Cambridge IGCSE Physics

Giáo trình luyện thi chuyên sâu

Song ngữ Anh–Việt

8020 ENGLISH
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Lời mở đầu · Foreword

Cuốn sách này thuộc bộ giáo trình luyện thi chương trình quốc tế của **8020 English (8020 Education)** — trung tâm luyện thi trọng điểm **IELTS · SAT · AP · IB · A-level · IGCSE** và săn học bổng du học. Toàn bộ nội dung được biên soạn bởi đội ngũ **Giáo sư · Tiến sĩ · Thạc sĩ** tốt nghiệp các trường top đầu thế giới, bám sát khung chương trình chính thức, trình bày đầy đủ lý thuyết, ví dụ mẫu, hình minh hoạ và hệ thống bài tập có lời giải chi tiết.

This book is part of the 8020 English international exam-prep series: complete English theory with Vietnamese explanations, worked examples, illustrations and fully-solved practice, aligned to the official framework.

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9.0 IELTS cao nhất	**1570** SAT cao nhất
5/5 AP — điểm tuyệt đối	**90/100** IB Diploma
100% GV $\geq$ 8.0 IELTS / 1500 SAT	**CMU** Tiến sĩ ĐH #1 Hoa Kỳ về CS

> **Đội ngũ tiêu biểu:** Thầy Châu Cát Tường (Academic Head, ThS Western Sydney, top 1% IELTS 8.5) · TS Nguyễn Anh Huy (Carnegie Mellon, cựu kỹ sư Amazon) · TS Nguyễn Phước Trường (Toán, ĐH Klagenfurt) · cùng đội ngũ giảng viên SAT 1500–1600, IELTS 8.0–8.5.

Kết quả học viên — điểm thi thật: IELTS 8.0–9.0 · SAT 1550 / 1570 / 1590 · AP 5/5 (Calculus BC, Microeconomics) · IB 90/100 (Economics) · Duolingo 110 · PTE 90 · TOEFL 120. **Bảng vàng SAT:** Khánh Đăng 1510 · Thảo Nguyên 1520 · Tâm Anh 1530.

“Cuối cùng đã đậu vào trường top như mong muốn.” — Phan Thị Thanh Hằng, IELTS Overall 8.5.

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ĐỘI NGŨ

ĐỘI NGŨ GIÁO VIÊN TẬN TÂM

**Tối thiểu 8.0 IELTS Overall*

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IELTS 8.5 Overall

Gv. Nguyễn Khanh
IELTS 8.0 Overall

Gv. Nguyễn Đan Vy
IELTS 8.0 Overall

Giảng viên 8020 — IELTS 8.5 & 8.0 Overall (British Council · IDP · Cambridge)

KẾT QUẢ HỌC VIÊN

THÀNH TÍCH HỌC VIÊN

Bảng điểm thi thật – chất lượng được giám sát nghiêm ngặt. Một số học viên chỉ cần 1–2 khóa để đạt kết quả mong muốn.

Học viên 8020 — IELTS 8.0 Overall (bảng điểm thật)

ĐỘI NGŨ

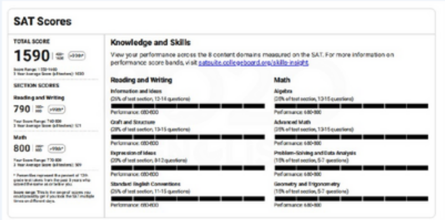
ĐỘI NGŨ GIÁO VIÊN TẬN TÂM

**Tối thiểu 1500 SAT Overall*

Thầy Quang Minh

Đại học Bách Khoa Hà Nội

SAT 1590 | IELTS 8.0



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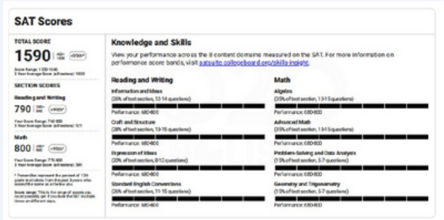
- Học sinh đạt 1450–1560 SAT
- Dạy nhanh band 1400–1550+
- Chiến thuật làm bài & quản lý thời gian

Cô Phương Vy

Đại học Ngoại thương

SAT 1590 | IELTS 8.0



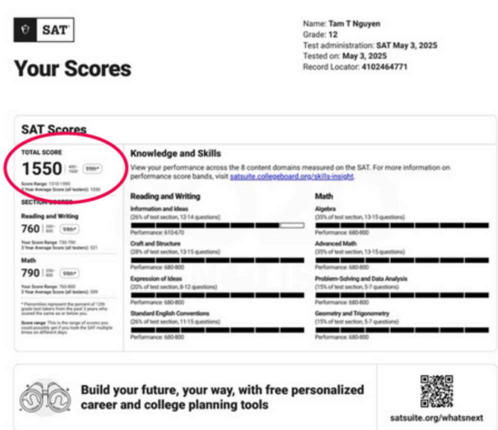
THẾ MẠNH & KINH NGHIỆM

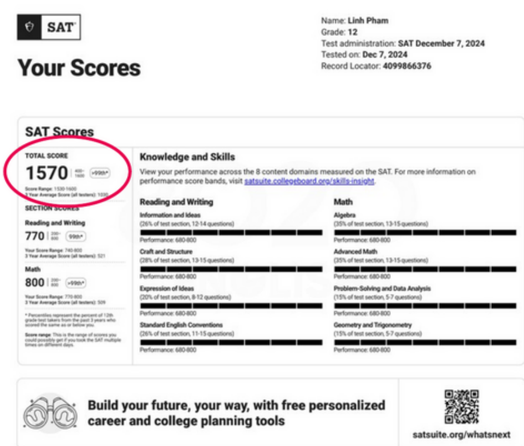
- SAT Verbal Instructor (Springboard, QAS)
- Dạy lớp nhỏ & xây dựng tài liệu riêng
- Chuyên Reading & Writing: Logic – Grammar

Giảng viên 8020 — SAT 1590 (ĐH Bách Khoa Hà Nội & ĐH Ngoại thương)

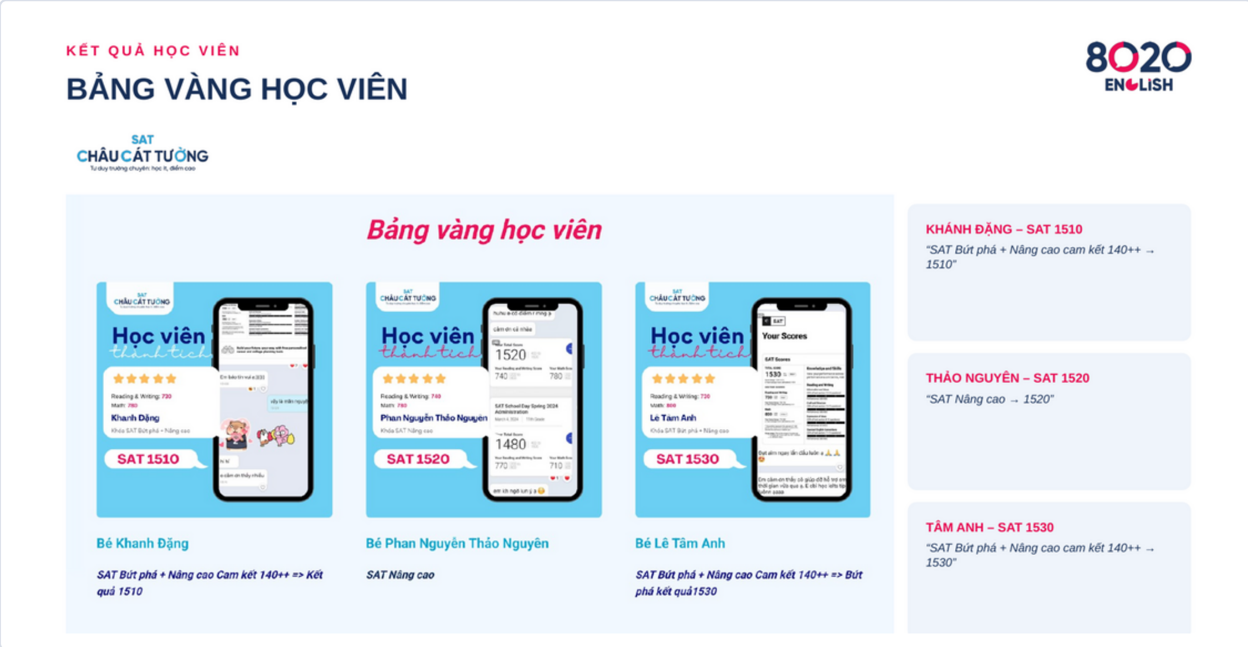
KẾT QUẢ HỌC VIÊN

TUTOR 1-1 – ĐIỂM SỐ ẤN TƯỢNG

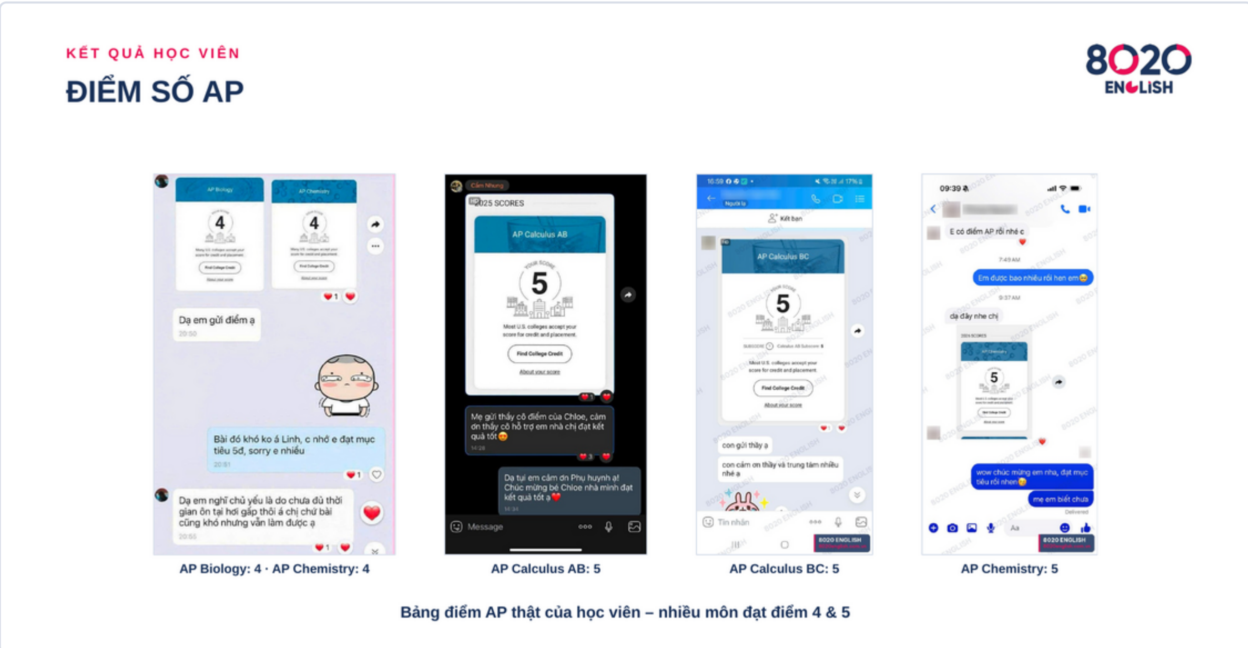




Học viên 8020 — SAT 1550 & 1570 (College Board)



Bảng vàng SAT — Học viên đạt 1510 · 1520 · 1530



Điểm AP thật — Calculus AB/BC 5/5 · Biology & Chemistry 4–5 (College Board)

Mục lục • Contents

Data used throughout this book (Cambridge IGCSE Physics 0625 data-sheet values): gravitational field strength / free-fall acceleration $g = 10\,\mathrm{N/kg}$ (i.e. $10\,\mathrm{m/s^2}$); speed of light in vacuum $c = 3.0 \times 10^8\,\mathrm{m/s}$; speed of sound in air $\approx 340\,\mathrm{m/s}$; density of water $= 1000\,\mathrm{kg/m^3}$; specific heat capacity of water $= 4200\,\mathrm{J/(kg\,^\circ C)}$. Content marked **(Supplement)** goes beyond Core level and is examined only on the Extended papers — Core-level readers may treat these as enrichment.

Motion, Forces and Energy

Mục tiêu Unit: Đại lượng vật lý & đo lường (chiều dài, thời gian, thể tích, chữ số có nghĩa); chuyển động (đồ thị quãng đường–thời gian, vận tốc–thời gian, phương trình chuyển động thẳng biến đổi đều – Supplement, rơi tự do & vận tốc giới hạn); khối lượng, trọng lượng, khối lượng riêng; lực và hiệu ứng của lực, cộng vector lực, ba định luật Newton, định luật Hooke, chuyển động tròn (Supplement), mô-men lực & nguyên lý cân bằng, trọng tâm & độ ổn định; động lượng (Supplement); công, năng lượng, công suất, hiệu suất, nguồn năng lượng, sơ đồ Sankey; áp suất trong chất rắn & chất lỏng.

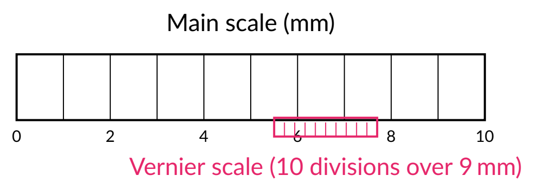
1.1 Physical Quantities and Measurement

Physics measurements combine a **number** and a **unit**. The base SI units used throughout this book are: length in metres (m), mass in kilograms (kg), time in seconds (s), and (from Chapter 4) electric current in amperes (A) and temperature in kelvin (K, Chapter 2). **Scalars** have magnitude only (distance, speed, mass, energy, temperature, pressure, work, power); **vectors** have magnitude *and* direction (displacement, velocity, acceleration, force, momentum, weight). Two vector quantities of the same type can only be combined correctly if their directions are taken into account — this is the key difference between scalar and vector arithmetic, explored fully in Section 1.4.

SI prefixes: nano (n) $= 10^{-9}$; micro (μ) $= 10^{-6}$; milli (m) $= 10^{-3}$; centi (c) $= 10^{-2}$; kilo (k) $= 10^{3}$; mega (M) $= 10^{6}$; giga (G) $= 10^{9}$. E.g. 1 km $= 1000$ m, 1 mm $= 0.001$ m, 1 cm^3 $= 1 \times 10^{-6}$ m^3 (be careful: volume conversions cube the length-conversion factor).

Measuring length: a metre rule reads to the nearest mm; a **vernier caliper** reads to 0.1 mm (0.01 cm) and is used for the external/internal size of small objects; a **micrometer screw gauge** reads to 0.01 mm and is used for very small diameters (e.g. wire thickness). **Measuring time:** a stopwatch (reaction-time error typically ± 0.2 s to ± 0.5 s); for short/repeated intervals, timing multiple oscillations (e.g. 20 swings of a pendulum) and dividing by the number of oscillations reduces the percentage error caused by human reaction time. **Measuring volume:** a regular solid's volume is calculated from its measured dimensions (e.g. a cuboid: $V = l \times w \times h$); an irregular solid's volume is found by the **displacement method** — the rise in level when it is fully submerged in a measuring cylinder of liquid equals its volume.

Derived units are combinations of base units: speed $=$ distance/time has units m/s; density $=$ mass/volume has units kg/m^3; force $=$ mass $\times$ acceleration has units kg $\cdot$ m/s^2, given the special name newton (N). **Precision and significant figures:** every measurement is only as precise as the least precise instrument or reading used to obtain it — a calculated answer should never be quoted to more significant figures than the least precise piece of data used in the calculation (e.g. if a length is measured to 2 significant figures, an area or volume calculated from it should also be quoted to about 2 significant figures, not to the 8 digits shown on a calculator display).



A vernier caliper's sliding scale has 10 divisions spanning 9 mm of the main scale, so each vernier division is 0.1 mm smaller than a main-scale division — the vernier division that lines up exactly with a main-scale mark gives the second decimal place (in mm) of the reading.

Ví dụ 1 · Reading a vernier caliper and a micrometer

(a) A vernier caliper's main scale reads 23 mm just before the 0 of the vernier scale, and the 4th vernier division lines up exactly with a main-scale mark. Find the reading.
(b) A micrometer screw gauge's main (sleeve) scale reads 5.5 mm and the thimble scale reads 27 divisions, where each thimble division $= 0.01$ mm. Find the reading.

(a) Vernier reading $= 23\,\text{mm} + (4 \times 0.1\,\text{mm}) = 23.0 + 0.4 = 23.4$ mm.
(b) Micrometer reading $= 5.5 + (27 \times 0.01) = 5.5 + 0.27 = 5.77$ mm.

GIẢI THÍCH TIẾNG VIỆT

VN

Thước cặp (vernier caliper) đọc chính xác tới 0.1 mm: đọc vạch chính ngay trước vạch 0 của du xích, sau đó tìm vạch du xích trùng khít với một vạch trên thước chính để lấy chữ số thập phân. Panme (micrometer) đọc chính xác tới 0.01 mm: cộng số đọc trên thang ống (mm) với số đọc trên thang tròn nhân 0.01 mm. Với thể tích vật rắn không đều, dùng **phương pháp đo thể tích chất lỏng bị chiếm chỗ**: nhúng chìm vật vào ống đong, độ dâng mực nước chính là thể tích vật. Đơn vị dẫn xuất (như m/s, kg/m^3, N) được tạo từ các đơn vị cơ bản; kết quả tính toán không nên viết nhiều chữ số có nghĩa hơn số liệu đo ban đầu.

1.1.1 Experimental Uncertainty and Good Practice

Khái niệm cốt lõi

Every measurement carries some uncertainty. A **systematic error** shifts every reading by the same amount, in the same direction (e.g. a ruler with a worn end, a top-pan balance that is not zeroed correctly, or consistently reading a scale from the same wrong angle) — repeating the measurement and averaging *does not* reduce a systematic error, because every repeat is shifted by the same fixed amount; it can only be removed by correcting the instrument or method (e.g. re-zeroing the balance, or subtracting a known zero-error). A **random error** causes readings to scatter unpredictably above and below the true value (e.g. the observer's varying reaction time when starting/stopping a stopwatch, or slightly different by-eye judgements of a needle position) — taking **repeat readings and calculating a mean** reduces the effect of random error on the final result, because the scatter tends to average out.

Choosing an instrument of appropriate precision: always select the measuring instrument whose precision matches the size of the quantity being measured — a vernier caliper or micrometer (Section 1.1) is far more appropriate than a metre rule for the diameter of a wire or small ball bearing. **Avoiding parallax error:** when reading the position of a pointer against a scale (e.g. a ruler, a balance needle, or the meniscus of a liquid in a measuring cylinder), the eye must be positioned exactly in line with the pointer and perpendicular to the scale — otherwise the reading appears to shift depending on the viewing angle (*parallax error*, a systematic error if the observer always views from the same wrong angle). Using a **set-square** held upright against the ruler, or a **fiducial marker** (a fixed pointer or pin placed exactly at the object's edge) held at eye level, forces the eye into the correct line of sight and removes this error.

Percentage uncertainty $= \dfrac{\text{absolute uncertainty}}{\text{measured value}} \times 100\%$. For a repeated or divided measurement (e.g. timing n identical oscillations and dividing by n to get the period of one oscillation), the *same fixed absolute* timing uncertainty becomes a much smaller *percentage* of the (larger) total time, so dividing by a large n reduces the percentage uncertainty in the final single-oscillation value.

Ví dụ mẫu · Timing a pendulum for greater precision

A student uses a stopwatch with a reaction-time uncertainty of ± 0.3 s on any single stopped reading. She first times one swing of a pendulum directly, obtaining 1.8 s; she then times 25 complete swings together, obtaining a total of 45.0 s. For each method, find the period of one swing and the percentage uncertainty in that period, and compare.

Timing 1 swing: $T = 1.8$ s. Percentage uncertainty $= \dfrac{0.3}{1.8} \times 100\% = 16.7\%$.

Timing 25 swings: $T = \dfrac{45.0}{25} = 1.80$ s (the same period, as expected). The same ± 0.3 s reaction-time uncertainty now applies to the *total* time of 45.0 s, so the uncertainty in the period itself is only $\dfrac{0.3}{25} = \pm 0.012$ s, giving a percentage uncertainty of $\dfrac{0.012}{1.80} \times 100\% = 0.67\%$. Timing many oscillations together reduces the percentage uncertainty from about 17% to under 1%, without needing a more precise stopwatch.

GIẢI THÍCH TIẾNG VIỆT

VN

Sai số hệ thống (systematic error) làm mọi lần đo lệch cùng một lượng, cùng một hướng (ví dụ cân chưa chỉnh về 0) — lấy trung bình **không** khắc phục được, phải hiệu chỉnh dụng cụ/phương pháp. Sai số ngẫu nhiên (random error) làm các lần đo dao động ngẫu nhiên quanh giá trị thật (ví dụ thời gian phản xạ khi bấm đồng hồ) — đo lặp lại nhiều lần rồi lấy **trung bình** sẽ giảm ảnh hưởng của sai số ngẫu nhiên. Cần chọn dụng cụ đo có độ chính xác phù hợp với đại lượng cần đo, và dùng ê-ke hoặc vật đánh dấu cố định (fiducial marker) đặt ngang tầm mắt để tránh **sai số thị sai (parallax)** khi đọc thước hoặc mực chất lỏng. Khi đo thời gian một dao động ngắn (như con lắc đơn), nên đo tổng thời gian của nhiều dao động (ví dụ 20–25 dao động) rồi chia cho số dao động — sai số tuyệt đối của đồng hồ bấm giờ không đổi, nhưng khi chia cho số dao động lớn thì sai số phần trăm của chu kỳ giảm đi rất nhiều.

1.2 Motion

Khái niệm cốt lõi

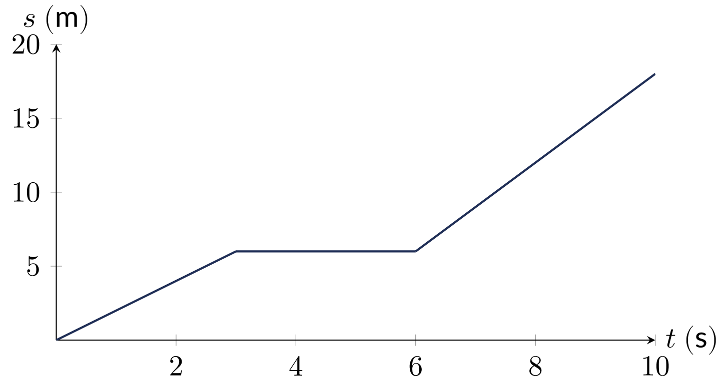
Speed $= \dfrac{\text{distance}}{\text{time}}$ (a scalar). **Velocity** is speed in a stated direction (a vector) — average velocity $= \dfrac{\text{displacement}}{\text{time}}$. **Acceleration** is the rate of change of velocity: $a = \dfrac{v-u}{t}$, where u is initial velocity and v is final velocity. A negative value of a (when $v < u$) represents **deceleration**.

On a **distance–time graph**, the gradient is speed (a horizontal line means the object is at rest, and a curved line means the speed is changing). On a **speed–time graph**, the gradient is acceleration and the **area under the graph** is the distance travelled; a horizontal line means constant speed (zero acceleration), and a straight sloped line means uniform (constant) acceleration.

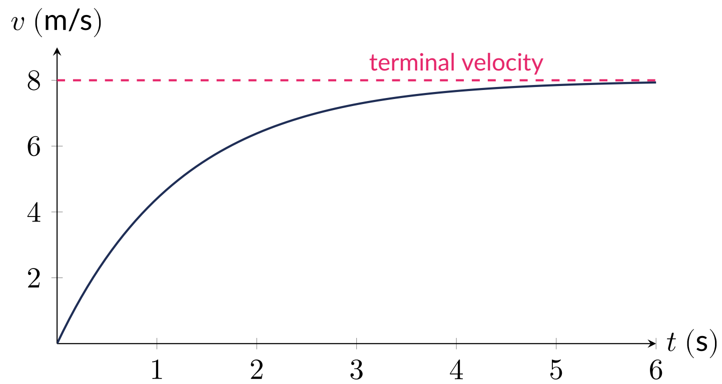
GIẢI THÍCH TIẾNG VIỆT

VN

Tốc độ = quãng đường / thời gian (đại lượng vô hướng). Vận tốc là tốc độ theo một hướng xác định (đại lượng có hướng). Trên đồ thị quãng đường–thời gian, **độ dốc** chính là tốc độ; trên đồ thị vận tốc–thời gian, **độ dốc** là gia tốc và **diện tích dưới đồ thị** là quãng đường đi được. Gia tốc âm (khi $v < u$) nghĩa là vật đang **giảm tốc**.



A distance–time graph: a constant non-zero gradient means constant speed (here $2\,\text{m/s}$ for 0–3 s); a zero gradient (flat section, 3–6 s) means the object is at rest; the steeper straight-line gradient from 6–10 s ($3\,\text{m/s}$) means a greater constant speed. A curved distance–time graph (not shown here) would indicate a continuously changing speed, i.e. acceleration.



A falling object accelerates fastest at first (weight $>$ air resistance); as speed grows, air resistance grows too, so acceleration falls to zero once air resistance $=$ weight — the object then falls at constant **terminal velocity**.

(Supplement) For *uniform* acceleration: $v = u + at$, $s = \dfrac{(u+v)}{2}t$, $s = ut + \frac{1}{2}at^2$, $v^2 = u^2 + 2as$. Each links only four of the five quantities (s, u, v, a, t) — identify the three you know and the one you want, then pick the equation that omits the fifth.

Equation	Use when …	Missing quantity
$v = u + at$	you know u, a, t and want v (no distance given)	s
$s = \dfrac{(u+v)}{2}t$	you know u, v, t and want s (no acceleration given)	a
$s = ut + \frac{1}{2}at^2$	you know u, a, t and want s (final velocity not given)	v
$v^2 = u^2 + 2as$	you know u, a, s and want v, with **no time** given	t

(Supplement) Choosing the correct SUVAT equation: identify which of the five quantities (s, u, v, a, t) is *not* mentioned in the question, and use the one equation that omits it.

Ví dụ 2 · Uniform acceleration from rest

A cyclist accelerates uniformly from rest to $8.0\,\text{m/s}$ in $4.0\,\text{s}$. Find the acceleration and the distance covered.

$a = \dfrac{v-u}{t} = \dfrac{8.0-0}{4.0} = 2.0\,\text{m/s}^2$. $\quad s = \dfrac{(u+v)}{2}t = \dfrac{0+8.0}{2}(4.0) = 16\,\text{m}$.

Ví dụ 3 · Free fall

A stone is dropped from rest and falls for $3.0\,\text{s}$ before hitting the ground (ignore air resistance, $g = 10\,\text{m/s}^2$). Find its speed and the distance fallen.

$v = u + at = 0 + (10)(3.0) = 30\,\text{m/s}$. $\quad s = \frac{1}{2}at^2 = \frac{1}{2}(10)(3.0)^2 = 45\,\text{m}$.

(!) Lỗi thường gặp: In the *absence* of air resistance, all objects — regardless of mass — fall with the **same acceleration** g: a heavier object has more weight (more force), but also proportionally more mass (more inertia to accelerate), and $a = \dfrac{F}{m} = \dfrac{mg}{m} = g$ cancels the mass entirely. The common belief that "heavier objects fall faster" only *appears* true in air, because air resistance affects light, low-density objects (e.g. a feather or a sheet of paper) proportionally far more than dense, heavy ones — it is not a fundamental property of free fall itself.

(!) Lỗi thường gặp: A horizontal line on a speed–time graph means **constant speed** (zero acceleration) — it does *not* mean the object is at rest. Only a horizontal line on a **distance–time** graph means the object is stationary. Also, a straight (non-horizontal) line on a distance–time graph means *constant speed*, not constant acceleration — constant acceleration gives a *curved* distance–time graph.

1.3 Mass, Weight and Density

Mass (m, kg) is the amount of matter in an object, measured with a balance — it is the same everywhere in the universe. **Weight** (W, N) is the force of gravity on that mass: $W = mg$, where g is the gravitational field strength, measured with a spring balance (newtonmeter). Weight changes with location (e.g. $g_{\text{Moon}} \approx 1.6\,\text{N/kg}$, about one-sixth of Earth's) even though mass does not.

Density: $\rho = \dfrac{m}{V}$ (units kg/m^3 or g/cm^3; $1\,\text{g/cm}^3 = 1000\,\text{kg/m}^3$). An object floats in a fluid of greater density and sinks in a fluid of lower density than itself; a floating object displaces a weight of fluid equal to its own weight. Two immiscible liquids of different density settle into layers with the denser liquid at the bottom.

Material	Density (g/cm^3)	Density (kg/m^3)
Air (at sea level)	0.0012	1.2
Ice	0.92	920
Water	1.0	1000
Aluminium	2.7	2700
Steel (iron)	7.9	7900
Lead	11.3	11300
Gold	19.3	19300

Typical densities of common materials. Any object denser than the fluid surrounding it sinks in that fluid; anything less dense floats — this is why ice ($0.92\,g/cm^3$) floats in water ($1.0\,g/cm^3$), and why a steel ship floats when shaped into a hollow hull, despite steel itself being far denser than water.

Ví dụ 4 · Density of a regular solid

A metal block has mass 540 g and volume $200\,cm^3$. Find its density.

$\rho = \frac{m}{V} = \frac{540}{200} = 2.7\,g/cm^3 = 2700\,kg/m^3$.

Ví dụ 5 · Density of an irregular solid by displacement

A stone of mass 158 g is lowered into a measuring cylinder containing $60\,cm^3$ of water; the water level rises to $80\,cm^3$. Find the stone's density, and state whether it would float in a liquid of density $2.5\,g/cm^3$.

Volume of stone $= 80 - 60 = 20\,cm^3$. $\rho = \frac{158}{20} = 7.9\,g/cm^3$.

Since $7.9 > 2.5\,g/cm^3$, the stone is denser than the liquid, so it would **sink**.

Ví dụ 6 · Weight on Earth and the Moon

An astronaut has mass 70 kg. Find her weight on Earth ($g = 10\,N/kg$) and on the Moon ($g = 1.6\,N/kg$).

Earth: $W = mg = (70)(10) = 700\,N$. Moon: $W = (70)(1.6) = 112\,N$ — her *mass* is unchanged.

(!) Lỗi thường gặp: Do not confuse **mass** (kg, the amount of matter in an object, unaffected by location, measured with a balance) with **weight** (N, the force of gravity acting on that mass, $W = mg$, which *does* change with location, measured with a spring balance). Colloquial phrases like "how heavy" or "how much does it weigh" refer to weight, but everyday scales at home are calibrated to display mass in kg (assuming g on Earth) — physics answers must keep the two quantities, and their units (kg vs N), strictly separate.

GIẢI THÍCH TIẾNG VIỆT

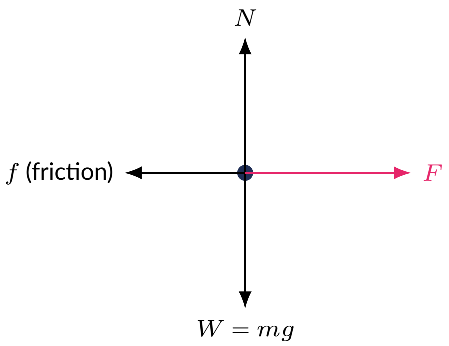
VN

Khối lượng không đổi ở mọi nơi, nhưng trọng lượng $W = mg$ phụ thuộc vào cường độ trường hấp dẫn g tại vị trí đó — vì vậy một phi hành gia có cùng khối lượng trên Mặt Trăng nhưng trọng lượng chỉ bằng khoảng $1/6$ so với trên Trái Đất. Khối lượng riêng $\rho = m/V$ quyết định vật nổi hay chìm khi so với chất lỏng xung quanh; với vật rắn không đều, thể tích được đo bằng phương pháp chiếm chỗ chất lỏng. Cần phân biệt rõ ràng khối lượng (kg, không đổi) và trọng lượng (N, phụ thuộc vị trí) — đây là lỗi rất phổ biến của học sinh.

1.4 Forces, Newton's Laws and Hooke's Law

A resultant force acting on an object can change its **speed**, change its **direction** of motion, and/or change its **shape** (stretch, compress, bend, or twist it) — often several of these together. **Friction** is a contact force that opposes relative sliding between two touching surfaces; **air resistance** (drag) is a similar opposing force exerted by air (or any fluid) on an object moving through it, and it increases as speed increases. Both friction and air resistance transfer kinetic energy to thermal energy (and sometimes sound), and both always act in the direction opposing the (relative) motion or attempted motion.

> **1st law:** an object stays at rest or moves at constant velocity unless a resultant (net) force acts on it. **2nd law:** $F = ma$ (resultant force = mass $\times$ acceleration). **3rd law:** if A exerts a force on B, B exerts an equal and opposite force on A, acting on *different* objects (so the pair never cancels each other out for a single object).



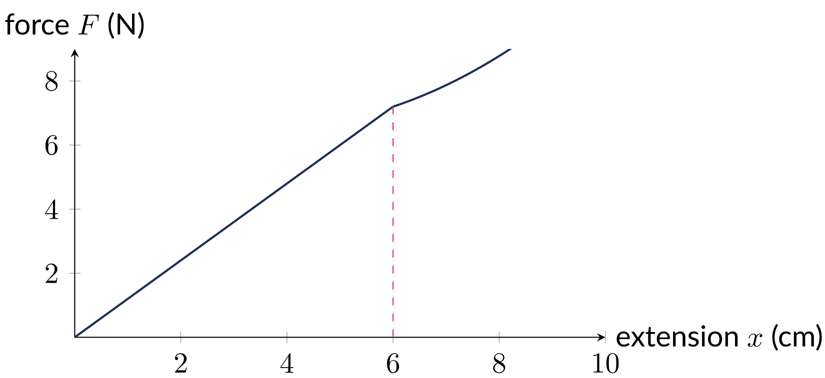
Free-body diagram of a block pulled across a rough horizontal surface: normal force N, weight W, applied force F, and friction f opposing relative sliding. If $F > f$ the block accelerates; if $F = f$ it moves at constant velocity (1st law) or stays at rest.

Ví dụ 7 · Newton's second law

A resultant force of 15 N acts on a 3.0 kg trolley. Find its acceleration.

$a = \dfrac{F}{m} = \dfrac{15}{3.0} = 5.0\,\text{m/s}^2$.

Hooke's law: the extension of a spring is proportional to the applied force, $F = kx$, up to the *limit of proportionality*, where k is the spring constant (units N/m). Beyond this limit, the spring extends more per newton of force and may not return to its original length when the force is removed (it has been permanently, or *plastically*, deformed, rather than *elastically* deformed).



Force–extension graph for a spring: a straight line through the origin (extension $\propto$ force) up to the limit of proportionality, then a curve of decreasing gradient beyond it.

Ví dụ 8 · Hooke's law

A spring with spring constant $k = 50\,\text{N/m}$ is stretched by a force of $10\,\text{N}$, within its limit of proportionality. Find the extension.

$x = \dfrac{F}{k} = \dfrac{10}{50} = 0.20\,\text{m} = 20\,\text{cm}$.

(!) Lỗi thường gặp: Newton's third law pairs act on **two different objects** and are always the *same type* of force (e.g. both gravitational, or both contact/normal forces) — they can never be used to explain why a *single* object is in equilibrium. A table pushing up on a book (normal force) and the book's weight pulling it down are *not* a Newton's-third-law pair (different objects would be required, e.g. Earth pulling the book down and book pulling Earth up); they merely happen to be equal in size because the book is in equilibrium.

VN **GIẢI THÍCH TIẾNG VIỆT**

Định luật 1 Newton: vật giữ nguyên trạng thái (đứng yên hoặc chuyển động thẳng đều) khi lực hợp bằng 0 (các lực cân bằng), **không phải là không có lực nào tác dụng**. Định luật 2: $F = ma$ áp dụng cho **lực hợp**. Định luật 3: cặp lực luôn tác dụng lên **hai vật khác nhau** nên không triệt tiêu nhau — dễ nhầm với hai lực cân bằng tác dụng lên **cùng một vật** (ví dụ: phản lực và trọng lực của một cuốn sách trên bàn, đó KHÔNG phải cặp lực định luật 3). Ma sát và lực cản không khí luôn ngược chiều chuyển động và chuyển hóa động năng thành nhiệt.

1.4.1 Stopping Distances: Thinking Distance and Braking Distance

Khái niệm cốt lõi

The distance a vehicle travels before it comes to a complete stop after the driver first notices a hazard is the **stopping distance**: **stopping distance** $=$ **thinking distance** $+$ **braking distance**. **Thinking distance** is the distance travelled at the vehicle's original (constant) speed during the driver's **reaction time** — the interval between seeing the hazard and physically applying the brakes, during which no deceleration has yet occurred. **Braking distance** is the distance travelled once the brakes are applied, while the vehicle decelerates to rest.

Thinking distance $d_{\text{think}} = v \times t_{\text{reaction}}$ — directly **proportional to speed** v for a fixed reaction time, so doubling the speed doubles the thinking distance. Braking distance follows from the work–energy principle ($F_{\text{brake}}\,d_{\text{brake}} = \frac{1}{2}mv^2$ for a roughly constant braking force, so $d_{\text{brake}} \propto v^2$) — **doubling the speed quadruples the braking distance** for the same braking force.

Factors that **increase thinking distance** (increase reaction time): tiredness, alcohol or drugs, illness, and distractions such as using a mobile phone. Factors that **increase braking distance** at a given speed: a wet, icy, or loose road surface (reduces friction/grip between tyres and road); worn tyres or worn brakes; a larger vehicle mass or heavier load (more kinetic energy must be removed for the same braking force); and travelling downhill.

Speed	Thinking distance	Braking distance	Total stopping distance
$10\,\text{m/s}$	$7.0\,\text{m}$	$8.3\,\text{m}$	$15.3\,\text{m}$
$20\,\text{m/s}$	$14\,\text{m}$	$33.3\,\text{m}$	$47.3\,\text{m}$
$30\,\text{m/s}$	$21\,\text{m}$	$75\,\text{m}$	$96\,\text{m}$

Illustrative stopping distances assuming a reaction time of 0.7 s and a constant braking deceleration of $6.0\,\text{m/s}^2$. Thinking distance grows in direct proportion to speed; braking distance grows with the *square* of speed, so it dominates the total stopping distance at higher speeds.

Ví dụ mẫu · Stopping distance calculation

A car travelling at $20\,\text{m/s}$ has a driver reaction time of 0.7 s; the brakes then produce a constant deceleration of $5.0\,\text{m/s}^2$. Find (a) the thinking distance, (b) the braking distance, (c) the total stopping distance.

(a) $d_{\text{think}} = v\,t_{\text{reaction}} = (20)(0.7) = 14\,\text{m}$.

(b) Using $v^2 = u^2 + 2as$ with final speed 0: $0 = 20^2 - 2(5.0)d_{\text{brake}} \Rightarrow d_{\text{brake}} = \dfrac{400}{10} = 40\,\text{m}$.

(c) Total stopping distance $= 14 + 40 = 54\,\text{m}$.

(!) Lỗi thường gặp: Do not assume that doubling a vehicle's speed simply doubles its total stopping distance. **Thinking distance** is directly proportional to speed ($d = vt$), but **braking distance** is proportional to speed *squared* (from $v^2 = 2a\,d_{\text{brake}}$, or equivalently the work–energy principle, since kinetic energy $\propto v^2$) — so doubling the speed roughly **quadruples** the braking distance, making the *total* stopping distance more than double.

VN **GIẢI THÍCH TIẾNG VIỆT**

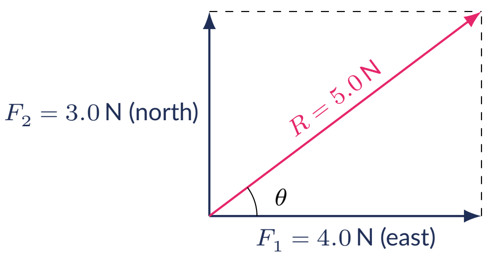
Quãng đường dừng xe $=$ quãng đường phản ứng (thinking distance) $+$ quãng đường phanh (braking distance). Quãng đường phản ứng tỉ lệ **thuận** với tốc độ (do thời gian phản ứng của tài xế không đổi), còn quãng đường phanh tỉ lệ với **bình phương** tốc độ (vì động năng $\propto v^2$) — vì vậy tốc độ tăng gấp đôi thì quãng đường phanh tăng gấp **bốn** lần. Các yếu tố làm tăng quãng đường phản ứng: mệt mỏi, rượu bia, mất tập trung (dùng điện thoại). Các yếu tố làm tăng quãng đường phanh: đường trơn trượt/ướt, lốp hoặc phanh mòn, xe chở nặng, xuống dốc.

1.4.2 Vectors and the Resultant of Forces

When two or more forces act on an object along the **same straight line**, their resultant (net) force is found simply by adding forces acting in one direction and subtracting forces acting in the opposite direction (as already used with Newton's second law above).

When two forces act at an **angle** to each other — most commonly at right angles — their resultant must be found by **vector addition**: draw the two force vectors to scale, tip-to-tail (or, equivalently, complete the parallelogram formed by the two vectors drawn from a common starting point); the single vector from the very start to the very end (the diagonal of the parallelogram) is the resultant, giving both its magnitude and its direction.

For two forces F_1 and F_2 acting at right angles to each other, the resultant has magnitude $R = \sqrt{F_1^2 + F_2^2}$ (Pythagoras' theorem), at an angle $\theta = \tan^{-1}\left(\dfrac{F_2}{F_1}\right)$ measured from the direction of F_1, turned towards F_2.



Parallelogram (tip-to-tail) rule for adding two forces at right angles: complete the rectangle formed by F_1 and F_2; the diagonal from the common starting point is the resultant R, with magnitude $R = \sqrt{F_1^2 + F_2^2}$ and direction $\theta = \tan^{-1}(F_2/F_1)$ measured from the direction of F_1.

Ví dụ 9 · Resultant of two perpendicular forces

A boat's engine pushes it forward with a force of 4.0 N (east) while a current pushes it with a force of 3.0 N (north). Find the magnitude and direction of the resultant force.

$R = \sqrt{F_1^2 + F_2^2} = \sqrt{4.0^2 + 3.0^2} = \sqrt{16 + 9} = \sqrt{25} = 5.0$ N.

$\theta = \tan^{-1}\left(\frac{3.0}{4.0}\right) = \tan^{-1}(0.75) = 36.9^\circ$ north of east.

GIẢI THÍCH TIẾNG VIỆT

VN

Khi hai lực tác dụng theo cùng một đường thẳng, hợp lực tính bằng cách cộng hoặc trừ đại số các lực đó. Khi hai lực hợp với nhau một góc (thường là góc vuông), phải dùng phép cộng vector: vẽ hai vector nối đuôi nhau (hoặc hoàn thành hình bình hành) — vector từ điểm đầu đến điểm cuối chính là hợp lực. Với hai lực vuông góc, độ lớn hợp lực tính bằng định lý Pythagoras $R = \sqrt{F_1^2 + F_2^2}$, hướng tính bằng $\tan\theta = F_2/F_1$ so với hướng của F_1.

1.4.3 Circular Motion (Supplement)

Khái niệm cốt lõi

(Supplement) An object moving in a circle at **constant speed** is still **accelerating**, because its **velocity** (a vector) is continuously changing **direction**, even though its magnitude (speed) stays the same. This acceleration — and therefore the resultant (net) force needed to produce it, called the **centripetal force** — points towards the centre of the circle at every instant, perpendicular to the object's velocity. Because this force is always perpendicular to the motion, it does *no work* on the object, so the object's speed and kinetic energy remain constant throughout the motion.

Everyday examples: friction between the tyres and the road provides the centripetal force needed for a car to go round a bend; tension in a string provides it for a ball being swung in a horizontal circle; gravitational attraction provides it for a satellite orbiting a planet. If the centripetal force is suddenly removed (e.g. the string snaps), the object does *not* fly radially outward — by Newton's first law, with no resultant force acting, it travels in a straight line at constant speed, along the tangent to the circle at the point where the force was removed.

GIẢI THÍCH TIẾNG VIỆT

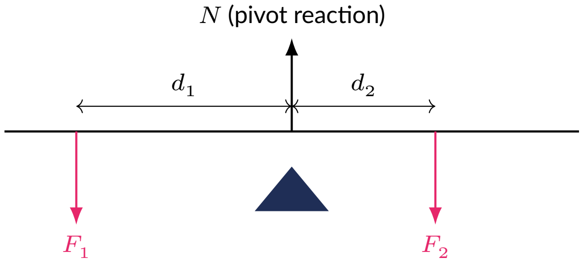
VN

(Supplement) Một vật chuyển động tròn đều (tốc độ không đổi) vẫn có gia tốc, vì vận tốc (đại lượng vector) liên tục đổi hướng dù độ lớn (tốc độ) không đổi. Gia tốc này hướng vào tâm đường tròn, nên lực hướng tâm (lực hợp tác dụng lên vật) cũng luôn hướng vào tâm và vuông góc với vận tốc tại mọi thời điểm — do đó không sinh công và không làm thay đổi tốc độ hay động năng của vật. Ví dụ: ma sát giữa lốp xe và mặt đường khi xe vào cua, lực căng dây khi quay một vật buộc dây, lực hấp dẫn giữ vệ tinh quay quanh hành tinh. Nếu lực hướng tâm biến mất đột ngột (ví dụ dây đứt), vật sẽ bay theo đường thẳng **tiếp tuyến** với quỹ đạo tại thời điểm đó (theo định luật 1 Newton), chứ không bay thẳng ra ngoài theo phương bán kính.

