Module 8: From the Universe to the Atom

8.4 Properties of the Nucleus

Note:
- Some past HSC questions in Section 8.4 of Module 8, incorrectly referred to 'mass defect' instead of 'mass loss' in questions about nuclear reactions. This has been corrected in adapting any questions for use in this book.
- Any past HSC questions that used the older symbol '*amu*' for the atomic mass unit have had this replaced by the current symbol '*u*' (as per IUPAC).
- The current Physics Syllabus now refers to kinetic energy as *K* instead of E_k or *KE*, so this has been changed where possible in questions using kinetic energy.

Multiple-choice questions: 1 mark each

1. What is an isotope?

(A) Atoms of the same element having the same number of protons, but with different numbers of neutrons.

(B) Elements that have the same chemical and physical properties and so have the same mass number.

(C) Different elements with the same atomic number, but different mass numbers and different chemical and physical properties.

(D) An atom with an unstable nucleus due to the nucleons within it.

2. What is a radioisotope?

(A) An artificially produced element that releases radiation as it decays.

(B) An unstable isotope that emits radiation as it decays to form a more stable isotope.

(C) A type of element that is produced during nuclear decays or transmutations.

(D) The product of a nuclear fusion process as it releases heat energy.

3. What does the term 'mass loss' refer to with respect to nuclear reactions?

(A) The total mass of the products plus the total mass of the reactants.

(B) The difference between the total mass of the products and the total mass of the reactants.

(C) The difference between the mass of a nucleus and the sum of the masses of the separate nucleons of which it is composed.

(D) The mass defect for a nuclear reaction.

4. What is the 'mass defect' for a nuclide?

(A) The difference between the total mass of the products and the total mass of the reactants in a nuclear fission reaction.

(B) The difference between the mass loss in a fission reaction compared to the mass loss in a fusion reaction.

(C) The difference between the mass of an atom and the sum of masses of the nucleons of which its nucleus is composed, plus all of its electrons.

(D) The difference between the mass of a metal atom and the mass of its nucleus.

5. What is the binding energy of a nucleus?

(A) The energy required to assemble protons and neutrons into a nucleus during a fusion reaction.

(B) The amount of energy required to remove the electrons from around an atomic nucleus.

(C) The energy required to assemble the protons and neutrons into nucleons.

(D) The amount of energy required to split a nucleus into its individual protons and neutrons.

6. How does the binding energy per nucleon relate to the stability of a nucleus?

(A) The greater the binding energy per nucleon, the less energy released by the formation of the nucleus.

(B) The greater the binding energy per nucleon, the greater the stability of the nucleus.

(C) The lower the binding energy per nucleon, the greater the stability of the nucleus.

(D) The greater the binding energy per nucleon, the lower the stability of the nucleus.

7. How does the amount of energy released per nucleon in a single fission reaction compare to the amount of energy released per nucleon in a single fusion reaction?

(A) This energy cannot be compared.

(B) No difference in the amount of energy.

(C) Less energy would be released.

(D) More energy would be released.

8. W... atoms in a nuclear reaction, such as fission or fusion, lose mass?

(A) Due to the conservation of energy, the mass loss appears as energy, where $E = mc^2$.

(B) Due to the law of conservation of energy, the mass loss is converted into binding energy.

(C) The nucleus separates into the individual protons and neutrons.

(D) The energy that is released can only be measured in electronvolts (eV).

9. Carbon-12 is an isotope of carbon with a mass number of 12.
What is the *mass number* of an isotope?

(A) The number of electrons orbiting the nucleus of at atom.

(B) The number of protons plus the number of neutrons in an atom.

(C) The number of protons plus the number of electrons in an atom.

(D) The number of protons, neutrons and electrons in an atom.

10. How many neutrons are there in the isotope $^{56}_{26}Fe$?

(A) 82 neutrons

(B) 26 neutrons

(C) 56 neutrons

(D) 30 neutrons

11. What happens in a fission reaction?

(A) Strong nuclear forces overcome the attractive electrostatic forces between the protons.

(B) A nucleus absorbs a large amount of energy so that it becomes more stable.

(C) A nucleus splits into smaller, more stable fission fragments.

(D) A nucleus splits into larger, more stable fission fragments.

12. What occurs in radioactive decay?

(A) The unstable atoms of an element are changed into more stable atoms of a completely different element.

(B) A more stable nucleus is formed by alpha (α) particles being emitted.

(C) A more stable nucleus is formed by beta (β) particles being emitted.

(D) The stable atoms of an element are changed into less stable atoms and gamma rays (γ) are released.

13. What is the half-life ($t_{\frac{1}{2}}$) of a radioisotope?

(A) Half the period of time that it takes an unstable nucleus to decay.

(B) The decay period for half the nucleons in an isotope.

(C) The time it takes for half of its atoms to undergo radioactive decay.

(D) Half the time needed for all the atoms to decay.

14. Carbon-14 can be used to determine the age of the remains or fossils of living organism. The half-life ($t_{\frac{1}{2}}$) of ^{14}C is 5730 years.

How long will it take for only 12.5% of the original carbon-14 to be found in a fossil?

(A) 22.290 years

(B) 2865 years

(C) 11,460 years

(D) 17,190 years

15. Oxygen-15 has a very short half-life of 122.2 seconds.

What fraction of a sample of ^{15}O will remain after 4 half-lives?

(A) $\frac{1}{32}$

(B) $\frac{1}{16}$

(C) $\frac{1}{8}$

(D) $\frac{1}{4}$

16. What is the purpose of control rods in a nuclear reactor?

(A) To absorb neutrons to ensure the chain reaction is controlled.

(B) To keep the fuel rods separated from one another during the chain reaction.

(C) To slow high energy neutrons down to the lower energies needed for the reaction.

(D) To initiate the fission chain reaction and keep it going.

17. What happens in a fusion reaction?

(A) The electrostatic forces between the protons overcome the strong nuclear force.

(B) Two larger nuclei are combined to form a smaller nucleus.

(C) Two smaller nuclei are combined to form a larger nucleus.

(D) A nucleus splits into larger, less stable fusion fragments.

Short-answer questions

18. Complete the table below to identify each of subatomic particles that are being described in (a), (b) and (c).

	Name of sub-atomic particle	*Where found in an atom*	*Electrical charge*	*Mass*
(a)	....	Nucleus	Positive	About the same as a neutron
(b)	....	Nucleus	No charge (neutral)	About the same as a proton
(c)	....	In a cloud surrounding the nucleus	Negative	$\frac{1}{2000}$ the mass of a proton

... 3 marks

19. Complete the table below to identify each type of radiation that are being described in (a), (b) and (c) and indicate whether its ionising ability is high, medium or low.

	Type of radiation	*Nature of radiation*	*Charge*	*Deflection in a magnetic field*	*Penetrating power*	*Ionising ability*
(a)	....	helium nucleus	+2	small	low	....
(b)	....	electron	–1 or +1	large	medium	....
(c)	....	high energy photon	0	none	high	....

... 6 marks

20. Distinguish between the processes of nuclear fission and transmutation.

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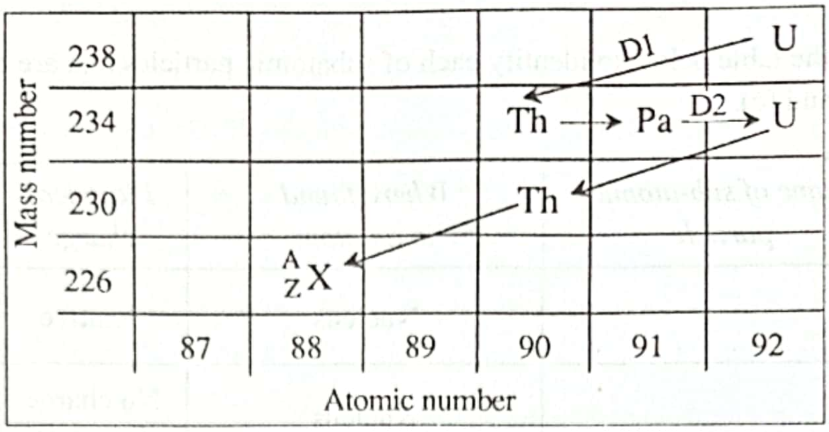
2017 HSC Q34(b)(i) ... 2 marks

21. The chart below shows part of a series of nuclear decays that occur naturally in uranium.



(a) Write nuclear equation that account for the alpha decay in D1 and the beta decay in D2. The equations should be balanced in terms of nucleons and should show all charged articles produced in the decays.

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(b) State the chemical symbol of element X and the values of A and Z in $^{A}_{Z}X$.

