

Exercise walk-through

5.3

Binding energy, fission and fusion (133–136)

Pearson Edexcel · International A-Level · Physics

Separate free, forced and damped oscillations

Term	Physical meaning
Free oscillation	After release, motion occurs at a natural frequency.
Forced oscillation	A periodic external force drives the motion.
Damping	Oscillation energy transfers to other stores.
Resonance	Large response near a natural frequency under comparable driving.

Use the evidence

One oscillator can be forced and damped at the same time.

A linked explanation earns its conclusion

People supply a periodic driving force.



Drive near a natural frequency → efficient energy transfer → larger amplitude.



Damper opposes motion and does work
→ energy transfers to thermal stores.



For comparable driving, less oscillation energy means a smaller steady amplitude.

Fuel supply and consumption rate both matter

Core hydrogen declines → core fusion weakens.



Gravity contracts and heats the core; shell burning and later helium fusion accompany giant expansion.



Sun-like star loses outer layers → white dwarf without sustained fusion.



Massive stars burn faster; later collapse/supernova can leave a neutron star or black hole.

Exercises 2.1·2.2

2.1 A nucleus has proton number $Z = 8$ and mass number $A = 18$. State proton and neutron numbers. Distinguish binding energy from binding energy per nucleon. [4]

$$Z = 8$$

$$A = 18$$

2.2 A nucleus of $A = 12$ has mass deficit 0.098 u . Calculate binding energy in joules and MeV per nucleon. Use $1 \text{ u} = 1.66 \times 10^{-27} \text{ kg}$, $c_0 = 3.00 \times 10^8 \text{ m s}^{-1}$ and $1 \text{ MeV} = 1.60 \times 10^{-13} \text{ J}$. [4]

$$A = 12$$

$$\Delta m = 0.098 \text{ u}$$

Exercises 2.1·2.2

2.1 A nucleus has proton number $Z = 8$ and mass number $A = 18$. State proton and neutron numbers. Distinguish binding energy from binding energy per nucleon. [4]

$Z = 8$

$A = 18$

2.1 Eight protons, ten neutrons. Binding energy is the total energy to separate the nucleus into free nucleons; per-nucleon binding energy divides that total by A .

2.2 A nucleus of $A = 12$ has mass deficit 0.098 u . Calculate binding energy in joules and MeV per nucleon. Use $1 \text{ u} = 1.66 \times 10^{-27} \text{ kg}$, $c_0 = 3.00 \times 10^8 \text{ m s}^{-1}$ and $1 \text{ MeV} = 1.60 \times 10^{-13} \text{ J}$. [4]

$A = 12$

$\Delta m = 0.098 \text{ u}$

2.2 Convert mass deficit before applying rest energy.

$$E_b = \Delta mc_0^2 = (0.098 \text{ u})(1.66 \times 10^{-27} \text{ kg/u})(3.00 \times 10^8 \text{ m s}^{-1})^2 = 1.46 \times 10^{-11} \text{ J}$$

Total energy. Divide by nucleon count and energy conversion.

$$\frac{E_b}{A} = \frac{1.46412 \times 10^{-11} \text{ J}}{12(1.60 \times 10^{-13} \text{ J/MeV})} = 7.63 \text{ MeV per nucleon}$$

Result.

Exercise 2.3

2.3 Nuclei X and Y have $A_X = 20$, $E_{b,X} = 150$ MeV and $A_Y = 60$, $E_{b,Y} = 510$ MeV. Compare their binding energy per nucleon and identify which has more tightly bound nucleons. [3]

X: 20; 150 MeV

Y: 60; 510 MeV

3 Exam-style questions

Exercise 2.3

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3 Exam-style questions

2.3

$$\frac{E_{b,X}}{A_X} = \frac{150 \text{ MeV}}{20} = 7.5 \text{ MeV per nucleon}$$

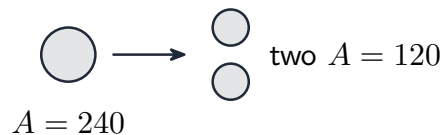
X.

$$\frac{E_{b,Y}}{A_Y} = \frac{510 \text{ MeV}}{60} = 8.5 \text{ MeV per nucleon}$$

Y. Y has greater binding per nucleon, hence more tightly bound nucleons.

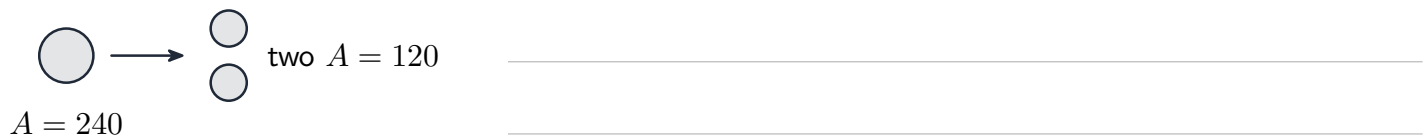
Exercise 3.1

3.1 A heavy nucleus of mass number 240 with binding energy 7.6 MeV per nucleon splits into two mass-number 120 products, each at 8.5 MeV per nucleon. Ignoring other products for this simplified model, find released energy in MeV and joules. Explain its origin without claiming total energy is destroyed. Use $1 \text{ MeV} = 1.60 \times 10^{-13} \text{ J}$. [5]



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3.1 Compare total binding energies, not just their vertical difference.

$$Q = 2A_p\epsilon_p - A_r\epsilon_r = 2(120)(8.5 \text{ MeV}) - 240(7.6 \text{ MeV}) = 216 \text{ MeV}$$

Energy.

$$Q_J = Q_{MeV}(1.60 \times 10^{-13} \text{ J/MeV}) = (216 \text{ MeV})(1.60 \times 10^{-13} \text{ J/MeV}) = 3.46 \times 10^{-11} \text{ J}$$

Conversion. Products have greater total binding and smaller total rest mass; the decrease becomes kinetic/radiation energy while total energy is conserved.

Exercise 3.2

3.2 Explain why fusion of some light nuclei and fission of some heavy nuclei both release energy. Explain separately why sustained stellar fusion needs high temperature and sufficiently high density/confinement. [6]

light nuclei

heavy nuclei

fusion conditions

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3.2 The binding-per-nucleon curve peaks near iron/nickel. Appropriate light-nucleus fusion moves towards greater binding per nucleon; heavy-nucleus fission can do the same from the other side. Greater total product binding means lower product rest energy and released energy. High temperature gives nuclei enough kinetic energy for close approach despite electrical repulsion; density/confinement gives sufficient close encounters and retains the reacting material.

Exercise 3.3

3.3 A proposed fusion reaction has reactant rest masses totalling 5.030 u and product rest masses totalling 5.010 u. Calculate energy per reaction and the reaction rate for 1.0 MW of released nuclear power. Explain why using a mass difference per nucleon would give the wrong rate. Use the constants from 2.2. [6]

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reactants 5.030 u

products 5.010 u

3.3 Find total reactant-minus-product mass.

$$\Delta m = m_r - m_p = (5.030 - 5.010) \text{ u} = 0.020 \text{ u}$$

$$Q = \Delta mc_0^2 = (0.020 \text{ u})(1.66 \times 10^{-27} \text{ kg/u})(3.00 \times 10^8 \text{ m s}^{-1})^2 = 2.99 \times 10^{-12} \text{ J}$$

Energy. Power is energy per reaction times reaction rate.

$$\dot{N} = \frac{P}{Q} = \frac{1.0 \times 10^6 \text{ J s}^{-1}}{2.988 \times 10^{-12} \text{ J}} = 3.35 \times 10^{17} \text{ s}^{-1}$$