1.4.4 Moments and Equilibrium

The **moment** (turning effect) of a force about a pivot is $M = F \times d$, where d is the *perpendicular* distance from the pivot to the line of action of the force (unit: N·m). A larger force, or a larger perpendicular distance, produces a bigger turning effect — this is why long spanners and door handles placed far from the hinge require less force to turn.

> **Principle of moments:** an object is in **rotational equilibrium** when the sum of clockwise moments about any pivot equals the sum of anticlockwise moments about that same pivot. An object is in full (static) equilibrium when *both* (a) the resultant force is zero and (b) the resultant moment is zero. The **centre of mass** is the single point where an object's entire weight may be considered to act; an object is more **stable** (harder to topple) when it has a **low** centre of mass and a **wide** base, because its weight line then stays within the base over a larger range of tilt.



A uniform beam pivoted at its centre of mass: it balances when the anticlockwise moment $F_1 d_1$ equals the clockwise moment $F_2 d_2$.

Ví dụ 10 · Principle of moments

(a) A 600 N child sits 1.5 m from the pivot of a uniform seesaw. Find the distance from the pivot at which a 450 N child must sit on the other side to balance it.
(b) A uniform plank pivoted at its centre carries a 20 N weight at 0.80 m from the pivot on the left, and two weights on the right: 8.0 N at 0.50 m and an unknown weight W at 1.0 m. Find W for balance.

(a) Anticlockwise moment = clockwise moment: $(600)(1.5) = (450)(d) \Rightarrow d = \dfrac{900}{450} = 2.0$ m.
(b) Anticlockwise (left) moment $= (20)(0.80) = 16$ N · m. Clockwise (right) moments must sum to 16 N · m: $(8.0)(0.50) + W(1.0) = 16 \Rightarrow 4.0 + W = 16 \Rightarrow W = 12$ N.

> **(!) Lỗi thường gặp:** When applying the principle of moments, every moment must be taken about the **same pivot**, and you must be consistent about which sense of rotation (clockwise or anticlockwise) you treat as positive. A force whose line of action passes exactly through the chosen pivot has **zero** perpendicular distance from it and therefore contributes **zero** moment about that pivot, no matter how large the force itself is.

Ví dụ mẫu · Principle of moments (unknown distance)

A uniform plank pivoted off-centre is held in rotational equilibrium by two downward forces: 40 N acting 0.50 m to the left of the pivot, and 80 N acting on the right side of the pivot. Find the distance from the pivot at which the 80 N force must act.

Anticlockwise moment (left side) $= (40)(0.50) = 20$ N · m. For equilibrium, the clockwise moment (right side) must equal this:
$(80)\,d = 20 \Rightarrow d = \dfrac{20}{80} = 0.25$ m.

GIẢI THÍCH TIẾNG VIỆT

VN

Mô-men lực $M = F \times d$, với d là khoảng cách **vuông góc** từ trục quay đến giá của lực. Nguyên lý mô-men: tổng mô-men theo chiều kim đồng hồ bằng tổng mô-men ngược chiều kim đồng hồ khi vật cân bằng quay, và tất cả mô-men phải được tính quanh **cùng một trục**. Vật có trọng tâm **càng thấp** và đế **càng rộng** thì càng **ổn định**, khó bị lật đổ hơn.

1.5 Momentum (Supplement)

Khái niệm cốt lõi

Momentum: $p = mv$ (kg·m/s), a vector in the direction of v. For an isolated (closed) system, **total momentum is conserved**: momentum before = momentum after any collision or explosion. **Impulse:** $F\Delta t = \Delta p$ — force × time = change in momentum; this is why extending the contact time (e.g. airbags, crumple zones, bending your knees on landing) reduces the peak force for a given change in momentum.

Ví dụ 11 · Conservation of momentum

A 2.0 kg trolley moving at 3.0 m/s collides and sticks to a stationary 1.0 kg trolley. Find their common velocity after impact.

$p_{\text{before}} = (2.0)(3.0) + 0 = 6.0\,\text{kg}\cdot\text{m/s}$. $\quad v = \dfrac{6.0}{2.0 + 1.0} = 2.0\,\text{m/s}$.

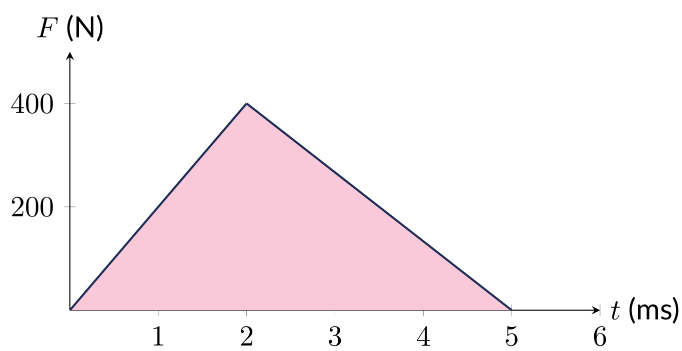
GIẢI THÍCH TIẾNG VIỆT

VN

Động lượng của một hệ kín (không có ngoại lực) luôn được bảo toàn: tổng động lượng trước va chạm bằng tổng động lượng sau va chạm, dù va chạm là mềm (dính vào nhau) hay đàn hồi, hay là một vụ nổ (từ đứng yên tách thành hai phần chuyển động ngược chiều). Cần chọn một chiều dương và gán dấu $+/-$ cho vận tốc trước khi cộng — quên dấu âm cho vật chuyển động ngược chiều là lỗi rất phổ biến. Xung lực $F\Delta t = \Delta p$ giải thích vì sao kéo dài thời gian va chạm (túi khí, uốn gối khi tiếp đất) làm giảm lực tác dụng lên cơ thể.

1.5.1 Impulse and Force–Time Graphs (Supplement)

(Supplement) Impulse $= F\Delta t = \Delta p$ (units N · s, equivalent to kg · m/s). On a graph of force against time, the **area under the graph** represents the impulse delivered — and therefore the change in momentum produced — even when the force is not constant throughout the impact.



A typical impact force–time graph (e.g. a ball being struck, or a car's crumple zone deforming): force rises rapidly, peaks, then falls back to zero. The shaded **area** under the graph equals the impulse $F\Delta t = \Delta p$ delivered during the impact.

Ví dụ mẫu · Impulse from a force–time graph

(Supplement) During a collision lasting 8.0 ms, the force on a hockey puck of mass 0.17 kg (initially at rest) rises uniformly from 0 to a peak of 300 N over the first 3.0 ms, then falls uniformly back to 0 over the remaining 5.0 ms. Find (a) the impulse delivered (the area of the triangular force–time graph), (b) the puck's speed immediately after being struck.

(a) Impulse $=$ area of triangle $= \frac{1}{2} \times$ base $\times$ height $= \frac{1}{2}(8.0 \times 10^{-3})(300) = 1.2$ N · s.

(b) Since impulse $= \Delta p = mv - mu$ and $u = 0$: $1.2 = (0.17)v \Rightarrow v = \dfrac{1.2}{0.17} = 7.1$ m/s (to 2 s.f.).

GIẢI THÍCH TIẾNG VIỆT

VN (Supplement) Xung lực $F\Delta t = \Delta p$ — trên đồ thị lực theo thời gian, **diện tích** dưới đồ thị chính là xung lực (độ biến thiên động lượng), kể cả khi lực thay đổi theo thời gian trong suốt va chạm (không phải hằng số). Đây là lý do túi khí, đệm giảm chấn, hoặc vùng biến dạng (crumple zone) của xe hơi kéo dài thời gian va chạm Δt để giảm lực đỉnh F tác dụng lên người, với cùng một độ biến thiên động lượng Δp cần tạo ra.

1.5.2 Elastic and Inelastic Collisions (Supplement)

Khái niệm cốt lõi

(Supplement) In *any* collision (or explosion) within an isolated system, **momentum is always conserved**. Collisions are further classified by what happens to **kinetic energy**: in an **elastic collision**, total kinetic energy is also conserved (KE before = KE after) — the objects separate again after impact, without any permanent change of shape. In an **inelastic collision**, momentum is still conserved, but total kinetic energy is *not* conserved: some kinetic energy is transferred to other energy stores, such as thermal energy (heat), sound, and the energy needed to permanently deform the colliding objects. A collision in which the objects stick together and move with a common final velocity (as in Ví dụ 11) is an extreme case of an inelastic collision, called a **perfectly inelastic collision**.

Ví dụ mẫu · Elastic collision (equal masses)

(Supplement) A trolley A of mass 2.0 kg moving at 5.0 m/s collides elastically with an identical stationary trolley B of mass 2.0 kg. After the collision, A is at rest and B moves off at 5.0 m/s. Verify that both momentum and kinetic energy are conserved.

Momentum: before $= (2.0)(5.0) + (2.0)(0) = 10$ kg · m/s; after $= (2.0)(0) + (2.0)(5.0) = 10$ kg · m/s — conserved.
Kinetic energy: before $= \frac{1}{2}(2.0)(5.0)^2 + 0 = 25$ J; after $= 0 + \frac{1}{2}(2.0)(5.0)^2 = 25$ J — also conserved, confirming the collision is **elastic**. (This exchange of velocities is a general feature of a head-on elastic collision between two objects of *equal* mass, one of which is initially at rest.)

Ví dụ mẫu · Inelastic collision and energy loss

(Supplement) A trolley of mass 3.0 kg moving at 8.0 m/s collides and sticks to a stationary trolley of mass 1.0 kg. Find the common velocity after the collision, and show that kinetic energy is not conserved.

Momentum: $(3.0)(8.0) + 0 = 24\,\text{kg}\cdot\text{m/s}$. $v = \dfrac{24}{3.0+1.0} = 6.0\,\text{m/s}$.
KE before $= \frac{1}{2}(3.0)(8.0)^2 = 96\,\text{J}$. KE after $= \frac{1}{2}(3.0+1.0)(6.0)^2 = \frac{1}{2}(4.0)(36) = 72\,\text{J}$.
KE lost $= 96 - 72 = 24\,\text{J}$ (transferred to heat and sound as the trolleys deform and couple together) — momentum is conserved ($24\,\text{kg}\cdot\text{m/s}$ before and after) but kinetic energy is **not**, confirming the collision is **inelastic**.

(!) Lỗi thường gặp: **Momentum is always conserved** in a collision (provided no external resultant force acts), **but kinetic energy is only conserved if the collision is elastic**. Do not assume $\Delta E_k = 0$ automatically just because momentum is conserved — check whether the question describes the collision as elastic, or calculate KE before and after separately to check. Two objects that stick together after colliding can *never* do so elastically (kinetic energy is always lost whenever objects permanently deform or fuse together on impact).

VN GIẢI THÍCH TIẾNG VIỆT

(Supplement) Động lượng luôn được bảo toàn trong va chạm (khi không có ngoại lực), nhưng động năng chỉ được bảo toàn nếu va chạm là **va chạm đàn hồi** (elastic) — động năng trước và sau va chạm bằng nhau, hai vật tách rời sau va chạm. Trong **va chạm không đàn hồi** (inelastic), động lượng vẫn bảo toàn nhưng động năng giảm, phần năng lượng mất đi chuyển thành nhiệt, âm thanh, hoặc làm biến dạng vật. Va chạm mà hai vật dính vào nhau (như Ví dụ 11) là trường hợp đặc biệt gọi là va chạm **hoàn toàn không đàn hồi**. Lỗi phổ biến: học sinh nhầm tưởng động năng luôn bảo toàn giống như động lượng — cần kiểm tra đề bài có nói "đàn hồi" hay không, hoặc tính động năng trước/sau để kiểm chứng.

1.6 Energy, Work, Power and Energy Resources

Energy cannot be created or destroyed, only transferred or transformed between stores (kinetic, gravitational potential, elastic, chemical, thermal/internal, nuclear, ...) — this is the **principle of conservation of energy**. **Work done** $W = Fd$ (force × distance moved in the direction of the force); doing work on an object transfers energy to it.

Gravitational PE: $E_p = mgh$. **Kinetic energy:** $E_k = \frac{1}{2}mv^2$. **Power:** $P = \dfrac{W}{t} = \dfrac{E}{t}$ (watts, J/s). **Efficiency** $= \dfrac{\text{useful energy output}}{\text{total energy input}} \times 100\%$, always less than 100% in practice because some energy is always transferred to (usually unwanted) thermal energy stores.

Ví dụ 12 · Work done and gravitational PE

A crane lifts a $500\,\text{kg}$ load through a height of $10\,\text{m}$. Find the work done (gain in GPE).
$W = mgh = (500)(10)(10) = 50000\,\text{J} = 50\,\text{kJ}$.

Ví dụ 13 · Power and efficiency

A machine does $6000\,\text{J}$ of useful work in $3.0\,\text{s}$, using $9000\,\text{J}$ of electrical energy input. Find the power output and the efficiency.
$P = \dfrac{W}{t} = \dfrac{6000}{3.0} = 2000\,\text{W} = 2.0\,\text{kW}$. Efficiency $= \dfrac{6000}{9000} \times 100\% = 66.7\%$.

1.6.1 The Work–Energy Principle and Power

Work–energy principle: the work done by the *resultant* force on an object equals its change in kinetic energy: $W_{\text{resultant}} = \Delta E_k = \frac{1}{2}mv^2 - \frac{1}{2}mu^2$. This is simply Newton's second law re-expressed in terms of energy, and it is often the fastest route to a distance or a force when **time is not given** (compare with the SUVAT equations of Section 1.2, which all involve time).

Power in terms of force and velocity: since $P = \dfrac{W}{t} = \dfrac{Fd}{t} = F \times \dfrac{d}{t}$, for an object moving at (instantaneous or constant) velocity v in the direction of the force, $P = Fv$.

Ví dụ mẫu · Work–energy principle: braking distance

A car of mass 1000 kg travelling at 25 m/s is brought to rest by a constant resultant braking force of 6250 N. Find the braking distance.

By the work–energy principle, the work done by the resultant (braking) force equals the change in kinetic energy:

$F\,d = \frac{1}{2}mv^2 - \frac{1}{2}mu^2 = 0 - \frac{1}{2}(1000)(25)^2 = -312500$ J (the resultant force acts opposite to the motion, removing kinetic energy).

Taking magnitudes: $(6250)\,d = 312500 \Rightarrow d = \dfrac{312500}{6250} = 50$ m.

Ví dụ mẫu · Power and constant velocity ($P = Fv$)

A lift (elevator) and its load have a total weight of 6000 N. The lift motor raises it at a constant velocity of 1.5 m/s. Find the power developed by the motor (assume no friction, so the driving force equals the weight).

At constant velocity, the driving (upward) force F equals the weight, since the resultant force is zero: $F = 6000$ N.

$P = Fv = (6000)(1.5) = 9000$ W $= 9.0$ kW.

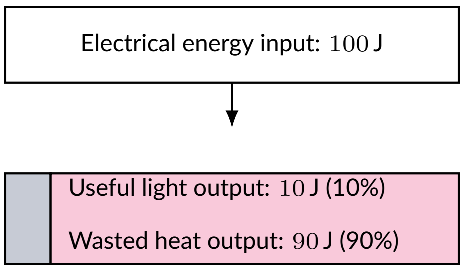
VN GIẢI THÍCH TIẾNG VIỆT

Nguyên lý công–năng lượng: công của **lực hợp** tác dụng lên vật bằng độ biến thiên động năng của vật, $W_{\text{hợp}} = \Delta E_k = \frac{1}{2}mv^2 - \frac{1}{2}mu^2$ — rất hữu ích khi đề bài **không cho thời gian**. Công suất theo lực và vận tốc: vì $P = W/t = Fd/t$ và $d/t = v$, nên $P = Fv$ khi vật chuyển động với vận tốc v theo phương của lực — áp dụng cho xe chuyển động đều hay thang máy nâng vật với vận tốc không đổi.

Energy resources are grouped as **renewable** (replenished as fast as used: solar, wind, hydroelectric, geothermal, tidal, wave, biofuel) and **non-renewable** (finite, being used up far faster than they form: coal, oil, natural gas — the fossil fuels — and nuclear fuel). Fossil fuels and biofuel release energy by combustion; a power station burning fuel boils water to steam, which drives a turbine connected to a generator.

Resource	Type	Key drawback
Coal, oil, natural gas	Non-renewable	CO_2 emissions, finite supply
Nuclear fuel	Non-renewable	Radioactive waste, accident risk
Solar	Renewable	Unavailable at night / low light
Wind	Renewable	Unreliable, needs wind, visual/noise impact
Hydroelectric	Renewable	High set-up cost, floods land
Geothermal	Renewable	Only viable in certain locations

Every energy resource is ultimately used to generate electricity or provide direct heat; all combustion-based resources release stored chemical energy as thermal energy.



Simplified energy-flow (Sankey-style) diagram for a filament lamp: the width of each output band is proportional to the share of the input energy it carries — most of the electrical energy supplied is wasted as heat, and only a small fraction leaves as useful light.

VN **GIẢI THÍCH TIẾNG VIỆT**

Năng lượng không tự sinh ra hay mất đi, chỉ chuyển hóa từ dạng này sang dạng khác — phần "hao phí" thường chuyển thành nhiệt (không mất đi, chỉ không còn hữu ích). Hiệu suất $= \dfrac{\text{năng lượng hữu ích}}{\text{năng lượng đầu vào}} \times 100\%$ luôn nhỏ hơn 100% trong thực tế. Nguồn năng lượng **tái tạo** (mặt trời, gió, thủy điện, địa nhiệt, sóng, thủy triều, nhiên liệu sinh học) được bổ sung liên tục; nguồn **không tái tạo** (than, dầu, khí đốt, nhiên liệu hạt nhân) đang cạn kiệt nhanh hơn tốc độ hình thành. Sơ đồ Sankey biểu diễn dòng năng lượng bằng độ rộng của dải tỉ lệ với lượng năng lượng, giúp hình dung trực quan phần năng lượng hữu ích và phần hao phí.

1.7 Pressure

Pressure: $p = \dfrac{F}{A}$ (pascals, Pa $=$ N/m^2) — the same force spread over a smaller area produces a greater pressure (e.g. a sharp knife or a drawing pin has a very small contact area, so a modest force creates a large pressure; a wide tyre or snowshoe has a large contact area, spreading the same weight over more area to reduce pressure on soft ground). **(Supplement)** Pressure in a liquid: $p = h\rho g$ (depth $\times$ density $\times$ g) — it depends only on depth and density, not on the shape or cross-section of the container, and acts equally in all directions at a given depth.

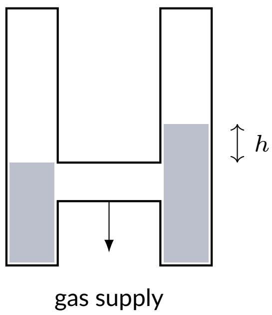
Ví dụ 14 · Pressure of a solid on a surface

A box exerts a force of 200 N over a base area of $0.50\,\text{m}^2$. Find the pressure on the floor.
$p = \dfrac{F}{A} = \dfrac{200}{0.50} = 400$ Pa.

Ví dụ 15 · Liquid pressure and atmospheric pressure

(Supplement) (a) Find the pressure due to a 5.0 m column of water ($\rho = 1000\,\text{kg/m}^3$). (b) Atmospheric pressure at sea level is about 101000 Pa. Find the *total* pressure (liquid + atmosphere) acting on a diver at that depth.
(a) $p = h\rho g = (5.0)(1000)(10) = 50000$ Pa $= 50$ kPa.
(b) Total pressure $= 50000 + 101000 = 151000$ Pa ≈ 151 kPa.

Atmospheric pressure arises from the weight of the column of air above a surface, and decreases with altitude (there is less air, and less dense air, above you as you climb). A simple mercury **barometer** (a mercury-filled tube inverted in a mercury reservoir) measures atmospheric pressure from the height of the mercury column it supports; a **manometer** (a U-tube containing liquid, open to the atmosphere at one end and connected to a gas supply at the other) measures gas pressure from the difference in liquid levels between the two arms. A **hydraulic system** uses an enclosed liquid to transmit pressure equally in all directions (Pascal's principle): a small force on a small piston creates a pressure that acts equally on a larger piston, producing a much larger force there — this is how hydraulic car jacks and hydraulic brakes multiply force.



U-tube manometer: the gas pushes the liquid down on the connected side and up on the open side; the height difference h between the two liquid levels gives the gas pressure *above* atmospheric, $p_{\text{gas}} = p_{\text{atm}} + h\rho g$.

Ví dụ mẫu · Hydraulic lift (force multiplication)

(Supplement) A hydraulic car lift has a small piston of area $8.0\,\text{cm}^2$ and a large piston of area $240\,\text{cm}^2$, connected by an enclosed liquid. A force of 200 N is applied to the small piston. Find the force produced at the large piston.

By Pascal's principle, pressure is transmitted equally through the enclosed liquid: $p = \dfrac{F_1}{A_1} = \dfrac{200}{8.0} = 25\,\text{N/cm}^2$.
This same pressure acts on the large piston: $F_2 = pA_2 = (25)(240) = 6000$ N — the hydraulic lift multiplies the applied force by the ratio of the piston areas, $\dfrac{A_2}{A_1} = 30$.

VN GIẢI THÍCH TIẾNG VIỆT

Áp suất khí quyển do trọng lượng cột không khí phía trên gây ra, giảm dần theo độ cao. Áp kế thủy ngân (barometer) đo áp suất khí quyển; áp kế chữ U (manometer) đo áp suất khí bằng chênh lệch mực chất lỏng hai nhánh: $p_{\text{khí}} = p_{\text{khí quyển}} + h\rho g$. Ở độ sâu h trong chất lỏng, áp suất **tổng** tác dụng lên một vật bằng áp suất khí quyển **cộng** áp suất do cột chất lỏng gây ra. Hệ thống thủy lực dùng chất lỏng kín để truyền áp suất đều theo mọi hướng (nguyên lý Pascal): một lực nhỏ tác dụng lên pittông nhỏ tạo ra áp suất, áp suất này tác dụng lên pittông lớn hơn tạo ra lực lớn hơn nhiều.

1.8 Practice Problems

Bài tập luyện tập

A speed–time graph shows a car accelerating uniformly from 0 to 15 m/s in 5.0 s, then travelling at constant 15 m/s for 10 s, then decelerating uniformly to rest in 3.0 s. Find the total distance travelled.

(A) 210 m
(B) 187.5 m
(C) 195 m
(D) 225 m

Lời giải chi tiết

Distance = total area under the graph: $\frac{1}{2}(5.0)(15)+(15)(10)+\frac{1}{2}(3.0)(15) = 37.5+150+22.5 = 210$ m. **(A)**.

Bài tập luyện tập

A 1200 kg car has a driving force of 3600 N from its engine and a total resistive force of 600 N. Find its acceleration.

Lời giải chi tiết

Resultant force $= 3600 - 600 = 3000$ N. $a = \dfrac{F}{m} = \dfrac{3000}{1200} = \boxed{2.5\,\text{m/s}^2}$.

Bài tập luyện tập

(Supplement) Trolley A (2.0 kg) moves right at 6.0 m/s and collides head-on with trolley B (2.0 kg) moving left at 2.0 m/s. They couple together on impact. Find their common velocity after the collision (take rightward as positive).

Lời giải chi tiết

$p_{\text{before}} = (2.0)(6.0) + (2.0)(-2.0) = 12 - 4 = 8.0$ kg · m/s.

$v = \dfrac{8.0}{2.0 + 2.0} = \boxed{2.0\,\text{m/s}}$ (in A's original direction).

Bài tập luyện tập

An electric motor lifts a 50 kg load through 4.0 m in 5.0 s, using 2500 J of electrical energy. Find (a) the useful work done, (b) the power output, (c) the efficiency.

Lời giải chi tiết

(a) $W = mgh = (50)(10)(4.0) = 2000$ J.
(b) $P = \dfrac{W}{t} = \dfrac{2000}{5.0} = 400$ W.
(c) Efficiency $= \dfrac{2000}{2500} \times 100\% = \boxed{80\%}$.

Bài tập luyện tập

(Supplement) A submarine window of area $0.20\,\text{m}^2$ is at a depth of $50\,\text{m}$ in water of density $1000\,\text{kg/m}^3$. Find (a) the water pressure at that depth, (b) the total force pushing on the window.

Lời giải chi tiết

(a) $p = h\rho g = (50)(1000)(10) = 500000\,\text{Pa} = 500\,\text{kPa}$.
(b) $F = pA = (500000)(0.20) = \boxed{100000\,\text{N} = 100\,\text{kN}}$.

Bài tập luyện tập

A student measures the diameter of a wire with a micrometer screw gauge: the sleeve scale reads $3.0\,\text{mm}$ and the thimble scale reads 42 divisions of $0.01\,\text{mm}$ each. Find the diameter.

(A) $3.42\,\text{mm}$
(B) $3.24\,\text{mm}$
(C) $4.20\,\text{mm}$
(D) $3.052\,\text{mm}$

Lời giải chi tiết

Diameter $= 3.0 + (42 \times 0.01) = 3.0 + 0.42 = 3.42\,\text{mm}$. **(A)**.

Bài tập luyện tập

A rectangular block measures $5.0\,\text{cm} \times 4.0\,\text{cm} \times 2.0\,\text{cm}$ and has mass $312\,\text{g}$. Find its density in g/cm^3 and in kg/m^3.

Lời giải chi tiết

$V = 5.0 \times 4.0 \times 2.0 = 40\,\text{cm}^3$. $\rho = \dfrac{312}{40} = \boxed{7.8\,\text{g/cm}^3 = 7800\,\text{kg/m}^3}$.

Bài tập luyện tập

An irregular metal object of mass $270\,\text{g}$ is lowered into a measuring cylinder, raising the water level from $50\,\text{cm}^3$ to $80\,\text{cm}^3$. Find its density.

(A) $9.0\,\text{g/cm}^3$
(B) $3.4\,\text{g/cm}^3$
(C) $5.4\,\text{g/cm}^3$
(D) $6.75\,\text{g/cm}^3$

Lời giải chi tiết

$V = 80 - 50 = 30\,\text{cm}^3$. $\rho = \dfrac{270}{30} = 9.0\,\text{g/cm}^3$. **(A).**

Bài tập luyện tập

A spring stretches by $15\,\text{cm}$ under a force of $6.0\,\text{N}$, within its limit of proportionality. Find (a) the spring constant, (b) the extension produced by a $10\,\text{N}$ force.

Lời giải chi tiết

(a) $k = \dfrac{F}{x} = \dfrac{6.0}{0.15} = \boxed{40\,\text{N/m}}$.

(b) $x = \dfrac{F}{k} = \dfrac{10}{40} = \boxed{0.25\,\text{m} = 25\,\text{cm}}$.

Bài tập luyện tập

A uniform metre rule is pivoted at its $50\,\text{cm}$ mark (its centre of mass) and balances horizontally when a $3.0\,\text{N}$ weight hangs at the $20\,\text{cm}$ mark and an unknown weight W hangs at the $80\,\text{cm}$ mark. Find W.

(A) $1.0\,\text{N}$

(B) $2.0\,\text{N}$

(C) $3.0\,\text{N}$

(D) $4.5\,\text{N}$

Lời giải chi tiết

Distance of $3.0\,\text{N}$ weight from pivot $= 50 - 20 = 30\,\text{cm}$; distance of W from pivot $= 80 - 50 = 30\,\text{cm}$.
$(3.0)(30) = W(30) \Rightarrow W = 3.0\,\text{N}$. **(C).**

Bài tập luyện tập

A spanner of length $24\,\text{cm}$ is used to turn a nut, with the force applied perpendicular to the spanner at its far end. If a moment of $18\,\text{N}\cdot\text{m}$ is needed to loosen the nut, find the minimum force required.

Lời giải chi tiết

$M = Fd \Rightarrow F = \dfrac{M}{d} = \dfrac{18}{0.24} = \boxed{75\,\text{N}}$.

Bài tập luyện tập

A uniform plank of weight $40\,\text{N}$ and length $4.0\,\text{m}$ rests horizontally on two supports, one at each end. A $60\,\text{N}$ weight is placed $1.0\,\text{m}$ from the left end. Taking moments about the left support, find the force exerted by the right-hand support. (Hint: the plank's own weight acts at its centre, $2.0\,\text{m}$ from each end.)

Lời giải chi tiết

Taking moments about the left support: clockwise moments $= (60)(1.0)+(40)(2.0) = 60+80 = 140\,\text{N}\cdot\text{m}$.
This equals (right support force) × (4.0 m): $R \times 4.0 = 140 \Rightarrow R = \boxed{35\,\text{N}}$.

Bài tập luyện tập

Explain, using the idea of centre of mass and base area, why a Formula 1 racing car (wide, low chassis) is much more stable than a tall, narrow van.

Lời giải chi tiết

The racing car has a very **low** centre of mass and a relatively **wide** wheelbase, so the vertical line through its centre of mass stays within its base (the area enclosed by its wheels) even when it tilts through a large angle — it must tilt a long way before this line falls outside the base and it topples. The tall, narrow van has a **higher** centre of mass and a **narrower** base, so a much smaller tilt angle is enough to move the centre-of-mass line outside the base, making it far easier to topple.

Bài tập luyện tập

A resultant force of $24\,\text{N}$ gives a trolley an acceleration of $4.0\,\text{m/s}^2$. Find the trolley's mass.

(A) $4.0\,\text{kg}$

(B) $6.0\,\text{kg}$

(C) $8.0\,\text{kg}$

(D) $96\,\text{kg}$

Lời giải chi tiết

$m = \dfrac{F}{a} = \dfrac{24}{4.0} = 6.0\,\text{kg}$. **(B)**.

Bài tập luyện tập

(Supplement) A firework of total mass $2.0\,\text{kg}$, initially at rest, explodes into two fragments. One fragment of mass $0.50\,\text{kg}$ moves off at $12\,\text{m/s}$. Find the velocity of the other ($1.5\,\text{kg}$) fragment.

Lời giải chi tiết

Total momentum before $= 0$ (at rest), so total momentum after must also be 0:
$(0.50)(12) + (1.5)v = 0 \Rightarrow 6.0 + 1.5v = 0 \Rightarrow v = \boxed{-4.0\,\text{m/s}}$ (i.e. $4.0\,\text{m/s}$ in the opposite direction to the first fragment).

Bài tập luyện tập

A car of mass $900\,\text{kg}$ travelling at $20\,\text{m/s}$ is brought to rest by its brakes in $4.0\,\text{s}$. Find (a) the change in momentum, (b) the average braking force.

Lời giải chi tiết

(a) $\Delta p = mv - mu = 0 - (900)(20) = \boxed{-18000\,\text{kg}\cdot\text{m/s}}$ (magnitude $18000\,\text{kg}\cdot\text{m/s}$).

(b) $F = \dfrac{\Delta p}{t} = \dfrac{18000}{4.0} = \boxed{4500\,\text{N}}$ (opposing the motion).

Bài tập luyện tập

A ball of mass 0.20 kg falls from a height of 5.0 m. Ignoring air resistance, find its speed just before hitting the ground using energy conservation ($E_p \to E_k$), and check your answer against the free-fall equation $v^2 = u^2 + 2as$.

(A) 7.1 m/s

(B) 10 m/s

(C) 50 m/s

(D) 100 m/s

Lời giải chi tiết

Energy method: $mgh = \frac{1}{2}mv^2 \Rightarrow v = \sqrt{2gh} = \sqrt{2(10)(5.0)} = \sqrt{100} = 10$ m/s. **(B).**
Check via $v^2 = u^2 + 2as = 0 + 2(10)(5.0) = 100 \Rightarrow v = 10$ m/s — consistent, as expected (energy conservation and the kinematics equations describe the same free-fall motion).

Bài tập luyện tập

A 0.50 kg ball moves at 6.0 m/s. Find its kinetic energy.

Lời giải chi tiết

$E_k = \frac{1}{2}mv^2 = \frac{1}{2}(0.50)(6.0)^2 = \frac{1}{2}(0.50)(36) = \boxed{9.0\,\text{J}}$.

Bài tập luyện tập

A gas in a cylinder is connected to a U-tube manometer open to the atmosphere. The liquid in the manometer (density 1000 kg/m^3) is 30 cm higher on the open side than on the gas side. Atmospheric pressure is 101000 Pa. Find the gas pressure.

(A) 98000 Pa

(B) 104000 Pa

(C) 101000 Pa

(D) 131000 Pa

Lời giải chi tiết

Height difference contributes an extra pressure $= h\rho g = (0.30)(1000)(10) = 3000$ Pa above atmospheric (the gas is pushing the liquid down on its own side, so gas pressure = atmospheric + this extra pressure):
$p_{\text{gas}} = 101000 + 3000 = 104000$ Pa. **(B).**

Bài tập luyện tập

An object weighs 50 N on Earth ($g = 10$ N/kg). Find its mass, and its weight on a planet where $g = 4.0$ N/kg.

Lời giải chi tiết

$m = \dfrac{W}{g} = \dfrac{50}{10} = \boxed{5.0\,\text{kg}}$ (unchanged on the other planet).
$W_{\text{planet}} = mg_{\text{planet}} = (5.0)(4.0) = \boxed{20\,\text{N}}$.

Bài tập luyện tập

A block of wood floats in water with 70% of its volume submerged. If its total volume is $200\,\text{cm}^3$, and the density of water is $1.0\,\text{g/cm}^3$, use the fact that a floating object displaces its own weight of liquid to find the mass of the block.

Lời giải chi tiết

Volume of water displaced $= 70\% \times 200 = 140\,\text{cm}^3$, with mass $= 140 \times 1.0 = 140\,\text{g}$ (using $\rho_{\text{water}} = 1.0\,\text{g/cm}^3$).
Since the block floats, its weight equals the weight of water displaced, so its mass $= \boxed{140\,\text{g}}$ (its average density is $140/200 = 0.70\,\text{g/cm}^3$, less than water, consistent with floating).

Bài tập luyện tập

A car accelerates uniformly from $10\,\text{m/s}$ to $25\,\text{m/s}$ over a distance of $175\,\text{m}$. Find the acceleration and the time taken.

Lời giải chi tiết

$v^2 = u^2 + 2as \Rightarrow 25^2 = 10^2 + 2a(175) \Rightarrow 625 = 100 + 350a \Rightarrow a = \dfrac{525}{350} = \boxed{1.5\,\text{m/s}^2}$.
$t = \dfrac{v-u}{a} = \dfrac{25-10}{1.5} = \boxed{10\,\text{s}}$.

Bài tập luyện tập

A uniform see-saw of length $3.0\,\text{m}$ is pivoted at its centre. A $300\,\text{N}$ child sits at one end. How far from the pivot must a $450\,\text{N}$ adult sit, on the other side, to balance the see-saw?

(A) $0.67\,\text{m}$
(B) $1.0\,\text{m}$
(C) $1.5\,\text{m}$
(D) $2.25\,\text{m}$

Lời giải chi tiết

Child's distance from pivot $= 1.5\,\text{m}$ (half of $3.0\,\text{m}$). Anticlockwise moment $= (300)(1.5) = 450\,\text{N}\cdot\text{m}$.
$450 = (450)(d) \Rightarrow d = 1.0\,\text{m}$. **(B)**.

Bài tập luyện tập

A crate of weight $800\,\text{N}$ is pushed up a frictionless ramp of length $5.0\,\text{m}$ that rises to a height of $2.0\,\text{m}$, by a force acting parallel to the ramp. Using energy conservation, find the minimum force needed and the work done.

Lời giải chi tiết

Work done against gravity (gain in GPE) $= W_{\text{weight}} \times h = (800)(2.0) = 1600$ J.
Since the ramp is frictionless, the work done by the pushing force equals this GPE gain: $F \times 5.0 = 1600 \Rightarrow F = \boxed{320\,\text{N}}$; work done $= \boxed{1600\,\text{J}}$.

Bài tập luyện tập

A spring of natural length 12 cm stretches to 18 cm under a load of 4.0 N (within its limit of proportionality). Find the spring constant, and the length of the spring under a load of 7.0 N.

Lời giải chi tiết

Extension $= 18 - 12 = 6.0$ cm $= 0.060$ m. $k = \dfrac{F}{x} = \dfrac{4.0}{0.060} = \boxed{66.7\,\text{N/m}}$.
At 7.0 N: $x = \dfrac{7.0}{66.7} = 0.105$ m $= 10.5$ cm; new length $= 12 + 10.5 = \boxed{22.5\,\text{cm}}$.

Bài tập luyện tập

State and explain, in terms of forces, why a skydiver falling with an open parachute eventually reaches a constant (terminal) velocity.

Lời giải chi tiết

As the skydiver falls, air resistance acts upward, opposing the (constant) downward weight. Initially, weight exceeds air resistance, so there is a net downward force and the skydiver accelerates downward; as speed increases, air resistance increases too. Once air resistance grows to exactly equal the skydiver's weight, the resultant force becomes zero, so (by Newton's first law) the skydiver no longer accelerates and continues to fall at a constant **terminal velocity**.

Bài tập luyện tập

Two forces act on a stationary 4.0 kg object on a frictionless surface: 20 N to the right and 8.0 N to the left. Find the resultant force and the resulting acceleration.

(A) $3.0\,\text{m/s}^2$ right
(B) $3.0\,\text{m/s}^2$ left
(C) $7.0\,\text{m/s}^2$ right
(D) $5.0\,\text{m/s}^2$ right

Lời giải chi tiết

Resultant force $= 20 - 8.0 = 12$ N to the right. $a = \dfrac{F}{m} = \dfrac{12}{4.0} = 3.0\,\text{m/s}^2$ to the right. **(A)**.

Bài tập luyện tập

A block of density $1.2\,\text{g/cm}^3$ is placed in a liquid of density $1.5\,\text{g/cm}^3$. Explain, using densities, whether it floats or sinks.

Lời giải chi tiết

The block's density ($1.2\,\text{g/cm}^3$) is **less** than the liquid's density ($1.5\,\text{g/cm}^3$), so the block is less dense than the liquid it is placed in and will **float** (rising until the weight of liquid displaced by the submerged part equals the block's own weight).

Bài tập luyện tập

Two ice-skaters, initially at rest, push off from each other. Skater A (mass 60 kg) moves off at 2.0 m/s. If skater B has mass 50 kg, find B's speed after the push-off.

(A) 1.5 m/s

(B) 2.0 m/s

(C) 2.4 m/s

(D) 3.0 m/s

Lời giải chi tiết

Total momentum before $= 0$, so total momentum after $= 0$: $(60)(2.0) - (50)(v_B) = 0$ (taking A's direction as positive, B moves the opposite way)
$v_B = \dfrac{120}{50} = 2.4$ m/s (in the opposite direction to A). **(C).**

Bài tập luyện tập

A hydraulic press has a small piston of area $5.0\,\text{cm}^2$ and a large piston of area $100\,\text{cm}^2$. A force of 80 N is applied to the small piston. Using the fact that pressure is transmitted equally through the enclosed liquid, find the force produced at the large piston.

Lời giải chi tiết

Pressure at small piston $= \dfrac{F_1}{A_1} = \dfrac{80}{5.0} = 16\,\text{N/cm}^2$; this same pressure acts on the large piston (Pascal's principle, enclosed liquid):
$F_2 = pA_2 = (16)(100) = \boxed{1600\,\text{N}}$ — a hydraulic press multiplies force because pressure is transmitted equally but the areas differ.

Bài tập luyện tập

A ball rolls from rest down a smooth slope, reaching a speed of 6.0 m/s after descending a vertical height h. Ignoring friction and air resistance, find h.

(A) 0.60 m

(B) 1.8 m

(C) 3.6 m

(D) 6.0 m

Lời giải chi tiết

By energy conservation, GPE lost = KE gained: $mgh = \frac{1}{2}mv^2 \Rightarrow h = \dfrac{v^2}{2g} = \dfrac{36}{20} = 1.8$ m. **(B).**

Bài tập luyện tập

Two forces act on a point object on a frictionless surface: 6.0 N due east and 8.0 N due north. Find the magnitude of the resultant force.

(A) $10\,\mathrm{N}$
(B) $14\,\mathrm{N}$
(C) $2.0\,\mathrm{N}$
(D) $48\,\mathrm{N}$

Lời giải chi tiết

$R = \sqrt{F_1^2 + F_2^2} = \sqrt{6.0^2 + 8.0^2} = \sqrt{36 + 64} = \sqrt{100} = 10\,\mathrm{N}$. **(A)**.

Bài tập luyện tập

A hockey puck of mass $5.0\,\mathrm{kg}$ on frictionless ice is acted on by two forces at the same instant: $6.0\,\mathrm{N}$ due east and $8.0\,\mathrm{N}$ due north. Find (a) the magnitude of the resultant force, (b) the magnitude of the puck's resulting acceleration.

Lời giải chi tiết

(a) $R = \sqrt{6.0^2 + 8.0^2} = \sqrt{36 + 64} = \sqrt{100} = \boxed{10\,\mathrm{N}}$ (at $\tan^{-1}(8.0/6.0) = 53.1°$ north of east).
(b) $a = \dfrac{F}{m} = \dfrac{10}{5.0} = \boxed{2.0\,\mathrm{m/s^2}}$, in the same direction as the resultant force.

Bài tập luyện tập

(Supplement) A stone of mass $0.20\,\mathrm{kg}$ is whirled on the end of a string in a horizontal circle at a constant speed of $4.0\,\mathrm{m/s}$. (a) State the direction of the resultant force acting on the stone at any instant. (b) State whether the stone's kinetic energy changes during this motion, explaining your answer. (c) The string suddenly snaps. Describe, with a reason, the path the stone then follows.

Lời giải chi tiết

(a) The resultant (centripetal) force acts **towards the centre** of the circle at every instant, perpendicular to the stone's velocity.
(b) **No** — the kinetic energy stays constant, because $E_k = \frac{1}{2}mv^2$ depends only on speed, and the stone's speed does not change (only its direction changes); the tension force is always perpendicular to the velocity, so it does no work on the stone.
(c) Once the string breaks there is no resultant force on the stone, so by Newton's first law it travels in a $\boxed{\text{straight line at constant speed, along the tangent to the circle}}$ at the point where the string broke — not radially outward.

Bài tập luyện tập

A student wants to find the period (time for one complete swing) of a simple pendulum using a stopwatch with a reaction-time uncertainty of about $\pm 0.3\,\mathrm{s}$ on any single stopped time. Instead of timing one swing, she times 20 complete swings and obtains a total time of $24.6\,\mathrm{s}$. (a) Calculate the period of one swing. (b) Explain why timing 20 swings and dividing gives a more precise value of the period than timing a single swing directly.

Lời giải chi tiết

(a) $T = \dfrac{24.6}{20} = \boxed{1.23\,\mathrm{s}}$.
(b) The same fixed reaction-time uncertainty ($\pm 0.3\,\mathrm{s}$) applies to the single stopwatch reading

whether timing 1 swing or 20 swings. Over 20 swings this fixed uncertainty is a much smaller *percentage* of the (much larger) total time measured, so when the total time is divided by 20 to get the period, the resulting percentage uncertainty in the period is far smaller than if a single swing (a much shorter time) had been timed directly, where $\pm 0.3\,\text{s}$ would represent a large fraction of the measured time.

Bài tập luyện tập

A student times 30 oscillations of a pendulum, obtaining a total time of $54.0\,\text{s}$, using a stop-watch with a reaction-time uncertainty of $\pm 0.4\,\text{s}$. Find (a) the period of the pendulum, (b) the percentage uncertainty in the period.

Lời giải chi tiết

(a) $T = \dfrac{54.0}{30} = \boxed{1.80\,\text{s}}$.

(b) Percentage uncertainty $= \dfrac{0.4}{54.0} \times 100\% = \boxed{0.74\%}$ (to 2 s.f.).

Bài tập luyện tập

(Supplement) Trolley A (mass $1.5\,\text{kg}$) moving at $6.0\,\text{m/s}$ collides *elastically* head-on with an identical stationary trolley B (mass $1.5\,\text{kg}$). Which of the following correctly describes the trolleys' velocities immediately after the collision?

(A) Both move at $3.0\,\text{m/s}$

(B) A stops (0 m/s), B moves at $6.0\,\text{m/s}$

(C) A continues at $6.0\,\text{m/s}$, B remains at rest

(D) A bounces back at $6.0\,\text{m/s}$, B remains at rest

Lời giải chi tiết

For a head-on elastic collision between two equal masses, one initially at rest, the velocities are exchanged: A ends at rest and B moves off at $6.0\,\text{m/s}$.
Check momentum: before $= (1.5)(6.0) = 9.0\,\text{kg}\cdot\text{m/s}$; after $= (1.5)(0) + (1.5)(6.0) = 9.0\,\text{kg}\cdot\text{m/s}$ — conserved.
Check KE: before $= \frac{1}{2}(1.5)(6.0)^2 = 27\,\text{J}$; after $= \frac{1}{2}(1.5)(6.0)^2 = 27\,\text{J}$ — also conserved, confirming elastic. **(B).**

Bài tập luyện tập

(Supplement) A trolley of mass $5.0\,\text{kg}$ moving at $4.0\,\text{m/s}$ collides and sticks to a stationary trolley of mass $3.0\,\text{kg}$. Find (a) their common velocity after the collision, (b) the kinetic energy lost in the collision.