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Adapted from 1991 HSC Q Elective 7 (b) ... 2 + 2 = 4 marks

22. Explain the difference between an uncontrolled fission reaction and a controlled fission reaction.

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... 3 marks

23. The grid below shows the mass numbers and atomic numbers of some radioactive elements.

Mass Number						
234						
230						
226						
222						
218			X			
214	Y	Z				
210						
206						
Atomic Number	81	82	83	84	85	86

(a) Use the information on the grid to write the balanced equation that occurs when element X undergoes spontaneous decay to form Y.

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(b) Identify the particle that would be emitted in the transformation of element Y to element Z. Explain why.

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1985 HSC Q Elective 7 (b) ... 2 + 2 = 4 marks

24. (a) In a nuclear fission reaction, a nucleus of $^{235}_{92}U$ absorbs a neutron and then splits to release $^{95}_{38}Sr$ and two neutrons.

What other nucleus must be formed in this fission?

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(b) The mass difference between the reactants and products in a typical U-235 fission reaction is 0.2234 *u* per fissioned nucleus.

Calculate the energy in joules released per fission.

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1988 HSC Q Elective 7 (e)(iii) & adapted (e)(iv) ... 2 + 2 = 4 marks

25. A sample of nitrogen-14 is bombarded with α particles. The consequent transmutation can be described by the incomplete nuclear equation below.

$$^{14}_{7}\mathrm{N} + ^{4}_{2}\mathrm{He} \rightarrow ^{1}_{1}\mathrm{H} + X$$

(a) What is the atomic number of X?

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(b) What is the mass number of X?

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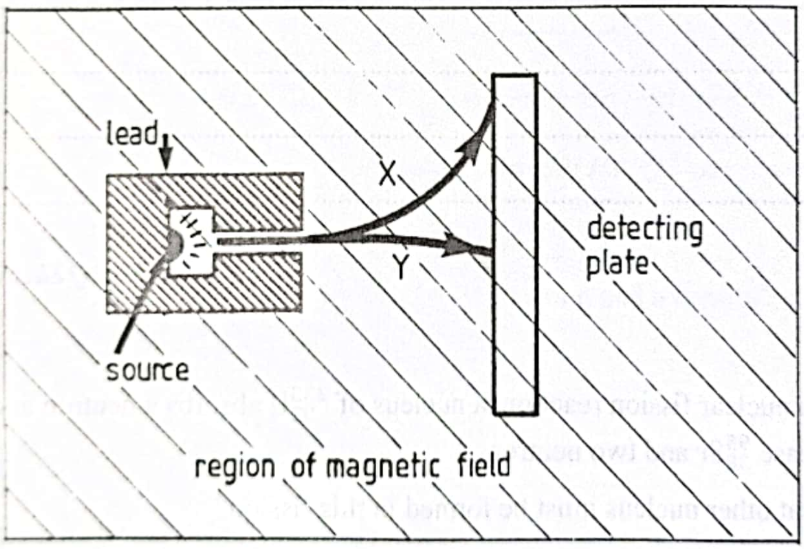
(c) Identify the isotope X. ....

Adapted 1984 HSC Q Elective 7 (g) with a new Q for part (c)... 1 + 1 + 1 = 3 marks

26. A radioactive source emits α and β particles into a region of uniform magnetic field.



The schematic diagram above shows the trajectories of α and β particles emitted with the same velocity from the source.

Which path, X or Y, better represents the trajectory of the β particles? Give reasons for your answer.

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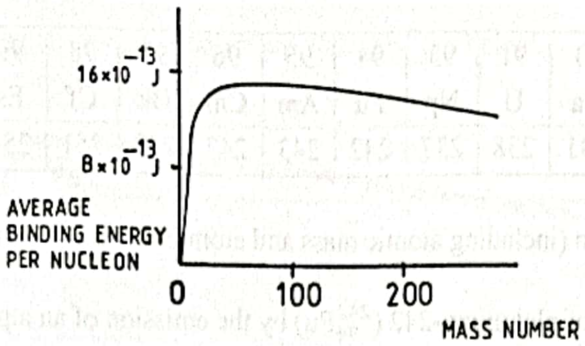
1985 HSC Q Elective 7 (a) ... 2 marks

27. The graph below shows how the average binding energy per nucleon varies with mass number.



Use the graph above to answer these questions.

(a) Why is a nucleus with a mass number of 200 not as stable as a nucleus with a mass number of 50?

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(b) Why is spontaneous fission a possibility for a nucleus of mass number 200, but not for a nucleus of mass number 20?

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Adapted 1983 HSC Q Elective 7 (e) ... 1 + 2 = 3 marks

28. What are two difficulties that must be overcome in order to achieve a sustained fusion reaction on Earth? Explain why.

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1990 HSC Q Elective 7 (d) ... 2 marks

29. This question refers to the section of the Periodic Table below, showing the transuranium elements.

89	90	91	91	93	94	95	96	97	98	99	100	101	102	103
Ac	Th	Pa	U	Np	Pu	Am	Cm	Bk	Cf	Es	Fm	Md	No	Lr
227	232	231	238	237	242	243	247	249	251	254	253	256	254	257

Write an equation (including atomic mass and atomic numbers) for the following reactions:

(a) the decay of plutonium-242 ($^{242}_{94}Pu$) by the emission of an alpha particle.

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(b) the decay of uranium-238 ($^{238}_{92}U$) by the emission of a beta particle.

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1987 HSC Q Elective 7 (d) ... 2 + 2 = 4 marks

30. The first atomic bomb was a simple uranium-235 fission device. One mode of fission for uranium-235 is given below.

$$^{235}_{92}U + ^{1}_{0}n \rightarrow ^{139}_{54}Xe + ^{94}_{38}Sr + 3\,^{1}_{0}n$$

Calculate the mass loss and the energy released per 235U atom, given the following nuclear masses and other data:

$^{235}_{92}U$ = 234.9934 u $\qquad$ $^{139}_{54}Xe$ = 138.8883 u

$^{94}_{38}Sr$ = 93.8945 u $\qquad$ $^{1}_{0}n$ = 1.00867 u

$1\,u = 1.66 \times 10^{-27}$ kg $\qquad$ $c = 3.00 \times 10^{8}$ m s^{-1}

u = atomic mass unit

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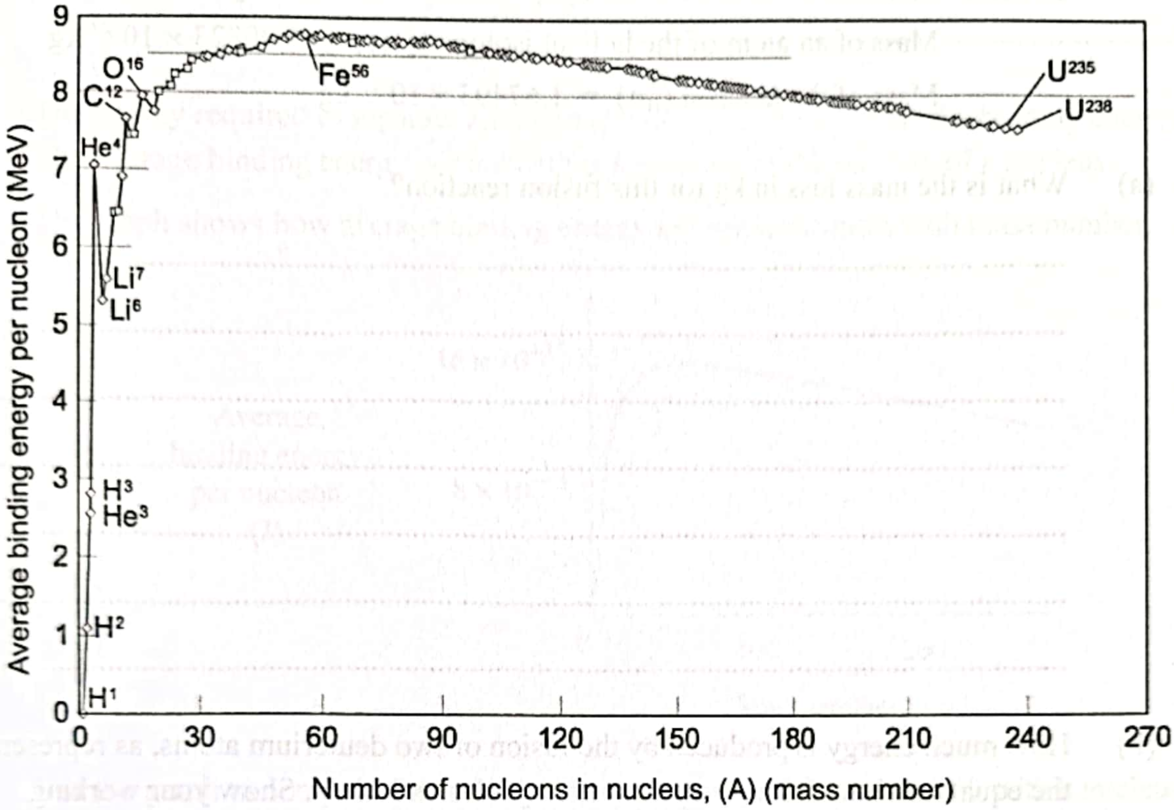
2004 HSC Q31(b)(ii) ... 4 marks

31. This graph shows the nuclear binding energy (in MeV) per nucleon as a function of the number of nucleons in the nucleus.

