mass of ${}^{238}_{92}\text{U}$	= 238.050788 u
Mass of ${}^{239}_{92}\text{U}$	= 239.054293 u
Mass of ${}^{240}_{94}\text{Pu}$	= 240.053811 u
Mass of ${}^{241}_{94}\text{Pu}$	= 241.056849 u
Mass of ${}^{242}_{94}\text{Pu}$	= 242.058741 u
Mass of the Sun	$M_{\odot} = 1.988 \times 10^{30}$ kg
Gravitational constant	$G = 6.67408 \times 10^{-11} \text{ m}^3 \text{ kg}^{-1} \text{ s}^{-2}$

Nuclei masses given are atomic masses.

1. Charged particles are scattered off a heavy nucleus. Sketch a typical differential cross-section that would be observed, as a function of scattering angle. How does this compare to a cross-section that would be found by modelling the nucleus as

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a) a point particle, and

b) a hard sphere?

Sketch a realistic density profile for a nucleus.

2. Sketch a table of nuclides. Give the approximate positions of isotopes of Helium, Oxygen, and Thorium. In which regions are nuclei stable and unstable in this picture?

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EXTRA SPACE FOR ANSWERS

3. Sketch the nuclear potential for a neutron and a proton. Describe the key features of your plot. 5

4. Consider the semi-empirical mass formula (given on page 1). Discuss the form of the asymmetry term. 5

EXTRA SPACE FOR ANSWERS

5. Consider an isobar $A = \text{const.}$ in the semi-empirical mass formula. Show there is a maximum binding energy when (ignore the pairing term and assume $Z(Z - 1) \approx Z^2$) 5

$$Z \approx \frac{A}{2} \frac{1}{1 + \frac{1}{4} \frac{a_C}{a_A} A^{2/3}}.$$

Does this show that heavy nuclei have more protons or more neutrons?

6. With the aid of a diagram, describe how to find the ground state of ${}^{29}_{14}\text{Si}$. 5

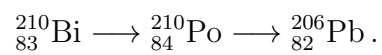
EXTRA SPACE FOR ANSWERS

7. What are the nuclear magic numbers? Discuss 3 pieces of evidence for them.

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8. Give the radioactive decay law for N nuclei with decay constant λ . An example of a decay chain is

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What type of decay does each arrow correspond to?

EXTRA SPACE FOR ANSWERS

9. For a nucleus (Z, A) give the reactions for the 3 types of possible β -decay. Discuss with the aid of a diagram how β -decay leads to the valley of stability in the table of nuclides.

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10. Given that the activation energy of ${}^{236}_{92}\text{U}$ is 6.2 MeV, what is the minimum energy α -particle which can induce fission when hitting a ${}^{232}_{90}\text{Th}$ target? Without knowing the mass, explain whether you expect this to be easier or harder to induce fission in ${}^{235}_{92}\text{U}$?

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EXTRA SPACE FOR ANSWERS

11. Consider a hot gas of nuclei at temperature T . One might expect that for fusion to be possible we need $T \sim V_C/k_B$, where V_C is the Coulomb barrier between the nuclei, and k_B is Boltzmann's constant. Give 2 reasons why fusion is possible in gases of much lower temperature. Illustrate your answer with a graph showing how the interplay of these two affects the reaction rate. 5

12. Give an account of the timeline involved in the production of Helium during Big Bang Nucleosynthesis. Helium production starts at $t \approx 300$ s when the neutron fraction is $1/6$. Hence show that the mass fraction of ${}^4\text{He}$ to Hydrogen is about $1/4$. 5