Lời giải chi tiết

(a) Momentum before $= (5.0)(4.0) = 20\,\text{kg}\cdot\text{m/s}$. $\quad v = \dfrac{20}{5.0 + 3.0} = \boxed{2.5\,\text{m/s}}$.

(b) KE before $= \frac{1}{2}(5.0)(4.0)^2 = 40\,\text{J}$. KE after $= \frac{1}{2}(8.0)(2.5)^2 = 25\,\text{J}$.
KE lost $= 40 - 25 = \boxed{15\,\text{J}}$ (transferred to heat and sound; momentum is conserved but kinetic energy is not, since the collision is inelastic).

Bài tập luyện tập

A car of mass $1500\,$kg travelling at $24\,$m/s is brought to rest by a constant resultant braking force of $7200\,$N. Using the work–energy principle, find the braking distance.

Lời giải chi tiết

KE lost $= \frac{1}{2}mu^2 = \frac{1}{2}(1500)(24)^2 = 432000\,$J. By the work–energy principle, this equals the work done by the braking force: $F\,d = 432000$.
$d = \dfrac{432000}{7200} = \boxed{60\,\text{m}}$.

Bài tập luyện tập

A car experiences a total resistive force of $800\,$N when travelling at a constant velocity of $30\,$m/s along a level road. Find the power output required from the engine to maintain this speed.

Lời giải chi tiết

At constant velocity, the driving force equals the resistive force: $F = 800\,$N.
$P = Fv = (800)(30) = \boxed{24000\,\text{W} = 24\,\text{kW}}$.

Bài tập luyện tập

A see-saw pivoted at its centre carries a $250\,$N weight at $1.2\,$m to the left of the pivot. Find the distance from the pivot, on the right side, at which a $300\,$N weight must be placed to balance the see-saw.

(A) $0.80\,$m
(B) $1.0\,$m
(C) $1.2\,$m
(D) $1.5\,$m

Lời giải chi tiết

Anticlockwise moment $= (250)(1.2) = 300\,$N · m. For equilibrium: $(300)\,d = 300 \Rightarrow d = 1.0\,$m. **(B)**.

Bài tập luyện tập

(Supplement) A hydraulic lift has a small piston of area $12\,\text{cm}^2$ and a large piston of area $300\,\text{cm}^2$. A force of $150\,$N is applied to the small piston. Find the force produced at the large piston.

Lời giải chi tiết

Pressure at the small piston $= \dfrac{F_1}{A_1} = \dfrac{150}{12} = 12.5\,\text{N/cm}^2$; this same pressure acts on the large piston (Pascal's principle):
$F_2 = pA_2 = (12.5)(300) = \boxed{3750\,\text{N}}$.

Bài tập luyện tập

An electric pump lifts 500 kg of water through a height of 15 m in 25 s. (a) Find the useful work done (gain in gravitational PE). (b) Find the useful power output of the pump. (c) If the pump is 80% efficient, find the electrical power input required.

Lời giải chi tiết

(a) $W = mgh = (500)(10)(15) = \boxed{75000\,\text{J} = 75\,\text{kJ}}$.

(b) $P_{\text{useful}} = \dfrac{W}{t} = \dfrac{75000}{25} = \boxed{3000\,\text{W} = 3.0\,\text{kW}}$.

(c) Efficiency $= \dfrac{P_{\text{useful}}}{P_{\text{input}}} \times 100\% \Rightarrow P_{\text{input}} = \dfrac{P_{\text{useful}}}{0.80} = \dfrac{3000}{0.80} = \boxed{3750\,\text{W} = 3.75\,\text{kW}}$.

Bài tập luyện tập

A uniform rectangular crate of weight 400 N stands on a rough horizontal floor; its base is 0.80 m wide, and its centre of mass (assume uniform density) lies 1.2 m above the floor, directly above the centre of the base. A horizontal force is applied at the very top of the crate (height 1.2 m) in an attempt to tip it over its bottom edge nearest the force. Taking moments about that bottom edge, find the minimum horizontal force needed to just tip the crate over.

Lời giải chi tiết

At the point of tipping, the crate is about to rotate about the bottom edge nearest the applied force. The weight (acting vertically through the centre of mass, a horizontal distance of half the base width $= 0.40$ m from that edge) supplies a restoring (anticlockwise) moment: $(400)(0.40) = 160\,\text{N}\cdot\text{m}$.
The applied horizontal force (acting at height 1.2 m, so its perpendicular distance from the same edge is 1.2 m) supplies the tipping (clockwise) moment $F \times 1.2$.
At the point of tipping these are equal: $F(1.2) = 160 \Rightarrow F = \dfrac{160}{1.2} = \boxed{133\,\text{N}}$ (to 3 s.f.) — any force greater than this would tip the crate over.

Bài tập luyện tập

(Supplement) State one similarity and one difference between an elastic collision and a perfectly inelastic collision, in terms of momentum and kinetic energy.

Lời giải chi tiết

Similarity: momentum is conserved in *both* types of collision (total momentum before = total momentum after), provided no external resultant force acts.
Difference: in an elastic collision, total kinetic energy is also conserved (KE before = KE after) and the two objects separate again after impact; in a perfectly inelastic collision, the objects stick together and move with a common final velocity, and total kinetic energy **decreases** — some kinetic energy is transferred to other energy stores such as heat and sound, even though momentum is unchanged.

Bài tập luyện tập

A car travels at $15\,\mathrm{m/s}$; the driver's reaction time is 0.6 s, and the brakes then provide a constant deceleration of $5.0\,\mathrm{m/s^2}$. Find (a) the thinking distance, (b) the braking distance, (c) the total stopping distance.

Lời giải chi tiết

(a) $d_{\text{think}} = v\,t_{\text{reaction}} = (15)(0.6) = \boxed{9.0\,\mathrm{m}}$.

(b) $v^2 = u^2 + 2as \Rightarrow 0 = 15^2 - 2(5.0)d_{\text{brake}} \Rightarrow d_{\text{brake}} = \dfrac{225}{10} = \boxed{22.5\,\mathrm{m}}$.

(c) Total stopping distance $= 9.0 + 22.5 = \boxed{31.5\,\mathrm{m}}$.

Bài tập luyện tập

(Supplement) During an impact lasting 6.0 ms, the force on a ball of mass 0.20 kg (initially at rest) rises uniformly from 0 to a peak of 300 N over the first 2.0 ms, then falls uniformly back to 0 over the remaining 4.0 ms. Find (a) the impulse delivered, (b) the ball's speed immediately after impact.

(A) $0.45\,\mathrm{N\cdot s}$; $2.25\,\mathrm{m/s}$

(B) $0.90\,\mathrm{N\cdot s}$; $4.5\,\mathrm{m/s}$

(C) $1.8\,\mathrm{N\cdot s}$; $9.0\,\mathrm{m/s}$

(D) $0.90\,\mathrm{N\cdot s}$; $0.45\,\mathrm{m/s}$

Lời giải chi tiết

(a) Impulse $=$ area of the triangular force–time graph $= \frac{1}{2} \times$ base $\times$ height $= \frac{1}{2}(6.0 \times 10^{-3})(300) = 0.90\,\mathrm{N\cdot s}$.

(b) Since impulse $= \Delta p = mv - mu$ and $u = 0$: $v = \dfrac{0.90}{0.20} = 4.5\,\mathrm{m/s}$. **(B)**.

CAMBRIDGE IGCSE • Unit 2

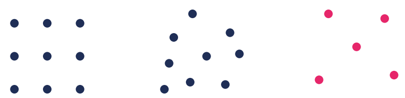
Thermal Physics

Mục tiêu Unit: Mô hình động học phân tử của vật chất (ba thể, chuyển động Brown, khuếch tán, sự thay đổi trạng thái ở cấp độ hạt); áp suất khí & các định luật khí – Boyle, Charles, định luật áp suất (Supplement), thang nhiệt độ Kelvin; sự giãn nở nhiệt & ứng dụng; phân biệt nhiệt độ với nội năng; nhiệt dung riêng, nhiệt dung, phương pháp hỗn hợp; nhiệt hoá riêng, phân biệt bay hơi với sôi; ba cơ chế truyền nhiệt (dẫn nhiệt, đối lưu, bức xạ) & các ứng dụng thực tế (bình giữ nhiệt, cách nhiệt nhà ở, tấm thu năng lượng mặt trời).

2.1 The Kinetic Particle Model of Matter

Khái niệm cốt lõi

Solid: particles vibrate about fixed positions, held in a regular lattice by strong forces of attraction — fixed shape, fixed volume, and the highest density of the three states. **Liquid:** particles are still close together (roughly the same average separation as in the solid) but the forces are weak enough, and the particles have enough energy, that they can slide past one another — a liquid has a fixed volume but takes the shape of whatever container holds it, and its density is close to (usually slightly less than) that of the solid. **Gas:** particles move rapidly and randomly in straight lines between collisions, with an average separation roughly ten times greater than in a liquid or solid, and negligible forces of attraction between them (except during the brief moment of a collision) — a gas has no fixed shape or volume, expands to fill any container, is easily compressed, and has a much lower density than the liquid or solid form of the same substance.



Particle arrangement in the three states: a regular, close-packed lattice with particles only vibrating (solid); an irregular but still close-packed arrangement that can flow (liquid); widely-spaced, fast, randomly-moving particles (gas).

2.1.1 Brownian Motion: Evidence for Moving Particles

The kinetic particle model claims that gas molecules are in continuous, random motion — but individual molecules are far too small to see even under a powerful microscope. **Brownian motion** is the key piece of indirect evidence for this claim. The classic demonstration uses a **smoke cell**: smoke (which contains solid soot particles, each still large enough to scatter light and be seen, though far larger than an air molecule) is trapped inside a small, sealed glass cell. The cell is illuminated strongly from the side, and viewed from above through a microscope positioned at right angles to the light beam, so that individual smoke particles show up as tiny, bright, scattered points of light against a dark background.

What is observed is that each bright speck does not move in a straight line or settle — it jitters continuously, changing direction erratically and unpredictably. The explanation follows directly from the kinetic particle model: the visible smoke particle is being bombarded, from all directions, by huge numbers of fast-moving, invisible air molecules every second. If the bombardment were perfectly even from every side at every instant, the impacts would cancel out and the smoke particle would not move at all. But because the collisions arrive from random directions at random moments, there is, at any instant, a slight statistical imbalance of impacts from one side — this net force is enough to push the (much larger, but still very light) smoke particle a small distance in a random direction, and the next instant the imbalance is in a different direction, producing the observed zig-zag jitter. Robert Brown first observed this effect in 1827 using pollen grains suspended in water and viewed under a microscope; the same reasoning applies (water molecules bombard the pollen grain), confirming that the phenomenon is general evidence for particles in continuous random motion, in both liquids and gases.

Diffusion — the spreading out of one substance through another due to the random motion of particles, without any stirring or other bulk movement — is further, independent evidence for the same model. A drop of coloured dye placed in still water gradually spreads throughout the liquid; a gas released in one corner of a room (e.g. the smell of perfume, or bromine gas released in a gas jar) gradually spreads to fill the whole space. Diffusion is much **faster in gases than in liquids**, because gas particles move faster (having more space and weaker attractive forces to overcome) and are far less crowded, so they travel further between collisions. Diffusion is also faster **at higher temperature**, because raising the temperature increases the average kinetic energy — and hence the average speed — of the particles.

GIẢI THÍCH TIẾNG VIỆT

VN

Mô hình động học phân tử giải thích ba thể qua khoảng cách và lực liên kết giữa các hạt: rắn (hạt sát nhau, chỉ dao động tại chỗ), lỏng (hạt gần nhau nhưng trượt qua nhau được), khí (hạt xa nhau, chuyển động tự do, mật độ thấp hơn nhiều). Chuyển động Brown là bằng chứng gián tiếp cho thấy các phân tử khí (hoặc chất lỏng) luôn chuyển động hỗn loạn không ngừng: hạt khói (hoặc hạt phấn hoa) đủ lớn để nhìn thấy, nhưng bị các phân tử khí/nước (quá nhỏ để nhìn thấy) va chạm không đều từ mọi phía tại mỗi thời điểm, khiến nó chuyển động giật lắc ngẫu nhiên — bản thân hạt lớn không thể bị một va chạm đơn lẻ làm chuyển động, nhưng sự mất cân bằng của rất nhiều va chạm đồng thời thì có thể. Khuếch tán nhanh hơn trong chất khí so với chất lỏng (do hạt khí chuyển động nhanh hơn và thưa hơn), và nhanh hơn khi nhiệt độ tăng (động năng trung bình của hạt tăng).

2.1.2 Change of State at the Particle Level

When a substance changes state, energy is transferred into or out of it, but this energy changes the **potential energy** associated with the bonds (forces of attraction) between particles — *not* their average kinetic energy. This is why temperature stays constant throughout a change of state (see the heating curve in Section 2.5), even though energy is being continuously supplied or removed.

- **Melting** (solid → liquid): energy supplied is used to partially overcome the strong forces holding particles in fixed lattice positions, giving them just enough freedom to slide past one another; the particles' average kinetic energy — and hence the temperature — does not change during melting.
- **Freezing / solidification** (liquid → solid): the reverse process; energy is *released* to the surroundings as particles lose enough energy to be locked into a fixed, ordered lattice by the forces of attraction between them.
- **Boiling and evaporation** (liquid → gas): energy supplied completely overcomes the remaining forces of attraction between particles, freeing them to move independently and fill any available space; again, this energy changes potential energy, not average kinetic energy, at the boiling point.
- **Condensation** (gas → liquid): the reverse of boiling/evaporation; as a gas is cooled (or compressed), particles slow down enough for the attractive forces between them to pull them back

together into the closer-packed, disordered arrangement of a liquid, releasing energy to the surroundings.

VN GIẢI THÍCH TIẾNG VIỆT

Khi đổi trạng thái, năng lượng trao đổi làm thay đổi **thế năng** liên kết giữa các hạt (phá vỡ hoặc hình thành liên kết), chứ **không** làm thay đổi động năng trung bình — vì vậy nhiệt độ không đổi trong suốt quá trình nóng chảy, đông đặc, sôi hay ngưng tụ. Nóng chảy/sôi cần hấp thụ năng lượng để phá vỡ liên kết; đông đặc/ngưng tụ giải phóng năng lượng khi liên kết hình thành trở lại.

2.1.3 Gas Pressure and the Kinetic Model

A gas exerts pressure on the walls of its container because its particles are moving rapidly and randomly in all directions, continually colliding with the walls. Each individual collision transfers a tiny amount of momentum to the wall, producing a minute force; but because enormous numbers of particles strike every part of the wall every second, the combined effect of all these impacts, spread over the wall's area, produces a steady, measurable **pressure** ($p = \text{force}/\text{area}$). Anything that increases the frequency or force of these collisions — more particles in the same volume, a smaller volume for the same number of particles, or faster-moving particles (higher temperature) — increases the pressure.

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Áp suất khí sinh ra do vô số phân tử khí chuyển động hỗn loạn va chạm liên tục vào thành bình chứa — mỗi va chạm truyền một lực rất nhỏ, nhưng tổng hợp hàng tỉ va chạm mỗi giây tạo ra áp suất đo được. Áp suất tăng khi: số phân tử trong cùng thể tích tăng, thể tích giảm (cùng số phân tử), hoặc nhiệt độ tăng (phân tử chuyển động nhanh hơn, va chạm mạnh và thường xuyên hơn).

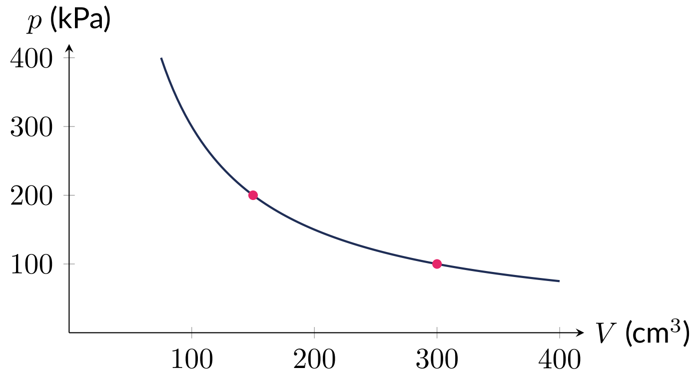
2.2 The Gas Laws (Supplement)

(Supplement) For a **fixed mass** of gas:

- **Boyle's law** (constant temperature): $p_1V_1 = p_2V_2$. Compressing the gas into a smaller volume packs the same number of molecules into less space, so they strike the walls more often — pressure rises as volume falls (pressure inversely proportional to volume).
- **The pressure law** (constant volume): $\frac{p_1}{T_1} = \frac{p_2}{T_2}$. Raising the temperature increases the average kinetic energy (and speed) of the molecules; in a fixed volume, this means more frequent, harder collisions with the walls, so pressure rises (pressure directly proportional to absolute temperature).
- **Charles' law** (constant pressure): $\frac{V_1}{T_1} = \frac{V_2}{T_2}$. Raising the temperature speeds up the molecules; for the pressure to stay the same, the gas must expand — spreading the same collision rate over a larger wall area and a longer average distance between collisions — so volume rises with absolute temperature (volume directly proportional to absolute temperature).

In every case, temperature **must** be measured in **kelvin** (an absolute scale), using $T(\text{K}) = \theta(^\circ\text{C}) + 273$. Combining all three gives the **combined gas law**, $\frac{p_1V_1}{T_1} = \frac{p_2V_2}{T_2}$, valid whenever mass is fixed and none of p, V, T is held constant.

Absolute zero ($0\,\text{K} = -273\,^\circ\text{C}$) is the (practically unreachable) temperature at which particles would have the minimum possible kinetic energy; an ideal gas's pressure and volume would both fall to zero. Because kinetic energy cannot be negative, the Kelvin scale has no negative values — this is why it is the correct scale for all gas-law calculations, and why average particle kinetic energy is directly proportional to *kelvin* (not Celsius) temperature.



p–V graph for a fixed mass of gas at constant temperature (Boyle's law): pressure is inversely proportional to volume, giving a hyperbola (pV = constant). The marked points correspond to Worked Example 1 below: $100\,\text{kPa}$ at $300\,\text{cm}^3$, and $200\,\text{kPa}$ at $150\,\text{cm}^3$.

Ví dụ 1 · Boyle's law – finding the new pressure

(Supplement) A gas at pressure $100\,\text{kPa}$ occupies $300\,\text{cm}^3$. At constant temperature it is compressed to $150\,\text{cm}^3$. Find the new pressure.

$$p_1V_1 = p_2V_2 \Rightarrow p_2 = \frac{p_1V_1}{V_2} = \frac{(100)(300)}{150} = \boxed{200\,\text{kPa}}.$$

Ví dụ 2 · Boyle's law – finding the new volume

(Supplement) A gas at pressure $250\,\text{kPa}$ occupies $180\,\text{cm}^3$. At constant temperature, it is allowed to expand until its pressure falls to $150\,\text{kPa}$. Find the new volume.

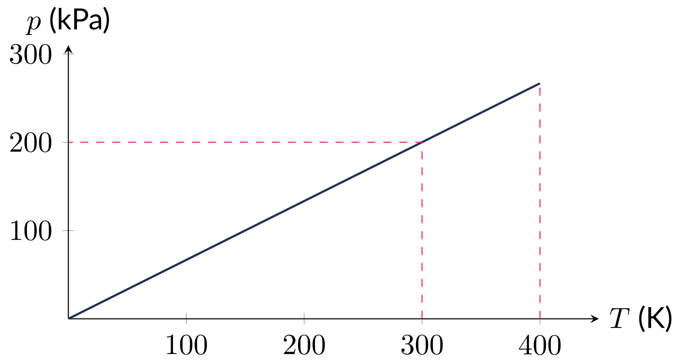
$$p_1V_1 = p_2V_2 \Rightarrow V_2 = \frac{p_1V_1}{p_2} = \frac{(250)(180)}{150} = \frac{45000}{150} = \boxed{300\,\text{cm}^3}.$$

Ví dụ 3 · Charles' law

(Supplement) A balloon has a volume of $800\,\text{cm}^3$ at 27°C, at constant (atmospheric) pressure. Find its volume after it is warmed to 87°C.

Convert to kelvin: $T_1 = 27 + 273 = 300\,\text{K}$; $T_2 = 87 + 273 = 360\,\text{K}$.

$$\frac{V_1}{T_1} = \frac{V_2}{T_2} \Rightarrow V_2 = V_1 \times \frac{T_2}{T_1} = 800 \times \frac{360}{300} = \boxed{960\,\text{cm}^3}.$$



Pressure–temperature graph for a fixed mass of gas at constant volume: a straight line through the origin *when T is measured in kelvin* — pressure is directly proportional to absolute (kelvin) temperature.

Ví dụ 4 · The pressure law

(Supplement) A fixed mass of gas in a sealed, rigid container has a pressure of 200 kPa at $27\,^\circ$C. Find its pressure when heated (at constant volume) to $127\,^\circ$C.

$T_1 = 27 + 273 = 300$ K; $T_2 = 127 + 273 = 400$ K.

$\dfrac{p_1}{T_1} = \dfrac{p_2}{T_2} \Rightarrow p_2 = p_1 \times \dfrac{T_2}{T_1} = 200 \times \dfrac{400}{300} = \boxed{266.7\,\text{kPa}}$.

Ví dụ 4b · Combined gas law

(Supplement) A fixed mass of gas occupies 600 cm^3 at a pressure of 100 kPa and a temperature of 27°C. It is heated and compressed until its pressure becomes 150 kPa and its temperature becomes 87°C. Using the combined gas law $\dfrac{p_1V_1}{T_1} = \dfrac{p_2V_2}{T_2}$, find the new volume.

$T_1 = 27 + 273 = 300$ K; $T_2 = 87 + 273 = 360$ K.

$\dfrac{p_1V_1}{T_1} = \dfrac{p_2V_2}{T_2} \Rightarrow V_2 = \dfrac{p_1V_1T_2}{T_1p_2} = \dfrac{(100)(600)(360)}{(300)(150)} = \dfrac{21600000}{45000} = \boxed{480\,\text{cm}^3}$.

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Định luật khí kết hợp $\dfrac{p_1V_1}{T_1} = \dfrac{p_2V_2}{T_2}$ áp dụng khi cả ba đại lượng p, V, T đều thay đổi đồng thời (khối lượng khí không đổi) — đây là dạng tổng quát chứa cả ba định luật Boyle, định luật áp suất và định luật Charles như những trường hợp riêng (khi một đại lượng được giữ không đổi). Luôn đổi nhiệt độ sang Kelvin trước khi thay số vào công thức.

Ví dụ 5 · Kelvin – Celsius conversion

Convert (a) the boiling point of water, 100°C, to kelvin; (b) the boiling point of liquid nitrogen, 77 K, to Celsius.

(a) $T = \theta + 273 = 100 + 273 = \boxed{373\,\text{K}}$.

(b) $\theta = T - 273 = 77 - 273 = \boxed{-196^\circ\text{C}}$.

Ví dụ 6 · Explaining gas pressure using kinetic theory

Use the kinetic particle model to explain why the pressure of a fixed mass of gas, held at constant volume, increases when the gas is heated.

Heating the gas increases the average kinetic energy of its molecules, so their average speed increases. Faster molecules hit the container walls (a) **more frequently** (they cross the fixed volume and return to the wall in less time) and (b) **with greater force** per collision (a larger momentum change per impact, since momentum $= mv$). Since the wall area is unchanged (constant volume), both effects increase the total force per unit area on the walls — that is, the pressure increases.

(!) Lỗi thường gặp: When using any gas-law equation, temperature must be substituted in **kelvin**, never in Celsius — a common error is to forget the $+273$ conversion, or to apply it with the wrong sign (remember $T(\text{K}) = \theta(^\circ\text{C}) + 273$, so kelvin is always *larger* than the Celsius value, and kelvin temperatures are never negative). Only p and V may be used directly in $^\circ$C-free everyday units (kPa, cm^3, etc.) — it is only T that must be absolute.

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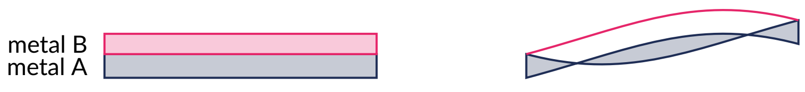
Ba định luật khí (khi khối lượng khí không đổi): định luật Boyle ($p_1V_1 = p_2V_2$, nhiệt độ không đổi — thể tích giảm thì áp suất tăng); định luật áp suất ($p_1/T_1 = p_2/T_2$, thể tích không đổi — nhiệt độ tăng thì áp suất tăng); định luật Charles ($V_1/T_1 = V_2/T_2$, áp suất không đổi — nhiệt độ tăng thì thể tích tăng). Cả ba đều giải thích được bằng thuyết động học phân tử: nhiệt độ tăng $\Rightarrow$ động năng trung bình của hạt tăng $\Rightarrow$ va chạm với thành bình nhanh và mạnh hơn. **Luôn đổi nhiệt độ sang Kelvin** ($T(\text{K}) = \theta(^\circ\text{C}) + 273$) trước khi thay vào công thức, vì các công thức này chỉ đúng với thang nhiệt độ tuyệt đối — không âm bao giờ.

2.3 Thermal Expansion

Most solids, liquids and gases **expand** when heated, and contract when cooled. At the particle level, the particles themselves do not get bigger — instead, heating increases the amplitude of vibration of particles in a solid, or the average separation between particles in a liquid or gas, so that the same number of particles occupies a larger volume. Gases expand far more than liquids for the same rise in temperature, and liquids expand more than solids, because the forces of attraction holding gas particles together are weakest (allowing the greatest increase in separation), while the strong, rigid bonds in a solid allow only a small increase in vibration amplitude.



A bimetallic strip: two different metals bonded together expand by different amounts for the same temperature rise (here, metal B expands more than metal A), so the strip bends toward the metal that expands **less** — used in thermostats and some fire alarms.

Applications of thermal expansion:

- **Expansion gaps** are left between sections of bridges, railway tracks, and concrete pavements, so that the material can expand freely in hot weather without buckling or cracking under the enormous forces that would otherwise build up.
- A **bimetallic strip** (two different metals bonded together) bends when heated, because the two metals expand by different amounts for the same temperature rise; this bending can open or close an electrical contact, and is used inside **thermostats** (to switch a heater or cooling system on/off automatically at a set temperature) and in some fire alarms.

- A **liquid-in-glass thermometer** relies on a liquid (traditionally mercury, or a coloured alcohol) expanding predictably up a narrow capillary tube as its temperature rises. A **thin-walled bulb with a large surface area** lets heat conduct into (or out of) the liquid quickly, giving a fast response time; a **narrow capillary tube** means a small volume expansion produces a long, easily-read movement of the liquid column, giving good sensitivity; and a liquid with a **large expansion per degree** similarly increases the sensitivity of the scale.

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Hầu hết vật chất giãn nở khi nóng lên vì các hạt dao động mạnh hơn (rắn) hoặc cách xa nhau hơn (lỏng, khí), chứ bản thân hạt không to ra; khí giãn nở nhiều nhất, rồi đến lỏng, rồi đến rắn (do lực liên kết giữa các hạt khí yếu nhất). Băng kép (bimetallic strip) gồm hai kim loại giãn nở khác nhau ghép với nhau nên uốn cong khi nhiệt độ thay đổi — dùng trong bộ điều nhiệt (thermostat) để tự động đóng/ngắt mạch điện. Khe giãn nở trên cầu và đường ray giúp tránh cong vênh, nứt gãy khi trời nóng. Nhiệt kế thuỷ ngân/cồn nhạy hơn khi bầu chứa mỏng, diện tích lớn (dẫn nhiệt nhanh) và ống mao dẫn hẹp (độ dịch chuyển lớn cho mỗi độ).

2.4 Temperature, Heat and Internal Energy

It is essential to distinguish three related but different ideas. **Temperature** is a measure of how hot or cold something is, on a chosen numerical scale (Celsius or kelvin) — physically, it measures the *average* kinetic energy of the particles in a substance. **Internal energy** is the *total* energy (the sum of the kinetic energies of all the particles, due to their random motion, *plus* the potential energies of all the particles, due to the forces of attraction/repulsion between them) stored within an object — it depends on the object's temperature, its state, and also on how much substance is present (its mass). **Heat** (or thermal energy transferred, often written Q) is energy that flows from a hotter region to a cooler region because of a temperature difference; once transferred, it becomes part of the internal energy of the substance that receives it.

A useful example of the difference between temperature and internal energy: a small cup of tea at $90\,^{\circ}$C and a large bathtub of water at the same $90\,^{\circ}$C have the *same temperature* (the water particles in each have the same average kinetic energy) — but the bathtub, having far more mass, has a much greater *internal energy*, and would need far more energy input to reach that temperature, and would release far more energy while cooling back down to room temperature.

VN GIẢI THÍCH TIẾNG VIỆT

Nhiệt độ đo động năng **trung bình** của các hạt (một con số trên thang đo). Nội năng là **tổng** động năng và thế năng của toàn bộ các hạt trong vật — phụ thuộc cả khối lượng, không chỉ nhiệt độ. Nhiệt (năng lượng nhiệt truyền đi, Q) là năng lượng chuyển từ nơi nóng sang nơi lạnh do chênh lệch nhiệt độ. Ví dụ: một tách trà và một bồn tắm đầy nước cùng ở 90°C có **cùng nhiệt độ**, nhưng bồn tắm có **nội năng lớn hơn nhiều** vì khối lượng nước lớn hơn.

2.5 Specific Heat Capacity and Thermal Capacity

Specific heat capacity c is the energy needed to raise the temperature of **1 kg** of a substance by **1** °C (or 1 K); it is a property of the *material*, independent of how much of it is present.

$$Q = mc\Delta\theta$$

where Q is the energy transferred (J), m is the mass (kg), c is the specific heat capacity (J/(kg °C)), and $\Delta\theta$ is the temperature change (°C). Water has an unusually *high* specific heat capacity, $c = 4200\,\text{J/(kg°C)}$ — this is why large bodies of water heat up and cool down much more slowly than land for the same energy exchange, moderating the climate of coastal regions.

Measuring specific heat capacity (electrical method): a known mass m of the substance is heated by an electrical heater of known power (or using a joulemeter to record energy supplied directly), while a thermometer records the temperature rise. For a **solid** (e.g. a metal block), the block has two holes drilled into it — one for the heater, one for the thermometer — and is wrapped in insulation (lagging) to reduce energy loss to the surroundings. For a **liquid**, a known mass is placed in an insulated container (to minimise heat loss) with an immersion heater and a thermometer, and the liquid is stirred gently and continuously so that its temperature is uniform throughout. In both cases, the ammeter, voltmeter and a stopwatch (or a joulemeter) give the electrical energy supplied, $E = IVt$; recording the initial and final steady temperatures gives $\Delta\theta$, and then

$$c = \frac{E}{m\Delta\theta}.$$

Precautions include using good insulation (to reduce energy losses to the surroundings, which would make the measured c too large), stirring liquids for a uniform temperature, and — for higher precision — accounting for the (usually much smaller) heat capacity of the container itself.

Ví dụ 7 · Heating with specific heat capacity

Find the energy needed to heat 2.0 kg of water from 20°C to 80°C ($c = 4200$ J/(kg°C)).

$Q = mc\Delta\theta = (2.0)(4200)(60) = \boxed{504000\,\text{J} = 504\,\text{kJ}}$.

Ví dụ 8 · Solving for an unknown mass

An electrical heater supplies 336 kJ of energy to a quantity of water, raising its temperature from 15°C to 95°C. Find the mass of water heated ($c = 4200$ J/(kg°C)).

$Q = mc\Delta\theta \Rightarrow m = \dfrac{Q}{c\Delta\theta} = \dfrac{336000}{(4200)(80)} = \dfrac{336000}{336000} = \boxed{1.0\,\text{kg}}$.

Thermal capacity (sometimes called *heat capacity*) $C = mc$ is the energy needed to raise the temperature of a *particular object* (of mass m, made of a material of specific heat capacity c) by $1\,^\circ$C: $Q = C\Delta\theta$. Unlike specific heat capacity, thermal capacity is **not** a fixed property of a material — it depends on how much of the material is present (its mass), so two different-sized blocks of the same metal have the same c but different thermal capacities C.

Ví dụ 9 · Thermal capacity

A copper block has a mass of 2.5 kg; the specific heat capacity of copper is 390 J/(kg°C). Find (a) the thermal capacity of the block, (b) the energy needed to raise its temperature by 15°C.

(a) $C = mc = (2.5)(390) = \boxed{975\,\text{J}/^\circ\text{C}}$.

(b) $Q = C\Delta\theta = (975)(15) = \boxed{14625\,\text{J} \approx 14.6\,\text{kJ}}$.

(!) Lỗi thường gặp: Do not confuse **specific** heat capacity (c, in J/(kg °C), a property of the *material only*) with **thermal capacity** ($C = mc$, in J/°C, a property of one particular *object*, which depends on its mass). A large block and a small block of the same metal have the same c but different C — the larger block needs more total energy for the same temperature rise.

2.5.1 The Method of Mixtures

The **method of mixtures** finds an unknown quantity (a final equilibrium temperature, or an unknown specific heat capacity) by equating the energy *lost* by a hotter substance to the energy *gained* by a cooler one, when the two are mixed in an insulated container with no energy lost to the surroundings:

$$\text{energy lost by hotter substance} = \text{energy gained by cooler substance.}$$

For each substance, $\Delta\theta$ must be calculated so that it comes out **positive** — for the hotter substance, $\Delta\theta = (\text{initial temperature} - \text{final temperature})$; for the cooler substance, $\Delta\theta = (\text{final temperature} - \text{initial temperature})$. A useful check is that the calculated final temperature must always lie *between* the two starting temperatures.

Ví dụ 10 · Mixing two masses of water at different temperatures

200 g of water at 80°C is mixed with 300 g of water at 20°C in an insulated container. Find the final temperature.
Energy lost by hot water = energy gained by cool water (same substance, so c cancels):

$$(0.200)(4200)(80-\theta) = (0.300)(4200)(\theta-20).$$

Dividing both sides by 4200: $0.200(80-\theta) = 0.300(\theta-20) \Rightarrow 16 - 0.200\theta = 0.300\theta - 6.0$.
$22 = 0.500\theta \Rightarrow \theta = \boxed{44\,°\text{C}}$.

Ví dụ 10b · Mixing water with a larger mass difference

250 g of water at 85°C is mixed with 750 g of water at 15°C in an insulated container. Find the final temperature.
Energy lost by hot water = energy gained by cool water (same substance, so c cancels):

$$(0.250)(85-\theta) = (0.750)(\theta-15).$$

$21.25 - 0.250\theta = 0.750\theta - 11.25 \Rightarrow 32.5 = 1.00\theta \Rightarrow \theta = \boxed{32.5\,°\text{C}}$.

Ví dụ 11 · Finding an unknown specific heat capacity

A 0.20 kg block of metal at 100°C is dropped into 0.50 kg of water at 20°C in an insulated calorimeter. The final steady temperature is 25°C. Find the specific heat capacity of the metal.
Energy lost by metal = energy gained by water:

$$(0.20)(c_{\text{metal}})(100-25) = (0.50)(4200)(25-20)$$

$$15\,c_{\text{metal}} = 10500 \;\Rightarrow\; c_{\text{metal}} = \boxed{700\,\text{J/(kg°C)}}.$$

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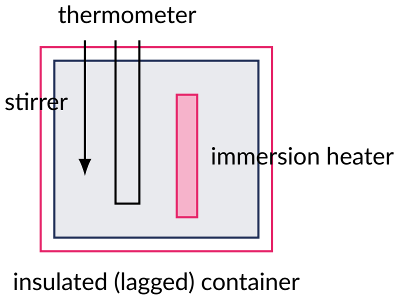
Nhiệt dung riêng c (J/(kg·°C)) là năng lượng cần để làm nóng 1 kg chất đó lên 1 °C — thuộc tính của **vật liệu**. Nhiệt dung $C = mc$ (J/°C) là năng lượng cần cho **cả một vật cụ thể** tăng 1 °C — phụ thuộc khối lượng, không phải chỉ vật liệu; đừng nhầm lẫn hai đại lượng này. Nước có c rất lớn nên hấp thụ/tỏa nhiệt chậm, giải thích vì sao biển điều hòa khí hậu ven biển. Phương pháp hỗn hợp: nhiệt lượng vật nóng tỏa ra = nhiệt lượng vật lạnh thu vào (không hao phí ra môi trường) — công cụ để tìm nhiệt độ cân bằng hoặc nhiệt dung riêng chưa biết; luôn kiểm tra nhiệt độ cuối phải nằm giữa hai nhiệt độ ban đầu.

2.5.2 Determining Specific Heat Capacity by Electrical Heating: Experimental Detail (Supplement)



Apparatus for measuring the specific heat capacity of a liquid by electrical heating: a known mass of liquid in an insulated (lagged) container, heated by an immersion heater of known electrical power (via an ammeter, voltmeter and stopwatch, or directly via a joulemeter), with a thermometer and stirrer used to obtain a uniform, accurately measured temperature rise.

(Supplement) A more detailed version of the electrical method pays close attention to the apparatus and to correcting for energy losses. The electrical energy supplied can be measured in two equivalent ways: (i) an **ammeter** (in series with the heater) and a **voltmeter** (in parallel across the heater), read together with a **stopwatch**, giving $E = IVt$; or (ii) a **joulemeter**, which is wired in series with the heater and displays the total electrical energy supplied directly, removing the need to read current and voltage separately (and reducing errors if the supply voltage or current drifts slightly during the experiment). For a **solid**, the block is usually a large regular cylinder or cube with two holes drilled into it (one snugly fitting the heater, one for the thermometer, often with a smear of oil to improve thermal contact) and the block is wrapped in an insulating jacket. For a **liquid**, the immersion heater and thermometer sit directly in a known mass of the liquid inside an insulated container, and the liquid is stirred **continuously and gently** throughout heating, so that the thermometer reads a temperature that is uniform throughout the liquid rather than just the temperature near the heater.

Even with good lagging, some energy is always lost to the surroundings (through the lagging itself, and by evaporation from an open liquid surface), so the measured temperature rise is always slightly **smaller** than it would be if all the electrical energy went into the substance being heated. Two common ways of reducing the effect of this error are: (a) using **efficient insulation** and carrying out the heating as **quickly** as possible (a high-power heater, so that the experiment finishes before much energy has had time to leak away); and (b) applying a **cooling correction** — starting the experiment a few degrees *below* room temperature and finishing a few degrees *above* it, so that the (small) energy lost to the surroundings while the substance is cooler than room temperature is roughly cancelled out by the (small) energy gained from the surroundings during that stage, and vice versa once the substance is hotter than room temperature.

Ví dụ 11b · Specific heat capacity from experimental data

(Supplement) In an experiment to find the specific heat capacity of an oil, 0.30 kg of the oil is placed in an insulated container and heated by an electrical immersion heater. The ammeter reads 3.0 A, the voltmeter reads 10 V, and the heater is switched on for 400 s. The oil's temperature rises from 18°C to 38°C. Assuming no heat losses, calculate the specific heat capacity of the oil.

Electrical energy supplied: $E = IVt = (3.0)(10)(400) = 12000$ J.

Temperature rise: $\Delta\theta = 38 - 18 = 20\,^\circ$C.

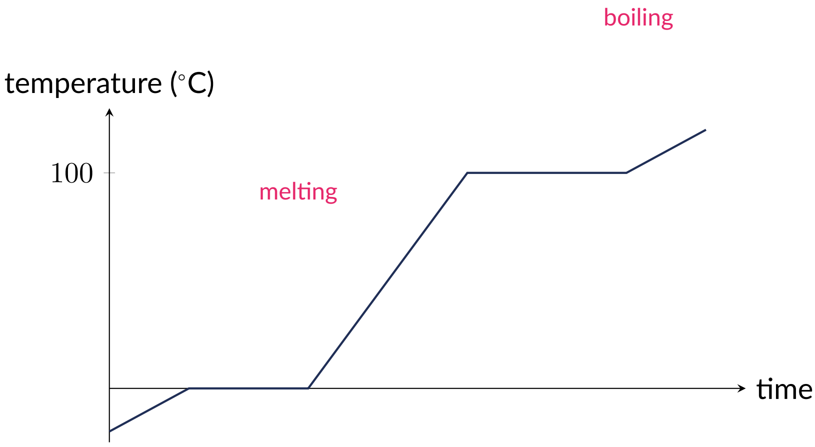
$$c = \frac{E}{m\Delta\theta} = \frac{12000}{(0.30)(20)} = \frac{12000}{6.0} = \boxed{2000\,\text{J}/(\text{kg}^\circ\text{C})}.$$

(!) Lỗi thường gặp: When calculating specific heat capacity from electrical heating data, failing to insulate the container well (or failing to correct for heat lost to the surroundings) makes the measured temperature rise **smaller** than it would be with no losses. Since $c = E/(m\Delta\theta)$, a smaller measured $\Delta\theta$ for the same supplied energy E makes the *calculated* specific heat capacity come out **too large** — this is a systematic error, not a random one, so repeating the reading does not remove it. Good lagging, gentle continuous stirring, a high heater power (to finish quickly), and — for the most accurate work — a cooling correction are all used to reduce this error.

VN **GIẢI THÍCH TIẾNG VIỆT**

Phương pháp gia nhiệt bằng điện có thể dùng joulemeter (đo trực tiếp năng lượng E) hoặc ampe kế + vôn kế + đồng hồ bấm giờ ($E = IVt$). Cách nhiệt tốt (bọc lớp cách nhiệt) và khuấy đều liên tục là bắt buộc để nhiệt độ đo được đồng đều và để giảm thất thoát nhiệt ra môi trường — nếu thất thoát nhiều, nhiệt độ đo được tăng ít hơn thực tế, khiến c tính được **lớn hơn** giá trị thật (sai số hệ thống, không giảm được bằng cách đo lại). Kỹ thuật sửa sai (correction) như bắt đầu dưới nhiệt độ phòng và kết thúc trên nhiệt độ phòng một lượng bằng nhau giúp phần nhiệt mất trước và sau bù trừ cho nhau.

2.6 Change of State: Latent Heat, Boiling and Evaporation



Heating curve for a pure substance (e.g. ice → water → steam): temperature is constant during melting and boiling, because the supplied energy changes the particles' potential energy (bonds), not their average kinetic energy. The slopes before, between and after the flat sections are generally different, since ice, water and steam each have different specific heat capacities.

Specific latent heat L is the energy needed to change the **state** of **1 kg** of a substance, *at constant temperature* (no temperature change, because this energy changes potential energy between particles, not kinetic energy):

$$Q = mL.$$

The **specific latent heat of fusion** applies to melting/freezing (solid ↔ liquid); the **specific latent heat of vaporisation** applies to boiling/condensation (liquid ↔ gas), and for a given substance is always considerably larger than the latent heat of fusion, since separating particles completely (to form a gas) requires overcoming far more of the attractive force than merely loosening a solid lattice into a liquid.

(!) Lỗi thường gặp: A common misconception is that a substance's temperature keeps rising as long as you keep heating it. In fact, **while a substance is changing state** (melting or boiling), its temperature remains **constant**, no matter how much extra energy is supplied — the thermometer reading only starts changing again once the change of state is complete (e.g. once *all* the ice has melted, or all the liquid has boiled away).

Substance	c (J/(kg °C))	L_{fusion} (J/kg)	$L_{\text{vaporisation}}$ (J/kg)
Water / Ice	4200 (water), 2100 (ice)	334000	2260000
Aluminium	900	397000	—
Copper	390	205000	—
Lead	130	23000	—

(Supplement) Approximate specific heat capacities and specific latent heats of fusion of some common substances. Only the values for water/ice (c, L_{fusion}, $L_{\text{vaporisation}}$) are required data for Cambridge IGCSE Physics; the other rows are given for comparison only.

Ví dụ 12 · Latent heat of fusion

Find the energy needed to melt 0.50 kg of ice at $0°$C (specific latent heat of fusion $L = 334000$ J/kg).

$Q = mL = (0.50)(334000) = \boxed{167000\,\text{J} = 167\,\text{kJ}}$.

Ví dụ 13 · Latent heat of vaporisation (condensation)

Find the energy **released** when 0.40 kg of steam at $100°$C condenses completely into water at $100°$C (specific latent heat of vaporisation $L = 2260000$ J/kg).

$Q = mL = (0.40)(2260000) = \boxed{904000\,\text{J} = 904\,\text{kJ}}$ (released to the surroundings).

Ví dụ 14 · Combined heating and change of state (multi-step)

(Supplement) Find the total energy needed to convert 0.20 kg of ice at $-10°$C completely into steam at $100°$C. For this problem, take the specific heat capacity of ice $= 2100$ J/(kg°C), $c_{\text{water}} = 4200$ J/(kg°C), $L_{\text{fusion}} = 334000$ J/kg, $L_{\text{vaporisation}} = 2260000$ J/kg.