Use this nuclear binding energy curve to answer the questions below.



(a) Determine the total nuclear binding energy for $^{16}_{8}O$ in MeV.

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(b) The isotope iron-56 has the greatest binding energy per nucleon.

Comment on the stability of iron-56 and compare this to the elements to its left and right on the above graph.

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Adapted 1989 HSC Elective 7 (e) for (a) & using a new graph, plus a new Q for part (b) ... 2 + 2 = 4 marks

32. When two deuterium atoms (^2_1H) undergo fusion, the following reaction occurs:

$$^2_1H + ^2_1H \rightarrow ^3_2He + ^1_0n$$

DATA: Mass of a deuterium atom (^2_1H) = 3.34449×10^{-27} kg
Mass of an atom of the helium isotope (^3_2He) = 5.00823×10^{-27} kg
Mass of the neutron (^1_0n) = 1.67493×10^{-27} kg

(a) What is the mass loss in kg for this fusion reaction?

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(b) How much energy is produced by the fusion of two deuterium atoms, as represented in the equation above? Give your answer in joules and MeV. Show your working.

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New Q for (a) ... 3 marks
Adapted 1983 HSC Q Elective 7 (f) for (b) ... 3 marks

33. Radium-226 decays by alpha emission. The mass of a radium nucleus is 226.0254 *u* and the total mass of the decay products, radon and helium, is 226.0202 *u*.

(a) Calculate the quantity of energy, in MeV per decay, involved in the reaction.

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(b) Is this reaction endothermic or exothermic? ....

Adapted 1989 HSC Q Elective 7 (d) ... 3 + 1 = 4 marks

34. (a) Define *mass defect.*

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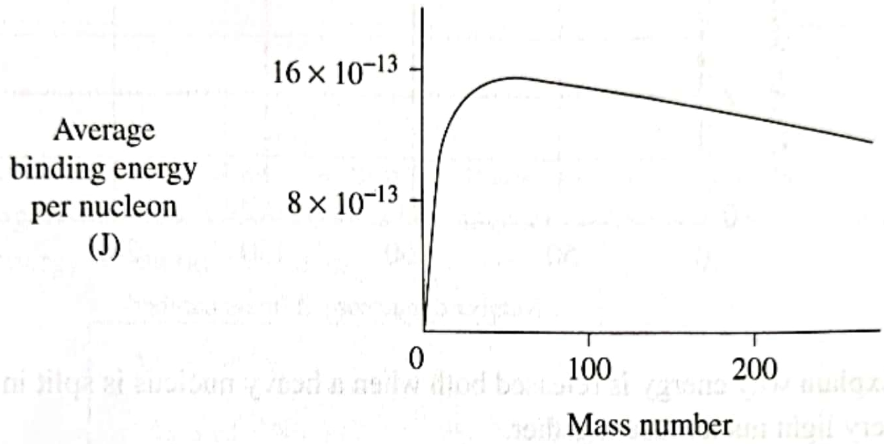
(b) The energy required to separate all the nucleons within a nucleus is the binding energy. The average binding energy per nucleon is a measure of the stability of a nucleus.

The graph shows how average binding energy per nucleon varies with mass number.



Use the graph to compare the stability of a nucleus of mass number 200 with a nucleus of mass number 50.

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2009 HSC Q31(c) ... 1 + 2 = 3 marks

35. Account for difference between stable isotopes and unstable isotopes, referring to the forces that act within the atomic nucleus.

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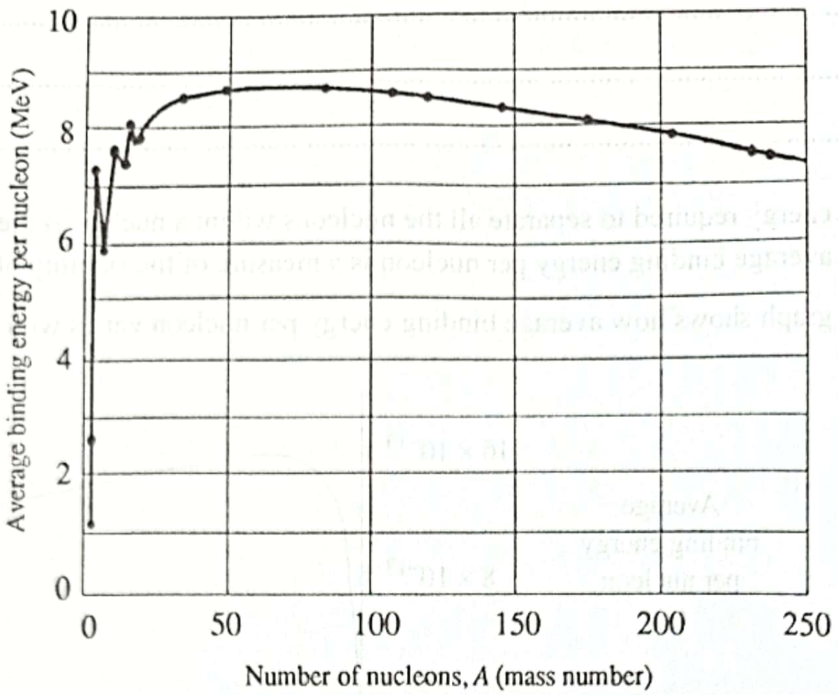
36. Use the information in the graph below to answer the questions.



(a) Explain why energy is released both when a heavy nucleus is split in two and when two very light nuclei fuse together.

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(b) Explain why the fusion of two deuterium ($^{2}_{1}H$) releases much more energy per nucleon than does the fission of uranium ($^{235}_{92}U$).

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Adapted 1991 HSC Q Elective 7 (d) ... 2 + 2 = 4 marks

37. In a particle accelerator, 84 MeV $^{12}_{6}C$ nuclei are directed to bombard a target containing $^{120}_{50}Sn$ nuclei.

(a) State the number of protons and neutrons in a $^{120}_{50}Sn$ nucleus.

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(b) It is observed that $^{14}_{7}N$ nuclei are produced in this bombardment. Assuming that there is only one other type of product, identify this product.

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(c) The kinetic energy (K) of an emerging $^{14}_{7}N$ nucleus is measured to be 49 MeV. Assuming that neither of the products had internal excitation energy, calculate the kinetic energy of the other nucleus.

Mass of ^{12}C	$= 12.00000\ u$
Mass of ^{14}N	$= 14.00307\ u$
Mass of ^{120}Sn	$= 119.90220\ u$
Mass of other product	$= 117.90612\ u$

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Adapted 1991 HSC Q Elective 7 (c) ... 2 + 2 + 4 = 8 marks

38. $${}^{235}_{92}\text{U} + {}^{1}_{0}\text{n} \rightarrow {}^{140}_{56}\text{Ba} + {}^{92}_{36}\text{Kr} + 4\,{}^{1}_{0}\text{n}$$

Explain why energy is released in this reaction.

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2011 HSC Q34(b)(ii) ... 2 marks

39. Uranium-238 undergoes a spontaneous transmutation naturally. As uranium-238 decays (${}^{238}_{92}\text{U}$), it emits an alpha particle, thorium-234 (${}^{234}_{90}\text{Th}$) and energy.

Mass of ${}^{238}_{92}\text{U}$	=	238.05079 u
Mass of ${}^{234}_{90}\text{Th}$	=	234.04360123 u
Mass of ${}^{4}_{2}\text{He}$	=	4.00260 u

(a) Write the full equation for this decay reaction.

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(b) What is the mass loss for this reaction?

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(c) What is the energy released by this reaction?

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(d) Is the binding energy of the products greater or less than the reactant? ....

Explain why...

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... 1 + 2 + 2 + 2 = 7 marks

40. A sample of a pure radioactive compound showed a certain level of radioactivity. After several months, the level of radioactivity has increased.

Explain why this occurred.

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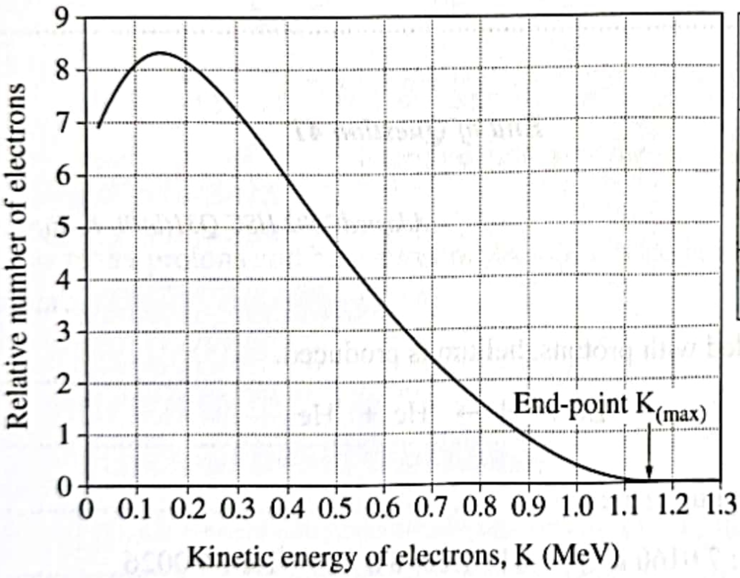
1984 HSC Q Elective 7 (a) ... 2 marks

41. The diagram shows the kinetic energy distribution of the electrons emitted in the spontaneous β-decay of $^{210}_{83}Bi$ into $^{210}_{84}Po$. The energy released during β-decay depends on the mass defect in the transmutation, as it does in nuclear fission.



Nucleus or particle	*Mass* (u)
^{210}Bi	209.938 57
^{210}Po	209.936 78
e	0.000 55

(a) Use the data to calculate the mass loss in the β-decay of $^{210}_{83}Bi$. (Assume that the anti-neutrino released is a massless particle.)

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Question 41 continues

Question 41 (continued)

(b) Account for the energy distribution of electrons emitted in this β-decay.

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End of Question 41

Adapted 2002 HSC Q31(b)(ii) & (iii) ... 3 + 4 = 7 marks

42. When lithium is bombarded with protons, helium is produced.

$$^{7}\text{Li} + {}^{1}\text{H} \rightarrow {}^{4}\text{He} + {}^{4}\text{He}$$

The masses of the various nuclei are:

^{7}Li : 7.0160 *u* ^{1}H : 1.0078 *u* ^{4}He : 4.0026

How much, if any, energy is released by this reaction? Show your working and give your answer in both joules and MeV.

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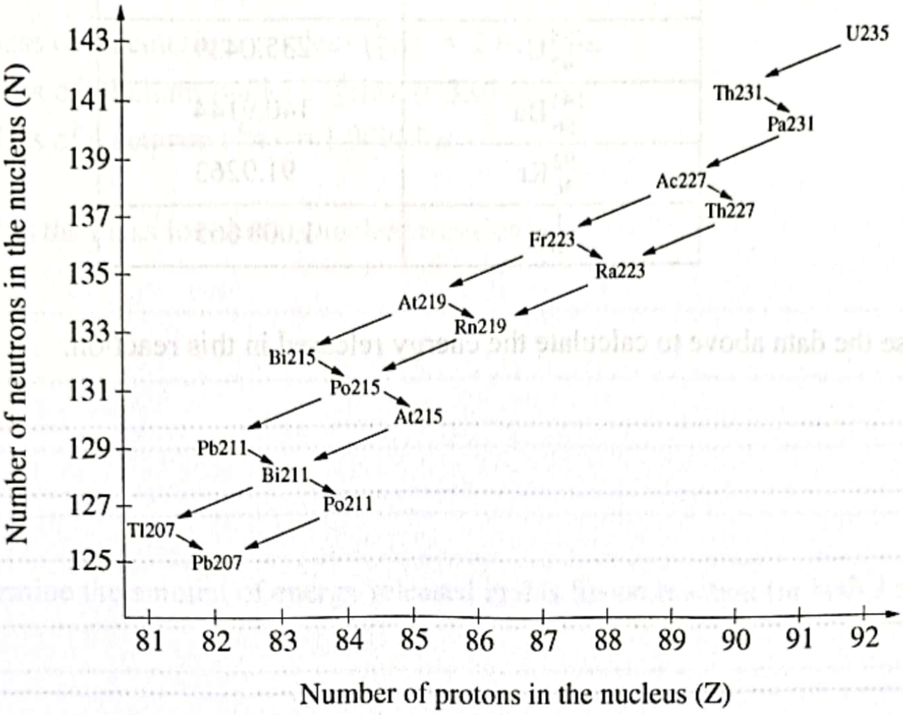
1982 HSC Q Elective 7 (c) ... 4 marks

43. Nuclear transmutations caused by natural radioactivity can be represented in diagrams such as the one shown. Each symbol represents a radioactive element and each arrow represents a transmutation.



(a) How many protons and how many neutrons are there in the nucleus of a Thorium-227 atom?

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(b) Write the equation for the α-decay of Francium-223.

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2008 HSC Q31(b) ... 1 + 2 = 3 marks

44. This equation describes a nuclear reaction:

$$^{235}_{92}U + ^{1}_{0}n \rightarrow ^{141}_{56}Ba + ^{92}_{36}Kr + 3^{1}_{0}n$$

Particle	Mass (u)
$^{235}_{92}U$	235.0439
$^{141}_{56}Ba$	140.9144
$^{92}_{36}Kr$	91.9263
$^{1}_{0}n$	1.008 665

(a) Use the data above to calculate the energy released in this reaction.

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(b) Apply Einstein's idea of the equivalence of mass and energy to explain the production of energy in the reaction above.

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2013 HSC Q35(b) ... 3 + 2 = 5 marks

45. The fusion of two nuclei of deuterium (^2_1H) to give one nucleus of helium (^3_2He) may one day be used in nuclear power generation. The equation for this reaction is:

$$^2_1H + ^2_1H \rightarrow ^3_2He + ^1_0n$$

DATA: Mass of a deuterium nucleus (^2_1H) = 2.01355 u
Mass of a helium nucleus (^3_2He) = 3.01492 u
Mass of a neutron (^1_0n) = 1.00967 u

(a) What is the mass loss in this nuclear reaction?

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(b) Determine the amount of energy released in this fusion reaction (in both J and MeV).

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Adapted 1996 HSC Q 35 (d)(i) ... 2 + 2 = 4 marks

46. The CNO cycle is a major source of energy in Main Sequence stars.
The following equation is part of the CNO cycle.

$$^{12}_6C + ^1_1H \rightarrow ^{13}_7N + \gamma$$

Determine, in MeV, the amount of energy released in this reaction, given that:

- mass of $^{12}_6C$ is 11.9967 u
- mass of ^1_1H is 1.0072 u
- mass of $^{13}_7N$ is 13.0019 u

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47. (a) Technetium-99m is used as a radioactive tracer in m[illegible] ... remain in the body or environment for long. This isotope has a very short half-life of 6 hours.

What is the decay constant for a sample of technetium-99m?

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(b) Sodium-24 has a half-life of 14.96 hours. If there are 800 g of ^{24}Na initially, how long will it take for 750 g of ^{24}Na to decay?

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(c) A sample of the radioisotope iodine-131 takes 56 days for a 192 mg sample of ^{131}I to decay to a final amount of 1.5 mg.

What is the half-life of ^{131}I?

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... 2 + 3 + 3 = 8 marks

47. (a) Technetium-99m is used as a radioactive tracer in nuclear medicine as it does not remain in the body or environment for long. This isotope has a very short half-life of 6 hours.

What is the decay constant for a sample of technetium-99m?

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(b) Sodium-24 has a half-life of 14.96 hours. If there are 800 g of ^{24}Na initially, how long will it take for 750 g of ^{24}Na to decay?

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(c) A sample of the radioisotope iodine-131 takes 56 days for a 192 mg sample of ^{131}I to decay to a final amount of 1.5 mg.

What is the half-life of ^{131}I?

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... 2 + 3 + 3 = 8 marks

48. (a) An atom of carbon-12 has 6 protons and 6 neutrons in its nucleus. The mass of a carbon-12 atom is 12.000 atomic mass unit. Show that the mass defect of one carbon-12 atom is 0.097 atomic mass unit.

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(b) How much energy is this mass defect equivalent to?

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2008 HSC Q31(c)(i) & (ii) ... 3 + 1 = 4 marks

49. The following is a nuclear reaction that produces a neutron.

$$^{4}_{2}\alpha + ^{9}_{4}\text{Be} \rightarrow ^{12}_{6}\text{C} + ^{1}_{0}\text{n}$$

The table shows the masses of the particles in the reaction.

Particle	*Mass (u)*
$^{4}_{2}\alpha$	4.0012
$^{9}_{4}\text{Be}$	9.0122
$^{12}_{6}\text{C}$	12.0000
$^{1}_{0}\text{n}$	1.0087

Using the data from the table, calculate the energy (in J) released in this reaction.