Stage 1 — heat ice from $-10°$C to $0°$C:
$Q_1 = mc_{\text{ice}}\Delta\theta = (0.20)(2100)(10) = 4200$ J.
Stage 2 — melt the ice at constant $0°$C:
$Q_2 = mL_{\text{fusion}} = (0.20)(334000) = 66800$ J.
Stage 3 — heat the water from $0°$C to $100°$C:
$Q_3 = mc_{\text{water}}\Delta\theta = (0.20)(4200)(100) = 84000$ J.
Stage 4 — boil the water at constant $100°$C:
$Q_4 = mL_{\text{vaporisation}} = (0.20)(2260000) = 452000$ J.

Total: $Q = Q_1 + Q_2 + Q_3 + Q_4 = 4200 + 66800 + 84000 + 452000 = \boxed{607000\,\text{J} = 607\,\text{kJ}}$.

Ví dụ 14b · Heating a solid to its melting point, then melting it

Find the total energy needed to warm 0.40 kg of ice from $-8°$C up to $0°$C, and then melt it completely at $0°$C. (Specific heat capacity of ice $= 2100$ J/(kg°C); specific latent heat of fusion of ice $L = 334000\,\text{J/kg}$.)

Stage 1 — warm the ice from -8°C to 0°C (temperature rises; ice remains solid):
$Q_1 = mc_{\text{ice}}\Delta\theta = (0.40)(2100)(8) = 6720\,\text{J}$.

Stage 2 — melt the ice completely at constant 0°C (temperature does not change while melting):
$Q_2 = mL = (0.40)(334000) = 133600\,\text{J}$.

Total: $Q = Q_1 + Q_2 = 6720 + 133600 = \boxed{140320\,\text{J} \approx 140.3\,\text{kJ}}$.

Ví dụ 15 · Power, energy and time for an electric heater

A $2.5\,\text{kW}$ immersion heater raises the temperature of $5.0\,\text{kg}$ of water from 15°C to 90°C. Assuming no heat losses, find the time taken.

$Q = mc\Delta\theta = (5.0)(4200)(75) = 1575000\,\text{J}$.

$P = \dfrac{Q}{t} \Rightarrow t = \dfrac{Q}{P} = \dfrac{1575000}{2500} = \boxed{630\,\text{s} = 10.5\text{ min}}$.

2.6.1 Evaporation versus Boiling

Although both involve a liquid turning into a gas, **evaporation** and **boiling** are physically distinct processes. **Evaporation** occurs at *any* temperature, only at the liquid's free *surface*, and happens because a small fraction of particles near the surface, at any moment, happen to have enough kinetic energy to escape the attractive forces of their neighbours and leave the liquid — this occurs gradually and continuously, without bubbles. Because it is the fastest, highest-energy particles that escape first, evaporation **cools** the liquid left behind: removing high-energy particles lowers the *average* kinetic energy (and hence the temperature) of the remaining liquid. **Boiling**, in contrast, occurs at one fixed temperature (the boiling point, for a given pressure) and takes place throughout the *entire volume* of the liquid at once — bubbles of vapour form inside the liquid (not just at the surface) and rise to escape; boiling does not, by itself, change the liquid's temperature (it stays at the boiling point throughout).

The **rate of evaporation** increases with: (i) **higher temperature** (more particles have enough energy to escape); (ii) **larger surface area** (more particles are exposed at the surface, where escape is possible); (iii) **a draught / air movement across the surface** (moving air sweeps away escaping vapour particles before they can return to the liquid, keeping the local vapour concentration low); (iv) **lower humidity** (a lower concentration of vapour already in the surrounding air means fewer returning particles, so net evaporation is faster).

(!) Lỗi thường gặp: Do not confuse boiling with evaporation. Boiling happens at **one fixed temperature**, throughout the **whole volume** of the liquid, with visible bubbles; evaporation happens at **any temperature**, only at the liquid's **surface**, with no bubbles, and (unlike boiling) it noticeably **cools** the remaining liquid.

VN GIẢI THÍCH TIẾNG VIỆT

Bay hơi xảy ra ở **mọi nhiệt độ**, chỉ tại bề mặt chất lỏng, và làm **lạnh đi** phần chất lỏng còn lại (các hạt nhanh nhất, năng lượng cao nhất thoát ra trước, làm giảm động năng trung bình của phần còn lại). Sôi xảy ra ở **một nhiệt độ cố định**, trong **toàn bộ thể tích** chất lỏng (có bọt khí), và bản thân sự sôi không làm thay đổi nhiệt độ. Tốc độ bay hơi tăng khi: nhiệt độ cao hơn, diện tích bề mặt lớn hơn, có gió/luồng khí thổi qua, và độ ẩm không khí thấp hơn. Trong quá trình đổi trạng thái, nhiệt độ **không đổi** dù vẫn cung cấp nhiệt liên tục; bài toán nhiều giai đoạn phải **cộng** năng lượng của từng giai đoạn riêng biệt.

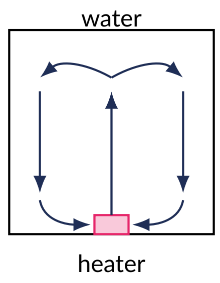
2.7 Transfer of Thermal Energy: Conduction, Convection and Radiation

Khái niệm cốt lõi

Conduction is the transfer of thermal energy through a material by particle-to-particle contact, without the material as a whole moving. In all solids, more energetic (faster-vibrating) particles pass on some of their kinetic energy to neighbouring particles through the bonds between them. In **metals**, conduction is much faster because metals also contain a *"sea"* of free (delocalised) electrons, which can move quickly throughout the metal, carrying kinetic energy far more efficiently than vibration alone — this is why metals are good thermal conductors, while non-metals, wood, plastic, and gases (which lack both a rigid lattice and free electrons) are poor conductors (good *insulators*).
Convection is the transfer of thermal energy through a **fluid** (a liquid or a gas) by the bulk movement of the fluid itself. When part of a fluid is heated, it expands, becomes *less dense* than the surrounding cooler fluid, and rises; cooler, denser fluid then sinks to take its place, setting up a continuous circulation called a **convection current**. Convection **cannot** occur in solids, because the particles are fixed in position (they can only vibrate, not flow past one another in bulk).
Radiation (specifically *infrared radiation*) is the transfer of thermal energy by electromagnetic waves. Unlike conduction and convection, radiation requires **no medium** at all — it can travel through a vacuum (this is how the Sun's energy reaches the Earth). All objects continuously emit and absorb infrared radiation; **dark, matte (dull) surfaces** are much better emitters and absorbers of infrared radiation than **light-coloured, shiny (polished) surfaces**, which instead reflect most incident radiation and are poor emitters.

Mechanism	Medium needed?	Mechanism of transfer
Conduction	Solid (best); some in liquids/gases	Vibrating particles / free (delocalised) electrons pass energy to neighbours
Convection	Fluid only (liquid or gas); none in solids	Bulk movement of heated, less-dense fluid rising, replaced by cooler, denser fluid sinking
Radiation	None — travels through a vacuum	Emission/absorption of infrared electromagnetic waves

Summary of the three heat-transfer mechanisms and the conditions required for each.



Convection current in a beaker of water heated from below: water directly above the heater is warmed, expands, becomes less dense, and rises; it cools and sinks at the sides (becoming denser again), and is replaced by more rising warm water from the centre, forming a continuous circulating current.

2.7.1 Everyday Applications

- **Vacuum flask (thermos):** reduces energy loss/gain by **all three** mechanisms at once — the vacuum between its double glass walls contains no particles, so it prevents conduction and convection; its silvered (shiny) inner surfaces reflect radiant heat back into the flask, reducing radiative loss; and its plastic stopper is both a poor conductor and prevents convection currents of air escaping at the top.
- **House insulation: cavity wall insulation** fills the gap between a house's inner and outer walls with foam or fibre, trapping pockets of air (a poor conductor) and reducing heat loss by conduction and convection through the wall. **Loft (attic) insulation** — a thick layer of fibreglass or mineral wool laid across the ceiling space — works the same way, since hot air rising by convection inside a house would otherwise carry a great deal of energy up and out through an uninsulated roof.
- **Cooling fins** (e.g. on a motorcycle or car engine, or on a computer's heat sink) are thin metal fins with a large surface area attached to a hot component; the large surface area increases the rate of heat loss both by convection (more surface in contact with moving air) and by radiation, keeping the component cool.
- **Solar water heaters** use panels painted matte black, facing the Sun, to absorb as much incoming solar (infrared and visible) radiation as possible and convert it into thermal energy, heating water flowing through pipes inside the panel.
- Household **radiators** are often painted a dark, matte colour (though — despite the name — they lose most of their heat to a room by **convection**: air warmed at the radiator's surface rises, circulates around the room, and is replaced by cooler air sinking back down to the radiator).
- **Land and sea breezes:** on a sunny day, land warms up faster than the sea (land has a much lower effective heat capacity for the same energy input); air above the land warms, expands, and rises, while cooler, denser air flows in from over the sea to replace it — felt at ground level as a cool **sea breeze**. At night, the land cools faster than the sea, and the circulation reverses, producing a **land breeze** blowing out to sea.

> **(!) Lỗi thường gặp:** Do not describe a vacuum flask as working by only "stopping heat from escaping" through a single mechanism. It must be described in terms of **all three** — the vacuum stops conduction and convection, while the silvering reduces radiation, and the stopper reduces conduction/convection through the top.

Substance	c (J/(kg °C))	Melting point (°C)	Boiling point (°C)
Water	4200	0	100
Copper	390	1085	2560
Aluminium	900	660	2470
Iron	450	1540	2860
Ethanol (alcohol)	2500	-114	78

Approximate specific heat capacities and melting/boiling points of some common substances, for comparison. Water's unusually high c and its wide liquid range (0–100 °C) make it especially useful for temperature regulation and as a coolant.

VN **GIẢI THÍCH TIẾNG VIỆT**

Dẫn nhiệt cần các hạt tiếp xúc trực tiếp (tốt nhất trong kim loại nhờ "biển" electron tự do); đối lưu cần chất lưu di chuyển được (chỉ xảy ra trong lỏng/khí, do chất lưu nóng giãn nở, giảm khối lượng riêng, rồi nổi lên — **không xảy ra trong chất rắn**); bức xạ là sóng điện từ (hồng ngoại) nên truyền được cả trong chân không. Bề mặt **đen xỉn** hấp thụ/phát xạ nhiệt tốt hơn bề mặt **sáng bóng**, vốn phản xạ nhiệt tốt hơn. Bình giữ nhiệt chống cả ba cơ chế cùng lúc: chân không (chặn dẫn nhiệt & đối lưu), lớp bạc (chặn bức xạ), nút nhựa (dẫn nhiệt kém). Cách nhiệt tường/mái nhà giữ lại lớp không khí dẫn nhiệt kém. Gió biển hình thành do đất nóng lên nhanh hơn biển vào ban ngày, tạo dòng đối lưu.

2.7.2 Comparing Thermal Conductivities of Different Materials

Different materials conduct thermal energy at very different rates. **Metals** are the best conductors, because of their free (delocalised) electrons, which move quickly through the whole metal and carry kinetic energy far more effectively than particle vibration alone. **Non-metallic solids** such as wood, brick, glass and plastic conduct much more slowly, since they must rely only on the (much slower) transfer of vibration from particle to particle. **Gases**, such as air, are the poorest conductors of all, because their particles are far apart and collide with each other only occasionally. This is precisely why insulating materials such as wool, fibreglass and expanded polystyrene foam work well: they are not, in themselves, unusually poor conductors as solids — instead, their fibrous or foamed structure traps many small pockets of still **air**, and it is this trapped air (a very poor conductor, and too finely divided for convection currents to form within it) that does most of the insulating.

Material	Approx. k (W/(m K))	Category
Copper	400	metal – excellent conductor
Aluminium	240	metal – very good conductor
Steel / iron	50	metal – good conductor
Glass	1.0	non-metal solid – poor conductor
Water	0.6	liquid – poor conductor (relies mainly on convection)
Wood	0.15	non-metal solid – good insulator
Expanded polystyrene foam	0.03	trapped-air insulator – excellent insulator
Air (still, not moving)	0.025	gas – best insulator of these

(Supplement) Approximate thermal conductivity values for common materials, illustrating the huge range involved: copper conducts roughly $400/0.025 = 16000$ times faster than still air, and about 400 times faster than wood.

Ví dụ 15b · Comparing window constructions

(Supplement) A single-glazed window consists of one 4 mm pane of glass. A double-glazed window of the same overall size instead uses two 4 mm panes of glass separated by a sealed 12 mm gap of trapped, still air. Explain, using thermal conductivity, why the double-glazed window loses heat from a warm room much more slowly than the single-glazed window.

In the single-glazed window, heat is conducted through only 4 mm of glass ($k \approx 1.0\,\mathrm{W/(m.K)}$). In the double-glazed window, heat must additionally cross a 12 mm layer of trapped air ($k \approx 0.025\,\mathrm{W/(m.K)}$, about 40 times poorer a conductor than glass) — and because the sealed gap is narrow, convection currents cannot circulate strongly within it, so this air layer transfers heat almost entirely by (very slow) conduction rather than by convection. Since most of the total thickness crossed by the double-glazed window is occupied by this very poor conductor, far less thermal energy per second is conducted through it than through the single sheet of glass, even though slightly more glass is used overall.

VN GIẢI THÍCH TIẾNG VIỆT

Kim loại dẫn nhiệt tốt nhất nhờ "biển" electron tự do; chất rắn phi kim (gỗ, gạch, kính, nhựa) dẫn nhiệt kém hơn nhiều vì chỉ truyền năng lượng qua dao động của hạt; khí (như không khí) dẫn nhiệt kém nhất vì các hạt cách xa nhau, ít va chạm. Vật liệu cách nhiệt (len, sợi thủy tinh, xốp polystyrene) hoạt động chủ yếu bằng cách giữ lại các túi khí nhỏ đứng yên bên trong cấu trúc xốp/sợi của chúng, chứ bản thân sợi vật liệu không nhất thiết dẫn nhiệt kém hơn các chất rắn khác. Cửa sổ hai lớp kính cách nhiệt tốt hơn cửa một lớp vì lớp không khí kẹp ở giữa (dẫn nhiệt rất kém, và quá hẹp để đối lưu mạnh hình thành) chiếm phần lớn bề dày mà nhiệt phải đi qua.

2.8 Practice Problems

Bài tập luyện tập

(Supplement) A fixed mass of gas at pressure $150\,\text{kPa}$ occupies $400\,\text{cm}^3$. At constant temperature it is compressed to $240\,\text{cm}^3$. Find the new pressure.

(A) $250\,\text{kPa}$

(B) $200\,\text{kPa}$

(C) $225\,\text{kPa}$

(D) $300\,\text{kPa}$

Lời giải chi tiết

$p_1V_1 = p_2V_2 \Rightarrow p_2 = \dfrac{(150)(400)}{240} = \dfrac{60000}{240} = \boxed{250\,\text{kPa}}$. **(A)**.

Bài tập luyện tập

A $1.5\,\text{kg}$ metal block ($c = 900\,\text{J}/(\text{kg}^\circ\text{C})$) is heated from 25°C to 145°C by a $300\,\text{W}$ electric heater. Find (a) the energy required, (b) the time taken (assume no losses).

Lời giải chi tiết

(a) $Q = mc\Delta\theta = (1.5)(900)(120) = 162000\,\text{J}$.

(b) $t = \dfrac{Q}{P} = \dfrac{162000}{300} = \boxed{540\,\text{s} = 9.0\,\text{min}}$.

Bài tập luyện tập

Find the energy needed to convert $0.20\,\text{kg}$ of water at 100°C completely into steam at 100°C (specific latent heat of vaporisation $L = 2260000\,\text{J/kg}$).

Lời giải chi tiết

$Q = mL = (0.20)(2260000) = \boxed{452000\,\text{J} = 452\,\text{kJ}}$.

Bài tập luyện tập

A vacuum flask has double glass walls with a vacuum between them, silvered (shiny) inner surfaces, and a plastic stopper. Explain how *each* feature reduces heat loss.

Lời giải chi tiết

Vacuum: contains no particles, so it cannot transfer energy by conduction or convection. **Silvered surfaces:** reflect infrared radiation back into the flask (shiny surfaces are poor emitters/absorbers, good reflectors), reducing radiative loss. **Plastic stopper:** a poor thermal conductor, reducing conduction loss through the top, and also stops convection currents of air escaping.

Bài tập luyện tập

(Supplement) A fixed mass of gas at 17°C has a pressure of 180 kPa in a sealed rigid container. Find its pressure at 77°C.

(A) 198 kPa
(B) 217.2 kPa
(C) 180 kPa
(D) 240 kPa

Lời giải chi tiết

$T_1 = 17 + 273 = 290$ K; $T_2 = 77 + 273 = 350$ K. $p_2 = p_1 \dfrac{T_2}{T_1} = 180 \times \dfrac{350}{290} = \boxed{217.2\,\text{kPa}}$. **(B).**

Bài tập luyện tập

Convert (a) 40°C to kelvin, (b) 310 K to $^\circ$C.

Lời giải chi tiết

(a) $T = 40 + 273 = \boxed{313\,\text{K}}$. (b) $\theta = 310 - 273 = \boxed{37^\circ\text{C}}$ (approximately human body temperature).

Bài tập luyện tập

100 g of water at 90°C is mixed with 400 g of water at 10°C. Find the final temperature.

(A) 26°C
(B) 32°C
(C) 40°C
(D) 50°C

Lời giải chi tiết

$(0.100)(90-\theta) = (0.400)(\theta-10) \Rightarrow 9.0-0.100\theta = 0.400\theta-4.0 \Rightarrow 13.0 = 0.500\theta \Rightarrow \theta = \boxed{26^\circ\text{C}}$. **(A).**

Bài tập luyện tập

A 0.30 kg block of metal at 150°C is dropped into 0.40 kg of water at 18°C. The mixture reaches a final temperature of 30°C. Find the specific heat capacity of the metal.

Lời giải chi tiết

Energy gained by water $= (0.40)(4200)(30-18) = (0.40)(4200)(12) = 20160$ J.
This equals energy lost by metal: $(0.30)(c)(150-30) = (0.30)(c)(120) = 36c$.

$36c = 20160 \Rightarrow c = \boxed{560\,\text{J}/(\text{kg}^\circ\text{C})}$.

Bài tập luyện tập

Explain, in terms of particles, why evaporation causes cooling of the liquid left behind.

Lời giải chi tiết

The particles in a liquid have a range of speeds (kinetic energies). Evaporation occurs when the **fastest**, highest-energy particles near the surface escape into the surrounding air. Removing these highest-energy particles **lowers the average kinetic energy** of the particles remaining in the liquid — and since temperature is a measure of average kinetic energy, the remaining liquid's temperature falls.

Bài tập luyện tập

State *two* differences between boiling and evaporation.

Lời giải chi tiết

(1) Boiling occurs at one fixed temperature (the boiling point); evaporation occurs at *any* temperature.
(2) Boiling occurs throughout the whole volume of the liquid (bubbles form inside it); evaporation occurs only at the liquid's free surface.

Bài tập luyện tập

Find the total energy needed to convert 0.50 kg of ice at 0°C completely into water at 20°C. ($L_{\text{fusion}} = 334000\,\text{J/kg}$, $c_{\text{water}} = 4200\,\text{J}/(\text{kg}^\circ\text{C})$.)

Lời giải chi tiết

Stage 1 (melt at 0°C): $Q_1 = mL = (0.50)(334000) = 167000\,\text{J}$.
Stage 2 (heat water $0 \to 20^\circ$C): $Q_2 = mc\Delta\theta = (0.50)(4200)(20) = 42000\,\text{J}$.
Total $= 167000 + 42000 = \boxed{209000\,\text{J} = 209\,\text{kJ}}$.

Bài tập luyện tập

Why are the wires and elements in electric kettles and cooking pots usually made of metal, while their handles are made of plastic or wood?

Lời giải chi tiết

Metals are good thermal **conductors** (they contain free/delocalised electrons that carry energy quickly), so a metal base/element transfers heat efficiently to the water or food. Plastic and wood are poor conductors (good insulators), so a handle made from them stays cool enough to hold safely even when the metal body of the pot or kettle is very hot.

Bài tập luyện tập

A bridge is built with small gaps between adjacent concrete sections. Explain why these gaps are necessary.

Lời giải chi tiết

Concrete (like most solids) **expands** when its temperature rises, for example in hot summer weather. If sections were built with no gaps, adjacent expanding sections would push against each other, creating very large internal stresses that could crack or buckle the bridge. The expansion gaps leave room for this thermal expansion to happen safely without damaging the structure.

Bài tập luyện tập

Two identical metal spheres, one painted matte black and one polished shiny silver, are heated to the same temperature and left to cool in identical surroundings. Which sphere cools faster, and why?

(A) The shiny sphere, because it absorbs radiation better

(B) The black sphere, because it is a better emitter of infrared radiation

(C) They cool at the same rate, since they are the same metal

(D) The shiny sphere, because metal conducts heat

Lời giải chi tiết

A matte black surface is a much better **emitter** of infrared radiation than a shiny silver surface (which mostly reflects radiation rather than emitting/absorbing it), so the black sphere radiates energy away faster and cools more quickly. **(B)**.

Bài tập luyện tập

(Supplement) A gas occupies $600\ \text{cm}^3$ at a pressure of 120 kPa. Find the volume it would occupy at a pressure of 200 kPa, at the same temperature.

Lời giải chi tiết

$$p_1V_1 = p_2V_2 \Rightarrow V_2 = \frac{(120)(600)}{200} = \boxed{360\ \text{cm}^3}.$$

Bài tập luyện tập

Explain, using the kinetic particle model, why a gas exerts pressure on the walls of its container, and why heating the gas (at constant volume) increases this pressure.

Lời giải chi tiết

Gas particles move rapidly and randomly, continually colliding with the container walls; each collision transfers a tiny force to the wall, and the sum of these many collisions per second produces the gas pressure. Heating the gas increases the particles' average kinetic energy, so they move faster: they hit the walls **more often** and with **greater force** per collision, so (at constant volume) the pressure increases.

Bài tập luyện tập

A 1.0 kg block of ice at $0°$C requires 334 kJ to melt completely. Find the specific latent heat of fusion of ice, and use it to find the energy needed to melt 250 g of ice.

Lời giải chi tiết

$L = \frac{Q}{m} = \frac{334000}{1.0} = \boxed{334000\,\text{J/kg}}$.
For 0.25 kg: $Q = mL = (0.25)(334000) = \boxed{83500\,\text{J} = 83.5\,\text{kJ}}$.

Bài tập luyện tập

250 g of water at $95°$C is mixed with 250 g of water at $15°$C. Find the final temperature, and explain why the answer is exactly the average of the two starting temperatures.

Lời giải chi tiết

Since the masses and specific heat capacities are identical: $(0.250)(95-\theta) = (0.250)(\theta-15) \Rightarrow 95-\theta = \theta-15 \Rightarrow 110 = 2\theta \Rightarrow \theta = \boxed{55°\text{C}}$, exactly the mean of $95°$C and $15°$C. This is because, with equal masses of the *same* substance, the energy-balance equation reduces to a simple average of the two temperatures.

Bài tập luyện tập

State whether each is mainly conduction, convection, or radiation: (a) warming your hands by a bonfire without touching it; (b) a metal spoon becoming hot after being left in a cup of hot tea; (c) warm air rising above a radiator and circulating around a room.

Lời giải chi tiết

(a) **Radiation** (infrared, needs no medium, works even through the air gap and would work through a vacuum).
(b) **Conduction** (energy passed particle-to-particle, and by free electrons, along the solid metal spoon).
(c) **Convection** (bulk movement of heated, less dense air rising, setting up a current).

Bài tập luyện tập

A thermometer bulb is made of thin glass with a wide surface area, and contains a liquid with a large expansion per degree. Explain why each feature makes the thermometer respond more quickly and sensitively to temperature changes.

Lời giải chi tiết

Thin glass, wide surface area: allows heat to be conducted into (or out of) the liquid quickly, so the liquid reaches the surrounding temperature rapidly (faster response time).
Large expansion per degree: a liquid that expands a lot for a small temperature change produces a large, easily-read movement along the capillary tube for each degree, making the scale more sensitive (a bigger movement per degree).

Bài tập luyện tập

(Supplement) A sealed gas cylinder contains gas at $15\,^\circ$C and 400 kPa. The manufacturer states the cylinder is safe up to 600 kPa. Find the maximum safe temperature (in $^\circ$C) for this gas at constant volume.

Lời giải chi tiết

$T_1 = 15 + 273 = 288$ K. $\dfrac{p_1}{T_1} = \dfrac{p_2}{T_2} \Rightarrow T_2 = T_1 \times \dfrac{p_2}{p_1} = 288 \times \dfrac{600}{400} = 432$ K.

In $^\circ$C: $\theta_2 = 432 - 273 = \boxed{159^\circ\text{C}}$.

Bài tập luyện tập

Explain why fanning yourself with a piece of card on a hot day makes you feel cooler, even though the air itself is not cooled by the fan.

Lời giải chi tiết

Fanning increases air movement across your skin, which speeds up the **evaporation** of sweat (moving air sweeps away the water vapour that has just evaporated, keeping the humidity just above your skin low, so more water molecules can escape). Faster evaporation removes energy from your skin more quickly, giving a greater cooling effect – the air's own temperature is unchanged, but the rate of evaporative cooling increases.

Bài tập luyện tập

0.40 kg of water at 18°C is heated to boiling point (100°C) and then 0.10 kg of it boils away as steam. Find the total energy supplied. ($c_{\text{water}} = 4200$ J/(kg$^\circ$C), $L_{\text{vaporisation}} = 2260000$ J/kg.)

Lời giải chi tiết

Stage 1 (heat all 0.40 kg from 18°C to 100°C): $Q_1 = (0.40)(4200)(82) = 137760$ J.
Stage 2 (boil away 0.10 kg at 100°C): $Q_2 = (0.10)(2260000) = 226000$ J.
Total $= 137760 + 226000 = \boxed{363760\text{ J} \approx 364\text{ kJ}}$.

Bài tập luyện tập

A copper rod and a wooden rod of the same size have one end each placed in a flame. After one minute, the far end of the copper rod is too hot to touch, but the far end of the wooden rod is still cool. Explain this observation.

(A) Copper has a higher specific heat capacity than wood

(B) Copper is a much better thermal conductor than wood

(C) Wood absorbs more radiation than copper

(D) Copper has a lower density than wood

Lời giải chi tiết

Copper is a metal, containing many free (delocalised) electrons that move quickly and carry thermal energy rapidly along the rod, in addition to particle-to-particle vibration – making it a much better **conductor** than wood, which has no free electrons and conducts heat very poorly (an insulator). **(B)**.

Bài tập luyện tập

(Supplement) A fixed mass of gas has volume $500\,\text{cm}^3$ at pressure $101\,\text{kPa}$ and temperature $27°\text{C}$ ($300\,\text{K}$). It is compressed to $250\,\text{cm}^3$ and simultaneously heated to $127°\text{C}$ ($400\,\text{K}$). Using the combined gas law $p_1V_1/T_1 = p_2V_2/T_2$, find the new pressure.

Lời giải chi tiết

$$\frac{p_1V_1}{T_1} = \frac{p_2V_2}{T_2} \Rightarrow p_2 = \frac{p_1V_1T_2}{T_1V_2} = \frac{(101)(500)(400)}{(300)(250)} = \frac{20200000}{75000} = \boxed{269.3\,\text{kPa}}.$$

Bài tập luyện tập

(Supplement) A fixed mass of gas has a volume of $400\,\text{cm}^3$ at $27°\text{C}$, at constant pressure. Find its volume when heated to $327°\text{C}$.

Lời giải chi tiết

$T_1 = 27 + 273 = 300\,\text{K}$; $T_2 = 327 + 273 = 600\,\text{K}$. $\dfrac{V_1}{T_1} = \dfrac{V_2}{T_2} \Rightarrow V_2 = V_1\dfrac{T_2}{T_1} = 400 \times \dfrac{600}{300} = \boxed{800\,\text{cm}^3}$.

Bài tập luyện tập

(Supplement) A gas in a cylinder fitted with a piston of cross-sectional area $50\,\text{cm}^2$ ($= 0.0050\,\text{m}^2$) is compressed at constant temperature from $600\,\text{cm}^3$ at $100\,\text{kPa}$ to $200\,\text{cm}^3$. Find (a) the new pressure, (b) the force the gas now exerts on the piston.

Lời giải chi tiết

(a) $p_1V_1 = p_2V_2 \Rightarrow p_2 = \dfrac{(100)(600)}{200} = 300\,\text{kPa} = 300000\,\text{Pa}$.

(b) $F = pA = (300000)(0.0050) = \boxed{1500\,\text{N}}$.

Bài tập luyện tập

A metal block has a mass of $4.0\,\text{kg}$ and specific heat capacity $500\,\text{J}/(\text{kg}°\text{C})$. Find (a) the thermal capacity of the block, (b) the energy required to raise its temperature from $20°\text{C}$ to $70°\text{C}$.

Lời giải chi tiết

(a) $C = mc = (4.0)(500) = \boxed{2000\,\text{J}/°\text{C}}$.

(b) $Q = C\Delta\theta = (2000)(50) = \boxed{100000\,\text{J} = 100\,\text{kJ}}$.

Bài tập luyện tập

Explain how (a) cavity wall insulation and (b) loft insulation reduce heat loss from a house, in terms of the mechanisms of heat transfer involved.

Lời giải chi tiết

(a) **Cavity wall insulation:** foam or fibre fills the gap between the inner and outer walls, trapping small pockets of air; air is a poor thermal conductor, so this reduces heat loss by **conduction** through the wall, and the trapped, separated pockets prevent air inside the cavity circulating, reducing **convection** as well.
(b) **Loft insulation:** a thick layer of fibreglass or mineral wool laid across the ceiling space similarly traps air and reduces conduction; without it, warm air (heated inside the house and rising by convection) would lose a great deal of energy by conduction through an uninsulated roof.

Bài tập luyện tập

Explain why washing on a clothesline dries faster on a warm, windy day with the clothes spread out, than on a cool, still day with the clothes bunched together.

Lời giải chi tiết

Higher **temperature** gives more water particles enough kinetic energy to escape the surface of the wet fabric, increasing the evaporation rate. **Wind** sweeps away water vapour as it evaporates, keeping the humidity just above the fabric low so more particles can escape (rather than returning to the liquid). Spreading the clothes out increases the exposed **surface area**, allowing more particles to evaporate at the surface at once. All three factors combine to increase the rate of evaporation on the warm, windy day with clothes spread out.

Bài tập luyện tập

Explain (a) why cooling fins on a motorcycle engine have a large surface area, and (b) why solar water-heating panels are usually painted matte black.

Lời giải chi tiết

(a) A larger surface area increases the rate at which thermal energy can be transferred away from the hot engine to the surrounding air, by both convection (more surface in contact with moving air) and radiation (more area emitting infrared radiation), keeping the engine cooler.
(b) A matte black surface is a much better **absorber** of infrared and visible radiation than a light or shiny surface, so the panel absorbs as much of the Sun's radiated energy as possible, converting it efficiently into thermal energy to heat the water flowing through it.

Bài tập luyện tập

In an experiment to find the specific heat capacity of aluminium, a 1.0 kg aluminium block is heated by an electrical immersion heater fitted into a hole drilled in the block. The ammeter reads 5.0 A, the voltmeter reads 12 V, and the heater is switched on for exactly 300 s (5.0 minutes). The block's temperature rises from $20°$C to $40°$C. Assuming no heat losses, find the specific heat capacity of aluminium.

(A) 600 J/(kg°C)

(B) 750 J/(kg°C)

(C) 900 J/(kg°C)

(D) 1200 J/(kg°C)

Lời giải chi tiết

Electrical energy supplied: $E = IVt = (5.0)(12)(300) = 18000$ J.
Temperature rise: $\Delta\theta = 40 - 20 = 20\,^\circ$C.
$c = \dfrac{E}{m\Delta\theta} = \dfrac{18000}{(1.0)(20)} = \boxed{900\,\text{J/(kg}^\circ\text{C)}}$. **(C).**

Bài tập luyện tập

150 g of water at 70°C is mixed with 350 g of water at 10°C in an insulated container. Find the final temperature.

Lời giải chi tiết

$(0.150)(70-\theta) = (0.350)(\theta-10) \Rightarrow 10.5-0.150\theta = 0.350\theta-3.5 \Rightarrow 14.0 = 0.500\theta \Rightarrow \theta = \boxed{28\,^\circ\text{C}}$.

Bài tập luyện tập

(Supplement) A fixed mass of gas has a volume of 300 cm^3 at a pressure of 200 kPa and a temperature of 17°C (290 K). It is allowed to expand to 180 cm^3 while being heated to 77°C (350 K). Using $\dfrac{p_1V_1}{T_1} = \dfrac{p_2V_2}{T_2}$, find the new pressure.

Lời giải chi tiết

$p_2 = \dfrac{p_1V_1T_2}{T_1V_2} = \dfrac{(200)(300)(350)}{(290)(180)} = \dfrac{21000000}{52200} = \boxed{402.3\,\text{kPa}}$ (to 1 d.p.).

Bài tập luyện tập

(Supplement) A fixed mass of gas has a volume of 250 cm^3 at a pressure of 150 kPa and a temperature of 27°C (300 K). It is compressed to 100 cm^3 and its pressure rises to 450 kPa. Using the combined gas law, find the new temperature, in °C.

Lời giải chi tiết

$\dfrac{p_1V_1}{T_1} = \dfrac{(150)(250)}{300} = 125$. $\dfrac{p_2V_2}{T_2} = 125 \Rightarrow T_2 = \dfrac{p_2V_2}{125} = \dfrac{(450)(100)}{125} = 360$ K.
In °C: $\theta_2 = 360 - 273 = \boxed{87^\circ\text{C}}$.

Bài tập luyện tập

Wool and fibreglass are widely used as insulating materials in coats and in house roofs. Which of the following best explains why they are good thermal insulators?

(A) They are very good conductors of heat, so heat passes through them quickly and evenly

(B) Their fibrous structure traps many small pockets of still air, which is a very poor conductor

(C) They are unusually dense materials compared with metals

(D) They absorb infrared radiation better than metals do

Lời giải chi tiết

The fibres themselves are not exceptionally poor conductors compared with other solids; the insulating effect comes mainly from the many small pockets of **trapped, still air** within the fibrous structure. Air is a very poor conductor, and the pockets are too small for convection currents to form within them, so heat transfer through the material is greatly reduced. **(B).**

Bài tập luyện tập

Find the total energy needed to change $0.15\,\text{kg}$ of ice at -20°C into water at 25°C. ($c_{\text{ice}} = 2100\,\text{J}/(\text{kg}^\circ\text{C})$, $L_{\text{fusion}} = 334000\,\text{J}/\text{kg}$, $c_{\text{water}} = 4200\,\text{J}/(\text{kg}^\circ\text{C})$.)

Lời giải chi tiết

Stage 1 (warm ice from -20°C to 0°C): $Q_1 = (0.15)(2100)(20) = 6300\,\text{J}$.
Stage 2 (melt ice at 0°C): $Q_2 = (0.15)(334000) = 50100\,\text{J}$.
Stage 3 (warm water from 0°C to 25°C): $Q_3 = (0.15)(4200)(25) = 15750\,\text{J}$.
Total: $Q = 6300 + 50100 + 15750 = \boxed{72150\,\text{J} \approx 72.2\,\text{kJ}}$.

Bài tập luyện tập

An electric kettle rated at $2.0\,\text{kW}$ contains $0.60\,\text{kg}$ of water at 20°C. (a) Find the time needed to heat the water to boiling point (100°C). (b) The kettle is accidentally left switched on for a further 2.0 minutes after reaching 100°C. Find the mass of water boiled away as steam in this time, assuming all the extra energy goes into vaporising water. ($c_{\text{water}} = 4200\,\text{J}/(\text{kg}^\circ\text{C})$, $L_{\text{vaporisation}} = 2260000\,\text{J}/\text{kg}$.)

Lời giải chi tiết

(a) $Q = mc\Delta\theta = (0.60)(4200)(80) = 201600\,\text{J}$. $t = \dfrac{Q}{P} = \dfrac{201600}{2000} = \boxed{100.8\,\text{s}}$.
(b) Extra energy supplied: $Q = Pt = (2000)(120) = 240000\,\text{J}$.
Mass boiled away: $m = \dfrac{Q}{L} = \dfrac{240000}{2260000} = \boxed{0.106\,\text{kg} \approx 106\,\text{g}}$.

Bài tập luyện tập

An insulated calorimeter has a thermal capacity of $80\,\text{J}/^\circ\text{C}$ and contains $0.30\,\text{kg}$ of water at 15°C. A $0.10\,\text{kg}$ block of metal at 200°C (specific heat capacity $380\,\text{J}/(\text{kg}^\circ\text{C})$) is dropped into the water. Find the final temperature of the water, taking into account the heat absorbed by the calorimeter itself.

Lời giải chi tiết

Energy lost by metal = energy gained by water + energy gained by calorimeter:

$$(0.10)(380)(200-\theta) = (0.30)(4200)(\theta-15) + (80)(\theta-15).$$

$38(200-\theta) = 1340(\theta-15) \Rightarrow 7600 - 38\theta = 1340\theta - 20100 \Rightarrow 27700 = 1378\theta$.
$\theta = \dfrac{27700}{1378} = \boxed{20.1\,^\circ\text{C}}$ (to 3 s.f.).

Bài tập luyện tập

Using the table of specific latent heats of fusion (water/ice 334000 J/kg, aluminium 397000 J/kg, lead 23000 J/kg), calculate the energy needed to melt 50 g of aluminium and the energy needed to melt 50 g of lead, both starting exactly at their melting points. Explain why the two values are so different.

Lời giải chi tiết

Aluminium: $Q = mL = (0.050)(397000) = \boxed{19850\,\text{J} \approx 19.9\,\text{kJ}}$.
Lead: $Q = mL = (0.050)(23000) = \boxed{1150\,\text{J} = 1.15\,\text{kJ}}$.
Melting aluminium needs roughly 17 times more energy per kilogram than melting lead. This reflects much stronger forces of attraction between particles in aluminium's solid lattice — the same reason aluminium has a far higher melting point (660°C) than lead (327°C): more energy is needed to loosen the stronger aluminium bonds enough for the particles to flow past one another as a liquid.

Waves

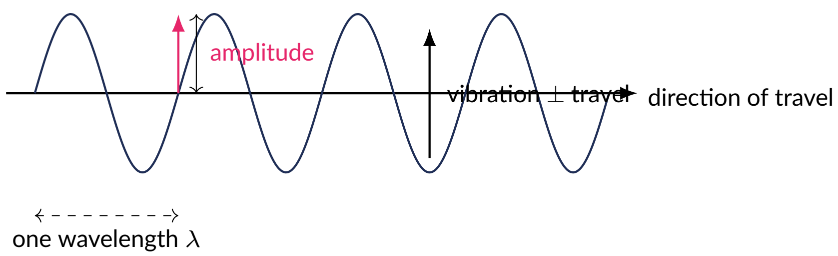
> **Mục tiêu Unit:** Tính chất chung của sóng (sóng ngang/dọc, biên độ, bước sóng, tần số, chu kỳ, vận tốc sóng, mặt sóng, bể sóng nước – ripple tank); phản xạ, khúc xạ, nhiễu xạ áp dụng cho **mọi** loại sóng; ánh sáng: gương phẳng, khúc xạ, chiết suất, góc tới hạn, phản xạ toàn phần & cáp quang, tán sắc; thấu kính hội tụ (Supplement); quang phổ điện từ đầy đủ (bước sóng, tần số, ứng dụng, nguy hiểm); âm thanh: bản chất sóng dọc, tốc độ trong các môi trường, âm nghe được, độ cao/độ to qua dao động ký, siêu âm, tiếng vọng & âm vang.

3.1 General Properties of Waves

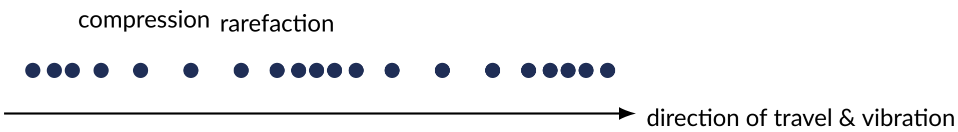
A **wave** is a disturbance that transfers **energy** (and sometimes information) from one place to another *without transferring matter* — the medium through which a wave travels (where one exists) returns to its original, undisturbed position once the wave has passed. A cork floating on a pond bobs up and down as a ripple passes underneath it, but it does not drift toward the source of the ripple; only the disturbance (and the energy carried by it) moves outward.

Khái niệm cốt lõi

> In a **transverse** wave, the particles of the medium (or, for electromagnetic waves, the oscillating electric and magnetic fields) vibrate *perpendicular* to the direction the wave travels — examples include all electromagnetic waves (light, radio, etc.), water waves, and waves on a stretched string. In a **longitudinal** wave, the particles vibrate *parallel to* (along the same line as) the direction of travel, producing alternating regions of **compression** (particles bunched close together, higher pressure/density) and **rarefaction** (particles spread apart, lower pressure/density) — sound waves are the standard example.



(a) Transverse wave (e.g. light, water ripples)



(b) Longitudinal wave (e.g. sound)

(a) Transverse wave: particles vibrate perpendicular to the direction of travel; the amplitude and wavelength λ (distance between adjacent points vibrating in phase, e.g. crest to crest) are marked. (b) Longitudinal wave: particles vibrate parallel to the direction of travel, producing compressions (particles close together) and rarefactions (particles spread apart) that travel along the wave's length.

Amplitude: the maximum displacement of a particle (or field) from its undisturbed (rest) position. **Wavelength** λ: the distance between two adjacent, corresponding points on a wave that are vibrating in phase (e.g. crest to crest, or compression to compression), measured in metres. **Frequency** f: the number of complete waves (oscillations) passing a fixed point per second, measured in hertz (Hz $=$ 1/s). **Period** T: the time taken for one complete oscillation, $T = \frac{1}{f}$. **Wave equation:** $v = f\lambda$ — true for *every* type of wave, mechanical or electromagnetic. A **wavefront** is a line (or surface) joining points on adjacent waves that are vibrating in phase (e.g. all the points currently at a crest); wavefronts are always perpendicular to the direction of travel (the *ray*), and successive wavefronts are one wavelength apart.

The ripple tank is the standard laboratory device for studying general wave behaviour using water waves, since the wavefronts are directly visible (often projected as bright/dark lines onto a screen below a shallow glass-bottomed tank). A vibrating dipper or motor-driven bar generates repeated *plane* (straight) or *circular* wavefronts of known frequency, which can then be used to demonstrate, visibly and quantitatively, the three behaviours common to *all* waves:

- **Reflection** off a straight barrier placed in the tank — the reflected wavefronts obey the law of reflection (angle of incidence $=$ angle of reflection, both from the normal to the barrier), exactly as with light hitting a mirror.
- **Refraction** as the waves cross a boundary into a region of shallower water (a submerged glass plate reduces the depth) — water waves travel more slowly in shallower water, so their wavelength decreases (frequency is fixed by the dipper and does not change) and, if the waves meet the boundary at an angle, their direction of travel bends.
- **Diffraction** as the waves pass through a gap in a barrier, or around the edge of an obstacle — the wavefronts spread out into the "shadow" region behind the gap or obstacle; the spreading is most pronounced when the gap width is comparable to the wavelength.

A single dipper touching the water repeatedly at one point produces expanding **circular** wavefronts (like the ripples from a dropped stone), while a straight bar vibrating along its length produces **plane** (straight, parallel) wavefronts — the water-wave equivalent of a distant point source versus a very wide, distant source of light. Because the pattern of ripples moves quickly, a stroboscope (a flashing light synchronised with, or close to, the dipper's frequency) is often used to make the wavefronts appear to freeze or move slowly, so that their spacing (wavelength) can be measured accurately and the whole class can observe reflection, refraction and diffraction happening in real time on a screen below the tank.

VN **GIẢI THÍCH TIẾNG VIỆT**

Sóng truyền **năng lượng** (đôi khi cả thông tin), **không truyền vật chất** — môi trường trở lại vị trí ban đầu sau khi sóng đi qua (ví dụ nút chai bập bềnh tại chỗ khi sóng nước đi qua, không trôi theo sóng). Sóng ngang: hạt (hoặc trường) dao động **vuông góc** với hướng truyền (ánh sáng, sóng nước); sóng dọc: hạt dao động **song song** với hướng truyền, tạo vùng nén và vùng giãn (âm thanh). Phương trình sóng $v = f\lambda$ áp dụng cho **mọi** loại sóng; chu kỳ $T = 1/f$. **Bể sóng nước (ripple tank)** là dụng cụ chuẩn để quan sát trực tiếp phản xạ, khúc xạ, nhiễu xạ của sóng nước — các mặt sóng (wavefront) luôn vuông góc với hướng truyền.

Ví dụ 1 · The wave equation — finding speed

A water wave in a ripple tank has frequency 2.0 Hz and wavelength 0.50 m. Find its speed.
$v = f\lambda = (2.0)(0.50) = 1.0$ m/s.

Ví dụ 2 · The wave equation — finding frequency and speed from the period

A wave has period $T = 0.020$ s and wavelength 8.5 m. Find its frequency and its speed.

$f = \dfrac{1}{T} = \dfrac{1}{0.020} = 50$ Hz. $\quad v = f\lambda = (50)(8.5) = 425$ m/s.

Two different graphs are commonly used to describe the very same wave, and it is essential to check *which* quantity is plotted along the horizontal axis before reading off any value from either one.

Two different graphs for the *same* transverse wave, which can look identical in shape. (a) Displacement plotted against **distance** along the wave — a "snapshot" of every particle at one instant: the horizontal spacing between repeats is the **wavelength** λ. (b) Displacement plotted against **time** at one single fixed point, as the wave passes it: the horizontal spacing between repeats is the **period** T. The vertical scale (maximum height) gives the **amplitude** on either graph.

(!) Lỗi thường gặp: A displacement–**distance** graph and a displacement–**time** graph for the same wave are often drawn as the same-looking sine curve, but the horizontal axis means something completely different on each one. Reading the horizontal repeat-spacing off a displacement–**distance** graph gives the **wavelength** λ (in metres); reading the horizontal repeat-spacing off a displacement–**time** graph gives the **period** T (in seconds) — never the other way around, and never assume a graph must be showing distance just because it "looks like" a wave. Always read the *label* on the horizontal axis first.

Ví dụ thêm · Synthesis — combining both wave graphs

A transverse wave is investigated with two separate measurements taken on the same wave. A displacement–**distance** graph (a snapshot along the wave) shows the pattern repeating every 1.2 m, with a maximum displacement of 4.0 cm. A displacement–**time** graph, recorded at one fixed point as the wave passes, shows the pattern repeating every 0.030 s. Find (a) the amplitude, (b) the wavelength, (c) the period and frequency, and (d) the speed of the wave.

(a) Amplitude $= 4.0$ cm (the maximum displacement — the same value on either graph).

(b) Wavelength: read only from the displacement–**distance** graph, $\lambda = 1.2$ m.

(c) Period: read only from the displacement–**time** graph, $T = 0.030$ s. Frequency $f = \dfrac{1}{T} = \dfrac{1}{0.030} = 33.3$ Hz (3 s.f.).

(d) Speed $v = f\lambda = (33.3)(1.2) = 40.0$ m/s (equivalently $v = \lambda/T = 1.2/0.030 = 40.0$ m/s).

3.2 Reflection, Refraction and Diffraction of Waves (General)

These three behaviours apply, in principle, to *every* type of wave — mechanical (water, sound, waves on a string) and electromagnetic (light, radio, etc.) alike.

Law of reflection: the angle of incidence i equals the angle of reflection r, both measured from the **normal** — the line perpendicular to the reflecting surface at the point where the wave strikes it. **Refraction** is a change in a wave's **speed** (and usually its **direction** and **wavelength**) as it crosses a boundary between two different media; the wave's **frequency never changes** during refraction, because frequency is fixed by the source that generates the wave. **Diffraction** is the spreading of a wave as it passes through a gap or around the edge of an obstacle; the amount of spreading depends on the size of the gap (or obstacle) *relative to* the wavelength.

A helpful way to picture *why* a wave changes direction on refracting into a medium where it travels more slowly: imagine a row of marching soldiers (representing a wavefront) walking from firm ground onto soft mud at an angle. The soldiers who reach the mud first slow down immediately, while those still on firm ground continue at full speed; because one end of the marching line is held back before the other, the whole line **swings around**, changing the direction the row is facing — exactly as a wavefront bends when it crosses at an angle into a slower medium. If the row meets the boundary "head on" (perpendicular to it), every soldier slows at the same instant and the line's direction does not change at all — matching the fact that a wave travelling straight along the normal ($0°$ incidence) refracts with no change in direction.

Diffraction is most pronounced — the wave spreads out most strongly into the region behind the gap — when the **gap width is approximately equal to the wavelength**. A gap much *wider* than the wavelength produces very little spreading (the wave continues mostly in its original direction, like light through an open doorway); a gap much *narrower* than the wavelength lets very little wave energy through at all. This is why sound (with wavelengths from a few centimetres to several metres in air) diffracts noticeably around corners and through doorways — you can hear someone talking around a corner even though you cannot see them — while visible light (wavelength around 5×10^{-7} m, many millions of times smaller than a doorway) shows no noticeable diffraction through everyday gaps and appears to travel in perfectly straight lines (hence sharp shadows).

(!) Lỗi thường gặp: Refraction changes a wave's **speed** and (if it enters at an angle) its **direction**, and its **wavelength** always changes to match the new speed ($v = f\lambda$ with f fixed) — but refraction **never** changes the **frequency**. The frequency is determined only by the source; it is the same in both media, even though the wave travels at a different speed and has a different wavelength in each.

(!) Lỗi thường gặp: Diffraction does not "always happen the same amount" — it is most noticeable specifically when the **gap size is comparable to the wavelength**. Do not assume a wave always spreads out significantly through any gap; a wave passing through a gap far larger than its own wavelength shows almost no spreading at all.

VN GIẢI THÍCH TIẾNG VIỆT

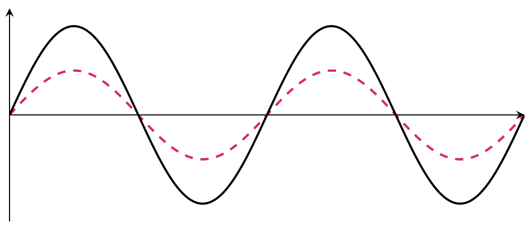
Định luật phản xạ (góc tới $=$ góc phản xạ, đo từ pháp tuyến) và hiện tượng khúc xạ, nhiễu xạ áp dụng cho **mọi** loại sóng. Khúc xạ làm thay đổi **tốc độ**, **hướng đi** và **bước sóng**, nhưng **không bao giờ** làm thay đổi **tần số** (tần số chỉ do nguồn phát quyết định). Nhiễu xạ (uốn quanh vật cản/qua khe hẹp) rõ nhất khi kích thước khe **gần bằng bước sóng** — đây là lý do sóng âm (bước sóng cỡ mét) nhiễu xạ mạnh qua cửa hay quanh góc tường, trong khi ánh sáng (bước sóng cỡ micromet) hầu như không nhiễu xạ qua các khe thông thường nên bóng của vật luôn có viền sắc nét.

3.2.1 Interference and Superposition of Waves (Supplement)

(Supplement) When two waves of the *same type* travelling through the same region of a medium meet at a point, the **principle of superposition** states that the resultant displacement at that point, at that instant, is simply the sum of the displacements that each wave would have produced there on its own (with direction taken into account). Once the two waves have passed through one another, each continues on its own way completely unaffected by the encounter — only while the two waves overlap does their combined effect appear.

(Supplement) **Constructive interference** occurs where a crest of one wave meets a crest of the other (or a trough meets a trough): the two displacements add together, producing a resultant wave of **larger amplitude** than either individual wave. **Destructive interference** occurs where a crest of one wave meets a trough of the other: the displacements act in opposite directions and (partly, or — if the amplitudes are equal — completely) cancel, producing a resultant of **reduced or zero amplitude**. Whether constructive or destructive interference occurs at a particular point depends on the **path difference** — the difference between the distances travelled by the two waves from their respective sources to that point: a path difference equal to a **whole number of wavelengths** $(0, \lambda, 2\lambda, \dots)$ gives constructive interference, while a path difference equal to a **whole number plus a half wavelength** $(\frac{1}{2}\lambda, 1\frac{1}{2}\lambda, \dots)$ gives destructive interference (provided the two sources start out exactly in step with one another).

Constructive interference: two waves in phase



Two waves of equal amplitude and wavelength, exactly in phase (the dashed navy and pink curves, which overlap exactly), combine by superposition into a resultant wave (solid black) of **twice** the amplitude of either individual wave — constructive interference. If the pink curve were instead exactly out of step (shifted by half a wavelength), the two curves would cancel to give a resultant of zero amplitude — destructive interference.

Ví dụ thêm · Path difference and interference

(Supplement) Two loudspeakers, driven by the same signal so that they emit sound exactly in phase, produce sound of wavelength 0.80 m. A listener stands at a point where the path length from speaker A is 4.0 m and from speaker B is 4.8 m. State whether the listener experiences constructive or destructive interference at this point.

Path difference $= 4.8 - 4.0 = 0.8$ m $= 1 \times \lambda$ (exactly one whole wavelength).

Since the path difference is a whole number of wavelengths, the two waves arrive at the listener **in phase**, so **constructive interference** occurs and the listener hears a **loud** sound.

VN GIẢI THÍCH TIẾNG VIỆT

Khi hai sóng **cùng loại** gặp nhau tại một điểm, độ dịch chuyển tổng hợp bằng **tổng** độ dịch chuyển của từng sóng riêng lẻ tại điểm đó (**nguyên lý chồng chất**). **Giao thoa tăng cường** (constructive) xảy ra khi đỉnh gặp đỉnh (hoặc đáy gặp đáy) — biên độ tổng hợp **lớn hơn**; **giao thoa triệt tiêu** (destructive) xảy ra khi đỉnh gặp đáy — biên độ tổng hợp **giảm hoặc bằng 0**. Kết quả phụ thuộc vào **hiệu quãng đường** (path difference) từ hai nguồn tới điểm đó: hiệu quãng đường bằng **số nguyên lần bước sóng** cho giao thoa tăng cường; bằng **số nguyên cộng nửa bước sóng** cho giao thoa triệt tiêu.

3.2.2 The Doppler Effect (Supplement, qualitative)

(Supplement) When a wave source and an observer are moving *relative* to one another, the observer detects a frequency (and wavelength) different from the frequency actually being emitted by the source — this is the **Doppler effect**. As a source **approaches** a stationary observer, successive wavefronts are emitted from positions progressively closer to the observer, so they arrive **compressed together** (a shorter observed wavelength), which the observer detects as a **higher** frequency — for sound, a higher pitch. As the source **recedes** (moves away), successive wavefronts are emitted from positions progressively further from the observer, so they arrive **stretched out** (a longer observed wavelength), detected as a **lower** frequency — a lower pitch. The source's own emitted frequency never actually changes; only the frequency *detected* by the observer changes, because of the relative motion between source and observer.

> **(Supplement) Doppler effect (qualitative):** source approaching observer ⇒ observed frequency **increases** (pitch rises, for sound; light shifts towards the blue/violet end of the spectrum — **blueshift**). Source receding from observer ⇒ observed frequency **decreases** (pitch falls, for sound; light shifts towards the red end of the spectrum — **redshift**). The everyday example is an ambulance or police siren, which sounds distinctly higher-pitched while approaching and suddenly drops to a noticeably lower pitch as it passes and moves away. The very same effect, applied to light instead of sound, is how astronomers detect that most distant galaxies are moving away from us: light received from them is systematically **redshifted** (its spectral features are shifted to longer wavelengths) compared with the same features measured from a stationary source in the laboratory — one of the key pieces of evidence for an expanding universe.

Ví dụ thêm · Doppler reasoning — ambulance siren

(Supplement) An ambulance drives past a pedestrian standing on the pavement, sounding its siren continuously at one constant frequency. Explain why the pedestrian hears a higher-pitched sound while the ambulance approaches, and a lower-pitched sound once it has passed and is moving away.

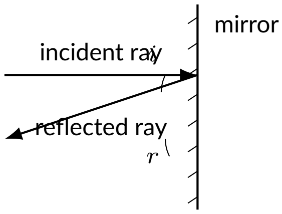
While the ambulance **approaches**, it moves closer to the pedestrian in the time between emitting successive sound wavefronts, so each new wavefront is emitted slightly nearer to the pedestrian than the last; the wavefronts arrive **compressed** (closer together in time), which the ear detects as a **higher frequency** — a higher-pitched siren. Once the ambulance has passed and is **moving away**, each new wavefront is emitted slightly further from the pedestrian than the last, so the wavefronts arrive **stretched out** (further apart in time), detected as a **lower frequency** — a lower-pitched siren. The siren itself emits at one constant, unchanging frequency throughout; only the *observed* frequency changes, because of the ambulance's motion relative to the stationary pedestrian.

GIẢI THÍCH TIẾNG VIỆT

VN Hiệu ứng Doppler: khi nguồn sóng và người quan sát chuyển động tương đối với nhau, tần số **quan sát được** khác với tần số nguồn thực sự phát ra. Nguồn **tiến lại gần**: tần số quan sát **tăng** (âm thanh nghe cao hơn; ánh sáng lệch về phía **xanh** – blueshift). Nguồn **lùi ra xa**: tần số quan sát **giảm** (âm thanh nghe trầm hơn; ánh sáng lệch về phía **đỏ** – redshift). Ví dụ quen thuộc: còi xe cứu thương nghe cao hơn khi tiến lại gần và trầm hẳn xuống khi xe đi qua rồi rời xa. Cùng nguyên lý này, các nhà thiên văn dùng hiện tượng **dịch chuyển đỏ** (redshift) của ánh sáng từ các thiên hà xa xôi để suy ra chúng đang chuyển động ra xa Trái Đất — một bằng chứng quan trọng cho vũ trụ đang giãn nở.

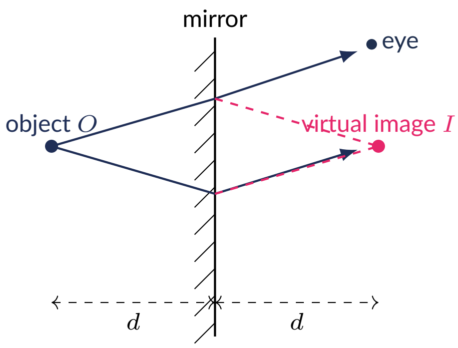
3.3 Light: Reflection at Plane Mirrors

Applying the general law of reflection to light striking a plane (flat) mirror: the angle of incidence equals the angle of reflection, both measured from the normal at the point of incidence, and the incident ray, the reflected ray and the normal all lie in the same plane.



Reflection at a plane mirror: angle of incidence i equals angle of reflection r, both measured from the normal (dashed line, perpendicular to the mirror surface).

A plane mirror always forms an image that is: **virtual** (the reflected rays only *appear* to diverge from behind the mirror — no light actually passes through the image location, so it cannot be captured on a screen), **upright** (the same way up as the object), **laterally inverted** (left and right are swapped, though top and bottom are not), the **same size** as the object (magnification $= 1$), and the **same perpendicular distance** behind the mirror as the object is in front of it.



Ray diagram for a plane mirror: two rays leave object O, reflect off the mirror (law of reflection), and diverge toward the eye. Tracing the reflected rays straight backward (dashed) locates the virtual image I, exactly as far behind the mirror as O is in front ($d = d$).

Ví dụ 3 · Plane mirror image position

An object stands 1.2 m in front of a plane mirror. A student then walks toward the mirror until she is 0.50 m from it. Find (a) the original image distance behind the mirror, and (b) how far the image has moved when she is 0.50 m from the mirror.

(a) Image distance behind mirror = object distance in front $= 1.2$ m.

(b) New image distance $= 0.50$ m behind the mirror. The image has moved $1.2 - 0.5 = 0.70$ m closer to the mirror — the image always moves at the *same* speed as the object, since image distance always equals object distance.

(!) Lỗi thường gặp: Lateral inversion is not the same as being "upside down." A plane mirror image is always **upright** (top stays at top) — it is left and right that are swapped. This is why text held up to a mirror reads backward (e.g. an ambulance often has "AMBULANCE" printed *laterally reversed* on the front of the vehicle, so that it reads correctly when seen in the rear-view mirror of the car ahead), while a photograph of yourself upside-down would show a completely different kind of change (top/bottom flip), which a plane mirror never produces.

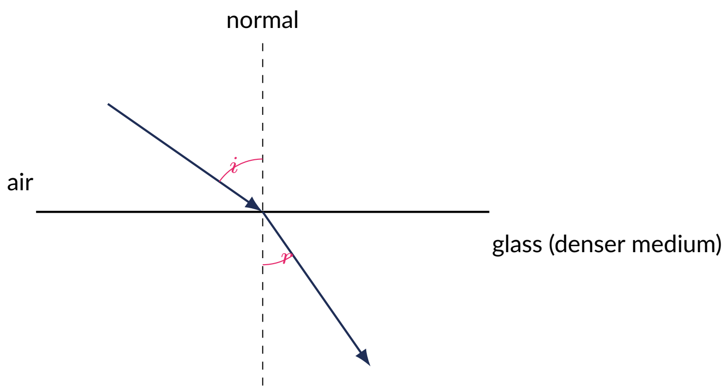
VN GIẢI THÍCH TIẾNG VIỆT

Ảnh qua gương phẳng luôn là ảnh **ảo** (không hứng được trên màn), **cùng chiều** (không lộn ngược trên–dưới), **ngược trái–phải** (lộn ngược trái–phải, gọi là **lộn ảnh bên**), **cùng kích thước**, và cách gương một khoảng **bằng đúng** khoảng cách từ vật đến gương. Lộn ảnh bên (trái–phải) hoàn toàn khác với lộn ngược (trên–dưới) — gương phẳng chỉ gây ra lộn ảnh bên, không bao giờ làm ảnh bị lộn ngược.

3.4 Refraction of Light and Refractive Index (Supplement)

(Supplement) Light bends **towards** the normal when it enters an optically **denser** (higher-index) medium, because it slows down there; it bends **away** from the normal when it leaves a denser medium for a less dense one, because it speeds up. (A ray travelling exactly *along* the normal, at 0°, passes straight through undeviated — it still changes speed, but there is no direction to bend toward.) The **refractive index** of a medium, for light entering it from air, is defined as $n = \dfrac{\sin i}{\sin r}$, where i is the angle of incidence in air and r is the angle of refraction inside the medium. Refractive index is also the ratio of speeds, $n = \dfrac{c}{v}$ (speed of light in vacuum/air divided by the speed of light in the medium) — the higher the refractive index, the more the light slows down and the more it bends.

Everyday refraction effects follow directly from this bending. A straw standing in a glass of water appears to "bend" sharply at the water's surface, because light leaving the submerged part of the straw refracts away from the normal on leaving the (denser) water for the (less dense) air, changing direction before it reaches the observer's eye — the straw itself has not moved, only the apparent path of the light coming from it. On a much larger scale, a **mirage** on a hot road forms because air just above the hot tarmac is much less dense (and so has a slightly lower refractive index) than the cooler air higher up; light from the sky refracts gradually as it passes through this changing air density, curving upward into the driver's line of sight and appearing to the eye as a shimmering "pool of water" on the road ahead, when it is in fact a refracted patch of sky.



Refraction at an air–glass boundary: entering the denser (slower) medium, the ray bends **toward** the normal ($r < i$); its frequency is unchanged, but its speed and wavelength both decrease. Leaving the glass back into air, the same ray would bend **away** from the normal by the same two angles, in reverse.

Ví dụ 4 · Refraction — air into glass

(Supplement) Light travelling in air hits a glass block ($n = 1.50$) at an angle of incidence $i = 40^\circ$. Find the angle of refraction.

$$\sin r = \frac{\sin i}{n} = \frac{\sin 40^\circ}{1.50} = \frac{0.643}{1.50} = 0.429 \Rightarrow r = \arcsin(0.429) \approx 25.4^\circ.$$

Ví dụ 5 · Refraction — air into water

(Supplement) Light travelling in air hits the surface of water ($n = 1.33$) at an angle of incidence $i = 50^\circ$. Find the angle of refraction.

$\sin r = \frac{\sin i}{n} = \frac{\sin 50^\circ}{1.33} = \frac{0.766}{1.33} = 0.576 \Rightarrow r = \arcsin(0.576) \approx 35.2^\circ$. (Water bends light less sharply than glass, since its refractive index is lower.)

Ví dụ 6 · Real and apparent depth

(Supplement) A fish appears, to an observer looking straight down from directly above, to be at a depth of 1.2 m below the surface of a pond. If the refractive index of water is $n = 1.33$, find the fish's true (real) depth.

$n = \frac{\text{real depth}}{\text{apparent depth}} \Rightarrow \text{real depth} = n \times \text{apparent depth} = 1.33 \times 1.2 = 1.6$ m (rounded to 2 s.f.).

GIẢI THÍCH TIẾNG VIỆT

VN

Ánh sáng bẻ **lại gần pháp tuyến** khi đi vào môi trường chiết quang hơn (đi chậm lại), và **ra xa pháp tuyến** khi đi ra môi trường kém chiết quang hơn (đi nhanh lên). Chiết suất $n = \sin i / \sin r = c/v$ — n càng lớn, ánh sáng càng chậm lại nhiều và càng bẻ cong nhiều. Vì ánh sáng bị khúc xạ tại mặt nước, độ sâu **biểu kiến** (nhìn thấy) của vật dưới nước luôn **nhỏ hơn** độ sâu thực — đây là lý do vật dưới nước (hoặc đáy hồ bơi) trông có vẻ nông hơn thực tế.

3.4.1 Refractive Index as a Ratio of Speeds (Supplement)

(Supplement) Since $n = \frac{c}{v}$, the speed of light inside any medium can always be found by rearranging: $v = \frac{c}{n}$. Because $n > 1$ for every transparent medium denser than a vacuum, light *always* travels more slowly inside such a medium than it does in a vacuum (or air) — the larger the refractive index, the slower the light travels inside the medium, and the more sharply it bends on entering or leaving it.

Medium	Refractive index n
Air (vacuum)	1.00
Water	1.33
Glass (typical)	1.50
Diamond	2.42

Typical refractive indices for light entering from air. A larger n means light bends more sharply on entering the medium, and travels more slowly once inside it.

Ví dụ thêm · Speed of light in a medium

(Supplement) Ordinary glass has a refractive index of 1.50. Find the speed of light travelling inside this glass ($c = 3.0 \times 10^8$ m/s).

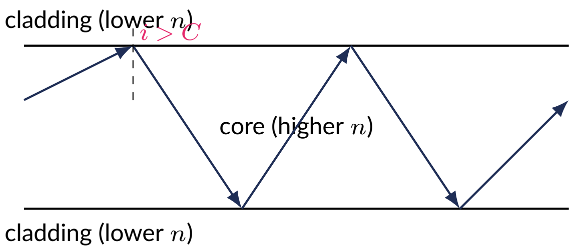
$v = \dfrac{c}{n} = \dfrac{3.0 \times 10^8}{1.50} = 2.0 \times 10^8$ m/s — light travels at only two-thirds of its vacuum speed inside this glass.

VN **GIẢI THÍCH TIẾNG VIỆT**

Vì $n = c/v$ nên tốc độ ánh sáng trong một môi trường luôn tính được bằng $v = c/n$. Do $n > 1$ với mọi môi trường trong suốt đặc hơn chân không, ánh sáng luôn đi **chậm hơn** trong môi trường đó so với trong chân không/không khí — n càng lớn thì ánh sáng càng chậm và càng bẻ cong nhiều khi khúc xạ. Chiết suất tiêu biểu: không khí ≈ 1.00, nước 1.33, thủy tinh 1.50, kim cương 2.42.

3.5 Critical Angle and Total Internal Reflection (Supplement)

(Supplement) The **critical angle** C is the angle of incidence, measured *inside* the denser medium, at which the angle of refraction is exactly 90° (the refracted ray grazes along the boundary); $\sin C = \dfrac{1}{n}$. If light travelling inside a denser medium strikes a boundary with a less-dense medium at an angle of incidence **greater than** C, none of the light can refract out at all — instead **total internal reflection (TIR)** occurs, and *all* of the light reflects back into the denser medium, obeying the ordinary law of reflection ($i = r$).



Total internal reflection guiding light along an optical fibre: at every core–cladding boundary the ray strikes at an angle greater than the critical angle C, so it is completely reflected back into the core — the signal is guided along the whole length of the fibre (even around gentle bends) by repeated total internal reflection, with almost no loss of light.

Ví dụ 7 · Critical angle and optical fibres

(Supplement) Find the critical angle of glass with $n = 1.50$, and explain how this allows an optical fibre to carry light along its length.

$\sin C = \dfrac{1}{n} = \dfrac{1}{1.50} = 0.667 \Rightarrow C = \arcsin(0.667) \approx 41.8^\circ$.

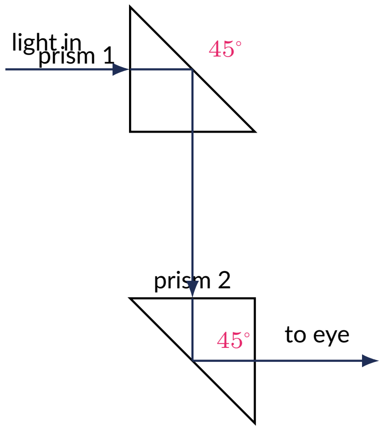
An optical fibre is a thin, flexible strand of glass with a core of slightly higher refractive index than the surrounding cladding. Light entering one end strikes the internal core–cladding boundary at an angle greater than the critical angle every time, so it repeatedly undergoes total internal reflection along the fibre's length, keeping virtually all the light energy trapped inside and guiding it — even around gentle curves — to the far end.

Ví dụ thêm · Critical angle of diamond

(Supplement) Diamond has an unusually high refractive index, $n = 2.42$. Find its critical angle.

$\sin C = \frac{1}{n} = \frac{1}{2.42} = 0.413 \Rightarrow C = \arcsin(0.413) \approx 24.4°$.
This is a much *smaller* critical angle than ordinary glass ($\approx 42°$) — light inside a cut diamond strikes many of its internal facets at angles greater than this small critical angle and undergoes repeated total internal reflection, which (together with dispersion) is largely responsible for a diamond's characteristic brilliance and "fire."

(Supplement) Total internal reflection is also used deliberately in right-angled glass prisms, which act as highly efficient mirrors in **periscopes** and binoculars: light entering perpendicular to one face strikes the hypotenuse face at $45°$, an angle greater than the critical angle of ordinary glass ($\approx 42°$), so it is totally internally reflected through $90°$ with (unlike a silvered mirror) no loss of light to absorption at a metal surface. Two such prisms, arranged appropriately, let a periscope's user see over an obstacle by reflecting the light path twice.



A periscope using two $45°$–$45°$–$90°$ prisms: light enters and leaves each prism perpendicular to a short face (undeviated), then strikes the long hypotenuse face at $45°$ to its normal — greater than the critical angle of ordinary glass ($\approx 42°$) — so total internal reflection turns the beam through $90°$ inside each prism, letting the viewer see over an obstacle with virtually no light lost to absorption, unlike an equivalent pair of silvered mirrors.

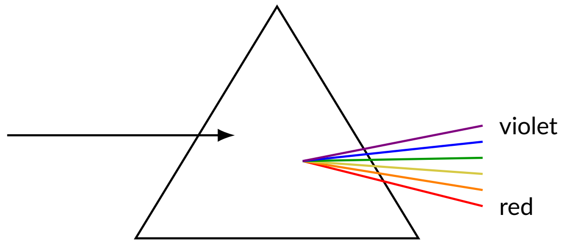
(!) Lỗi thường gặp: (Supplement) Total internal reflection can only occur when light travels from an optically **denser** medium toward a **less dense** one (e.g. glass → air, never air → glass), and only when the angle of incidence — measured *inside* the denser medium — exceeds the critical angle C. Likewise, in $n = \frac{\sin i}{\sin r}$ for light entering a medium from air, i must always be the angle in the **less dense** medium (air) and r the angle inside the denser medium; mixing these up, or trying to apply $\sin C = 1/n$ to light travelling from a less dense into a denser medium, gives a meaningless result.

VN **GIẢI THÍCH TIẾNG VIỆT**

Phản xạ toàn phần chỉ xảy ra khi ánh sáng đi từ môi trường **chiết quang hơn sang kém hơn** với góc tới (đo bên trong môi trường chiết quang hơn) **lớn hơn góc tới hạn** C ($\sin C = 1/n$). Đây là nguyên lý của cáp quang (ánh sáng phản xạ toàn phần liên tục vào thành lõi sợi cáp) và của lăng kính phản xạ toàn phần dùng trong kính tiềm vọng (periscope) — hiệu quả hơn gương tráng bạc vì không hao hụt ánh sáng do hấp thụ.

3.6 Dispersion of White Light

White light (e.g. sunlight) is a mixture of colours of different wavelengths, and glass (like other transparent media) has a slightly *higher* refractive index for shorter-wavelength (violet) light than for longer-wavelength (red) light. Passing white light through a triangular glass **prism** therefore splits it into a continuous **spectrum** of colours — red, orange, yellow, green, blue, indigo, violet — because each colour is refracted through a slightly different angle at both faces of the prism; **red** light (longest visible wavelength, lowest refractive index) is refracted *least*, while **violet** light (shortest visible wavelength, highest refractive index) is refracted *most*. This splitting effect is called **dispersion**. The same combination of refraction, internal reflection and dispersion inside spherical raindrops is responsible for rainbows.



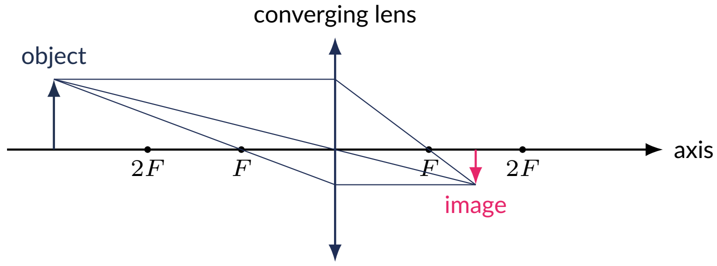
Dispersion of white light through a triangular prism: each colour refracts by a different amount at each face (violet most, red least), spreading white light out into a spectrum.

VN **GIẢI THÍCH TIẾNG VIỆT**

Ánh sáng trắng là hỗn hợp nhiều màu có bước sóng khác nhau. Khi đi qua lăng kính, mỗi màu khúc xạ với góc khác nhau (tím lệch nhiều nhất vì chiết suất thủy tinh với tím lớn nhất, đỏ lệch ít nhất) — hiện tượng này gọi là **tán sắc**, cũng chính là nguyên lý tạo ra cầu vồng (khúc xạ, phản xạ bên trong, và tán sắc ánh sáng bên trong hạt mưa).

3.7 Thin Converging Lenses (Supplement)

(Supplement) A **converging (convex) lens** is thicker in the middle than at the edges and bends parallel rays of light inward so that they meet at the **principal focus** F, a distance from the lens (on each side) called the **focal length** f. Only three standard rays are needed to construct the image of a point on an object: (1) a ray travelling **parallel** to the principal axis refracts through the (far) principal focus F; (2) a ray passing through the **optical centre** of the lens continues **undeviated** (straight through); (3) a ray passing through the (near) principal focus F on its way to the lens emerges **parallel** to the axis.



Ray diagram for an object beyond $2F$ of a converging lens ($f = 2$ units here, object at 6 units, image at 3 units): all three standard rays meet at the image, which forms between F and $2F$ on the far side — **real, inverted, and diminished** (smaller than the object).

(Supplement) **Object beyond** $2F$: image real, inverted, diminished, forms between F and $2F$ (e.g. a **camera** lens forming an image of a distant scene on its sensor/film). **Object at** $2F$: image real, inverted, same size, forms at $2F$ on the far side. **Object between** F **and** $2F$: image real, inverted, magnified, forms beyond $2F$ (e.g. a **projector** lens, magnifying a small slide/film onto a distant screen). **Object at** F: emerging rays are parallel — no image forms at any finite distance. **Object inside** F: image **virtual**, upright, magnified, on the *same* side as the object — the **magnifying glass** case (the human **eye**'s own lens works similarly in reverse, focusing a real, inverted, diminished image of the world onto the retina, which the brain then interprets right-way-up). **Linear magnification:** $m = \dfrac{\text{image height}}{\text{object height}} = \dfrac{\text{image distance } v}{\text{object distance } u}$.

These five cases correspond directly to how converging lenses are used in practice. A **camera** always keeps its subject beyond $2F$ (everyday photography subjects are effectively "far" compared with the lens's short focal length), so it always forms a real, inverted, diminished image on the sensor or film — the camera's focusing mechanism moves the lens slightly to keep this image sharply positioned on the sensor as the subject distance changes. A **projector** deliberately places its small, brightly-lit slide or film between F and $2F$, so that a real, inverted, *magnified* image is thrown onto a distant screen (the slide itself must be loaded upside-down, so that the inverted projected image appears the right way up). A **magnifying glass** is simply a converging lens with the object held inside F, producing the enlarged, upright, virtual image the eye perceives. The human **eye** itself contains a converging lens system (cornea and lens together) that keeps forming a real, inverted, diminished image on the retina for objects at almost any distance beyond F — the brain, from long experience, automatically interprets this inverted retinal image as being the right way up.

Ví dụ 8 · Lens image-characteristics reasoning

(Supplement) An object is placed between F and $2F$ of a converging lens. State and explain the characteristics of the image formed.

Since the object lies between F and $2F$, the three standard construction rays converge on the far side of the lens *beyond* $2F$ (further from the lens than the object is), producing an image that is **real** (formed where rays actually cross, so it could be captured on a screen), **inverted** (upside down relative to the object), and **magnified** (larger than the object, since the image forms further from the lens than $2F$ while the object is closer than $2F$) — this is the arrangement used in a slide/film **projector**.

Ví dụ 9 · Linear magnification of a lens

(Supplement) An object of height 2.0 cm is placed 30 cm from a converging lens; the resulting real image forms 45 cm from the lens. Find the magnification and the image height.

$m = \dfrac{v}{u} = \dfrac{45}{30} = 1.5.$ Image height $= m \times$ object height $= 1.5 \times 2.0 = 3.0$ cm.

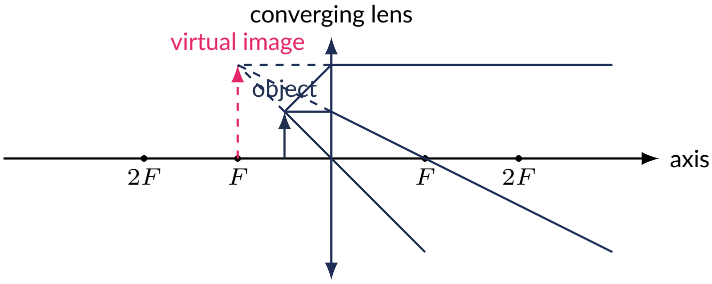
GIẢI THÍCH TIẾNG VIỆT

VN

Với thấu kính hội tụ, chỉ cần vẽ 2 trong 3 tia đặc trưng để xác định ảnh: tia song song trục chính qua F; tia qua quang tâm đi thẳng; tia qua F ló ra song song trục chính. Vị trí vật quyết định tính chất ảnh: xa hơn $2F$ (ảnh thật, ngược chiều, nhỏ hơn — máy ảnh); tại $2F$ (ảnh thật, ngược chiều, bằng vật); giữa F và $2F$ (ảnh thật, ngược chiều, phóng to — máy chiếu); trong F (ảnh **ảo**, cùng chiều, phóng to — kính lúp, và cũng là cách mắt người tạo ảnh thật thu nhỏ trên võng mạc theo chiều ngược lại). Độ phóng đại $m = v/u =$ chiều cao ảnh / chiều cao vật.

3.7.1 Magnifying Glass: Object Inside F (Supplement)

(Supplement) When an object is placed *inside* the focal length of a converging lens (closer to the lens than F), the three standard construction rays never actually meet on the far side of the lens at all — they emerge **diverging** from one another. Tracing these diverging emergent rays straight backward, however, shows that they appear to come from a single point on the *same* side of the lens as the object, further from the lens than the object itself. This point locates a **virtual**, **upright**, **magnified** image — precisely what the eye sees when using the lens as a **magnifying glass**.



Ray diagram for an object placed *inside* F ($f = 2$ units here, object 1 unit from the lens): the three refracted rays diverge on the far side of the lens and never meet there; tracing them straight backward (dashed) shows they meet at a point 2 units behind the object, on the **same** side as the object. The image is therefore **virtual**, **upright**, and **magnified** ($\times 2$ in this diagram) — the magnifying-glass case.

Ví dụ thêm · Magnifying-glass magnification

(Supplement) A small object 5.0 mm tall is held 3.0 cm from a converging lens used as a magnifying glass; the resulting virtual image forms 9.0 cm from the lens, on the same side as the object. Find the magnification and the image height.

$m = \frac{v}{u} = \frac{9.0}{3.0} = 3.0$ (magnification is a ratio, so it has *no units*). Image height $= m \times$ object height $= 3.0 \times 5.0 = 15$ mm $= 1.5$ cm.

GIẢI THÍCH TIẾNG VIỆT

VN Khi vật đặt **trong** tiêu cự F của thấu kính hội tụ, ba tia chuẩn không gặp nhau ở phía bên kia thấu kính (chúng loe ra); kéo dài ngược các tia loe này về phía vật cho một điểm ảnh **ảo**, **cùng chiều**, **phóng to**, nằm cùng phía với vật — đây chính là nguyên lý của **kính lúp**. Độ phóng đại vẫn tính bằng $m = v/u =$ chiều cao ảnh/chiều cao vật, và m **không có đơn vị** (chỉ là một tỉ số).

3.8 The Electromagnetic Spectrum

All electromagnetic waves are **transverse** waves that require no medium (they travel through a vacuum) and travel at the *same* speed in a vacuum, $c = 3.0 \times 10^8$ m/s (and very nearly this speed in air) — they differ from one another only in frequency and wavelength, related as always by $c = f\lambda$.

Band	Wavelength	Frequency	Typical use(s)	Danger / precaution
Radio	> 1 m (up to km)	$< 3.0 \times 10^8$ Hz	Broadcasting, communications	None significant at normal power
Microwave	1 mm–1 m	3.0×10^8–3.0×10^{11} Hz	Satellite & mobile links, cooking	Internal heating of body tissue/water
Infrared	700 nm–1 mm	3.0×10^{11}–4.0×10^{14} Hz	Remote controls, thermal imaging, grilling	Skin burns from intense exposure
Visible	400–700 nm	4.0×10^{14}–7.5×10^{14} Hz	Vision, photography, optical fibres	None at normal levels (lasers can harm eyes)
Ultraviolet	10–400 nm	7.5×10^{14}–3.0×10^{16} Hz	Sterilising, fluorescent lamps, security ink	Skin/eye damage, skin cancer – ionising
X-rays	0.01–10 nm	3.0×10^{16}–3.0×10^{19} Hz	Medical & security imaging, flaw detection	Cell damage, cancer – lead shielding
Gamma rays	< 0.01 nm	$> 3.0 \times 10^{19}$ Hz	Cancer therapy, sterilising equipment, tracers	Most ionising – lead/concrete shielding

The electromagnetic spectrum, arranged in order of **increasing frequency** (decreasing wavelength). All seven bands travel at the same speed c in a vacuum; the three highest-frequency bands (ultraviolet, X-rays, gamma rays) carry enough energy per photon to be **ionising** and require exposure precautions.

Dangers and precautions: ultraviolet, X-rays and gamma rays are **ionising** — they carry enough energy to remove electrons from atoms/molecules in living cells, which can damage or kill cells, or (with excessive exposure) cause cancer through damage to DNA. The three standard precautions used by workers who handle ionising radiation are: **shielding** (e.g. lead aprons/screens for X-rays, thick lead or concrete for gamma rays), **limiting exposure time** (badges that record cumulative dose, rotating staff), and **increasing distance** from the source (radiation intensity falls off rapidly with distance).

Ví dụ 10 · Wavelength from frequency

Find the wavelength of a radio wave of frequency 100 MHz ($= 1.0 \times 10^8$ Hz).

$$\lambda = \frac{c}{f} = \frac{3.0 \times 10^8}{1.0 \times 10^8} = 3.0\,\text{m}.$$

Ví dụ 11 · Frequency from wavelength

An X-ray has a wavelength of 1.0×10^{-10} m. Find its frequency.

$$f = \frac{c}{\lambda} = \frac{3.0 \times 10^8}{1.0 \times 10^{-10}} = 3.0 \times 10^{18}\,\text{Hz}.$$

VN **GIẢI THÍCH TIẾNG VIỆT**

Toàn bộ quang phổ điện từ truyền với cùng tốc độ $c = 3.0 \times 10^8$ m/s trong chân không (không cần môi trường vật chất), chỉ khác nhau về tần số/bước sóng. Tia UV, tia X và tia gamma mang năng lượng photon cao, có tính **ion hóa** nên gây hại cho tế bào sống nếu tiếp xúc quá liều —

ba biện pháp phòng ngừa chuẩn là: **che chắn** (chì, bê tông), **hạn chế thời gian tiếp xúc**, và **tăng khoảng cách** tới nguồn phóng xạ.

3.9 Sound

Production of sound: sound is produced whenever an object **vibrates** — a guitar string, a loudspeaker cone, human vocal cords, a tuning fork — and these vibrations disturb the particles of a surrounding medium, setting up a **longitudinal** pressure wave that spreads outward as alternating compressions and rarefactions. Because sound is carried by particles colliding with their neighbours, it requires a material medium (solid, liquid or gas) to travel through, and **cannot travel through a vacuum** — famously demonstrated by an electric bell ringing inside a sealed jar: as air is pumped out, the sound fades and eventually disappears completely, even though the bell (visible through the glass) is still clearly vibrating.

Sound travels **fastest in solids**, slower in liquids, and **slowest in gases** (speed in air $\approx 340\,\text{m/s}$; in water $\approx 1500\,\text{m/s}$; in steel $\approx 5000\,\text{m/s}$). In solids and liquids, particles are packed closely together and strongly bonded, so a vibration is passed from particle to particle almost immediately; in a gas, particles are far apart and move randomly, so a vibration takes much longer, on average, to be passed from one particle to the next by a collision.

(!) Lỗi thường gặp: Sound **cannot** travel through a vacuum, unlike light and all other electromagnetic waves (which need no medium at all). This is why the loud explosions and engine roars in many science-fiction films set in space are physically impossible — in a true vacuum, with no particles to carry the vibration, there would be complete silence, however violent the on-screen action.

The human ear can typically detect sound frequencies from about 20 Hz to 20000 Hz — this range is called the **audible range**. Frequencies below 20 Hz are called **infrasound**, and frequencies above 20000 Hz are called **ultrasound**; both are inaudible to humans. **Ultrasound** has several important applications precisely because it can be produced as a narrow, directional beam and (unlike X-rays) is non-ionising: **medical imaging** (e.g. prenatal scans — ultrasound pulses reflect at boundaries between different body tissues, and timing the returning echoes builds up an image, without exposing the patient or foetus to ionising radiation); **industrial flaw detection** (a pulse sent into a metal casting or weld reflects off any internal crack or void, revealing its size and depth from the echo timing, without needing to damage or cut open the component); and **sonar / echo sounding** (measuring water depth, or detecting submarines and shoals of fish, from the time taken for a reflected pulse to return).

Pitch (how high or low a note sounds) corresponds to the **frequency** of a sound wave — a higher frequency is heard as a higher pitch. **Loudness** (how loud or soft a sound is) corresponds to the **amplitude** of the wave — a larger amplitude (the source vibrating with greater energy) is heard as a louder sound. Both properties can be read directly from a sound wave displayed on an oscilloscope (CRO).

Oscilloscope-style traces. (a) Same frequency (pitch), different amplitude: the taller (navy) trace is **louder**; the shorter (pink) trace is **softer**. (b) Same amplitude (loudness), different frequency: the more closely-spaced (navy) trace is

higher-pitched; the more widely-spaced (pink) trace is **lower-pitched**.

Reverberation and echoes: in an enclosed space, sound reflects repeatedly off walls, floors and ceilings. If the reflected sound arrives back very soon after the original (a short delay, in a small or well-furnished room), the reflections blend together with the original sound and with each other, perceived as a single, slightly prolonged sound — this is **reverberation**, and it is very noticeable in large, hard-surfaced empty spaces such as an empty concert hall or a cathedral. If instead the reflecting surface is far enough away that the reflected sound arrives noticeably later (typically more than about 0.1 s after the original, so the brain perceives it as a separate, repeated sound), it is heard as a distinct **echo**.

Excessive reverberation makes speech and music sound muddled, since each syllable or note overlaps with the lingering reflections of the ones before it; concert-hall and recording-studio designers control this by lining hard, sound-reflecting surfaces (bare stone, glass, tiled floors) with soft, sound-**absorbing** materials — heavy curtains, carpets, padded seating, acoustic foam panels — which convert some of the sound energy into heat instead of reflecting it, shortening the reverberation time to a level appropriate for the room's use (a long reverberation time can suit a cathedral organ, but would make a lecture hall very hard to understand).

Ví dụ 12 · Echo timing — depth of water (sonar)

A ship's sonar sends an ultrasound pulse downward; the echo returns after 0.80 s. Speed of sound in water $= 1500$ m/s. Find the depth of the seabed.

Total distance travelled (down and back) $= vt = (1500)(0.80) = 1200$ m. Depth $= \dfrac{1200}{2} = 600$ m.

Ví dụ 13 · Echo timing — distance to a cliff (air)

A hiker shouts toward a distant cliff face and hears the echo exactly 1.0 s later. Speed of sound in air $= 340$ m/s. Find the distance to the cliff.

Total distance travelled (to the cliff and back) $= vt = (340)(1.0) = 340$ m. Distance to cliff $= \dfrac{340}{2} = 170$ m.

Ví dụ 14 · Reading frequency from an oscilloscope trace

A microphone signal is displayed on an oscilloscope with the time-base set to 5.0 ms per division. One complete wave cycle occupies exactly 4.0 divisions on the screen. Find the period and the frequency of the sound, and state whether it lies within the audible range.

$T = 4.0 \times 5.0$ ms $= 20$ ms $= 0.020$ s. $f = \dfrac{1}{T} = \dfrac{1}{0.020} = 50$ Hz — within the audible range (20–20000 Hz), so this would be heard as a low-pitched note.