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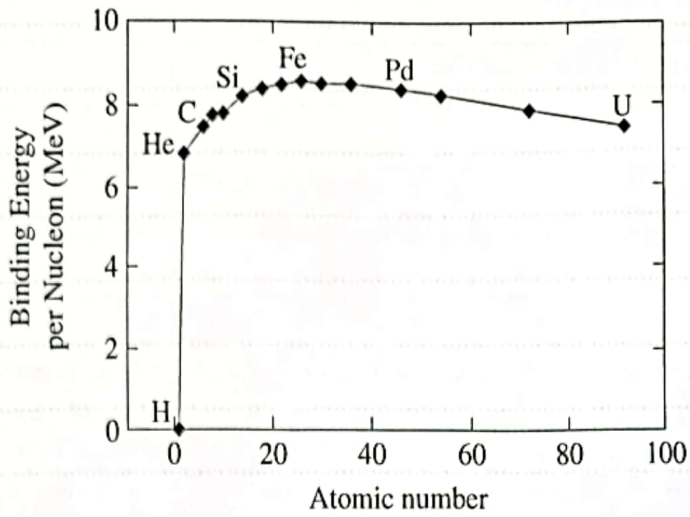
Adapted 2018 HSC Q34(b)(ii) ... 3 marks

50. The graph shows the binding energy per nucleon.

Using this diagram, explain how energy may be released in a nuclear reaction.



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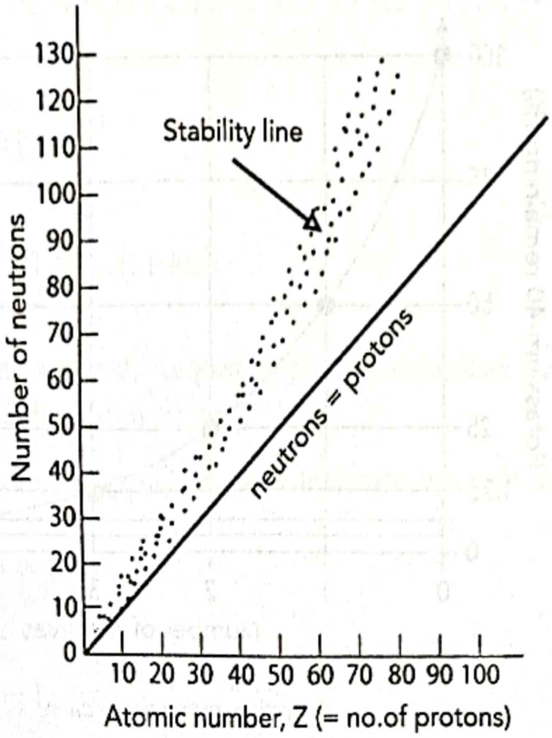
2014 HSC Q35(b)(ii) ... 3 marks

51. The stability of a nucleus is dependent on the number of neutrons compared to the number of protons. The graph below shows the number of neutrons plotted versus the number of protons. The band of stability is above the line on the graph that has a slope of 1.



(a) In stable nuclei with up to about 20 protons, the ratio of neutrons to protons is around 1:1.

What trend is shown on the graph for stable nuclei with an atomic number between around 20–83?

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(b) Explain why this trend occurs.

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(c) Will a nuclide with 90 neutron and 60 proton be stable or will it undergo decay? Explain why.

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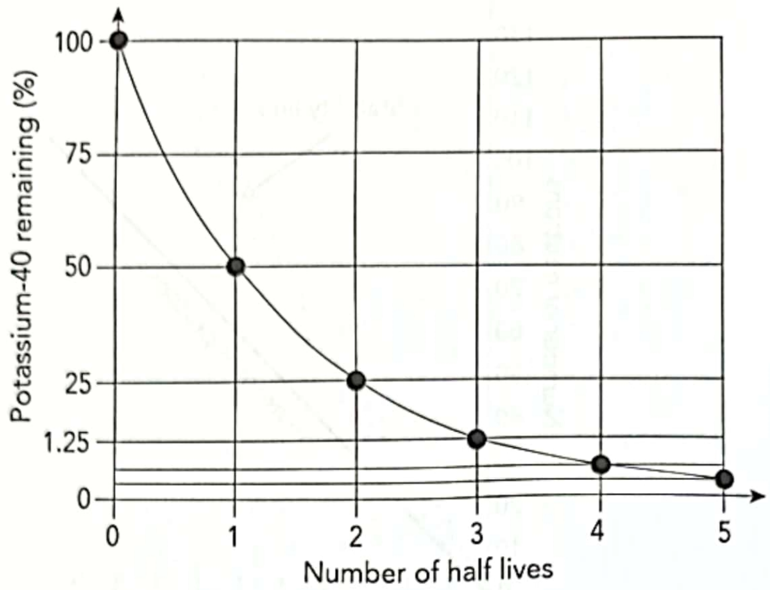
... 1 + 2 + 2 = 5 marks

52. Scientists can use the radioisotope potassium-40 to determine the age of a rock containing a fossil and so determine the fossil's age. Each half-life of K-40 is 1.251×10^9 years. Potassium-40 decays to argon-40 (plus radiation), as shown in the graph below.



Potassium-argon decay curve

Use the graph above to answer these questions.

(a) If the fraction of K-40 found in a sample of rock was found to be ¼, what is the approximate age of a fossil found in this rock?

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(b) Calculate the approximate decay constant, in year^{-1}, for potassium-40.

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...2 + 2 = *4 marks*

8.4 Properties of the Nucleus

Multiple choice: 1 mark each

1. A	2. B	3. B	4. C	5. D	6. B	7. C	8. A
9. B	10. D	11. C	12. A	13. C	14. D	15. B	16. A
17. C							

Explanations:

1. **A** Isotopes are atoms with the same number of protons (so, same atomic number, Z), but with different numbers of neutrons. Hence they have different mass numbers, A. So (A) is the answer, and (B) is incorrect. Different elements cannot have the same atomic number, Z. So (C) is incorrect. While some isotopes are unstable (radioisotopes), many other isotopes are stable. So (D) is incorrect.

2. **B** A radioisotope is an isotope of an element that is unstable and so it releases radiation as it decays to form a more stable isotope. So (B) is the answer. Radioisotopes are often artificially produced. However, some occur naturally or are formed by other natural processes. So (A) is incorrect. Nuclear decay, transmutations and fusion may produce both stable isotopes and radioisotopes. So (C) and (D) are incorrect.

3. **B** The mass loss in a nuclear reaction is the difference between the total mass of all the products of the reaction and the total mass of the reactants. So (B) is the answer. It is not their sum, so (A) is incorrect. The difference between the mass of a nucleus and the mass of its separate nucleons is the 'mass defect' for the particular nuclide, not the 'mass loss' in a nuclear reaction. So (C) is incorrect. The term 'mass defect' does not apply to a nuclear reaction. So (D) is incorrect.

4. **C** 'Mass defect' is a term that only applies to each specific type of nuclide, i.e. Ca^{48}, U^{235}, He^3, He^4, etc. It is the difference between the mass of an atom of the specific nuclide and the sum of the masses of all the protons, neutrons and separate electrons that are contained in that nuclide. So (C) is the answer and (D) is incorrect. 'Mass defect' does not apply to nuclear reactions. So (A) and (B) are incorrect.

5. **D** Binding energy is the energy equivalent to the 'mass defect', as determined by $E = mc^2$. It is the energy needed to split a nuclide up into its component protons, neutrons and electrons. So (D) is the answer. Energy is released in fusion reactions, not used by fusion reactions. So (A) is incorrect. The energy needed to remove electrons is ionisation energy, not binding energy. So (B) is incorrect. Energy is released, not required, in assembling a nucleus from its individual protons and neutrons. So (C) is incorrect.

6. **B** The binding energy is the energy that must be supplied to a nuclide to split it into its component sub-atomic particles. So, the greater the binding energy per nucleon, the more stable the nuclide is and the more energy will be released in the formation of the nuclide. So (B) is the answer and (A) is incorrect. Both (C) and (D) are incorrect, as each statement is opposite to the actual situation.

7. **C** Fission involves very large atoms splitting into fragments about half the size of the original atom. There are over 200 nucleons in the original fissionable nuclei. So, while the amount of energy released from a fission reaction is large, the amount of energy per nucleon is relatively small compared to the energy released per nucleon in a fusion reaction. This is because a fusion reaction involves nuclides with only a few nucleons. So (C) is the answer and (A), (B) and (D) are incorrect.