Ví dụ thêm · Musical note — period, frequency and wavelength

A note played on a musical instrument has a period of 2.5 ms. Find (a) its frequency, and (b) its wavelength as it travels through air at 340 m/s.

(a) $f = \dfrac{1}{T} = \dfrac{1}{0.0025} = 400$ Hz.

(b) $\lambda = \dfrac{v}{f} = \dfrac{340}{400} = 0.85$ m.

Ví dụ thêm · Ultrasound depth measurement

An ultrasound pulse sent into a patient's abdomen reflects off the boundary of an internal organ; the echo returns to the transducer after 2.6×10^{-5} s (that is, $26\,\mu$s). Taking the speed of ultrasound in soft tissue as 1540 m/s, find the depth of the boundary below the skin.

Round-trip distance $= vt = (1540)(2.6 \times 10^{-5}) = 0.0400\,\text{m} = 4.00\,\text{cm}$. Depth $= \dfrac{4.00}{2} = 2.00\,\text{cm}$.

(!) Lỗi thường gặp: When calculating a distance from an echo (sonar depth, cliff distance, ultrasound flaw depth, etc.), the timed interval t is always for the **round trip** — there *and* back — so the distance to the reflecting surface is only *half* of $v \times t$. Forgetting to divide by 2 is one of the most common errors in echo/sonar calculations.

VN **GIẢI THÍCH TIẾNG VIỆT**

Âm thanh sinh ra do vật **dao động**, là sóng dọc, cần môi trường vật chất để truyền (**không truyền được trong chân không**, khác hẳn ánh sáng) — và truyền nhanh nhất trong chất rắn, chậm nhất trong chất khí (vì hạt trong rắn/lỏng sát nhau và liên kết mạnh, truyền dao động nhanh hơn). Con người nghe được từ 20 Hz đến $20\,000$ Hz; **siêu âm** ($> 20\,000$ Hz) dùng trong y tế (siêu âm thai), công nghiệp (dò khuyết tật kim loại), và định vị dưới nước (sonar). **Độ cao** của âm ứng với **tần số**; **độ to** ứng với **biên độ**. Khi tính khoảng cách bằng tiếng vọng, quãng đường sóng đi **gấp đôi** khoảng cách thực (đi và về), nên phải **chia 2** sau khi nhân tốc độ với thời gian. **Âm vang** (reverberation) là các phản xạ liên tiếp hòa vào âm gốc trong phòng kín; **tiếng vọng** (echo) là một phản xạ riêng biệt nghe được rõ ràng sau một khoảng trễ đủ lớn.

3.10 Practice Problems

Bài tập luyện tập

A wave has period $T = 0.020$ s and wavelength 8.5 m. Find its speed.

(A) 425 m/s
(B) 340 m/s
(C) 170 m/s
(D) 850 m/s

Lời giải chi tiết

$f = \dfrac{1}{T} = \dfrac{1}{0.020} = 50\,\text{Hz}$. $v = f\lambda = (50)(8.5) = 425\,\text{m/s}$. **(A).**

Bài tập luyện tập

(Supplement) Light travels from air into a glass block ($n = 1.60$) at an angle of incidence of $50°$. Find the angle of refraction.

Lời giải chi tiết

$\sin r = \dfrac{\sin 50°}{1.60} = \dfrac{0.766}{1.60} = 0.479 \Rightarrow r = \boxed{28.6°}$ (bent towards the normal, as expected entering a denser medium).

Bài tập luyện tập

(Supplement) A transparent material has a critical angle of 39°. Find its refractive index.

(A) 1.59
(B) 1.29
(C) 1.45
(D) 1.75

Lời giải chi tiết

$n = \dfrac{1}{\sin C} = \dfrac{1}{\sin 39^\circ} = \dfrac{1}{0.629} = 1.59$. **(A).**

Bài tập luyện tập

State one use and one danger of (a) ultraviolet radiation and (b) X-rays.

Lời giải chi tiết

(a) **UV** — use: fluorescent lamps / sterilising water / detecting forged banknotes. Danger: causes skin damage and skin cancer, and eye damage, with excess exposure (hence sunscreen and UV-blocking eyewear are used).
(b) **X-rays** — use: imaging broken bones, airport security scanning. Danger: ionising radiation that can damage living cells and cause cancer, so medical/security staff use lead shielding and minimise exposure time.

Bài tập luyện tập

A fishing boat sends an ultrasound pulse straight down; the echo from the seabed returns after 0.60 s. Speed of sound in seawater $= 1500$ m/s. Find the depth of the water.

Lời giải chi tiết

Total (round-trip) distance $= vt = (1500)(0.60) = 900$ m. Depth $= \dfrac{900}{2} = \boxed{450\,\text{m}}$.

Bài tập luyện tập

An object is placed 2.0 m in front of a plane mirror. Explain why an observer in front of the mirror cannot optically distinguish the virtual image from a genuine (laterally-reversed) duplicate object placed 2.0 m *behind* the mirror.

Lời giải chi tiết

The image of the object forms exactly 2.0 m behind the mirror (image distance = object distance), the same size and orientation (laterally inverted, upright) as a genuine duplicate object would appear at that position. Since the light rays entering the observer's eye have exactly the same directions and divergence in both cases, there is no optical way to distinguish a virtual image from a real object positioned at the same apparent location — this is precisely why mirror images look so convincingly "real."

Bài tập luyện tập

(Supplement) A swimming pool appears to be 1.5 m deep when viewed from directly above the water's surface. If the refractive index of water is 1.33, find the true (real) depth of the pool.

(A) 1.13 m
(B) 2.0 m
(C) 1.995 m
(D) 1.5 m

Lời giải chi tiết

$n = \dfrac{\text{real depth}}{\text{apparent depth}} \Rightarrow$ real depth $= n \times$ apparent depth $= 1.33 \times 1.5 = 1.995$ m ≈ 2.0 m. **(C)**.

Bài tập luyện tập

(Supplement) Find the critical angle for a transparent plastic of refractive index $n = 1.4$, and state what happens to a ray inside the plastic that strikes a boundary with air at an angle of $50°$.

Lời giải chi tiết

$\sin C = \dfrac{1}{1.4} = 0.714 \Rightarrow C = \boxed{45.6°}$.
Since $50° > C$, the ray undergoes **total internal reflection** at the boundary rather than refracting out.

Bài tập luyện tập

(Supplement) An object 3.0 cm tall is placed 20 cm from a converging lens, forming a real image 50 cm from the lens. Find the magnification and the image height.

Lời giải chi tiết

$m = \dfrac{v}{u} = \dfrac{50}{20} = 2.5.$ Image height $= 2.5 \times 3.0 = \boxed{7.5\text{ cm}}$.

Bài tập luyện tập

Explain, in terms of the position of the object relative to F, how a converging lens is used as a magnifying glass.

Lời giải chi tiết

For a converging lens to work as a magnifying glass, the object must be placed *inside* the focal length F (closer to the lens than the principal focus). The emerging rays then diverge and never actually meet on the far side, so tracing them backwards (to where they *appear* to come from) produces a **virtual**, **upright**, and **magnified** image on the *same* side of the lens as the object — this is what the eye sees when using a magnifying glass.

Bài tập luyện tập

Explain why a glass prism splits white light into a spectrum, and state which colour is deviated the most.

(A) Red; because it has the shortest wavelength

(B) Violet; because it has the highest refractive index in glass

(C) Green; because it is in the middle of the spectrum

(D) All colours deviate equally; glass has one refractive index

Lời giải chi tiết

Glass has a slightly different refractive index for each colour (wavelength) of light, so each colour is refracted by a different amount as it enters and leaves the prism; violet light experiences the highest refractive index in glass and so is bent (deviated) the most, while red light is bent the least. **(B)**.

Bài tập luyện tập

List the seven regions of the electromagnetic spectrum from the *longest* to the *shortest* wavelength.

Lời giải chi tiết

$\boxed{\text{Radio} \rightarrow \text{microwave} \rightarrow \text{infrared} \rightarrow \text{visible light} \rightarrow \text{ultraviolet} \rightarrow \text{X-ray} \rightarrow \text{gamma ray}}$, in order of decreasing wavelength (equivalently, increasing frequency).

Bài tập luyện tập

A wave source vibrates 150 times in $3.0\,\text{s}$, producing waves of wavelength $2.0\,\text{m}$. Find the frequency and the wave speed.

(A) $f = 50\,\text{Hz},\ v = 100\,\text{m/s}$

(B) $f = 50\,\text{Hz},\ v = 25\,\text{m/s}$

(C) $f = 450\,\text{Hz},\ v = 900\,\text{m/s}$

(D) $f = 0.02\,\text{Hz},\ v = 0.04\,\text{m/s}$

Lời giải chi tiết

$f = \dfrac{150}{3.0} = 50\,\text{Hz}. \qquad v = f\lambda = (50)(2.0) = 100\,\text{m/s}.$ **(A)**.

Bài tập luyện tập

Explain why diffraction of sound around an open doorway is very noticeable, while diffraction of visible light around the same doorway is not.

Lời giải chi tiết

Diffraction is most pronounced when the size of the gap is comparable to the wavelength of the wave passing through it. A typical doorway (roughly a metre wide) is comparable in size to the wavelength of sound (also of the order of centimetres to metres), so sound diffracts (spreads out) strongly and can be heard clearly around corners. Visible light has a wavelength of only a few hundred nanometres — many millions of times smaller than the doorway — so essentially no noticeable diffraction occurs, and light appears to travel in straight lines through the doorway.

Bài tập luyện tập

(Supplement) A ray of light inside a glass fibre ($n = 1.5$) strikes the fibre wall at 45° to the normal. Determine whether total internal reflection occurs, showing your working.

Lời giải chi tiết

Critical angle: $\sin C = \dfrac{1}{1.5} = 0.667 \Rightarrow C = 41.8^\circ$.
Since the angle of incidence (45°) is **greater than** C (41.8°), $\boxed{\text{total internal reflection does occur}}$.

Bài tập luyện tập

An oscilloscope trace of a musical note shows 5 complete cycles occupying 25 ms of screen width. Find the frequency of the note.

(A) 100 Hz
(C) 125 Hz
(B) 200 Hz
(D) 5 Hz

Lời giải chi tiết

$T = \dfrac{25\,\text{ms}}{5} = 5.0\,\text{ms} = 0.0050\,\text{s}$. $f = \dfrac{1}{T} = \dfrac{1}{0.0050} = 200\,\text{Hz}$. **(B)**.

Bài tập luyện tập

Sound travels at approximately $340\,\text{m/s}$ in air and about $1500\,\text{m/s}$ in water, but cannot travel at all through a vacuum. Explain this pattern in terms of the particle model.

Lời giải chi tiết

Sound is a longitudinal wave that travels by particles colliding with (and passing vibrations to) their neighbours, so it needs a material medium. In a **vacuum** there are no particles at all, so there is nothing to carry the vibration — sound cannot travel. In a **liquid** (water) particles are much more closely packed and strongly bonded than in a gas (air), so vibrations pass from particle to particle much more quickly, giving a higher wave speed in water than in air.

Bài tập luyện tập

A microwave oven uses radiation of frequency 2.45×10^9 Hz. Find its wavelength.

Lời giải chi tiết

$$\lambda = \frac{c}{f} = \frac{3.0 \times 10^8}{2.45 \times 10^9} = \boxed{0.122\,\text{m} \approx 12.2\,\text{cm}}.$$

Bài tập luyện tập

(Supplement) An object is placed exactly at the focal point F of a converging lens. Describe what happens to the emerging rays and what kind of image (if any) is formed.

Lời giải chi tiết

Rays leaving an object placed exactly at F emerge from the lens travelling **parallel** to each other (parallel to the principal axis). Parallel rays never converge and never appear to diverge from a single point either, so **no image is formed** at any finite distance — this is the reverse case of parallel rays entering the lens and converging at F.

Bài tập luyện tập

(Supplement) Light travels from glass ($n = 1.52$) into air. Find the critical angle for this glass–air boundary.

(A) 41.1°

(B) 48.9°

(C) 33.4°

(D) 65.4°

Lời giải chi tiết

$\sin C = \dfrac{1}{1.52} = 0.658 \Rightarrow C = \arcsin(0.658) = 41.1^\circ$. **(A).**

Bài tập luyện tập

A student sees a rainbow after a rain shower with the Sun behind her. Explain, in terms of refraction, internal reflection and dispersion, how the rainbow's colours are produced.

Lời giải chi tiết

Sunlight entering a spherical raindrop is first **refracted** as it enters the water (slowing down, and — because different colours refract by slightly different amounts — beginning to split, i.e. **disperse**, into its component colours). The light then undergoes (partial) **internal reflection** off the inside back surface of the droplet, before refracting again as it leaves the drop, dispersing further. Because each colour leaves the droplet at a very slightly different angle, an observer positioned correctly relative to the Sun and the rain sees each colour arriving from droplets at a slightly different angle in the sky, spreading the colours into the familiar rainbow band (red on the outer edge, violet on the inner edge).

Bài tập luyện tập

Two sound waves have frequencies 256 Hz and 512 Hz, both travelling through the same air at 340 m/s. Compare their wavelengths.

Lời giải chi tiết

$\lambda_1 = \dfrac{v}{f_1} = \dfrac{340}{256} = 1.33$ m. $\lambda_2 = \dfrac{v}{f_2} = \dfrac{340}{512} = 0.664$ m.

The higher-frequency wave (512 Hz) has $\boxed{\text{half the wavelength}}$ of the lower-frequency wave, since both travel at the same speed and $v = f\lambda$ (so f and λ are inversely proportional at fixed

v).

Bài tập luyện tập

A radar gun emits a pulse of microwaves at $c = 3.0 \times 10^8$ m/s; the reflected pulse from a car returns after 2.0×10^{-6} s. Find the distance to the car at the moment of reflection.

Lời giải chi tiết

Round-trip distance $= ct = (3.0 \times 10^8)(2.0 \times 10^{-6}) = 600$ m.
Distance to car $= \frac{600}{2} = \boxed{300\,\text{m}}$.

Bài tập luyện tập

In a ripple tank, a dipper vibrating at 6.0 Hz produces water waves of wavelength 3.0 cm. Find the speed of the waves.

(A) 0.18 m/s
(B) 2.0 m/s
(C) 18 m/s
(D) 0.50 m/s

Lời giải chi tiết

$v = f\lambda = (6.0)(0.030) = 0.18$ m/s. **(A)**.

Bài tập luyện tập

A ray of light strikes a plane mirror at an angle of incidence of 35° from the normal. Find the angle of reflection, and the angle between the incident and reflected rays.

Lời giải chi tiết

By the law of reflection, angle of reflection = angle of incidence $= \boxed{35^\circ}$.
The angle turned through between the incident ray's direction and the reflected ray's direction is $180^\circ - 2i = 180 - 2(35) = \boxed{110^\circ}$.

Bài tập luyện tập

An ambulance often has the word "AMBULANCE" printed in laterally-reversed lettering on the front of the vehicle. Explain why, using the properties of a plane mirror image.

Lời giải chi tiết

A plane mirror produces an image that is **laterally inverted** (left–right reversed) but otherwise upright and undistorted. A driver ahead sees the front of the ambulance only via their rear-view mirror; if the word were printed normally, it would appear reversed (illegible) in the mirror. By deliberately printing it *already* laterally reversed on the vehicle, the mirror's own left–right reversal cancels this out, so the driver sees the word "AMBULANCE" the right way round in their mirror.

Bài tập luyện tập

State *two* medical or industrial uses of ultrasound, and explain why ultrasound (rather than X-rays) is preferred for imaging a foetus during pregnancy.

Lời giải chi tiết

Uses: (1) prenatal medical imaging (scanning a foetus); (2) industrial flaw detection (finding cracks/voids inside metal castings or welds); (also acceptable: sonar/echo sounding for measuring water depth).
Ultrasound is non-ionising (unlike X-rays, which carry far more energy per photon), so repeated or prolonged exposure does not damage living cells or DNA — making it far safer than X-rays for imaging a developing foetus, where minimising radiation exposure is especially important.

Bài tập luyện tập

Explain the difference between reverberation and an echo, and state why reverberation is especially noticeable in a large, empty, hard-walled hall.

Lời giải chi tiết

An **echo** is a single, distinct reflection of sound that arrives back at the listener after a noticeable delay (typically more than about 0.1 s), so the brain perceives it as a clearly separate, repeated sound. **Reverberation** is the effect of many reflections arriving in quick succession, so closely spaced in time that they blend with the original sound (and with each other) into a single, prolonged sound rather than being heard as separate repeats. A large, empty, hard-walled hall reflects sound repeatedly off its many hard surfaces (with little absorption, since there is no soft furnishing or audience to absorb the sound energy), producing many overlapping reflections and therefore strong reverberation.

Bài tập luyện tập

A sound wave of frequency 500 Hz travels through air at 340 m/s. Find its wavelength, and explain whether it would diffract significantly through an open doorway of width 0.90 m.

Lời giải chi tiết

$\lambda = \frac{v}{f} = \frac{340}{500} = \boxed{0.68\,\text{m}}$.
Since the doorway's width (0.90 m) is **comparable to** this wavelength (0.68 m), the sound would diffract **significantly**, spreading out well beyond the doorway — consistent with the everyday experience of hearing sound clearly around an open door even when out of the line of sight.

Bài tập luyện tập

A railway worker presses her ear to a steel rail to detect an approaching train 1700 m away, rather than listening through the air. Given the speed of sound is about 5000 m/s in steel and 340 m/s in air, find the time for the sound to arrive via each path, and explain the advantage of listening through the rail.

Lời giải chi tiết

Via steel rail: $t = \frac{d}{v} = \frac{1700}{5000} = \boxed{0.34\,\text{s}}$. Via air: $t = \frac{1700}{340} = \boxed{5.0\,\text{s}}$.
Sound reaches the ear through the rail (a solid, with closely-packed, strongly-bonded particles that transmit vibrations quickly) far sooner — about 15 times faster — than through the air, giving much earlier warning of an approaching train.

Bài tập luyện tập

An ultrasound pulse sent into a metal block for flaw detection returns from the far surface after 4.0×10^{-5} s (that is, 40 microseconds). The speed of sound (ultrasound) in this metal is 6000 m/s. Find the thickness of the block.

(A) 24 cm
(B) 12 cm
(C) 6.0 cm
(D) 0.24 cm

Lời giải chi tiết

Round-trip distance $= vt = (6000)(4.0 \times 10^{-5}) = 0.24$ m. Thickness $= \frac{0.24}{2} = 0.12$ m $=$ 12 cm. **(B)**.

Bài tập luyện tập

(Supplement) An object 4.0 cm tall is placed 25 cm from a converging lens, forming a real image 75 cm from the lens on the far side. Find the magnification and the height of the image.

Lời giải chi tiết

$m = \frac{v}{u} = \frac{75}{25} = 3.0$ (no units — magnification is a ratio). Image height $= 3.0 \times 4.0 = \boxed{12\,\text{cm}}$.

Bài tập luyện tập

(Supplement) The refractive index of water is 1.33. Taking $c = 3.0 \times 10^8$ m/s, find the speed of light in water.

(A) 2.26×10^8 m/s
(B) 3.99×10^8 m/s
(C) 1.33×10^8 m/s
(D) 4.0×10^8 m/s

Lời giải chi tiết

$v = \frac{c}{n} = \frac{3.0 \times 10^8}{1.33} = 2.26 \times 10^8$ m/s. **(A)**.

Bài tập luyện tập

(Supplement) Diamond has a refractive index of 2.42. Calculate its critical angle.

Lời giải chi tiết

$\sin C = \dfrac{1}{2.42} = 0.413 \Rightarrow C = \arcsin(0.413) = \boxed{24.4^\circ}$.

Bài tập luyện tập

A tuning fork vibrates with a period of 2.5 ms. Find (a) its frequency, and (b) the wavelength of the sound it produces in air ($v = 340$ m/s).

Lời giải chi tiết

(a) $f = \dfrac{1}{T} = \dfrac{1}{0.0025} = \boxed{400\,\text{Hz}}$.

(b) $\lambda = \dfrac{v}{f} = \dfrac{340}{400} = \boxed{0.85\,\text{m}}$.

Bài tập luyện tập

An ultrasound pulse sent to locate the boundary of an internal organ returns to the transducer after 2.6×10^{-5} s. The speed of ultrasound in soft tissue is 1540 m/s. Find the depth of the boundary below the skin.

(A) 2.0 cm
(B) 4.0 cm
(C) 1.0 cm
(D) 0.5 cm

Lời giải chi tiết

Round-trip distance $= vt = (1540)(2.6 \times 10^{-5}) = 0.0400$ m $= 4.00$ cm. Depth $= \dfrac{4.00}{2} = 2.00$ cm. **(A)**.

Bài tập luyện tập

(Supplement) A periscope uses two right-angled glass prisms instead of two plane mirrors to redirect light through 90° twice. Explain, using the idea of total internal reflection, why this design loses less light than an equivalent design using ordinary silvered mirrors.

Lời giải chi tiết

Inside each prism, light strikes the hypotenuse face at 45°, which is greater than the critical angle of glass ($\approx 42^\circ$), so **total internal reflection** occurs and, in principle, all of the light is reflected at each face. A silvered mirror, by contrast, always absorbs a small fraction of the light energy at its metallic reflecting surface every time light reflects from it. Using two mirrors therefore causes two separate lots of light loss, producing a dimmer image than the prism periscope, which reflects with virtually no loss of light at either face.

Bài tập luyện tập

(Supplement) A ray of light travelling in air strikes one face of a glass prism ($n = 1.55$) at an angle of incidence of 35°, refracting into the glass. It then travels to a second face of the prism and strikes it at an angle of incidence of 50° to that face's normal. (a) Find the angle of refraction at the first face. (b) Find the critical angle of this glass. (c) State, with a reason, whether total internal reflection occurs at the second face.

Lời giải chi tiết

(a) $\sin r = \dfrac{\sin 35^\circ}{1.55} = \dfrac{0.574}{1.55} = 0.370 \Rightarrow r = \arcsin(0.370) = \boxed{21.7^\circ}$.

(b) $\sin C = \dfrac{1}{1.55} = 0.645 \Rightarrow C = \arcsin(0.645) = \boxed{40.2^\circ}$.

(c) Since the angle of incidence at the second face (50°) is **greater than** the critical angle (40.2°), $\boxed{\text{total internal reflection occurs at the second face}}$.

Bài tập luyện tập

A sound source vibrates at a constant frequency of 440 Hz. The sound travels first through air ($v = 340$ m/s) and then through water ($v = 1500$ m/s). Find the wavelength of the sound in each medium, and explain why the wavelength changes although the frequency does not.

Lời giải chi tiết

$\lambda_{\text{air}} = \dfrac{v}{f} = \dfrac{340}{440} = \boxed{0.773\,\text{m}}$. $\lambda_{\text{water}} = \dfrac{v}{f} = \dfrac{1500}{440} = \boxed{3.41\,\text{m}}$.

The frequency is fixed by the vibrating source and stays the same in both media; since $v = f\lambda$, a fixed frequency means wavelength is directly proportional to speed, so the much faster speed in water produces a proportionally longer wavelength there.

Bài tập luyện tập

(Supplement) Using the refractive indices $n = 1.00$ (air), 1.33 (water), 1.50 (glass) and 2.42 (diamond), and $c = 3.0 \times 10^8$ m/s, in which of these media does light travel *slowest*, and what is its approximate speed there?

(A) Diamond; 1.24×10^8 m/s
(B) Water; 2.26×10^8 m/s
(C) Glass; 2.0×10^8 m/s
(D) Air; 3.0×10^8 m/s

Lời giải chi tiết

Since $v = c/n$, the **largest** refractive index gives the **smallest** speed. Diamond has the largest n (2.42) of the four media, so light travels slowest in diamond: $v = \dfrac{3.0 \times 10^8}{2.42} = 1.24 \times 10^8$ m/s. **(A)**.

Bài tập luyện tập

(Supplement) Two speakers emit sound waves of wavelength 0.60 m, driven exactly in phase. A listener stands at a point where the path length from speaker A is 5.4 m and from speaker B is 6.0 m. State, with a reason, whether the listener experiences constructive or destructive interference at this point.

Lời giải chi tiết

Path difference $= 6.0 - 5.4 = 0.6\,\text{m} = 1 \times \lambda$ (exactly one whole wavelength).
Since the path difference is a whole number of wavelengths, the waves arrive in phase, so

constructive interference occurs (a loud sound is heard).

Bài tập luyện tập

(Supplement) Two loudspeakers driven exactly in phase emit sound of wavelength 0.40 m. At a certain point, the path difference between the two speakers is 0.20 m. What is heard at this point?

(A) A very loud sound (constructive interference)

(B) A very quiet or silent point (destructive interference)

(C) No sound reaches this point at all

(D) The pitch changes but not the loudness

Lời giải chi tiết

Path difference $= 0.20\,\text{m} = \frac{1}{2} \times 0.40\,\text{m} = \frac{1}{2}\lambda$ — exactly half a wavelength, so the two waves arrive out of phase (crest meets trough) and destructively interfere, producing a much quieter point. **(B)**.

Bài tập luyện tập

(Supplement) A car horn is sounded continuously as the car first approaches, then passes, and then moves away from a stationary pedestrian. Describe how the pitch heard by the pedestrian changes throughout, and explain this using the Doppler effect.

Lời giải chi tiết

While the car **approaches**, each successive sound wavefront is emitted closer to the pedestrian than the last, compressing the wavefronts together and raising the observed frequency — the pedestrian hears a **higher-than-normal pitch**. As the car passes and then **recedes**, each wavefront is emitted further away than the last, stretching the wavefronts out and lowering the observed frequency — the pedestrian hears a **lower-than-normal pitch**. Pitch: higher while approaching, drops to lower once moving away — the horn's actual emitted frequency never changes; only the *observed* frequency changes due to the relative motion (the Doppler effect).

Bài tập luyện tập

(Supplement) Light from a distant galaxy is observed to have its spectral lines shifted towards the red (longer-wavelength) end of the spectrum, compared with the same lines measured from a stationary source in the laboratory. What does this redshift indicate about the galaxy's motion?

(A) The galaxy is moving away from Earth

(B) The galaxy is moving towards Earth

(C) The galaxy is stationary relative to Earth

(D) The galaxy is rotating but not moving overall

Lời giải chi tiết

A shift to **longer** wavelength (lower frequency) is exactly the pattern expected, by the Doppler effect, from a source **receding** (moving away) from the observer. **(A)**.

Bài tập luyện tập

A displacement–**distance** graph for a wave shows the pattern repeating every 2.4 m, with a maximum displacement of 3.0 cm. Identify the amplitude and the wavelength shown by this graph.

Lời giải chi tiết

The horizontal axis is **distance**, so the repeat spacing gives the **wavelength**, not the period. Amplitude $= \boxed{3.0\,\text{cm}}$. Wavelength $\lambda = \boxed{2.4\,\text{m}}$.

Bài tập luyện tập

A displacement–**time** graph for a wave (recorded at one fixed point) shows the pattern repeating every 0.040 s. A student mistakenly reads this repeat spacing as a wavelength and writes "$\lambda = 0.040$ m." Which statement correctly identifies the student's error?

(A) No error – the reading is correct

(B) The horizontal axis is time, so the repeat spacing is the period T, not the wavelength

(C) The repeat spacing should have been divided by two

(D) The vertical axis, not the horizontal axis, should have been read

Lời giải chi tiết

Since the horizontal axis of this graph is **time**, the spacing between repeats gives the **period** $T = 0.040$ s, not a wavelength — a wavelength can only be read from a displacement–**distance** graph. **(B)**.

Bài tập luyện tập

A transverse water wave is studied with two instruments. A displacement–distance snapshot shows successive crests 0.50 m apart. A displacement–time trace at a fixed point shows successive crests passing every 0.25 s. Find the frequency and the speed of the wave.

Lời giải chi tiết

Wavelength (from the distance graph) $\lambda = 0.50$ m. Period (from the time graph) $T = 0.25$ s.

$f = \frac{1}{T} = \frac{1}{0.25} = \boxed{4.0\,\text{Hz}}$. $v = f\lambda = (4.0)(0.50) = \boxed{2.0\,\text{m/s}}$.

Bài tập luyện tập

A sound wave of frequency 680 Hz travels from air ($v = 340$ m/s) into water ($v = 1500$ m/s). Find the wavelength in each medium, and state which medium has the longer wavelength.

(A) Air: 0.50 m; water: 2.21 m – water has the longer wavelength

(B) Air: 2.0 m; water: 0.45 m – air has the longer wavelength

(C) Both media have the same wavelength since frequency is unchanged

(D) Air: 0.50 m; water: 0.227 m – air has the longer wavelength

Lời giải chi tiết

$\lambda_{\text{air}} = \dfrac{v}{f} = \dfrac{340}{680} = 0.50$ m. $\quad \lambda_{\text{water}} = \dfrac{v}{f} = \dfrac{1500}{680} = 2.21$ m.
Since frequency stays fixed at the source and $v = f\lambda$, the medium with the higher speed (water) has the proportionally longer wavelength. **(A)**.

Electricity and Magnetism

> **Mục tiêu Unit:** Từ tính (nam châm, đường sức, nam châm điện); tĩnh điện (nhiễm điện do cọ xát, ứng dụng & nguy hiểm); mạch điện (điện tích, dòng điện, hiệu điện thế, định luật Ohm, đồ thị I–V, mạch nối tiếp/song song – Supplement, công suất, năng lượng điện); an toàn điện (phích cắm 3 chân, cầu chì, nối đất); hiệu ứng điện từ (Supplement: lực từ, quy tắc bàn tay trái/phải, động cơ điện, cảm ứng điện từ, máy biến áp, truyền tải điện năng).

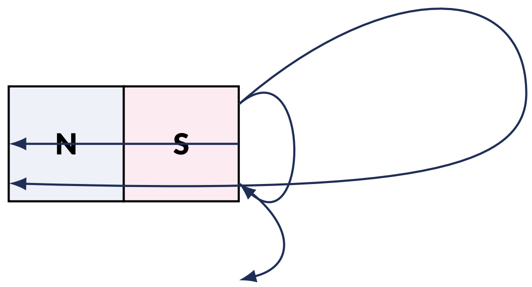
4.1 Magnetism

A **magnet** is an object that produces its own magnetic field and attracts certain materials. Every magnet has two **poles**, a north (N) pole and a south (S) pole, and the magnetic effect is strongest at the poles. Like poles **repel** one another (N–N or S–S), while unlike poles **attract** one another (N–S). This is the basis of the standard **test for whether an object is a magnet**: a genuine magnet will *repel* one pole of a known magnet (attraction alone is not conclusive, because an unmagnetised piece of iron is also attracted to *either* pole of a magnet — only repulsion proves both objects are magnetised).

> **Magnetic materials** (attracted to a magnet, can themselves be magnetised): iron, steel, cobalt, nickel — collectively called **ferromagnetic** materials. **Non-magnetic materials**: all other materials, including copper, aluminium, gold, wood, plastic, and most other metals and non-metals — these are not attracted to a magnet and cannot be magnetised.

When an unmagnetised piece of a magnetic material (e.g. an iron nail) is brought close to a magnet, it becomes an **induced magnet** — it develops its own north and south poles (the end nearer the permanent magnet's pole becomes the opposite pole, so it is always attracted, never repelled) and can then attract other magnetic objects itself. This **induced magnetism** disappears (fully for soft iron, largely for steel) once the permanent magnet is removed.

A simple way to picture why some materials are magnetic and others are not is to imagine a ferromagnetic material as being made up of many tiny regions, each behaving like a miniature magnet with its own tiny north and south pole. In an **unmagnetised** sample, these tiny regions point in random directions, so their individual effects cancel out overall and the material shows no net magnetism. In a **magnetised** sample, the tiny regions have been lined up so that they mostly point the same way, and their effects add together to give a strong overall magnetic field with poles at the ends of the material. This is also why an induced magnet forms almost instantly when a magnetic material is placed near a strong magnet (the tiny regions realign quickly), and why hitting or heating a magnet can weaken it (the impact/heat jumbles the alignment again).



Magnetic field pattern around a bar magnet: field lines emerge from the **N** pole, curve around, and re-enter at the **S** pole; they are closest together (field strongest) near the poles, and never cross.

> A **magnetic field** is a region of space where a magnetic material or another magnet experiences a force. **Field lines** are drawn (by convention) pointing *from N to S* outside the magnet; arrows show the direction a free north pole would move if placed there; lines are closer together where the field is stronger, and field lines never cross.

Plotting compass method: a small plotting compass is placed near the magnet, and a dot is marked at the position of its (north-seeking) pole tip; the compass is then moved so its tail sits on the previous dot, and a new dot is marked — repeating this traces out one complete field line, and the process is repeated starting from different points around the magnet to map the whole field pattern. The compass needle itself simply aligns with the local field direction at every point along the way.

> VN **GIẢI THÍCH TIẾNG VIỆT**
>
> Nam châm có hai cực Bắc (N) và Nam (S); **cùng cực thì đẩy nhau, khác cực thì hút nhau**. Cách kiểm tra một vật có phải nam châm hay không là dùng **lực đẩy** (chỉ có 2 nam châm thật mới đẩy nhau; hút nhau không đủ để kết luận, vì sắt chưa nhiễm từ cũng bị hút bởi cả hai cực). Vật liệu từ tính (sắt, thép, coban, niken – gọi chung là **sắt từ**) có thể bị nhiễm từ tạm thời khi đặt gần nam châm (**nhiễm từ do cảm ứng**), và mất từ tính khi lấy nam châm ra (đặc biệt với sắt non). Đường sức từ đi ra từ cực Bắc, vòng quanh và đi vào cực Nam; càng gần cực, đường sức càng dày (từ trường càng mạnh). Phương pháp la bàn dò: đặt la bàn nhỏ, đánh dấu đầu kim, di chuyển la bàn để đuôi kim trùng dấu vừa đánh, lặp lại để vẽ ra một đường sức hoàn chỉnh.

4.1.1 Permanent Magnets and Electromagnets

Steel is used to make **permanent magnets**: it is magnetically **"hard"** — difficult to magnetise, but once magnetised it retains its magnetism well and is not easily demagnetised (useful for compass needles, fridge magnets, loudspeakers). **Soft iron** is used for the cores of **electromagnets** and for other induced-magnetism applications (e.g. transformer cores, relay armatures): it is magnetically **"soft"** — very easy to magnetise strongly, but it also loses its magnetism almost completely and instantly once the magnetising field is removed. This is essential for an electromagnet, which must switch its magnetism on and off (with the current) rather than staying permanently magnetised.

> **Steel** → permanent magnets (hard to magnetise, retains magnetism). **Soft iron** → electromagnet cores, relays, transformer cores (easy to magnetise, loses magnetism instantly when the current is switched off).

A permanent magnet can be **demagnetised** (its ordered internal alignment disrupted, jumbling the tiny magnetic regions back into random orientations) in several ways: **hammering** or repeatedly dropping the magnet (mechanical shock disturbs the alignment); **heating** it strongly (above a temperature called the Curie point, thermal vibration randomises the alignment, and even below this temperature strong heating weakens it); or placing it inside a solenoid carrying a **decreasing alternating current**, which repeatedly reverses and shrinks the applied field, gradually scrambling the internal alignment in a controlled way. Conversely, a magnet can be strengthened (or an unmagnetised bar first magnetised) by stroking it repeatedly in the same direction with one pole of a strong magnet, or by placing it inside a solenoid carrying direct current.

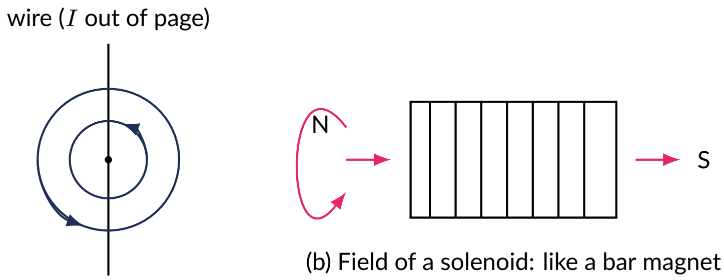
VN GIẢI THÍCH TIẾNG VIỆT

Thép dùng làm nam châm vĩnh cửu vì khó nhiễm từ nhưng giữ từ tính lâu dài (nam châm "cứng"). **Sắt non** dùng làm lõi nam châm điện vì dễ nhiễm từ mạnh nhưng mất từ tính gần như ngay lập tức khi ngắt dòng điện (nam châm "mềm") – điều này rất quan trọng vì nam châm điện cần bật/tắt từ tính theo ý muốn. Có thể **khử từ** một nam châm bằng cách đập/rung mạnh, nung nóng, hoặc đặt trong ống dây có dòng xoay chiều giảm dần; ngược lại có thể **nhiễm từ** bằng cách vuốt cùng chiều với một cực nam châm mạnh, hoặc đặt trong ống dây có dòng một chiều.

4.1.2 Magnetic Fields of Currents (Supplement)

(Supplement) An electric current always produces a magnetic field around itself. Around a long **straight wire**, the field lines are **concentric circles** centred on the wire, in planes perpendicular to it; the field is stronger closer to the wire (circles closer together) and weaker further away. The direction is given by the **right-hand grip rule**: grip the wire with the right hand, thumb pointing in the direction of *conventional current* (from + to −), and the curled fingers show the direction of the field lines.

Inside a **solenoid** (a long coil of wire), the fields of all the individual turns add together to produce a strong, uniform field along the axis, very similar in shape to the field of a bar magnet — with field lines emerging from one end (behaving as a N pole) and entering the other (S pole), and looping back around the outside. Applying the right-hand grip rule to the solenoid (curl the fingers in the direction of the current flowing around the coil) makes the thumb point along the axis in the direction of the field inside the coil, i.e. out of the N end.



(b) Field of a solenoid: like a bar magnet

(a) Field around a straight wire: concentric circles

(Supplement) (a) Right-hand grip rule around a straight current-carrying wire gives concentric circular field lines. (b) A solenoid's field, found the same way, matches the pattern of a bar magnet, with the field strongest and most uniform inside the coil.

VN GIẢI THÍCH TIẾNG VIỆT

(Supplement) Dòng điện luôn tạo ra từ trường xung quanh nó. Quanh một dây dẫn thẳng, đường sức là các **vòng tròn đồng tâm**; dùng **quy tắc nắm tay phải** (ngón cái chỉ chiều dòng điện, các ngón còn lại cuộn theo chiều đường sức) để xác định chiều từ trường. Bên trong ống dây (solenoid), từ trường của các vòng dây cộng dồn lại tạo ra từ trường mạnh, đều, có hình dạng giống hệt nam châm thẳng, với một đầu là cực Bắc và đầu kia là cực Nam.

4.2 Static Electricity

When two suitable insulating materials are rubbed together (e.g. a polythene rod with a cloth, or a plastic comb through dry hair), electrons are transferred from one surface to the other by friction. **Charge is never created or destroyed in this process** — only *transferred*: the material that gains electrons becomes negatively charged (excess of electrons), while the material that loses electrons becomes positively charged (deficit of electrons), and the two charges are always equal and opposite.

> **Like charges repel; unlike charges attract** — exactly analogous to magnetic poles. Charge is measured in **coulombs (C)**. Charging by friction is always due to the movement of (negatively charged) **electrons** only — protons are bound tightly inside the nucleus and never move between materials in these processes.

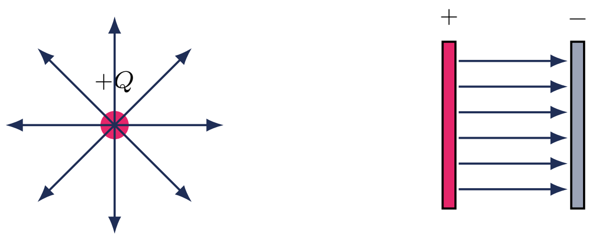
Charge is not infinitely divisible: every charge, however it is produced, is always an exact whole-number multiple of the tiny charge carried by a single electron, $e = 1.6 \times 10^{-19}$ C (this is called the **elementary charge**). The very large numbers of electrons transferred during ordinary charging by friction (typically many billions) is exactly why the resulting charge, though built from discrete electrons, appears as a smooth, continuously-adjustable quantity in everyday measurements.

Ví dụ 2b · Number of electrons transferred by friction

After rubbing a polythene rod with a cloth, the rod is found to carry a charge of -3.2×10^{-9} C. Given the charge of one electron is $e = 1.6 \times 10^{-19}$ C, find the number of (surplus) electrons on the rod.

Number of electrons $= \dfrac{\text{total charge}}{e} = \dfrac{3.2 \times 10^{-9}}{1.6 \times 10^{-19}} = \boxed{2.0 \times 10^{10} \text{ electrons}}$ — twenty billion excess electrons, transferred from the cloth onto the rod by friction.

An **electric field** exists in the region around any charged object, exerting a force on any other charge placed within it. By convention, electric field lines are drawn pointing *from positive to negative* — i.e. in the direction a small positive test charge would be pushed if placed at that point; the lines are closer together where the field is stronger.



(a) Radial field around an isolated point charge (b) Uniform field between charged parallel plates

(a) The field around an isolated positive point charge points radially outward in all directions, becoming weaker (field lines further apart) at greater distance. (b) Between two oppositely-charged parallel plates, the field lines are straight, parallel and evenly spaced (except near the edges), showing a **uniform** field of the same strength at every point between the plates.

> **(!) Lỗi thường gặp:** Charging by friction never *creates* charge out of nothing — it simply transfers existing electrons from one object to the other. If one object ends up with charge $+Q$, the other object it was rubbed against must end up with exactly $-Q$ (equal and opposite), since the total charge of an isolated system is always conserved.

(Supplement) Charging by induction allows an object to be charged *without* any direct contact or friction, using only the electric field of a nearby charged object. For example, bringing a negatively charged rod close to (but not touching) an isolated, initially neutral metal sphere repels the sphere's free electrons to the far side, leaving the near side positively charged (and the far side negatively charged) — this separation of charge is called *induction*. If the far side of the sphere is then earthed (briefly connected to the ground) while the rod is still present, the repelled electrons flow away to earth; removing the earth connection and then the rod leaves the sphere with a genuine, permanent *positive* charge (opposite in sign to the inducing rod), spread evenly over its surface.

VN GIẢI THÍCH TIẾNG VIỆT

Nhiễm điện do cọ xát là do sự **di chuyển của electron** từ vật này sang vật kia (không phải "tạo ra" điện tích) – vật mất electron thì nhiễm điện dương, vật nhận thêm electron thì nhiễm điện âm, và tổng điện tích luôn được bảo toàn. Điện tích cùng dấu đẩy nhau, trái dấu hút nhau. Đường sức điện trường quy ước đi từ **cực dương sang cực âm**. Điện tích không chia nhỏ vô hạn – luôn là bội số nguyên của điện tích electron $e = 1.6 \times 10^{-19}$ C. **(Supplement)** Nhiễm điện do hưởng ứng (cảm ứng) xảy ra khi một vật tích điện được đưa đến gần (không chạm) một vật trung hòa, làm điện tích trong vật trung hòa tách ra thành hai phía trái dấu; nếu nối đất phần điện tích cùng dấu với vật gây cảm ứng rồi tháo dây nối đất và đưa vật tích điện đi, vật ban đầu sẽ giữ lại điện tích **trái dấu** với vật gây cảm ứng.

4.2.1 Uses and Dangers of Static Electricity

Uses: **Spray painting** — the paint droplets and the object being sprayed are given opposite charges, so the droplets are attracted directly and evenly onto every surface (including the sides facing away from the nozzle), reducing wasted paint. **Photocopiers / laser printers** — a charged drum attracts oppositely-charged toner powder only in the pattern of the image/text, which is then transferred and fused onto paper. **Electrostatic precipitators / smoke precipitation** — waste gases from a chimney pass charged electrodes (or plates) that charge the soot/dust particles; the charged particles are then attracted to and collected on oppositely charged plates, removing them from the gas before it is released, reducing air pollution.

Dangers: Static charge can build up on ungrounded objects (e.g. a fuel tanker, or a person walking on synthetic carpet) until it discharges suddenly as a **spark**. This is a serious hazard during **aircraft or road-tanker refuelling**, where a spark could ignite flammable fuel vapour; **lightning** is a large-scale natural example, caused by the build-up and sudden discharge of static charge between storm clouds and the ground. **Precautions:** **earthing** (connecting a conductor to the ground with a wire so that charge safely and continuously flows away rather than building up) and **bonding** (connecting two objects, e.g. a fuel tanker and the aircraft/storage tank, with a conducting wire before transferring fuel, so both are kept at the same electric potential and no spark can jump between them).

VN GIẢI THÍCH TIẾNG VIỆT

Ứng dụng tĩnh điện: **sơn phun tĩnh điện** (giọt sơn và vật được tích điện trái dấu để sơn bám đều mọi mặt), **máy photocopy/máy in laser** (trống tích điện hút bột mực theo đúng hình ảnh/văn bản cần in), **lọc bụi tĩnh điện** (hạt bụi trong khí thải bị tích điện rồi hút vào tấm bản cực trái dấu, giảm ô nhiễm không khí). Nguy hiểm: tia lửa điện tĩnh có thể gây cháy nổ khi **tiếp nhiên liệu** (xe bồn, máy bay), và **sét** chính là hiện tượng phóng điện tĩnh quy mô lớn giữa đám mây và mặt đất. Biện pháp phòng ngừa: **nối đất** (dẫn điện tích an toàn xuống đất) và **nối đẳng thế (bonding)** giữa các thiết bị trước khi tiếp nhiên liệu để không có chênh lệch điện thế gây tia lửa.