8. **A** In nuclear reactions, there is a change in mass between the reactant and product particles. The change in mass is balanced by the energy produced or absorbed in the nuclear reaction, as per Einstein's equation, $E = mc^2$. So (A) is the answer. While some of the energy may be binding energy, it is also in the form of kinetic energy of the particles. So (B) is incorrect. The products consist of radiation and new atoms, not individual protons and neutrons. So (C) is incorrect. The energy can be measured in either eV (non-SI unit) or in joules (SI unit). So (D) is incorrect.

9. **B** The chemical formula for an element is: ${}^{A}_{Z}X$ … where X = element, Z = atomic number (= number of protons) and A = mass number (= number of protons + number of neutrons). In a neutral atom, Z = number of electrons.

So, the mass number (A) for carbon-12 refers the number of protons plus the number of neutrons it has. So (B) is the answer and (A), (C) and (D) are incorrect.

10. **D** The isotope X has the general formula: ${}^{A}_{Z}X$ … where Z is the atomic number (= number of protons) and A is the mass number (= number of protons + number of neutrons).

So, the isotope ${}^{56}_{26}Fe$ has an atomic number (Z) = 26, and a mass number (A) = 56.

$$\begin{aligned}\therefore \text{ number of neutrons } &= \text{mass number} - \text{number of protons } (= A - Z)\\ &= 56 - 26\\ &= 30 \text{ neutrons } \ldots \text{ as in (D)}\end{aligned}$$

11. **C** Fission reactions occur when a nucleus splits into smaller, more stable fission fragments. So (C) is the answer and (D) is incorrect. The nucleus releases energy during a fission reaction. So (B) is incorrect. The force that holds nucleons together in the nucleus of an atom is the strong nuclear force and it does this by overcoming the repulsive electrostatic forces between the protons. So (A) is incorrect.

12. **A** In radioactive decay, unstable atoms release radiation as α particles or β particles, as well as γ rays and so form more stable atoms with different atomic numbers that are therefore different elements. So (A) is the answer. The radiation emitted is not just α particles and not just β particles. So (B) and (C) are incorrect. More stable atoms are formed, not less stable atoms. So (D) is incorrect.

13. **C** The half-life of a radioactive isotope is the time taken for half the radioactive nuclei in a sample to decay, as in (C). This decay is not related to a single nucleus, nor to just the nucleons, but rather to the many atoms that are present initially in a sample. So (A) and (B) are incorrect. It takes a great many half-lives before all the atoms in a sample have decayed. So (D) is incorrect.

14. **D** If the half-life of carbon-14 (C-14) is 5730 years, there will be 50% of the C-14 left after 5730 years → 25% after 11,460 years (= 2 half-lives) → 12.5% after 17,190 years (= 3 half-lives) → 6.25% after 22,920 years (= 4 half-lives) → and so on. So (D) is the answer.

15. **B** There will be half the O-15 left after each half-life of 122.2 seconds:

$$100\% \xrightarrow{122.2\ s} 50\% \xrightarrow{122.2\ s} 25\% \xrightarrow{122.2\ s} 12.5\%$$

$$\xrightarrow{122.2\ s} 6.25\% \xrightarrow{122.2\ s} 3.125\%$$

So, after 4 half-lives = 4 × 122.2 s = 488.8 seconds, there will be 6.25% = 0.0625 left.

Checking the fractions given: $\frac{1}{32} = 0.03125$, $\frac{1}{16} = 0.0625$, $\frac{1}{8} = 0.125$, $\frac{1}{4} = 0.25$

$\therefore$ $\frac{1}{16}$ … as in (B), is the answer.

16. **A** In a controlled fission reaction in a nuclear reactor, the control rods contain neutron absorbing material to control the number of neutrons available in the reactor. So (A) is the answer. Control rods do not separate the fuel rods, nor do they initiate the fission chain reaction. So (B) and (D) are incorrect. A moderator such as heavy water is used to slow high energy neutrons down to the lower energies needed for fission to occur in a controlled way, not the control rods. So (C) is incorrect.

17. **C** Fusion reactions occur when two smaller nuclei are combined to form a larger nucleus. So (C) is the answer and (B) incorrect. The force that holds nucleons together in the nucleus of an atom is the strong nuclear force and it does this by overcoming the repulsive electrostatic forces between the protons. So (A) is incorrect. The larger nucleus formed by fusion is more stable, not less stable. So (D) is incorrect.

Short-answer questions

18. (a) proton

(b) neutron

(c) electron

19. (a) alpha (α) particle ... high

(b) beta (β) particle ... medium

(c) gamma (γ) radiation ... low

20. Transmutation is when an atomic nucleus changes (decays) into that of another element and releases radiation. Whereas nuclear fission involves the splitting of a 'heavy' nucleus to usually form two (but sometimes more) daughter nuclei with the release of up to several neutrons and a large amount of energy.

21. (a) D1: ${}^{238}_{92}U \rightarrow {}^{234}_{90}Th + {}^{4}_{2}He$ OR: ${}^{238}_{92}U \rightarrow {}^{234}_{90}Th + \alpha$

D2: ${}^{234}_{91}Pa \rightarrow {}^{234}_{92}U + {}^{0}_{-1}e$ OR: ${}^{234}_{91}Pa \rightarrow {}^{234}_{92}U + {}^{0}_{-1}\beta$

(b) X = Ra, A = 226 and Z = 88 (i.e. ${}^{226}_{88}Ra$)

22. An uncontrolled fission reaction occurs when the rate of fission is not controlled and a chain reaction occurs that accelerates rapidly, resulting in an explosion and the release of huge amounts of energy. Whereas a controlled fission reaction occurs when the rate of fission is achieved by keeping the fuel rods separated from one another so that they are near the critical mass density, and by using control rods that absorb neutrons to control the number of neutrons available in the reactor, and by using a moderator (e.g. heavy water) that slows high energy neutrons down to the lower energies needed for fission to occur in a controlled way.

[Note: The level of activity in the reactor is increased/decreased by the number of fuel rods or control rods that are inserted into the reactor core.]

23. (a) ${}^{218}_{83}X \rightarrow {}^{214}_{81}Y + {}^{4}_{2}He$ OR: ${}^{218}_{83}X \rightarrow {}^{214}_{81}Y + \alpha$

(b) A beta (β^-) particle.

Element **Y** and element **Z** have the same mass number.
As **Y** → **Z**, the atomic number (number of protons) increases by 1.
So, an electron [i.e. a beta (β^-) particle] is emitted.

[Note: A beta particle (β^-) particle) can also be written as ${}^{0}_{-1}e$.]

24. (a) The reaction is: ${}^{235}_{92}U + {}^{1}_{0}n \rightarrow {}^{95}_{38}Sr + {}^{139}_{54}Z + 2\,{}^{1}_{0}n$

$\therefore$ the other nucleus formed (Z) is ${}^{139}_{54}Xe$ [OR xenon-139]

(b) Energy released $= mc^2$

$= 0.2234 \times (1.661 \times 10^{-27}) \times (3 \times 10^8)^2$

$= 3.33 \times 10^{-11}$ J

25. (a) Atomic number of $X = 7 + 2 - 1$
$= 8$

(b) Mass number of $X = 14 + 4 - 1$
$= 17$

(c) Isotope X is ${}^{17}_{8}O$ [Note: Atomic number = 8, so element is oxygen.]

26. X represents the path of β particles, as β particles have a higher charge-to-mass ratio and so are deflected more by a magnetic field.

27. (a) The higher binding energy per nucleon of a nucleus of mass number 50 gives it greater nuclear stability than a nucleus with a mass number of 200.

(b) Spontaneous fission for a nucleus of mass number 200 would result in more stable nuclei with greater binding energy per nucleon, e.g. with mass numbers about 100. Whereas fission for a nucleus of mass number 20 would result in less stable nuclei, e.g. with mass numbers about 10 and so fission does not occur spontaneously for these nuclei.

28. • An enormous amount of energy is required to force two positively charged nuclei together. Extremely high temperatures are required for this and are difficult to achieve.
• It is also very difficult to contain the plasma used for the fusion reaction.

[Note: Magnetic containment has recently been achieved in small-scale fusion reactors and methods have recently been discovered to control instabilities in the contained plasmas. This is an area that is still being developed.]

29. (a) ${}^{242}_{94}Pu \rightarrow {}^{238}_{92}U + {}^{4}_{2}He$ OR: ${}^{242}_{94}Pu \rightarrow {}^{238}_{92}U + \alpha$

(b) ${}^{238}_{92}U \rightarrow {}^{238}_{93}Np + {}^{0}_{-1}e$ OR: ${}^{238}_{92}U \rightarrow {}^{238}_{93}Np + {}^{0}_{-1}\beta$

30. MASS BEFORE:

$^{235}_{92}U$ = 234.9934 u

$^{1}_{0}n$ = 1.00867 u

236.00207 u

MASS AFTER:

$^{139}_{54}Xe$ = 138.8883 u

$^{94}_{38}Sr$ = 93.8945 u

$3 \times ^{1}_{0}n$ = $3 \times 1.00867\ u$

235.80881 u

Mass loss = 236.00207 – 235.80881 = 0.19326 u

Energy, $E = mc^2 = 0.19326 \times 1.66 \times 10^{-27} \times (3.00 \times 10^8)^2 = 2.887 \times 10^{-11}$ J

$\therefore$ Energy released from fission = 2.887×10^{-11} J

31. (a) Binding energy per nucleon = 7.95 MeV [from graph]

Mass number of $^{16}_{8}O$ = 16, so $^{16}_{8}O$ has 16 nucleons [Note: A nucleon is a proton or neutron]

$\therefore$ total nuclear binding energy of $^{16}_{8}O$ = 7.95 × 16 = 127.2 MeV

[Note: You could have used a range from 7.9–7.99 MeV for the binding energy per nucleon of $^{16}_{8}O$. The actual value is 7.976, but you cannot discern this from the graph.]

(b) Since iron-56 has the greatest binding energy per nucleon, it is the most stable isotope shown. Hence it has greater stability than the elements to its left and to its right on the graph.

32. (a) Mass reactants $= 2 \times (3.34449 \times 10^{-27})$
$= 6.68898 \times 10^{-27}$ kg

Mass products $= (5.00823 \times 10^{-27}) + (1.67493 \times 10^{-27})$
$= 6.68316 \times 10^{-27}$ kg

$\therefore$ Mass loss $= (6.68898 \times 10^{-27}) - (6.68316 \times 10^{-27})$
$= 0.00582 \times 10^{-27}$
$= 5.82 \times 10^{-30}$ kg

(b) Energy released (in J), $E = mc^2$
$= 5.82 \times 10^{-30} \times (3 \times 10^8)^2$
$= 5.238 \times 10^{-13}$ J

Energy released (in eV) $= \dfrac{5.238 \times 10^{-13}}{1.602 \times 10^{-19}} = 3.2697 \times 10^6$ eV

$\therefore$ Energy released (in MeV) = 3.270 MeV

33. (a) Mass difference $= 226.0254 - 226.0202$
$= 0.0052\ u$

From Data Sheet: $1\ u = \frac{931.5}{c^2}$ MeV

$\therefore$ Energy released $= \Delta mc^2$
$= 0.0052 \times 931.5\ \text{MeV}/c^2 \times c^2$
$= 4.8438\ \text{MeV}$

(b) Exothermic [Note: This is because the mass of the reactants is greater than the mass of the products.]

34. (a) The mass defect of a nucleus is the difference between the actual mass of the specific atom and the total calculated mass of all its constituent nucleons (protons and neutrons) and its electrons.

(b) The stability of a particular nucleus is indicated by its binding energy per nucleon. The graph shows that atoms with a mass number 50 have the greatest binding energy per nucleon and atoms with a mass number 200 have a much lower binding energy per nucleon. Hence a nucleus with a mass number 50 is very stable, whereas a nucleus with a mass number 200 is less stable.

[Note: Atoms with a mass number of 50 do not all have the same binding energy because there are radioactive isotopes for almost every mass number. They have unstable proton:neutron ratios and hence they have a lower binding energy.]

35. In stable isotopes, the strong nuclear forces of attraction are greater than the electrostatic forces of repulsion that exist between the protons in the nucleus. If a nucleus is too large, the electrostatic repulsion between the protons is greater than the nuclear force between the nucleons, causing instability. This results in the emission of nuclear radiation and energy.

[Note: You could also have added: When the ratio of protons:neutrons varies from that of the most stable isotope of an element, the binding energy is reduced, and the isotope may be radioactive.]

36. (a) When such fusion or such fission occur, the product atoms in both cases are closer to the peak region where the nuclei are more stable (at around $A = 50$–60). Hence the products in both cases have a greater binding energy per nucleon, and so energy is released.

(b) The fusion of two deuterium ($^2_1$H) results in helium ($^4_2$He). Since the binding energy for these drops from around 7.3 MeV to 1.2 MeV, the $^4_2$He has about 6.1 MeV per nucleon more binding energy than $^2_1$H.

The fission of uranium-235 results in smaller atoms about half its size, e.g. with between 100–130 nucleons. So, the fission products have a binding energy of around 1 MeV per nucleon more than the U-235.

Hence the binding energy per nucleon is greater for the fusion of deuterium and so more energy is released per nucleon.

37. (a) Number protons = 50

Number neutrons = 120 – 50 = 70

(b) $^{120}_{50}\text{Sn} + ^{12}_{6}\text{C} \rightarrow ^{118}_{49}X + ^{14}_{7}\text{N}$

∴ the other product produced (X) is indium-118.

(c) Mass of reactants = mass ($^{12}_{6}\text{C} + ^{120}_{50}\text{Sn}$) = 12.00000 + 119.90220

= 131.90220 u

Mass of products = mass ($^{118}_{49}\text{In} + ^{14}_{7}\text{N}$) = 117.90612 + 14.00307

= 131.90919 u

Difference = 131.90919 – 131.90220 = 0.00699 u

∴ Energy absorbed = 0.00699 × 931.5 = 6.51 MeV

Overall, energy is conserved. So, energy of reactants = energy of products

∴ K of carbon = K (of nitrogen) + K (of indium) + energy absorbed in reaction

84 = 49 + K of indium + 6.51

∴ Kinetic energy, K, of indium = 28.49 MeV

38. The mass of the smaller product nuclei, Ba^{140} and Kr^{92} plus the four neutrons is less than the total mass of the U^{235} nucleus and neutron that reacted together. This loss of mass in the fission reaction results in a very large energy release, as $E = mc^2$.

39. (a) $^{238}_{92}\text{U} \rightarrow ^{234}_{90}\text{Th} + ^{4}_{2}\text{He} + \text{energy}$ [Note: $^{4}_{2}\text{He}$ could be replaced by α.]

(b) Mass of $^{238}_{92}\text{U}$ = 238.05079 u

Mass of ($^{234}_{90}\text{Th} + ^{4}_{2}\text{He}$) = 234.04360 + 4.00260

= 238.04620 u

∴ mass loss = 238.05079 – 238.04620

= 0.00459 u

(c) Energy released = mass loss × 931.5

= 0.00459 × 931.5

= 4.276 MeV

(d) Greater – this is due to the mass loss, as the total mass of the reactants is less than the total mass of the reactants.

40. Over time, radioactive substances decay and the daughter nuclei formed can also be radioactive. In this case, the decay has formed daughter nuclei that are a more radioactive product.

41. (a) $^{210}_{83}\text{Bi} \rightarrow {}^{210}_{84}\text{Po} + {}^{0}_{-1}\beta + {}^{0}_{0}\bar{\nu}$

$$\begin{aligned}
\text{Mass } {}^{210}_{83}\text{Bi} &= 209.938\,57\ u \\
\text{Mass } {}^{210}_{84}\text{Po} &= 209.936\,78\ u \\
\text{Mass } {}^{0}_{-1}\text{e}^- &= \underline{0.000\,55\ u} \\
\text{Mass } {}^{210}_{84}\text{Po} + {}^{0}_{-1}\text{e}^- &= \underline{209.937\,33\ u}
\end{aligned}$$

$$\begin{aligned}
\text{Mass loss} &= 209.938\,57\ u - 209.937\,33\ u = 0.00124\ u \\
&= 0.00124\ u \times 1.661 \times 10^{-27}\ \text{kg} \\
&= 2.05964 \times 10^{-30} = 2.060 \times 10^{-30}\ \text{kg}
\end{aligned}$$

(b) Mass loss = $0.00124\ u$

Energy released = $0.00124\ u \times 931.5\ \text{MeV}/c^2 = 1.15506 = 1.155\ \text{MeV}$

i.e. energy released as one $^{210}_{83}\text{Bi}$ atom changes to $^{210}_{84}\text{Po}$ is always 1.155 MeV.

In this decay, the 1.155 MeV of energy released is shared between all three products of the decay, i.e. between Po-210 , the β^- particle and anti-neutrino ($\bar{\nu}$). This occurs in varying proportions, but always so that the laws of conservation of energy are obeyed.

As a result, for the overall decay of Bi-210, K of the electrons produced varies as in the diagram, with very few electrons having K_{max}.