4.3 Electric Circuits: Charge, Current and Potential Difference

Electric current I is the rate of flow of electric charge; **electric charge** Q is measured in coulombs (C), and current is measured in amperes (A, or amps). Conventional current is defined as flowing from $+$ to $-$ around a circuit (the opposite direction to the actual flow of electrons in a metal wire, which flow from $-$ to $+$).

$$Q = It \qquad \Longleftrightarrow \qquad I = \frac{Q}{t}$$

where Q is charge in coulombs (C), I is current in amperes (A), and t is time in seconds (s). Current is measured with an **ammeter**, always connected **in series** in the part of the circuit whose current is being measured (so that all the charge passing through that component also passes through the ammeter); an ideal ammeter has (approximately) zero resistance, so it does not affect the current it is measuring.

Ví dụ 1 · Charge from current and time

A current of 5.0 A flows through a wire for 60 s (one minute). Find the charge that passes any point in the wire.
$Q = It = (5.0)(60) = \boxed{300\,\text{C}}$.

Potential difference (p.d.), or **voltage** V, between two points is the (electrical) energy transferred (work done) per unit charge passing between those two points:

$$V = \frac{W}{Q}$$

where W is the energy transferred (in joules, J) and Q is the charge (in coulombs, C) that passes; V is measured in volts (V), where 1 V $= 1$ J/C. Potential difference is measured with a **voltmeter**, always connected **in parallel** with (i.e. across) the component whose p.d. is being measured; an ideal voltmeter has (approximately) infinite resistance, so it draws negligible current and does not disturb the circuit it is measuring.

Ví dụ 2 · Energy transferred from charge and p.d.

A charge of 5.0 C passes through a lamp connected to a 12 V supply. Find the electrical energy transferred.
$W = QV = (5.0)(12) = \boxed{60\,\text{J}}$.

(!) Lỗi thường gặp: An **ammeter** must always be wired **in series** (broken into the current path itself) — never in parallel, since its very low resistance would short-circuit the component and could allow a dangerously large current to flow. A **voltmeter** must always be wired **in parallel** (connected across two points) — never in series, since its very high resistance would almost completely block the current in the circuit. A quick way to remember: *"Ammeter in series, sees all the current; voltmeter in parallel, feels the voltage gap."*

GIẢI THÍCH TIẾNG VIỆT

VN Dòng điện $I = Q/t$ (đơn vị ampe, A) đo bằng **ampe kế mắc nối tiếp**; hiệu điện thế $V = W/Q$ (đơn vị vôn, V) đo bằng **vôn kế mắc song song**. Đây là lỗi rất hay gặp: mắc ampe kế song song hoặc vôn kế nối tiếp sẽ làm sai lệch hoàn toàn mạch điện (ampe kế song song gây đoản mạch; vôn kế nối tiếp gần như chặn hết dòng điện).

4.4 Resistance, Ohm's Law and I--V Characteristics

Resistance R measures how strongly a component opposes the flow of current, defined by

$$R = \frac{V}{I} \qquad \text{(Ohm's Law, one useful rearrangement: } V = IR\text{)}$$

where R is in ohms (Ω), V is in volts, and I is in amps. A resistor is said to obey **Ohm's Law** if its resistance stays constant regardless of current — i.e. if V and I are directly proportional — which is true for a metal wire/resistor *only while its temperature stays constant*.

Ví dụ 3 · Ohm's law: finding current and power

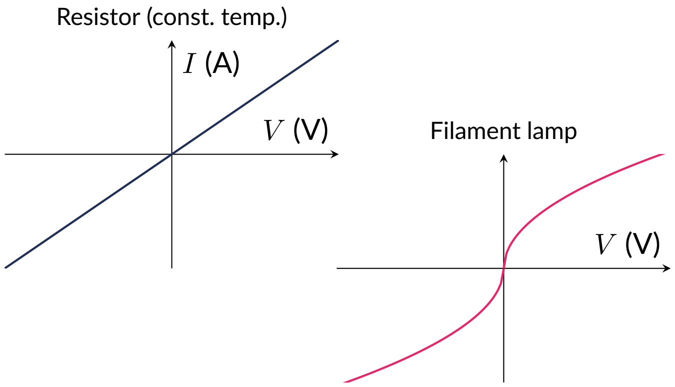
A resistor of resistance $15\,\Omega$ is connected across a 30 V supply. Find (a) the current through it and (b) the power it dissipates.

(a) $I = \frac{V}{R} = \frac{30}{15} = 2.0$ A.

(b) $P = VI = (30)(2.0) = 60$ W (check: $P = I^2R = (2.0)^2(15) = (4.0)(15) = 60$ W ✓).

4.4.1 I–V Characteristic Graphs

The **I–V characteristic** of a component is a graph of current I (usually on the vertical axis) against potential difference V across it, and reveals how its resistance behaves.



Left: a resistor at constant temperature gives a **straight line through the origin** — $I \propto V$, constant resistance (Ohm's Law obeyed), same behaviour for both current directions. **Right:** a filament lamp gives a **curve** that flattens (gradient $= 1/R$ decreases) as V (and hence current) increases, because the filament heats up, and resistance of a metal **increases** with temperature.

Resistor (constant temperature): straight line through the origin — constant resistance. **Filament lamp**: curve bending towards the V-axis as V increases — resistance *increases* with current, because the filament gets hotter (increased vibration of the metal ions makes it harder for the "sea" of free electrons to drift through), and metals have higher resistance at higher temperatures.

(Supplement) A **diode** conducts current in only one direction. In the **forward direction**, once the p.d. across it exceeds a small threshold (typically around 0.6 –0.7 V for silicon), current rises steeply with only a small further increase in V (very low resistance). In the **reverse direction**, an ideal diode allows (essentially) no current to flow at all, however large the reverse voltage — behaving as an almost infinite resistance. This makes diodes useful for converting a.c. into d.c. (rectification), since they only ever let current through one way.

VN GIẢI THÍCH TIẾNG VIỆT

Đồ thị I–V của điện trở ở nhiệt độ không đổi là **đường thẳng qua gốc tọa độ** (điện trở không đổi, tuân theo định luật Ohm). Đồ thị của bóng đèn dây tóc là một **đường cong** bẹt dần vì dây tóc nóng lên khi dòng điện tăng, làm điện trở kim loại **tăng theo nhiệt độ**. (Supplement) Diode chỉ cho dòng điện đi qua theo **một chiều** (chiều thuận, sau một ngưỡng điện áp nhỏ); theo chiều ngược lại, gần như không có dòng điện nào đi qua.

4.4.2 Factors Affecting the Resistance of a Wire

For a wire of a given material at constant temperature, resistance depends on three factors:

Length L: resistance is **directly proportional** to length ($R \propto L$) — a longer wire means electrons must travel further, colliding with more ions along the way. **Cross-sectional area** A: resistance is **inversely proportional** to area ($R \propto 1/A$) — a thicker wire gives electrons more "room," i.e. more parallel paths, to flow through, lowering resistance. **Material (resistivity)**: different materials resist current flow to very different extents even at the same dimensions and temperature — this material property is called **resistivity** ρ (unit Ω m). (Supplement) Combining all three factors gives

$$R = \frac{\rho L}{A}.$$

Ví dụ 4 · Resistance from resistivity, length and area

(Supplement) A resistance wire of resistivity $\rho = 1.10 \times 10^{-6}\,\Omega$ m has length 2.0 m and cross-sectional area 0.50 mm^2 $(= 5.0 \times 10^{-7}$ m$^2)$. Find its resistance.

$$R = \frac{\rho L}{A} = \frac{(1.10 \times 10^{-6})(2.0)}{5.0 \times 10^{-7}} = \frac{2.20 \times 10^{-6}}{5.0 \times 10^{-7}} = \boxed{4.4\,\Omega}.$$

If this same wire were instead cut in half (length 1.0 m, same area), its resistance would halve to $2.2\,\Omega$; if instead its cross-sectional area were doubled (same length), its resistance would also halve.

VN GIẢI THÍCH TIẾNG VIỆT

Điện trở của một dây dẫn **tỉ lệ thuận với chiều dài** (dây dài hơn thì cản trở dòng điện nhiều hơn) và **tỉ lệ nghịch với tiết diện** (dây dày hơn thì dễ dẫn điện hơn), đồng thời phụ thuộc vào **vật liệu** (điện trở suất ρ). (Supplement) Công thức đầy đủ: $R = \rho L/A$.

4.4.3 Resistance That Changes with Conditions: Thermistors and LDRs

Besides fixed resistors, some special components are deliberately designed so that their resistance changes strongly and predictably with an external condition, which makes them useful as **sensors** in circuits.

A **thermistor** has a resistance that **decreases** sharply as its temperature **increases** (the opposite behaviour to an ordinary metal wire) — used in temperature-sensing circuits, e.g. car engine thermometers and thermostats. A **light-dependent resistor (LDR)** has a resistance that **decreases** sharply as the light intensity falling on it **increases** — used in light-sensing circuits, e.g. automatically switching on street lamps or a camera's light meter.

Ví dụ 4b · Reasoning with a thermistor sensor circuit

A thermistor is connected in series with a fixed resistor and a battery of constant voltage. Explain what happens to the current in the circuit as the temperature falls.

As temperature falls, the thermistor's resistance **increases** (its defining property is the reverse of this: resistance falls as temperature rises, so a temperature *fall* means its resistance rises). Since it is in series with the fixed resistor, the total circuit resistance increases; with the supply voltage unchanged, $I = V/R_{\text{total}}$ means the current **decreases** as the temperature falls. (This is exactly how a simple thermistor-based temperature alarm or thermostat circuit can detect a change in temperature.)

GIẢI THÍCH TIẾNG VIỆT

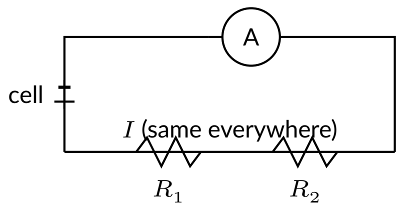
VN Nhiệt điện trở (thermistor) có điện trở **giảm** khi nhiệt độ **tăng** (ngược với dây kim loại thông thường) – dùng làm cảm biến nhiệt độ. Quang trở (LDR) có điện trở **giảm** khi cường độ ánh sáng **tăng** – dùng làm cảm biến ánh sáng (ví dụ: đèn đường tự động bật khi trời tối).

4.5 Series and Parallel Circuits

4.5.1 Series Circuits

In a **series circuit**, all components are connected end-to-end in a single loop, so there is only one path for current to flow.

Series circuit rules: (1) the **current is the same** at every point around the loop (charge cannot build up or disappear anywhere); (2) the total resistance is the **sum** of the individual resistances, $R_{\text{total}} = R_1 + R_2 + R_3 + \ldots$; (3) the supply p.d. is **shared (divides)** between the components, in direct proportion to each one's resistance — the sum of the individual p.d.s equals the supply p.d., $V_{\text{supply}} = V_1 + V_2 + V_3 + \ldots$



Series circuit: one cell, one ammeter (reads the single current common to the whole loop), and two resistors R_1, R_2 in the same loop.

Ví dụ 5 · Series circuit voltage divider

A $20\,$V supply is connected in series with a $3.0\,\Omega$ resistor R_1 and a $7.0\,\Omega$ resistor R_2. Find the current in the circuit and the p.d. across each resistor.

$R_{\text{total}} = R_1 + R_2 = 3.0 + 7.0 = 10\,\Omega$. $I = \dfrac{V}{R_{\text{total}}} = \dfrac{20}{10} = 2.0\,$A (same current through both resistors).

$V_1 = IR_1 = (2.0)(3.0) = 6.0\,$V. $V_2 = IR_2 = (2.0)(7.0) = 14\,$V.

Check: $V_1 + V_2 = 6.0 + 14 = 20\,$V = supply voltage ✓. The larger resistor takes the larger share of the voltage — this is the "voltage divider" principle.

GIẢI THÍCH TIẾNG VIỆT

VN Trong mạch nối tiếp: **dòng điện như nhau** tại mọi điểm, **điện trở tổng bằng tổng các điện trở thành phần**, và **hiệu điện thế nguồn được chia** cho các điện trở theo tỉ lệ thuận với giá trị điện trở (điện trở lớn hơn thì "gánh" phần điện áp lớn hơn).

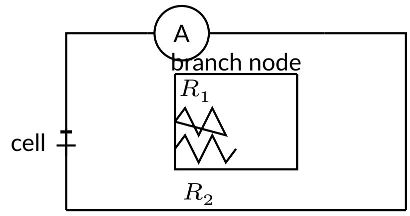
4.5.2 Parallel Circuits (Supplement)

In a **parallel circuit**, components are connected across separate branches between the same two points, so there are multiple paths for current.

(Supplement) **Parallel circuit rules:** (1) the **p.d. is the same** across every branch (all branches connect the same two points/nodes); (2) the **total current** from the supply equals the **sum** of the currents in each branch, $I_{\text{total}} = I_1 + I_2 + I_3 + \ldots$ (current divides, with more current flowing through the branch of *lower* resistance); (3) the total resistance is found from

$$\frac{1}{R_{\text{total}}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \ldots$$

and R_{total} is always **smaller** than the smallest individual branch resistance.



(Supplement) Parallel circuit: two resistors R_1, R_2 form separate branches between the same two nodes, so both have the *same* p.d. across them, while the ammeter (placed in the main line) reads the total current supplied.

Ví dụ 6 · Two resistors in parallel

(Supplement) A $12\,\Omega$ resistor and a $4.0\,\Omega$ resistor are connected in parallel across a 12 V supply. Find (a) the total (combined) resistance and (b) the current in each branch and the total current drawn from the supply.

(a) $\dfrac{1}{R_{\text{total}}} = \dfrac{1}{12} + \dfrac{1}{4.0} = \dfrac{1}{12} + \dfrac{3}{12} = \dfrac{4}{12} = \dfrac{1}{3} \Rightarrow R_{\text{total}} = 3.0\,\Omega.$

(b) $I_1 = \dfrac{V}{R_1} = \dfrac{12}{12} = 1.0$ A. $\quad I_2 = \dfrac{V}{R_2} = \dfrac{12}{4.0} = 3.0$ A.

$I_{\text{total}} = I_1 + I_2 = 1.0 + 3.0 = 4.0$ A (check via total resistance: $I_{\text{total}} = V/R_{\text{total}} = 12/3.0 = 4.0$ A ✓).

Ví dụ 7 · Three unequal resistors in parallel

(Supplement) Resistors of $2.0\,\Omega$, $3.0\,\Omega$ and $6.0\,\Omega$ are connected in parallel. Find the combined resistance.

$\dfrac{1}{R_{\text{total}}} = \dfrac{1}{2.0} + \dfrac{1}{3.0} + \dfrac{1}{6.0} = \dfrac{3}{6} + \dfrac{2}{6} + \dfrac{1}{6} = \dfrac{6}{6} = 1 \Rightarrow R_{\text{total}} = \boxed{1.0\,\Omega}.$

Notice this combined resistance ($1.0\,\Omega$) is smaller than *even the smallest* individual resistor ($2.0\,\Omega$) — adding another parallel path always gives current an easier ("wider") route overall, so total resistance can only ever decrease as branches are added.

(!) Lỗi thường gặp: The combined resistance of resistors in parallel is **always less than the smallest individual branch resistance** — never in between the values, and never larger. A common error is to average the resistances or simply add them as if in series; remember that adding more parallel branches always gives current more ways to flow, so it can only make the overall resistance smaller.

GIẢI THÍCH TIẾNG VIỆT

VN

Trong mạch song song: **hiệu điện thế như nhau** trên mọi nhánh, **dòng điện tổng bằng tổng dòng điện các nhánh**, và điện trở tương đương luôn **nhỏ hơn** điện trở nhỏ nhất trong các nhánh – đây là lỗi rất phổ biến khi học sinh nhầm tưởng điện trở tương đương nằm giữa các giá trị hoặc bằng tổng chúng.

4.5.3 Combined Series–Parallel Circuits (Supplement)

Many practical circuits combine both series and parallel sections. The standard method is to **simplify step by step**: first combine any parallel branches into a single equivalent resistance, then treat the resulting network as a simple series circuit (or vice versa, working from the inside outward).

Ví dụ 8 · Combined series–parallel circuit

(Supplement) A 24 V supply is connected in series with a $4.0\,\Omega$ resistor R_1, which then leads into two resistors $R_2 = 6.0\,\Omega$ and $R_3 = 3.0\,\Omega$ connected in parallel with each other. Find (a) the total resistance of the circuit, (b) the total current supplied, (c) the p.d. across the parallel section, and (d) the current through each of R_2 and R_3.

(a) Parallel section: $\dfrac{1}{R_{23}} = \dfrac{1}{6.0} + \dfrac{1}{3.0} = \dfrac{1}{6} + \dfrac{2}{6} = \dfrac{3}{6} = \dfrac{1}{2} \Rightarrow R_{23} = 2.0\,\Omega.$

This is now in series with R_1: $R_{\text{total}} = R_1 + R_{23} = 4.0 + 2.0 = 6.0\,\Omega.$

(b) $I_{\text{total}} = \dfrac{V}{R_{\text{total}}} = \dfrac{24}{6.0} = 4.0$ A — this is also the current through R_1, since R_1 carries *all* the current before it splits.

(c) P.d. across the parallel section: $V_{23} = I_{\text{total}} \times R_{23} = (4.0)(2.0) = 8.0$ V.

(check: p.d. across R_1 is $V_1 = I_{\text{total}} R_1 = (4.0)(4.0) = 16$ V; and $V_1 + V_{23} = 16 + 8.0 = 24$ V = supply ✓)

(d) $I_2 = \dfrac{V_{23}}{R_2} = \dfrac{8.0}{6.0} = \dfrac{4}{3} \approx 1.33$ A. $\qquad I_3 = \dfrac{V_{23}}{R_3} = \dfrac{8.0}{3.0} = \dfrac{8}{3} \approx 2.67$ A.

Check: $I_2 + I_3 = \dfrac{4}{3} + \dfrac{8}{3} = \dfrac{12}{3} = \boxed{4.0\text{ A} = I_{\text{total}}}$ ✓.

GIẢI THÍCH TIẾNG VIỆT

VN

(Supplement) Với mạch hỗn hợp (vừa nối tiếp vừa song song), phương pháp chuẩn là **rút gọn dần từng bước**: gộp phần song song thành một điện trở tương đương duy nhất trước, sau đó xử lý toàn mạch như mạch nối tiếp đơn giản. Dòng điện qua điện trở nối tiếp trước điểm chia bằng đúng tổng dòng điện của các nhánh song song sau đó.

4.6 Electrical Power, Energy and Cost

Electrical power:

$$P = IV = I^2R = \frac{V^2}{R}$$

(all three forms are equivalent, from substituting $V = IR$); P is in watts (W), where 1 W $= 1$ J/s.
Electrical energy transferred:

$$E = Pt$$

where t is time in seconds for energy in joules. For billing purposes, energy is instead usually measured in **kilowatt-hours (kWh)**:

$$E\,(\text{kWh}) = P\,(\text{kW}) \times t\,(\text{hours}), \qquad \text{Cost} = E\,(\text{kWh}) \times \text{price per kWh}.$$

Ví dụ 9 · Electrical energy and cost

An electric kettle rated at 2.5 kW is used for 0.40 h (24 minutes). Electricity costs \$0.25 per kWh. Find (a) the energy used, in kWh, and (b) the cost.
(a) $E = Pt = (2.5)(0.40) = 1.0$ kWh.
(b) Cost $= E \times$ price $= (1.0)(0.25) = \boxed{\$0.25}$.

Ví dụ 9c · Heat generated in an overloaded cable

A mains extension cable has a resistance of $0.80\,\Omega$. Find the heat energy generated in the cable in 60 s if it carries (a) its normal safe current of 5.0 A, and (b) an overloaded current of 15 A (three times as much, from too many appliances plugged in at once).
(a) $E = I^2Rt = (5.0)^2(0.80)(60) = (25)(0.80)(60) = 1200$ J.
(b) $E = I^2Rt = (15)^2(0.80)(60) = (225)(0.80)(60) = \boxed{10\,800\text{ J}}$ — nine times as much heat energy (since I^2 has increased by a factor of $3^2 = 9$) generated in the *same* cable in the *same* time, illustrating exactly why overloading a cable makes it dangerously hot.

Circuit symbols (standard): cell (long line $+$, short thick line $-$); battery (two or more cells in series); switch (open contact in the line); fixed resistor (rectangle box, or zig-zag); variable resistor / rheostat (rectangle with a diagonal arrow through it, or a zig-zag with a diagonal arrow); lamp (circle with a cross inside); ammeter (circle with letter A); voltmeter (circle with letter V); fuse (rectangle, sometimes shown as a small box in-line, marked with its current rating); diode (triangle pointing in the direction of conventional (forward) current flow, with a bar across the tip).

Component	Symbol description
Cell	one long thin line (+) and one short thick line (–), side by side
Battery	two or more cell symbols in a row (same polarity convention)
Switch	a break in the wire with a hinged lever that can close the gap
Fixed resistor	a plain rectangle in the wire (or a zig-zag line)
Variable resistor (rheostat)	a rectangle with a diagonal arrow drawn through it
Lamp	a circle with an $\times$ inside it
Ammeter	a circle containing the letter A
Voltmeter	a circle containing the letter V
Fuse	a small rectangle in the line, labelled with its current rating
Diode	a triangle (pointing in the forward-current direction) with a bar at its tip

Standard IGCSE circuit-diagram symbols used throughout this unit.

VN **GIẢI THÍCH TIẾNG VIỆT**

Công suất điện $P = IV = I^2R = V^2/R$; năng lượng điện $E = Pt$. Để tính hóa đơn tiền điện, năng lượng thường tính theo **kilowatt-giờ (kWh)**: $E\,(\text{kWh}) = P\,(\text{kW}) \times t\,(\text{giờ})$, rồi nhân với đơn giá mỗi kWh để ra chi phí. Các ký hiệu mạch điện chuẩn (pin, công tắc, điện trở, biến trở, đèn, ampe kế, vôn kế, cầu chì, diode) cần nhớ chính xác để vẽ và đọc sơ đồ mạch điện.

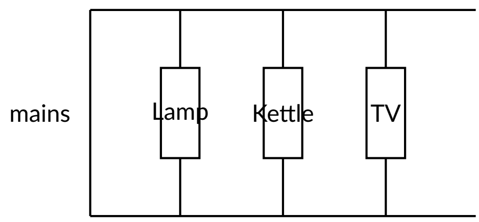
4.7 Practical Electricity and Safety

Mains electricity supplied to homes is **alternating current (a.c.)** — the current repeatedly reverses direction (and the voltage repeatedly reverses polarity) many times per second (e.g. 50 or 60 complete cycles per second, depending on the country) — unlike the **direct current (d.c.)** from a cell or battery, which flows in one direction only.

4.7.1 Why Household Wiring Uses Parallel Circuits

Lamps, sockets and appliances in a house are wired in **parallel** with each other across the live and neutral mains supply, never in series, for two decisive practical reasons:

> (1) Every appliance connected in parallel receives the **full mains voltage**, regardless of how many other appliances are also switched on — exactly as required, since appliances are designed to run at a fixed rated voltage (e.g. 230 V), not a fraction of it that would depend on what else happened to be plugged in. (2) Each appliance can be **switched on or off independently** of all the others (switching one branch off simply removes that one path, without affecting the current in any other branch) — if appliances were wired in series instead, switching just one of them off would break the single shared current path and switch *every* appliance in the house off at once, and a single blown lamp filament would cut power to the whole house.



Household appliances are wired in parallel branches across the live/neutral supply: each receives the full mains voltage and can be switched on or off without affecting the others.

VN **GIẢI THÍCH TIẾNG VIỆT**

Các thiết bị trong nhà được mắc **song song** (không phải nối tiếp) vì hai lý do: (1) mỗi thiết bị nhận đúng **điện áp định mức đầy đủ** dù có bao nhiêu thiết bị khác đang hoạt động; (2) mỗi thiết bị có thể **bật/tắt độc lập** – nếu mắc nối tiếp, tắt một thiết bị (hoặc một bóng đèn cháy) sẽ làm ngắt điện toàn bộ các thiết bị còn lại trong nhà.

Ví dụ 9b · Total current drawn by parallel household appliances

Two $60\,$W lamps and a $2.0\,$kW heater are all connected in parallel to the $230\,$V mains supply and switched on together. Find the total current drawn from the supply.

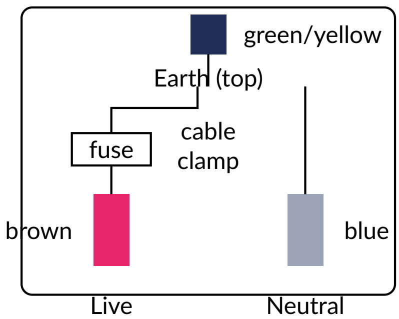
Since all three appliances are in parallel, each receives the full $230\,$V, and their powers simply add: $P_{\text{total}} = 60 + 60 + 2000 = 2120\,$W.

$I_{\text{total}} = \dfrac{P_{\text{total}}}{V} = \dfrac{2120}{230} = \boxed{9.22\,\text{A}}$ (to 3 s.f.) — equivalently, this equals the sum of each appliance's own current ($60/230 + 60/230 + 2000/230 = 0.261 + 0.261 + 8.70 = 9.22\,$A ✓).

4.7.2 The Three-Pin Plug

A standard mains plug has three wires, each with a specific colour code and role:

Live wire (brown): carries the alternating potential difference from the supply, alternating between positive and negative relative to earth; this is the wire that is dangerous to touch. **Neutral wire** (blue): completes the circuit back to the supply, and is normally at (or very close to) $0\,$V (earth potential). **Earth wire** (green-and-yellow stripes): a safety wire connected to the case/metal body of an appliance and to the ground; it carries no current in normal operation, only if a fault occurs.



Three-pin plug wiring: live (brown) passes through the **fuse** before connecting to the appliance; neutral (blue) and earth (green/yellow) connect directly. The cable's outer sheath is gripped firmly by a cable clamp so that a yank on the cord cannot pull any individual wire loose.

Fuse rating: the fuse (or circuit breaker) is chosen with a current rating just *above* the normal operating current of the appliance (common ratings: 3 A, 5 A, 13 A) — e.g. an appliance drawing $2.5\,$A normally should use a $3\,$A fuse (not, say, a $13\,$A fuse, which would allow a dangerously large fault current to flow for a long time before "blowing"). If the current exceeds the fuse's rating (e.g. due to a fault), the thin fuse wire inside heats up and **melts**, breaking the circuit and cutting off the current before wires overheat and start a fire; a **circuit breaker** does the same job electromagnetically/thermally and can simply be switched back on afterwards, instead of being replaced.

Why the fuse and switch are placed in the live wire: if they were instead placed in the neutral wire, the appliance would still be switched "off" from the user's point of view (no current flows), but the live wire — and hence the appliance's internal wiring and casing — would remain live and dangerous, at full mains potential, even with the switch open or the fuse blown. Placing the fuse and switch in the **live** wire ensures that, once they operate/switch off, the whole appliance is safely disconnected from the dangerous live potential.

Further electrical hazards: Damaged insulation on a cable can expose bare live wire, creating a serious shock risk if touched, or a fire risk if the bare wire touches another conductor; damaged cables should always be replaced rather than used. **Overloading** a single socket or circuit — by plugging in too many high-power appliances at once (e.g. via multiple adaptors) — can draw a total current greater than the wiring and fuse were designed for, causing the cable itself to overheat (even before the fuse blows, since the fuse only protects against currents above *its own* rating, not the rating of every individual cable in a shared adaptor) and creating a fire risk. **Damp or wet conditions** greatly increase the danger of electric shock, because water (especially with dissolved salts/impurities, as in tap water or sweat) conducts electricity far better than dry skin does, so a person with wet hands or standing on a wet floor offers a much lower-resistance path for current to flow through their body — this is why switches are kept well away from showers/baths, and why appliances are never operated with wet hands.

Earthing: the earth wire connects the metal casing of an appliance directly to the ground (0 V), providing a path of very low resistance. If a fault causes the live wire to touch the metal casing, a very large current flows suddenly through this low-resistance earth path (rather than through a person who might touch the casing) — this surge blows the fuse (or trips the circuit breaker) almost instantly, disconnecting the live supply, and keeps the casing safely near 0 V the whole time. **Double insulation** is an alternative safety strategy used in many modern appliances (marked with a □ symbol on the appliance): the appliance is built with two independent layers of insulation (and/or an all-plastic casing) so that no single fault could ever make an exposed part live, meaning no earth wire is needed at all — such appliances are supplied with only a two-core (live and neutral) cable.

A **residual current device (RCD)** gives an extra, faster layer of protection alongside (not instead of) the fuse. It continuously compares the current flowing *into* an appliance through the live wire with the current flowing *out* through the neutral wire; in normal operation these are exactly equal. If even a small current leaks away through a fault (e.g. through a person's body, or a damaged cable touching earth), the two currents no longer match, and the RCD instantly (within milliseconds) disconnects the supply — much faster than an ordinary fuse, which needs a large current to melt its wire. This makes RCDs especially valuable in situations with a higher shock risk, such as bathrooms or outdoor power tools.

(!) Lỗi thường gặp: **Earthing** and the **fuse** play two different, complementary safety roles: earthing provides a safe, low-resistance path so that fault current does *not* flow through a person touching the casing, while the fuse (or circuit breaker) then uses that resulting surge of current to *automatically disconnect* the supply. Earthing on its own, without a fuse, would let a dangerously large current keep flowing indefinitely; a fuse on its own, without earthing, would leave the casing live (and dangerous to touch) for as long as it takes the fault current to build up enough to blow the fuse.

GIẢI THÍCH TIẾNG VIỆT

VN

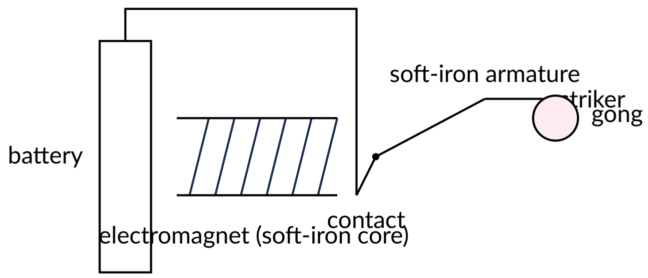
Điện lưới là **dòng điện xoay chiều (AC)**, khác với dòng một chiều (DC) của pin. Phích cắm 3 chân: dây **lửa (nâu)** mang điện áp nguy hiểm và đi qua **cầu chì**; dây **trung tính (xanh dương)** gần 0V; dây **tiếp đất (sọc xanh lá–vàng)** chỉ có dòng khi có sự cố. Cầu chì được chọn có định mức **lớn hơn một chút** so với dòng hoạt động bình thường, và nếu dòng vượt định mức thì dây chì nóng chảy, ngắt mạch trước khi dây dẫn quá nóng gây cháy. Công tắc và cầu chì luôn đặt ở dây **lửa** để khi ngắt, toàn bộ thiết bị được cách ly an toàn khỏi điện áp nguy hiểm. **Nối đất** và **cầu chì** có vai trò khác nhau: nối đất tạo đường dẫn điện trở thấp để dòng sự cố không đi qua người, còn cầu chì dùng chính dòng sự cố đó để tự động ngắt điện. **Cách điện kép** (không cần dây tiếp đất) dùng vỏ nhựa/hai lớp cách điện để đảm bảo không phần nào có thể nhiễm điện khi có sự cố. Các nguy hiểm khác: **dây cách điện bị hỏng** để lộ dây trần (nguy cơ giật điện/cháy); **quá tải ổ cắm/mạch điện** (cắm quá nhiều thiết bị công suất lớn cùng lúc khiến dây dẫn quá nóng); và **môi trường ẩm ướt** làm tăng nguy cơ giật điện vì nước dẫn điện tốt hơn nhiều so với da khô. **Thiết bị chống dòng rò (RCD)** liên tục so sánh dòng điện đi vào (dây lửa) và đi ra (dây trung tính); nếu có chênh lệch dù nhỏ (do dòng rò qua người hoặc sự cố), RCD ngắt điện gần như tức thì – nhanh hơn nhiều so với cầu chì thông thường, nên thường dùng ở nơi có nguy cơ điện giật cao như phòng tắm.

4.8 Electromagnetic Effects (Supplement)

4.8.1 Electromagnets and Their Uses

(Supplement) An **electromagnet** is a solenoid wound around a soft-iron core; its strength can be increased by: (1) increasing the **current** through the coil; (2) increasing the **number of turns** of wire; (3) using a **soft-iron core** instead of air (the core becomes strongly magnetised by induction while current flows, greatly boosting the field, and demagnetises almost instantly when the current is switched off).

Because an electromagnet's magnetism can be switched on and off (and its strength varied) simply by controlling the current, it is used in: **relays** (a small current in one circuit switches on an electromagnet, which then closes a switch in a completely separate, often higher-current, circuit — allowing a small control current to safely operate a large-current device); **electric bells** (an electromagnet repeatedly attracts and releases a spring-loaded striker/armature, which also breaks and remakes its own circuit each time, creating a continuous ringing action); and **cranes for lifting scrap iron/steel** (a large electromagnet is switched on to pick up magnetic scrap, then switched off to drop it exactly where wanted — something a permanent magnet could never do on demand).



(Supplement) The electric bell: current flows through the electromagnet, attracting the soft-iron armature so its striker hits the gong — but this same movement also breaks the contact, switching the electromagnet off; the armature springs back, remaking the contact, and the cycle repeats continuously for as long as the circuit is switched on.

4.8.2 The Motor Effect

(Supplement) When a current-carrying conductor is placed in a magnetic field (and the current is *not* parallel to the field), it experiences a mechanical force — the **motor effect**. For a straight conductor of length L carrying current I, placed at right angles to a magnetic field of flux density B:

$$F = BIL$$

giving the maximum force, which occurs when the current and the field are exactly perpendicular (if they are parallel, the force is zero).

Fleming's left-hand rule gives the direction of the force in the motor effect: hold the thumb, first finger and second finger of the **left** hand mutually at right angles; the **First** finger points in the direction of the (external) magnetic **Field**; the se**C**ond finger points in the direction of the (conventional) **Current**; the thu**M**b then points in the direction of the resulting **Motion** (force).

Ví dụ 10 · Motor effect force

(Supplement) A straight wire of length 0.50 m carries a current of 8.0 A at right angles to a magnetic field of flux density 0.25 T. Find the force on the wire.

$F = BIL = (0.25)(8.0)(0.50) = \boxed{1.0\,\text{N}}$.

Another everyday application of the motor effect is the **loudspeaker**: a coil of wire is attached to a paper or plastic cone and placed in the field of a permanent magnet. An alternating current (the electrical audio signal) through the coil experiences a force from the motor effect that continuously reverses direction as the current alternates, pushing and pulling the coil (and the attached cone) back and forth. These rapid vibrations of the cone push the surrounding air backwards and forwards, creating the sound wave that we hear — a higher-frequency audio signal makes the cone vibrate faster (higher-pitched sound), and a larger current makes the cone vibrate with greater amplitude (louder sound).

4.8.3 The Simple d.c. Electric Motor

A simple d.c. motor consists of a rectangular coil of wire mounted on an axle, free to rotate between the poles of a permanent magnet (or electromagnet). Current flowing through the two side-arms of the coil (each perpendicular to the field) produces forces in opposite directions on the two sides (by the motor effect and Fleming's left-hand rule) — since the two sides carry current in opposite directions relative to each other around the loop, the forces on them are also opposite, and together they form a **couple** (turning force) that rotates the coil.

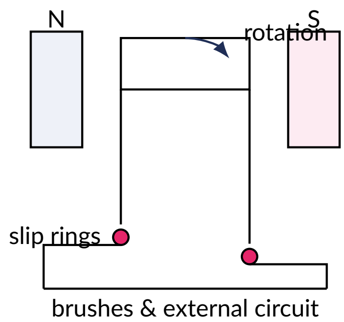
The **split-ring commutator**, together with brushes that press against it, reverses the direction of current through the coil every half-turn, exactly when the coil is vertical (momentarily aligned with the field, where the turning effect would otherwise become zero and then reverse). By reversing the current at this instant, the direction of the force on each side is also reversed, so the coil continues to be pushed around in the *same* rotational direction continuously, rather than oscillating back and forth.

4.8.4 Electromagnetic Induction and the Generator Effect

(Supplement) **Electromagnetic induction:** whenever a conductor moves through a magnetic field (or a magnetic field changes/moves relative to a conductor) so as to "cut" magnetic field lines, an **e.m.f.** (electromotive force, a voltage) is induced across the ends of the conductor; if the conductor is part of a complete circuit, this induced e.m.f. drives an induced current. The size of the induced e.m.f. increases with: (1) the **speed** of relative motion between conductor and field; (2) the **strength** of the magnetic field; (3) the **number of turns** of wire in the coil (for a coil-based conductor).

Fleming's right-hand rule gives the direction of an induced current (the "generator effect," the reverse situation to the motor effect): hold the thumb, first finger and second finger of the **right** hand mutually at right angles; thu**M**b points in the direction of **Motion** of the conductor; First finger points in the direction of the **Field**; seCond finger then points in the direction of the (conventionally) induced **Current**.

An **a.c. generator (alternator)** works on exactly this principle in reverse of a motor: an external force (e.g. a turbine) rotates a coil within a magnetic field (or rotates the magnet around a fixed coil). As the coil spins, the angle at which it cuts field lines continuously changes, so the size and direction of the induced e.m.f. continuously change too — the coil sides move essentially parallel to the field twice per rotation (inducing zero e.m.f. at those instants) and perpendicular to the field twice per rotation (inducing maximum e.m.f., but in *opposite* directions each time, since the two sides swap which pole they are moving towards every half turn) — producing a smoothly alternating (a.c.) output voltage, picked up from the rotating coil via slip rings and brushes.



(Supplement) A.c. generator: a coil rotated between magnetic poles has an alternating e.m.f. induced in it, which is carried to the external circuit via two slip rings and brushes (unlike the split-ring commutator of a d.c. motor, slip rings do *not* reverse the connection each half-turn, so the output genuinely alternates).

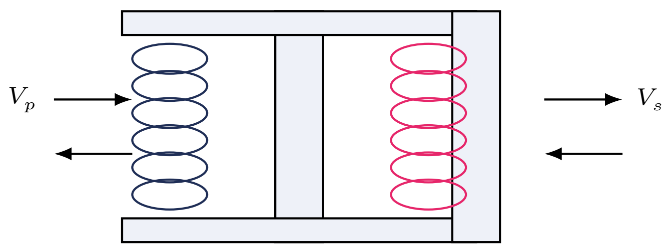
(!) Lỗi thường gặp: It is a common misconception that current gets "used up" as it flows around a circuit, losing charge component-by-component. In reality, **current (rate of flow of charge) is conserved** at every point in a series circuit — exactly the same current flows into and out of every component, including the cell/battery itself. What *is* "used up," or rather converted, is **energy**: each component transfers electrical energy to other forms (e.g. heat, light) as charge flows through it, so it is the p.d. (energy per unit charge) that is shared out and "drops" across each component, not the current or the charge itself.

VN GIẢI THÍCH TIẾNG VIỆT

(Supplement) Nam châm điện càng mạnh khi: dòng điện càng lớn, số vòng dây càng nhiều, và có **lõi sắt non**. Ứng dụng: **rơ-le** (dòng nhỏ điều khiển mạch dòng lớn), **chuông điện**, **cần cẩu nam châm** (hút rồi thả kim loại theo ý muốn). **Hiệu ứng động cơ**: dây dẫn mang dòng điện đặt trong từ trường chịu lực $F = BIL$, xác định chiều bằng **quy tắc bàn tay trái Fleming** (ngón trỏ = từ trường, ngón giữa = dòng điện, ngón cái = lực/chuyển động). Động cơ điện một chiều dùng **cổ góp vành khuyên (split-ring commutator)** để đảo chiều dòng điện mỗi nửa vòng quay, giúp khung dây quay liên tục theo một chiều. **Cảm ứng điện từ**: khi dây dẫn cắt các đường sức từ (do chuyển động tương đối), một suất điện động được sinh ra – càng mạnh khi tốc độ chuyển động, độ mạnh từ trường, và số vòng dây càng lớn. Chiều dòng cảm ứng xác định bằng **quy tắc bàn tay phải Fleming**. Máy phát điện xoay chiều hoạt động theo nguyên lý ngược lại với động cơ, tạo ra điện áp xoay chiều liên tục khi khung dây quay trong từ trường. **Lỗi thường gặp**: dòng điện **không hề bị "dùng hết"** khi qua mạch – dòng điện luôn được bảo toàn, chỉ có **năng lượng** là bị chuyển hóa và tiêu hao dần.

4.9 Transformers and Power Transmission (Supplement)

(Supplement) A **transformer** consists of two separate coils of wire — the **primary** (input) and **secondary** (output) — both wound around a common **soft-iron core**, but with no direct electrical connection between them. An alternating current in the primary coil produces a continuously *changing* magnetic field in the iron core; this changing field passes through the secondary coil and, by electromagnetic induction, induces an alternating e.m.f. in it.



(Supplement) Transformer schematic: primary and secondary coils share a common soft-iron core; a step-*up* transformer has $N_s > N_p$ (more secondary turns), a step-*down* transformer has $N_s < N_p$.

(Supplement) **Turns ratio:**

$$\frac{V_s}{V_p} = \frac{N_s}{N_p}$$

where V_p, V_s are the primary and secondary p.d.s and N_p, N_s are the number of turns on each coil. For an **ideal (100% efficient) transformer**, no power is lost, so input power equals output power:

$$I_p V_p = I_s V_s.$$

A **step-up** transformer has $N_s > N_p$, so $V_s > V_p$ (and, to conserve power, $I_s < I_p$); a **step-down** transformer has $N_s < N_p$, so $V_s < V_p$ (and $I_s > I_p$). Transformers work **only on alternating current (a.c.)** — a steady d.c. current in the primary produces a constant (unchanging) magnetic field, and since electromagnetic induction requires a *changing* field to induce an e.m.f., a d.c. supply induces no voltage in the secondary at all (except for a brief pulse at the instant of switching on/off).

Ví dụ 11 · Step-down transformer

(Supplement) A transformer has 2000 turns on its primary coil and 100 turns on its secondary coil, and is connected to the 230 V a.c. mains supply. If the primary current is 0.50 A, find (a) the secondary (output) voltage and (b) the secondary current (assume an ideal transformer).

(a) $V_s = V_p \times \dfrac{N_s}{N_p} = 230 \times \dfrac{100}{2000} = \boxed{11.5\,\text{V}}$ — this is a step-*down* transformer since $N_s < N_p$.

(b) $I_pV_p = I_sV_s \;\Rightarrow\; I_s = \dfrac{I_pV_p}{V_s} = \dfrac{(0.50)(230)}{11.5} = \dfrac{115}{11.5} = \boxed{10\,\text{A}}$.

Ví dụ 12 · Step-up transformer

(Supplement) A power-station step-up transformer has 1000 turns on its primary coil and $20\,000$ turns on its secondary coil, and its primary is supplied at 11 kV (from the generator). Find the secondary (transmission-line) voltage.

$V_s = V_p \times \dfrac{N_s}{N_p} = 11\,000 \times \dfrac{20\,000}{1000} = 11\,000 \times 20 = \boxed{220\,000\,\text{V} = 220\,\text{kV}}$ — a step-*up* transformer since $N_s > N_p$, exactly the type used to raise the voltage for efficient long-distance transmission.

Transformers appear throughout everyday life at both extremes of the turns ratio. **Step-down** transformers are found inside the small plug-in adaptors used to charge mobile phones and laptops, and to power doorbells and low-voltage garden lighting, converting the 230 V (or 110 V) mains supply down to just a few volts needed by the device — this same step-down principle is also used in arc-welding equipment, which needs a very *large current* at a *low* voltage, and which a step-down transformer conveniently supplies (recall $I_pV_p = I_sV_s$: stepping voltage *down* steps current *up* by the same factor). **Step-up** transformers are used not only at power stations to raise voltage for efficient transmission, but were also historically used in old cathode-ray tube televisions, which needed a very high voltage to accelerate electrons toward the screen.

> **(Supplement)** Real transformers are not perfectly 100% efficient: some energy is always lost as heat, mainly due to resistance in the copper windings (I^2R heating) and to small, unwanted "eddy current" and magnetisation losses in the iron core. **Efficiency** is defined as
>
> $$\text{Efficiency} = \frac{\text{output power}}{\text{input power}} \times 100\% = \frac{I_sV_s}{I_pV_p} \times 100\%,$$
>
> which equals exactly 100% only for an ideal transformer; well-designed power transformers typically achieve efficiencies above 95%.

Ví dụ 12b · Efficiency of a real transformer

(Supplement) A transformer has a primary current of 5.0 A at $V_p = 230$ V, and delivers a secondary current of 22 A at $V_s = 46$ V. Find the efficiency of this transformer.

Input power: $P_p = I_pV_p = (5.0)(230) = 1150$ W. Output power: $P_s = I_sV_s = (22)(46) = 1012$ W.