42. Mass of reactants = 7.016 + 1.0078
= 8.0238 u

Mass of products = 4.0026 + 4.0026
= 8.0052

Mass difference = 8.0238 – 8.0052
= 0.0186 u

Energy released (in J) = mc^2
$= 0.0186 \times 1.661 \times 10^{-27} \times (3 \times 10^8)^2$
$= 2.78 \times 10^{-12}$ J

Energy released (in MeV) = 0.0186×931.5
= 17.3259 MeV

43. (a) Reading from the diagram, number of protons = 90, number of neutrons = 137

[Note: Thorium-227 has atomic number (Z) = 90 & mass number (A) = 90 + 137 = 227]

(b) $^{223}_{87}\text{Fr} \rightarrow {}^{219}_{85}\text{At} + {}^{4}_{2}\text{He}$ [Note: $^{4}_{2}\text{He}$ can be replaced by α.]

44. (a) MASS BEFORE:

$^{235}_{92}\text{U} = 235.0439\ u$

$^{1}_{0}\text{n} = 1.008665\ u$

$\underline{236.052565\ u}$

MASS AFTER:

$^{141}_{56}\text{Ba} = 140.9144\ u$

$^{92}_{36}\text{Kr} = 91.9263\ u$

$3 \times {}^{1}_{0}\text{n} = 3.025995\ u$

$\underline{235.866695\ u}$

Mass loss, $\Delta m = 236.052565 - 235.866695 = 0.18587$ a

$\therefore$ energy released, $E = 0.18587 \times 931.5 = \underline{173.14\ \text{MeV}}$

OR

An alternative method to calculate the energy released (using 1 u = 1.661×10^{-27} kg):

Energy released, $E = mc^2 = =\ 0.182587 \times 1.661 \times 10^{-27} \times (3.00 \times 10^8)^2 = 2.779 \times 10^{-11}$ J

(b) The mass of the reactants is greater than the mass of the products, as some of the mass has been converted into energy (in the form of γ rays and the kinetic energy of the particles produced). Since $E = mc^2$, the mass that is lost (Δm) is equivalent to the energy produced: $E = (\Delta m)c^2 = K$ (product particles) + γ rays.

45. (a) Mass reactants $= 2 \times 2.01355$
$= 4.02710\ u$

Mass products $= 3.01492 + 1.00967$
$= 4.02359\ u$

$\therefore$ Mass loss $= 4.02710 - 4.02359$
$= 0.00351\ u$

(b) Energy released (in J), $E = mc^2$

$= 0.00351 \times (1.661 \times 10^{-27}) \times (3.0 \times 10^8)^2$

$= 5.247 \times 10^{-13}$ J

So, energy released $= \dfrac{5.247 \times 10^{-13}}{1.602 \times 10^{-19}}$ eV

$\therefore$ Energy released (in MeV) $= 3.275$ MeV

46. Mass difference $= (11.9967 + 1.0072) - (13.0019) = 0.002\ u$

Since $1\ u = 931.5\ \text{MeV}/c^2$

$\therefore$ energy released $= mc^2$

$= 0.002\ u \times 931.5\ \text{MeV}/c^2 \times c^2$

$= 1.863\ \text{MeV}$

47. (a) $t_{\frac{1}{2}} = 6 \text{ hours} = 6 \times 60 \times 60$

$= 2.16 \times 10^4$ seconds

$\therefore$ Decay constant, $\lambda = \dfrac{ln2}{t_{1/2}} = \dfrac{0.6931}{2.16 \times 10^4}$

$= 3.21 \times 10^{-5}\ \text{s}^{-1}$

(b) Decay constant, $\lambda = \dfrac{ln2}{t_{1/2}} = \dfrac{0.6931}{14.96 \text{ hours}}$

$= 0.04621\ \text{hour}^{-1}$

Since $N_t = N_0 e^{-\lambda t}$

$ln\left(\dfrac{N_t}{N_0}\right) = -\lambda t$

So, $ln\left(\dfrac{50}{800}\right) = -0.04621\ t$ [as 50 g will be left if 750 g decays]

$\therefore$ Time for 750 g to decay, $t = 59.998 = 60$ hours

(c) $N_t = N_0 e^{-\lambda t}$

$1.5 = 192\ e^{-\lambda\,(56\ days)}$

$\dfrac{1.5}{192} = e^{-\lambda\,(56\ days)}$

So, $ln\left(\dfrac{1.5}{192}\right) = -\lambda\,(56)$

$\therefore \lambda = \dfrac{ln\left(\frac{1.5}{192}\right)}{-56} = 0.086643976\ \text{day}^{-1}$

Since $\lambda = \dfrac{ln2}{t_{\frac{1}{2}}}$

$\therefore$ half-life of I-131, $t_{\frac{1}{2}} = \dfrac{ln2}{\lambda} = 7.999 = 8.0$ days

OR *Checking how many grams are left over 7 half-lives:*

192 g $\xrightarrow{1}$ 96 g $\xrightarrow{2}$ 48 g $\xrightarrow{3}$ 24 g $\xrightarrow{4}$ 12 g $\xrightarrow{5}$ 6 g $\xrightarrow{6}$ 3 g $\xrightarrow{7}$ 1.5 g

i.e. after 7 half-lives there will be 1.5 g left.

So, $7 \times t_{\frac{1}{2}} = 56$ days

$\therefore$ half-life of I-131, $t_{\frac{1}{2}} = \frac{56}{7} = 8$ days

48. (a) Mass of 6 protons $= 6 \times 1.673 \times 10^{-27}$ kg $= 10.038 \times 10^{-27}$ kg

Mass of 6 neutrons $= 6 \times 1.675 \times 10^{-27}$ kg $= 10.050 \times 10^{-27}$ kg

Mass of 6 electrons $= 6 \times 9.109 \times 10^{-31}$ kg $= 5.4654 \times 10^{-30}$ kg

Total mass of constituent particles in carbon-12 $= 2.0093 \times 10^{-26}$ kg

Mass of carbon-12 $= 12.000\ u \times 1.661 \times 10^{-27}$ kg $= 1.9932 \times 10^{-26}$ kg

Mass defect $= (2.0093 - 1.9932) \times 10^{-26}$ kg $= 0.0161 \times 10^{-26}$ kg $= 1.61 \times 10^{-28}$ kg

$= \frac{1.61 \times 10^{28}}{1.661 \times 10^{-27}} = 0.09693 = 0.097\ u$

$\therefore$ Mass defect of one C-12 atom $= 0.097\ u$

(b) $E = mc^2 = 1.61 \times 10^{-28}\text{ kg} \times (3 \times 10^8\text{ m s}^{-1})^2$

$= 1.45 \times 10^{-11}$ J

[OR: *Alternative calculation*: $E = mc^2 = 0.097\ u \times 931.5\text{ MeV/c}^2$

$= 90.4\text{ MeV } (\equiv 1.45 \times 10^{-11}\text{ J})$]

49. Mass reactants $= 4.0012 + 9.0122 = 13.0134\ u$

Mass products $= 12.000 + 1.0087 = 13.0087\ u$

$\therefore$ Mass loss $= 13.0087 - 13.0134 = -0.0047\ u$

$= 0.0047 \times 1.661 \times 10^{-27} = 7.8067 \times 10^{-30}$ kg

$\therefore$ energy released, $E = mc^2$

$= 7.8067 \times 10^{-30} \times 3.00 \times 10^8$

$= 7.026 \times 10^{-13}$ J

50. The graph shows the binding energy per nucleon is greatest around atomic number 26 (= Fe). When a heavier element (to the right of Fe) undergoes fission or decay to form a lighter element, the daughter nuclides always have a greater binding energy per nucleon and the total mass of the products is less. Energy equivalent to the loss of mass is released ($E = mc^2$).

Similarly, when a lighter element (to the left of Fe) undergoes fusion or nuclear bombardment to form a heavier element, the binding energy per nucleon increases and the total mass of the products is less. Hence there is a release of energy equivalent to the loss of mass.

51. (a) As the number of protons increases, the number of neutrons increases.

[Note: By around $Z = 40$ (e.g. Sn), the ratio becomes 1.25:1 and by around $Z = 80$ (e.g. Hg) the ratio becomes 1.5:1. The nuclei that lie above and below the line of stability are unstable and undergo radioactive decay. The graph also shows that there are no stable isotopes above atomic number 82.]

(b) The repulsion due to the electrostatic forces between protons in a larger nucleus makes the nucleus less stable, so more neutrons are required to maintain stability. Extra neutrons add extra space between the protons, thus decreasing their repulsions.

(c) It will be stable and so will not decay, because if this point is plotted on the graph, it falls on the line of stability.

51. (a) Since ¼ = 25% K-40 remaining, which takes 2 half lives,

$$\therefore \text{fossil's age} = 2 \times (1.251 \times 10^9)$$

$$= 2.5 \times 10^9 \text{ years}$$

(b) Decay constant, $\lambda = \dfrac{ln2}{t_{1/2}}$

$$= \frac{0.6931}{1.251 \times 10^9}$$

$$= 5.54 \times 10^{-10} \text{ years}^{-1}$$