Efficiency $= \dfrac{P_s}{P_p} \times 100\% = \dfrac{1012}{1150} \times 100\% = \boxed{88\%}$ — the remaining 12% of the input power ($1150 - 1012 = 138$ W) is lost as heat in the windings and core, rather than being delivered to the secondary circuit.

4.9.1 High-Voltage Power Transmission

Power lost to heating in transmission cables is $P_{\text{loss}} = I^2R_{\text{cable}}$, where I is the current flowing through the cable and R_{cable} is the cable's (fixed) resistance. Since electrical power delivered is $P = IV$, for a *fixed* amount of power to be transmitted, increasing the transmission voltage V allows the same power to be delivered with a much **smaller current** $I = P/V$ — and because power loss depends on the *square* of the current, even a modest reduction in current gives a dramatic reduction in power lost as heat. This is why national grids step voltage **up** to very high values (hundreds of kV) for transmission, then step it back **down** for safe use in homes and factories.

Ví dụ 13 · Comparing power loss at low and high transmission voltage

(Supplement) A power station must deliver 150 kW of power to a distant town through a transmission cable of total resistance $3.0\,\Omega$. Compare the power lost as heat in the cable if the power is transmitted at (a) 1500 V and (b) $150\,000$ V (150 kV).

(a) $I_1 = \dfrac{P}{V_1} = \dfrac{150\,000}{1500} = 100$ A. $\quad P_{\text{loss},1} = I_1^2 R = (100)^2(3.0) = (10\,000)(3.0) = 30\,000$ W $=$ 30 kW — a full 20% of the transmitted power wasted as heat.

(b) $I_2 = \dfrac{P}{V_2} = \dfrac{150\,000}{150\,000} = 1.0$ A. $\quad P_{\text{loss},2} = I_2^2 R = (1.0)^2(3.0) = \boxed{3.0\text{ W}}$ — utterly negligible (0.002% of the transmitted power).

Raising the transmission voltage by a factor of 100 reduces the current by the same factor of 100, and — since power loss depends on current *squared* — reduces the power lost as heat by a factor of $100^2 = 10\,000$ ($30\,000$ W $\to$ 3.0 W), which is exactly why electricity grids transmit power at very high voltage.

(!) Lỗi thường gặp: Transformers only work with **alternating current**. A transformer connected to a steady d.c. supply produces no continuous secondary voltage at all, because a constant current creates a constant (unchanging) magnetic field in the core, and electromagnetic induction requires a *changing* magnetic flux to induce an e.m.f. — no change, no induced voltage (beyond a brief transient at switch-on or switch-off).

VN GIẢI THÍCH TIẾNG VIỆT

(Supplement) Máy biến áp gồm hai cuộn dây (sơ cấp, thứ cấp) quấn quanh chung một lõi sắt non, không nối điện trực tiếp với nhau – hoạt động dựa trên **cảm ứng điện từ**, nên **chỉ hoạt động với dòng điện xoay chiều** (dòng một chiều không tạo ra từ trường biến thiên). Tỉ số vòng dây: $V_s/V_p = N_s/N_p$; với máy biến áp lý tưởng, công suất được bảo toàn: $I_pV_p = I_sV_s$. Máy tăng áp có $N_s > N_p$; máy hạ áp có $N_s < N_p$. Trong truyền tải điện năng, tăng điện áp lên rất cao giúp giảm dòng điện tương ứng, và vì hao phí nhiệt tỉ lệ với **bình phương dòng điện** ($P_{\text{hao phí}} = I^2R$), nên tăng điện áp truyền tải giúp giảm hao phí đi rất nhiều lần – đây là lý do lưới điện quốc gia luôn truyền tải ở điện áp cực cao rồi hạ áp trước khi đưa vào sử dụng. Máy biến áp thực tế không đạt hiệu suất 100% do hao phí nhiệt trong cuộn dây và lõi sắt; hiệu suất $= \dfrac{\text{công suất ra}}{\text{công suất vào}} \times 100\%$.

4.10 Practice Problems

Bài tập luyện tập

Two bar magnets are brought close together and are found to attract each other strongly. Explain why this observation *alone* is not enough to prove that both objects are magnets.

Lời giải chi tiết

A magnet attracts *any* unmagnetised magnetic material (e.g. a plain iron bar), not only another magnet, because it induces an opposite pole in the unmagnetised object which is then attracted. Attraction is therefore consistent with either "two magnets" or "one magnet and one unmagnetised magnetic object." Only **repulsion** is conclusive proof that both objects are genuinely magnetised, since an unmagnetised object can never repel a magnet (it can only be attracted, from either pole). Attraction is inconclusive; only mutual repulsion proves both are magnets.

Bài tập luyện tập

Explain why soft iron, rather than steel, is used for the core of an electromagnet in a relay.

Lời giải chi tiết

Soft iron is very easy to magnetise strongly (giving a powerful field while the current flows) but also loses almost all its magnetism **instantly** once the current is switched off. This is exactly what a relay needs: the electromagnet must switch cleanly on and off with the control current. Steel, by contrast, retains magnetism after the current stops (it is magnetically "hard"), so a steel-cored electromagnet would stay partly magnetised and might not release its armature properly when switched off. Soft iron magnetises easily and demagnetises instantly; steel would retain unwanted magnetism.

Bài tập luyện tập

(Supplement) A long straight wire carries a current. Describe the shape of its magnetic field, and state the rule used to find the field's direction.

Lời giải chi tiết

The field forms **concentric circles** centred on the wire, in planes perpendicular to the wire, becoming weaker further from the wire. The direction is found using the **right-hand grip rule**: with the right thumb pointing in the direction of conventional current, the curled fingers show the direction of the field lines. Concentric circles around the wire; direction from the right-hand grip rule.

Bài tập luyện tập

A plastic rod is rubbed with a cloth and becomes negatively charged. Explain, in terms of subatomic particles, what has happened, and state the charge on the cloth.

Lời giải chi tiết

Friction transfers **electrons** (never protons) from one material to the other. Since the rod ends up negatively charged, it must have **gained** electrons from the cloth. By conservation of charge, the cloth must have lost an equal number of electrons and therefore ends up with an equal and opposite charge. The cloth becomes positively charged, with charge equal in size to the rod's negative charge.

Bài tập luyện tập

(Supplement) Describe how an isolated neutral metal sphere can be given a permanent *positive* charge using a negatively charged rod, without ever touching the rod to the sphere.

Lời giải chi tiết

Bring the negatively charged rod close to (not touching) the sphere: it repels the sphere's free electrons to the far side, leaving the near side positive and the far side negative (charging by **induction**). While the rod is still held in place, briefly connect the far (negative) side of the sphere to earth: the repelled electrons flow away down to earth. Remove the earth connection *first* (while the rod is still present), then remove the rod. $\boxed{\text{The sphere is left with a permanent, evenly-spread positive charge (opposite to the rod).}}$

Bài tập luyện tập

A charged balloon that has been rubbed on a wool sweater carries a charge of -8.0×10^{-9} C. Given the charge of one electron is $e = 1.6 \times 10^{-19}$ C, find the number of excess electrons on the balloon.

(A) 5.0×10^{10}

(B) 1.6×10^{9}

(C) 1.28×10^{-27}

(D) 8.0×10^{9}

Lời giải chi tiết

Number of electrons $= \dfrac{\text{charge}}{e} = \dfrac{8.0 \times 10^{-9}}{1.6 \times 10^{-19}} = \boxed{5.0 \times 10^{10}}$. **(A)**.

Bài tập luyện tập

Explain why a fuel tanker is electrically bonded to an aircraft (with a conducting wire) before refuelling begins.

Lời giải chi tiết

Friction between flowing fuel and the pipework can generate static charge, which could build up to a large potential difference between the tanker and the aircraft. If that p.d. became large enough, a spark could jump between them, which could ignite flammable fuel vapour. Bonding the two with a conducting wire keeps them continuously at the **same electric potential**, so no p.d. (and hence no spark) can build up between them. $\boxed{\text{Bonding equalises potential between tanker and aircraft, preventing a spark that could ignite fuel vapour.}}$

Bài tập luyện tập

A current of 4.0 A flows through a heater for 2.0 minutes. Find the charge that flows.

(A) 480 C

(B) 8.0 C

(C) 240 C

(D) 120 C

Lời giải chi tiết

$t = 2.0\,\text{min} = 120\,\text{s}$. $Q = It = (4.0)(120) = \boxed{480\,\text{C}}$. **(A).**

Bài tập luyện tập

A charge of $8.0\,\text{C}$ passes through a motor connected to a $6.0\,\text{V}$ supply. Find the electrical energy transferred.

Lời giải chi tiết

$W = QV = (8.0)(6.0) = \boxed{48\,\text{J}}$.

Bài tập luyện tập

A resistor has resistance $25\,\Omega$ and is connected to a $50\,\text{V}$ supply. Find the current through it and the power it dissipates.

(A) $I = 2.0\,\text{A},\ P = 100\,\text{W}$
(B) $I = 0.50\,\text{A},\ P = 25\,\text{W}$
(C) $I = 2.0\,\text{A},\ P = 50\,\text{W}$
(D) $I = 25\,\text{A},\ P = 1250\,\text{W}$

Lời giải chi tiết

$I = \dfrac{V}{R} = \dfrac{50}{25} = 2.0\,\text{A}$. $P = VI = (50)(2.0) = 100\,\text{W}$ (check: $I^2R = (2.0)^2(25) = 100\,\text{W}$ ✓). **(A).**

Bài tập luyện tập

(Supplement) Describe the I–V characteristic of a diode, and state one practical use that depends on this behaviour.

Lời giải chi tiết

In the forward direction, a diode conducts almost no current until the p.d. across it exceeds a small threshold voltage (about 0.6–$0.7\,\text{V}$ for silicon), after which current rises very steeply for only a small further increase in voltage. In the reverse direction, an (ideal) diode conducts essentially **no current at all**, regardless of the voltage applied. $\boxed{\text{Conducts strongly one way only above a threshold voltage; blocks current the other way – used for rectifica}}$

Bài tập luyện tập

(Supplement) A wire of resistivity $8.0 \times 10^{-7}\,\Omega\,\text{m}$ has length $4.0\,\text{m}$ and cross-sectional area $2.0 \times 10^{-6}\,\text{m}^2$. Find its resistance.

(A) $1.6\,\Omega$
(B) $0.40\,\Omega$
(C) $16\,\Omega$
(D) $6.4\,\Omega$

Lời giải chi tiết

$R = \dfrac{\rho L}{A} = \dfrac{(8.0\times10^{-7})(4.0)}{2.0\times10^{-6}} = \dfrac{3.2\times10^{-6}}{2.0\times10^{-6}} = \boxed{1.6\,\Omega}$. **(A).**

Bài tập luyện tập

A 15 V supply is connected in series with a $2.0\,\Omega$ resistor and a $3.0\,\Omega$ resistor. Find the current in the circuit and the p.d. across the $3.0\,\Omega$ resistor.

(A) $I = 3.0$ A, $V = 9.0$ V

(B) $I = 5.0$ A, $V = 15$ V

(C) $I = 1.0$ A, $V = 3.0$ V

(D) $I = 3.0$ A, $V = 6.0$ V

Lời giải chi tiết

$R_{\text{total}} = 2.0 + 3.0 = 5.0\,\Omega$. $\quad I = \dfrac{15}{5.0} = 3.0$ A. $\quad V_3 = IR_3 = (3.0)(3.0) = 9.0$ V. **(A).**

Bài tập luyện tập

A 9.0 V battery is connected in series with a $4.0\,\Omega$ resistor and a second resistor R_2; the p.d. across R_2 is found to be 5.0 V. Find R_2.

Lời giải chi tiết

P.d. across the $4.0\,\Omega$ resistor: $V_1 = 9.0 - 5.0 = 4.0$ V. Current: $I = \dfrac{V_1}{R_1} = \dfrac{4.0}{4.0} = 1.0$ A (same current in series). $\quad R_2 = \dfrac{V_2}{I} = \dfrac{5.0}{1.0} = \boxed{5.0\,\Omega}$.

Bài tập luyện tập

(Supplement) Three resistors of $4.0\,\Omega$, $4.0\,\Omega$ and $8.0\,\Omega$ are connected in parallel across a 8.0 V supply. Find (a) the combined resistance and (b) the total current drawn from the supply.

Lời giải chi tiết

(a) $\dfrac{1}{R_{\text{total}}} = \dfrac{1}{4.0} + \dfrac{1}{4.0} + \dfrac{1}{8.0} = \dfrac{2}{8} + \dfrac{2}{8} + \dfrac{1}{8} = \dfrac{5}{8} \Rightarrow R_{\text{total}} = \dfrac{8}{5} = 1.6\,\Omega$.

(b) $I_{\text{total}} = \dfrac{V}{R_{\text{total}}} = \dfrac{8.0}{1.6} = \boxed{5.0\text{ A}}$.

Bài tập luyện tập

(Supplement) A 30 V supply is connected in series with a $2.0\,\Omega$ resistor R_1, followed by two resistors $R_2 = 8.0\,\Omega$ and $R_3 = 8.0\,\Omega$ in parallel with each other. Find (a) the total resistance, (b) the total current, and (c) the current through R_2.

Lời giải chi tiết

(a) $\frac{1}{R_{23}} = \frac{1}{8.0} + \frac{1}{8.0} = \frac{2}{8.0} = \frac{1}{4} \Rightarrow R_{23} = 4.0\,\Omega$. $R_{\text{total}} = R_1 + R_{23} = 2.0 + 4.0 = 6.0\,\Omega$.

(b) $I_{\text{total}} = \frac{30}{6.0} = 5.0\,\text{A}$.

(c) P.d. across parallel section: $V_{23} = I_{\text{total}} R_{23} = (5.0)(4.0) = 20\,\text{V}$. Since $R_2 = R_3$, the current splits equally: $I_2 = \frac{V_{23}}{R_2} = \frac{20}{8.0} = \boxed{2.5\,\text{A}}$ (and $I_3 = 2.5\,\text{A}$ too, by symmetry; check $I_2 + I_3 = 5.0\,\text{A} = I_{\text{total}}$ ✓).

Bài tập luyện tập

A 3.0 kW electric oven is used for 2.5 h. Electricity costs $0.18 per kWh. Find the energy used (in kWh) and the total cost.

(A) 7.5 kWh, $\$1.35$

(B) 5.5 kWh, $\$0.99$

(C) 7.5 kWh, $\$1.50$

(D) 1.2 kWh, $\$0.22$

Lời giải chi tiết

$E = Pt = (3.0)(2.5) = 7.5\,\text{kWh}$. Cost $= (7.5)(0.18) = \boxed{\$1.35}$. **(A)**.

Bài tập luyện tập

An appliance normally draws a current of 4.2 A from the mains. Which fuse rating (from 3 A, 5 A, 13 A) should be fitted, and why?

Lời giải chi tiết

The fuse should be rated just **above** the normal operating current: 3 A is too low (would blow immediately during normal use), so $\boxed{5\,\text{A}}$ is the correct choice — high enough to allow normal operation, but low enough to blow quickly if a fault causes the current to rise well above the appliance's normal 4.2 A. (A 13 A fuse would allow a much larger, more dangerous fault current to flow before blowing.)

Bài tập luyện tập

Explain how earthing a metal appliance casing protects a user if a fault causes the live wire to touch the casing.

Lời giải chi tiết

The earth wire gives the casing a path of very **low resistance** straight to the ground (0 V). If the live wire touches the casing, a very large current flows suddenly through this low-resistance earth path (rather than the higher-resistance path through a person who might touch the casing), and this current surge blows the fuse (or trips the circuit breaker) almost immediately, disconnecting the live supply — so the casing does not stay live for long, and a person touching it is protected. $\boxed{\text{Earth wire provides a low-resistance path so fault current blows the fuse instead of flowing through a perso}}$

Bài tập luyện tập

Explain why plugging too many high-power appliances into a single extension lead or socket (an "overloaded" circuit) is dangerous, even if none of the individual appliances exceeds the rating of its own plug fuse.

Lời giải chi tiết

Each appliance's own plug fuse only protects that single appliance's own cable, based on that appliance's own current. When several appliances are plugged into the same extension lead or socket, their currents all add together and must all flow through the *same shared* cable back to the wall socket — even if every individual appliance fuse is perfectly correctly rated, the total combined current through the shared extension cable can still be far larger than that cable was designed to carry safely. Since heating in a cable depends on I^2R, this excess combined current can make the shared cable dangerously hot, possibly melting its insulation or starting a fire, without necessarily blowing any single appliance's own fuse.

The shared cable carries the sum of all the currents, which can overheat it even though each appliance's own

Bài tập luyện tập

Explain why an electric appliance is far more dangerous to use with wet hands than with dry hands.

Lời giải chi tiết

Water (especially with dissolved salts or impurities, as in tap water or sweat) is a much better electrical conductor than dry human skin. Wet hands therefore present a much **lower-resistance** path for current to flow through the body if a person touches a live part, so — for the same potential difference — a much **larger, more dangerous current** flows through the body of someone with wet hands than someone with dry hands (recall $I = V/R$: lower resistance at the same voltage means higher current).

Water lowers the body's resistance, so wet hands allow a much larger, more dangerous shock current to flow

Bài tập luyện tập

Explain why some appliances (e.g. plastic hairdryers) use double insulation instead of an earth wire.

Lời giải chi tiết

A double-insulated appliance is built with two independent layers of insulation (often including an all-plastic outer casing), designed so that no single internal fault could ever make any exposed, touchable part of the appliance live. Since there is no metal casing that could become dangerously live, there is no need for an earth wire at all — such appliances use only a two-core (live and neutral) cable, and are marked with the double-insulation (□) symbol.

$\boxed{\text{No exposed conductive part can become live, so no earth connection is required.}}$

Bài tập luyện tập

(Supplement) State three ways to increase the strength of an electromagnet.

Lời giải chi tiết

(1) Increase the current; (2) increase the number of turns of wire; (3) use a soft-iron core (instead of air or a r

Bài tập luyện tập

(Supplement) A straight conductor of length 0.30 m carries a current of 6.0 A at right angles to a magnetic field of flux density 0.40 T. Find the force on the conductor.

(A) 0.72 N
(B) 7.2 N
(C) 0.072 N
(D) 2.0 N

Lời giải chi tiết

$F = BIL = (0.40)(6.0)(0.30) = \boxed{0.72\,\text{N}}$. **(A)**.

Bài tập luyện tập

(Supplement) Explain the role of the split-ring commutator in a simple d.c. motor.

Lời giải chi tiết

As the coil rotates, the split-ring commutator (together with the brushes pressing against it) reverses the direction of current flowing through the coil every half-turn, at the instant the coil passes through the vertical (momentarily aligned with the field, where the turning effect would otherwise drop to zero and then reverse the coil's rotation). By reversing the current at exactly this moment, the force on each side of the coil is also reversed, so the coil continues to rotate in the *same* direction continuously rather than oscillating back and forth.

The commutator reverses the coil current every half-turn, keeping rotation continuous in one direction.

Bài tập luyện tập

(Supplement) A transformer has 500 primary turns and 25 secondary turns, and is supplied at 230 V a.c. Find the secondary voltage, and state whether this is a step-up or step-down transformer.

(A) 11.5 V, step-down
(B) 4600 V, step-up
(C) 230 V, neither
(D) 57.5 V, step-down

Lời giải chi tiết

$V_s = V_p \times \frac{N_s}{N_p} = 230 \times \frac{25}{500} = 230 \times 0.05 = \boxed{11.5\,\text{V}}$, a **step-down** transformer since $N_s < N_p$. **(A)**.

Bài tập luyện tập

(Supplement) A step-up transformer has 400 primary turns and 2000 secondary turns; its primary is connected to a 12 V a.c. supply drawing a primary current of 2.5 A. Find (a) the secondary voltage and (b) the secondary current (assume 100% efficiency).

Lời giải chi tiết

(a) $V_s = V_p \times \frac{N_s}{N_p} = 12 \times \frac{2000}{400} = 12 \times 5 = 60\,\text{V}$.

(b) $I_pV_p = I_sV_s \Rightarrow I_s = \frac{I_pV_p}{V_s} = \frac{(2.5)(12)}{60} = \frac{30}{60} = \boxed{0.50\,\text{A}}$.

Bài tập luyện tập

(Supplement) Explain why transformers cannot be used with a direct current (d.c.) supply.

Lời giải chi tiết

A transformer works by electromagnetic induction: a *changing* magnetic flux in the iron core is needed to induce an e.m.f. in the secondary coil. A steady d.c. current in the primary produces a constant, unchanging magnetic field, so (apart from a brief pulse of induced e.m.f. at the very instant of switching the current on or off) there is no continuous change in flux, and therefore no continuous induced e.m.f. in the secondary. $\boxed{\text{No changing flux with steady d.c., so no continuous e.m.f. is induced – transformers need a.c.}}$

Bài tập luyện tập

(Supplement) Synthesis: A simple d.c. motor coil has one side of length 0.20 m carrying a current of 3.0 A at right angles to a magnetic field of flux density 0.50 T. This coil is powered by a 9.0 V battery, and the motor circuit (coil plus internal wiring) has a total resistance of $3.0\,\Omega$. Find (a) the force on this side of the coil due to the motor effect, and (b) the electrical power delivered to the motor circuit.

Lời giải chi tiết

(a) $F = BIL = (0.50)(3.0)(0.20) = \boxed{0.30\,\text{N}}$.
(b) $P = IV = (3.0)(9.0) = \boxed{27\,\text{W}}$ (check via I^2R: $(3.0)^2(3.0) = 27\,\text{W}$ ✓).

Bài tập luyện tập

(Supplement) Synthesis: A generator's step-up transformer converts its 20 kV output to 400 kV for transmission through a cable of resistance $2.0\,\Omega$, delivering 100 MW of power. Find (a) the transmission current, (b) the power lost in the cable, and (c) the percentage of the transmitted power that is lost.

Lời giải chi tiết

(a) $I = \frac{P}{V} = \frac{100 \times 10^6}{400 \times 10^3} = \frac{1.0 \times 10^8}{4.0 \times 10^5} = 250\,\text{A}$.
(b) $P_{\text{loss}} = I^2R = (250)^2(2.0) = (62\,500)(2.0) = 125\,000\,\text{W} = 125\,\text{kW}$.
(c) Percentage lost $= \frac{P_{\text{loss}}}{P} \times 100\% = \frac{125\,000}{100\,000\,000} \times 100\% = \boxed{0.125\%}$ — a very small fraction, confirming that transmission at 400 kV is highly efficient.

Bài tập luyện tập

Explain why current is described as "conserved" rather than "used up" as it flows around a series circuit, and identify what quantity actually decreases across each component instead.

Lời giải chi tiết

Current is the rate of flow of charge, and charge can neither be created nor destroyed within the circuit — exactly the same number of electrons (and hence the same current) must flow into and out of every component in a series loop, including the source itself, at every instant. What genuinely changes across each component is the **potential difference** (energy transferred per unit charge): each component converts some electrical energy into another form (heat, light, etc.), so the p.d. (not the current) "drops" as charge passes through it.

Current is conserved everywhere in the loop; it is p.d./energy that decreases as charge passes through each

Bài tập luyện tập

Sketch (in words) the electric field pattern (a) around an isolated positive point charge and (b) between two oppositely-charged parallel plates, and state one key difference between the two patterns.

Lời giải chi tiết

(a) Around an isolated positive point charge, field lines point **radially outward** in all directions, becoming further apart (field weaker) at greater distance from the charge. (b) Between two oppositely-charged parallel plates, field lines run **straight and parallel** from the positive plate to the negative plate, evenly spaced everywhere between the plates (except very close to the edges).

Key difference: the point-charge field weakens with distance (lines spread out); the parallel-plate field is unif

Bài tập luyện tập

Explain why a magnetic material such as iron can be unmagnetised in its normal state, yet becomes strongly magnetised almost instantly when placed near a strong magnet.

Lời giải chi tiết

A ferromagnetic material can be thought of as containing many tiny regions, each acting like a miniature magnet. In the unmagnetised state, these tiny regions point in random directions, so their fields cancel out overall, giving no net magnetism. When a strong external magnet is brought close, its field causes these tiny regions to line up so that most point the same way; their individual fields then add together, producing an overall magnetic field with a north and a south pole — this is why the effect happens almost instantly and disappears (partially or fully) once the external magnet is removed.

The tiny internal regions realign with the external field, adding their effects together to produce (or remove)

Bài tập luyện tập

Explain why a residual current device (RCD) can protect a person from electric shock even in situations where a standard fuse would not react quickly enough.

Lời giải chi tiết

An RCD continuously compares the current entering an appliance (through live) with the current leaving it (through neutral); in normal, safe operation these two currents are exactly equal. If a person accidentally provides an alternative path to earth (e.g. touching a live part), some current "leaks" away through their body instead of returning through the neutral wire, so the two currents become unequal. The RCD detects even this small imbalance and disconnects the supply within milliseconds. A fuse, in contrast, only reacts once the *total* current through it becomes large enough to melt its wire — a shock current through a person's body is often far too small to blow a normal fuse, but is easily large enough to be dangerous, which is exactly the gap an RCD closes.

An RCD detects tiny current imbalances (leakage) almost instantly, whereas a fuse only responds to a large t

Bài tập luyện tập

(Supplement) Explain, step by step, how an electric bell rings continuously while its push-button switch is held down.

Lời giải chi tiết

Pressing the switch completes the circuit, so current flows through the electromagnet's coil, magnetising its soft-iron core. The magnetised core attracts the soft-iron armature, pulling its attached striker against the gong (producing one "ring"). This same movement of the armature, however, also pulls it away from the spring contact, breaking the circuit — so the electromagnet immediately loses its magnetism (soft iron demagnetises almost instantly) and releases the armature. The spring pulls the armature back to its original position, which remakes the contact and completes the circuit again, restarting the whole cycle.

The bell's own motion continually breaks and remakes its own circuit, so it rings repeatedly for as long as the

Bài tập luyện tập

(Supplement) Explain how a loudspeaker uses the motor effect to convert an electrical audio signal into sound.

Lời giải chi tiết

The alternating current of the audio signal flows through a coil of wire attached to a paper/plastic cone, placed inside the field of a permanent magnet. By the motor effect, the current-carrying coil experiences a force from the magnetic field; because the audio current continuously alternates in direction, so does this force, pushing and pulling the coil (and the cone attached to it) rapidly back and forth. These vibrations of the cone push and pull the surrounding air, generating sound waves that match the frequency and amplitude of the original electrical signal.

The motor effect converts the alternating audio current into a rapidly vibrating force on the coil, which vibra

Bài tập luyện tập

(Supplement) Explain why an a.c. generator uses slip rings and brushes rather than a split-ring commutator (as used in a d.c. motor).

Lời giải chi tiết

A split-ring commutator is specifically designed to **reverse** the connection to the external circuit every half-turn, which is needed in a d.c. motor to keep the current (and hence the turning force) in the same rotational sense continuously. A generator, in contrast, is meant to produce a genuinely **alternating** output that matches the naturally alternating induced e.m.f. as the coil rotates. Slip rings maintain a continuous, unbroken (non-reversing) connection between each end of the coil and its own brush, so the output faithfully follows the coil's induced e.m.f. — rising, falling, reversing, and rising again — producing true alternating current rather than the "one-directional pulsing" output a commutator would force.

$\boxed{\text{Slip rings preserve the natural alternating pattern of the induced e.m.f.; a commutator would instead convert}}$

Bài tập luyện tập

(Supplement) A transformer has a primary current of 8.0 A at $V_p = 240$ V, and delivers a secondary current of 18 A at $V_s = 100$ V. Find the efficiency of the transformer.

(A) 93.75%

(B) 100%

(C) 44%

(D) 225%

Lời giải chi tiết

$P_p = I_p V_p = (8.0)(240) = 1920$ W. $\quad P_s = I_s V_s = (18)(100) = 1800$ W.

Efficiency $= \dfrac{P_s}{P_p} \times 100\% = \dfrac{1800}{1920} \times 100\% = \boxed{93.75\%}$. **(A).**

Bài tập luyện tập

Explain why household lamps, sockets and appliances are always wired in parallel with each other rather than in series.

Lời giải chi tiết

Wiring appliances in parallel means each one is connected directly across the full live-to-neutral mains supply, so every appliance always receives the complete rated voltage (e.g. 230 V) no matter how many other devices are switched on elsewhere in the house, and each device can be switched on or off completely independently of the others (switching off one branch, or a lamp filament failing, simply removes that one path without disturbing the current in any other branch). If appliances were instead wired in series, they would all share the single available current and each would only receive a fraction of the supply voltage (dividing between them, as in any series circuit), and switching off (or the failure of) any single appliance would break the one shared current path and cut power to *every* other device in the circuit.

$\boxed{\text{Parallel wiring gives every appliance full mains voltage and lets each switch on/off independently.}}$

Bài tập luyện tập

(Supplement) Synthesis: A 40 V battery is connected in series with a $5.0\,\Omega$ resistor R_1, followed by a parallel combination of $R_2 = 10\,\Omega$ and $R_3 = 15\,\Omega$. Find (a) the total resistance, (b) the total current, (c) the p.d. across R_1, and (d) the power dissipated in R_1.

Lời giải chi tiết

(a) Parallel section: $\dfrac{1}{R_{23}} = \dfrac{1}{10} + \dfrac{1}{15} = \dfrac{3}{30} + \dfrac{2}{30} = \dfrac{5}{30} = \dfrac{1}{6} \Rightarrow R_{23} = 6.0\,\Omega$. $R_{\text{total}} = R_1 + R_{23} = 5.0 + 6.0 = 11\,\Omega$.
(b) $I_{\text{total}} = \dfrac{V}{R_{\text{total}}} = \dfrac{40}{11} = \boxed{3.64\,\text{A}}$ (to 3 s.f.).
(c) $V_1 = I_{\text{total}} R_1 = (3.64)(5.0) = \boxed{18.2\,\text{V}}$ (check: $V_{23} = 40 - 18.2 = 21.8$ V, and $V_{23}/R_{23} = 21.8/6.0 = 3.63$ A $\approx I_{\text{total}}$ ✓).
(d) Using the exact fraction $I_{\text{total}} = \dfrac{40}{11}$ A: $P_1 = I_{\text{total}}^2 R_1 = \left(\dfrac{40}{11}\right)^2 (5.0) = \dfrac{8000}{121} = \boxed{66.1\,\text{W}}$ (equivalently $P_1 = I_{\text{total}} V_1 = (3.64)(18.2) = 66.2$ W, matching within rounding).

Bài tập luyện tập

Explain why a bird can perch safely on a single high-voltage power cable, while a person touching that cable while standing on the ground would be electrocuted.

Lời giải chi tiết

A bird standing on just one cable has both feet extremely close together on the *same* conductor, so there is an utterly negligible potential difference between them (the tiny length of wire between its feet has almost no resistance and carries no significant current branching through the bird) — with no meaningful p.d. across its body, almost no current flows through the bird, so it is unharmed. A person touching the same live cable while also in contact with the ground, however, has one part of their body at the cable's high potential and their feet at (or near) 0 V (earth potential) — this creates an enormous potential difference across their body, driving a large, dangerous current through them to earth.
The bird has no p.d. across its body (both feet on the same wire); a grounded person has a huge p.d. across t

Bài tập luyện tập

Three 100 W lamps and a 1.5 kW heater are connected in parallel to a 230 V mains supply and switched on together. Find the total current drawn from the supply.

Lời giải chi tiết

Total power: $P_{\text{total}} = 3(100) + 1500 = 300 + 1500 = 1800$ W.
$I_{\text{total}} = \dfrac{P_{\text{total}}}{V} = \dfrac{1800}{230} = \boxed{7.83\,\text{A}}$ (to 3 s.f.).

Bài tập luyện tập

(Supplement) Explain how a thermistor connected into a circuit with a fixed resistor and a warning buzzer could be used to build a simple "overheating" alarm for a piece of machinery.

Lời giải chi tiết

As the machinery's temperature rises, the thermistor's resistance **falls**. If the thermistor is wired so that this falling resistance causes the current in that part of the circuit (or the voltage across some other component, such as a relay coil) to rise past a threshold, this rising current/voltage can be used to trigger a switching circuit (e.g. a relay) that switches

on the warning buzzer once the temperature — and hence the current — exceeds a preset level.
Rising temperature lowers the thermistor's resistance, raising the current enough to trigger the alarm circuit

Nuclear Physics

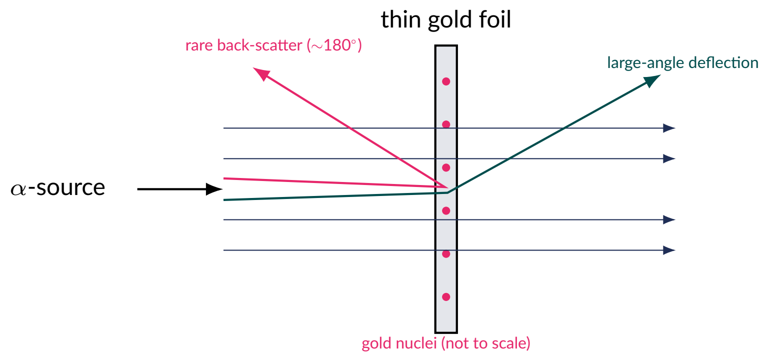
Mục tiêu Unit: Mô hình hạt nhân nguyên tử (thí nghiệm tán xạ alpha Rutherford, ký hiệu hạt nhân, đồng vị); bản chất phóng xạ (tự phát, ngẫu nhiên, phông nền); ba loại bức xạ hạt nhân alpha/beta/gamma và tính chất so sánh; chu kỳ bán rã & đồ thị phân rã; phương trình hạt nhân (Supplement: phân rã alpha, beta); ứng dụng & tác hại của bức xạ, phân hạch & nhiệt hạch (Supplement).

5.1 The Nuclear Model of the Atom

5.1.1 Rutherford's Alpha-Scattering Experiment

Before 1911, the accepted picture of the atom (J.J. Thomson's "plum pudding" model) was a sphere of positive charge with electrons embedded throughout it, like fruit in a pudding — mass and positive charge were thought to be spread out fairly evenly across the whole atom. Ernest Rutherford, together with Hans Geiger and Ernest Marsden, tested this picture directly with a scattering experiment, and the results forced a complete rethink of atomic structure.

Setup: a narrow beam of fast-moving **alpha particles** (helium nuclei, positively charged) from a radioactive source was directed at a **very thin sheet of gold foil** (only a few atoms thick, so that alpha particles would interact with at most one or two atoms as they passed through). A movable, rotatable detector screen coated with a scintillating (fluorescent) material was placed around the foil to record the angle through which each alpha particle was scattered (deflected) as tiny flashes of light, all inside an evacuated chamber (so that the alpha particles were not stopped or scattered by air molecules).



Rutherford's alpha-scattering experiment: a narrow beam of alpha particles is fired at a thin gold foil in vacuum. Most pass straight through with little or no deflection (navy paths); a few are scattered through large angles (green path); a very small number bounce back almost the way they came (pink path) — evidence for a tiny, dense, positively charged nucleus surrounded by mostly empty space.

Observations and their conclusions

- **Most alpha particles passed straight through the foil with little or no deflection.** *Conclusion:* an atom must be **mostly empty space** — otherwise the vast majority of alpha particles would have been stopped or scattered.
- **A small fraction of alpha particles were deflected through large angles (more than 90° in**

some cases). *Conclusion:* at the centre of each atom there must be a very **concentrated, dense region** capable of exerting a large force on a fast, massive alpha particle — far denser than the spread-out charge assumed in the plum-pudding model.

- **A very small number of alpha particles bounced back almost the way they had come ($\sim$180°).** *Conclusion:* this concentrated region must carry a large amount of **positive charge concentrated in a tiny volume** (the **nucleus**), so that it can strongly repel a positively charged alpha particle that happens to travel almost straight toward it head-on — repulsion this strong could not come from a diffuse positive charge spread through the whole atom.

Combining all three observations: the atom consists of a tiny, extremely dense, positively charged **nucleus** at its centre (containing almost all of the atom's mass), surrounded by mostly empty space in which electrons orbit at relatively large distances.

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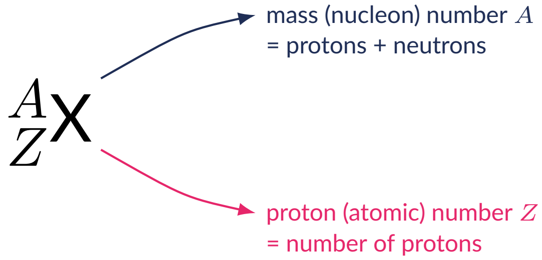
Trước thí nghiệm Rutherford, mô hình "bánh pudding" cho rằng điện tích dương và khối lượng trải đều khắp nguyên tử. Kết quả tán xạ hạt alpha qua lá vàng mỏng cho ba quan sát: (1) đa số hạt alpha xuyên thẳng qua ⇒ nguyên tử phần lớn là **khoảng trống**; (2) một số ít bị lệch góc lớn ⇒ có một vùng **rất đặc, tập trung** ở tâm nguyên tử; (3) rất hiếm hạt bật ngược trở lại gần như 180° ⇒ vùng đó mang **điện tích dương lớn, tập trung** (hạt nhân), đủ mạnh để đẩy ngược một hạt alpha (cũng mang điện dương) bay thẳng vào nó. Từ đó suy ra: nguyên tử có một **hạt nhân** nhỏ, đặc, mang điện dương ở tâm, chứa gần như toàn bộ khối lượng, còn electron chuyển động ở vùng không gian rộng lớn xung quanh, phần lớn là trống rỗng.

5.1.2 Nuclide Notation

Every nuclide (a specific type of nucleus) is described using the notation ${}^{A}_{Z}$X, where X is the chemical symbol of the element.



Nuclide notation: mass (nucleon) number A is written top-left, proton (atomic) number Z bottom-left, before the element symbol X. Number of neutrons $N = A - Z$.

Mass (nucleon) number A = total number of protons *and* neutrons in the nucleus. **Proton (atomic) number** Z = number of protons in the nucleus, which also fixes the element's identity in the periodic table. **Number of neutrons** $N = A - Z$. For a **neutral atom**, the number of **electrons** orbiting the nucleus equals the number of protons, Z (so the atom's overall charge is zero).

Ví dụ 1 · Protons, neutrons and electrons from nuclide notation

For the nuclide ${}^{23}_{11}$Na (sodium-23), state the number of protons, neutrons and electrons in a neutral atom.

Protons $= Z = 11$. Neutrons $= A - Z = 23 - 11 = \boxed{12}$. Electrons (neutral atom) $= Z = \boxed{11}$.

(Supplement) In an **ion**, the number of electrons no longer equals the number of protons: a **positive ion** (cation) has *fewer* electrons than protons (it has lost one or more electrons, leaving a net positive charge); a **negative ion** (anion) has *more* electrons than protons (it has gained one or more electrons, giving a net negative charge). Crucially, ionisation only adds or removes **electrons** — the number of protons and neutrons in the nucleus (and hence A and Z) is completely unaffected by an atom becoming an ion.

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Số khối A = số proton + số neutron; số hiệu nguyên tử (số proton) Z quyết định nguyên tố là gì; số neutron $N = A - Z$. Với nguyên tử trung hòa, số electron = số proton = Z. **(Supplement)** Khi nguyên tử trở thành ion, chỉ có số electron thay đổi (ion dương mất electron nên electron $<$ proton; ion âm nhận electron nên electron $>$ proton) — số proton và neutron trong hạt nhân không hề thay đổi khi ion hóa.

5.1.3 Isotopes

Isotopes are atoms of the *same* element (same proton number Z, and therefore the same chemical properties) but with *different* numbers of neutrons (and therefore different mass numbers A). Since isotopes of the same element have identical proton and electron arrangements, they react chemically in the same way — but their nuclei can be markedly different in stability, and some isotopes of an element are radioactive while others are not.

Real examples of isotopes:

- **Carbon-12** $({}^{12}_{6}\text{C})$ and **carbon-14** $({}^{14}_{6}\text{C})$: both have 6 protons, but carbon-12 has 6 neutrons (stable, the most common form of carbon) while carbon-14 has 8 neutrons (radioactive, used in radiocarbon dating).
- **Uranium-235** $({}^{235}_{92}\text{U})$ and **uranium-238** $({}^{238}_{92}\text{U})$: both have 92 protons; U-235 has 143 neutrons and is the isotope capable of sustaining a fission chain reaction (used as nuclear fuel), while the far more abundant U-238 has 146 neutrons and does not readily fission in the same way.
- **Chlorine-35** and **chlorine-37**: both have 17 protons, with 18 and 20 neutrons respectively — naturally occurring chlorine is a mixture of both isotopes.

Ví dụ 2 · Isotopes: carbon-12 and carbon-14

State the number of protons, neutrons and electrons (neutral atom) in ${}^{12}_{6}$C and ${}^{14}_{6}$C, and explain why they are isotopes of the same element.

${}^{12}_{6}$C: protons $= 6$, neutrons $= 12 - 6 = \boxed{6}$, electrons $= \boxed{6}$.
${}^{14}_{6}$C: protons $= 6$, neutrons $= 14 - 6 = \boxed{8}$, electrons $= \boxed{6}$.
Both nuclides have the **same proton number** ($Z = 6$, so both are carbon) but a **different number of neutrons** (6 vs 8) and hence a different mass number — this is exactly the definition of isotopes.

(Supplement) **Why does the nucleus not fly apart?** The nucleus packs together many positively charged protons at extremely close range, which strongly repel one another electrostatically. Stable nuclei do not fly apart because of the **strong nuclear force** — a much stronger, short-range attractive force that acts between *all* nucleons (both protons and neutrons), overcoming the electrostatic repulsion between protons at very short distances (roughly the size of a nucleus). Unlike the electrostatic force, the strong nuclear force falls away extremely quickly with distance and is negligible beyond the scale of the nucleus itself — which is why very large nuclei (with protons spread further apart on average) tend to be less stable and more likely to be radioactive.

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Đồng vị là các nguyên tử của **cùng một nguyên tố** (cùng số proton Z, cùng tính chất hóa học) nhưng **khác số neutron** (khác số khối A). Ví dụ: carbon-12 (6 neutron, bền) và carbon-14 (8 neutron, phóng xạ, dùng định tuổi carbon); uranium-235 (143 neutron, dùng làm nhiên liệu hạt nhân) và uranium-238 (146 neutron, phổ biến hơn). **(Supplement)** Lực hạt nhân mạnh (strong nuclear force) tác dụng giữa mọi nucleon ở khoảng cách rất ngắn, đủ mạnh để thắng lực đẩy tĩnh điện giữa các proton, giữ hạt nhân không bị vỡ tung.

5.2 Radioactivity: The Nature of Radioactive Decay

Radioactive decay is the spontaneous breakdown of an unstable nucleus, releasing energy in the form of radiation (alpha, beta, and/or gamma). Two properties define this process at the level of an individual nucleus:

Spontaneous: decay happens on its own, without needing to be triggered or caused by any outside event — it is not the result of a collision, an applied force, or any other external stimulus.
Random: it is impossible to predict exactly *when* any particular nucleus will decay, or to know in advance *which* nucleus in a sample will be next — every undecayed nucleus has the same probability of decaying in any given time interval, regardless of how long it has already existed.

Crucially, radioactive decay is a **nuclear** process, not a chemical one, and this has an important consequence: the rate of decay is completely **unaffected** by temperature, pressure, or the chemical form the atom is in (e.g. whether it is a pure element or bonded into a compound). This is very different from ordinary chemical reactions, whose rates *do* depend strongly on temperature, pressure and concentration — because chemical reactions involve rearranging outer electrons, whereas radioactive decay originates deep inside the nucleus, essentially shielded from these external, "everyday" physical and chemical conditions.

(!) Lỗi thường gặp: Radioactive decay is **random for any individual nucleus** — nothing can predict exactly when one particular atom will decay. However, for a **large sample** containing billions of nuclei, the overall decay rate follows a smooth, entirely predictable exponential curve (this is simply the statistics of very large numbers). Both statements are true at once: unpredictable individually, but statistically predictable in bulk — this is precisely why "half-life" is a meaningful, reliable quantity even though decay is random.

VN **GIẢI THÍCH TIẾNG VIỆT**

Phân rã phóng xạ mang tính **tự phát** (không cần tác nhân bên ngoài kích hoạt) và **ngẫu nhiên** (không thể biết chính xác nguyên tử nào, lúc nào sẽ phân rã). Vì đây là quá trình xảy ra sâu bên trong hạt nhân, tốc độ phân rã **không bị ảnh hưởng** bởi nhiệt độ, áp suất, hay việc nguyên tử đang ở dạng đơn chất hay hợp chất hóa học — khác hẳn phản ứng hóa học (vốn phụ thuộc mạnh vào nhiệt độ, áp suất). Dù ngẫu nhiên với từng hạt nhân riêng lẻ, với một mẫu lớn chứa hàng tỉ hạt nhân, tốc độ phân rã tổng thể vẫn tuân theo một đường cong có thể dự đoán chính xác — đó là lý do khái niệm "chu kỳ bán rã" vẫn có ý nghĩa và đáng tin cậy.

5.2.1 Detecting Radiation and Background Radiation

A **Geiger-Müller (GM) tube**, connected to a counter, is the standard instrument for detecting nuclear radiation in the laboratory: radiation entering the tube ionises gas inside it, producing a brief pulse of current each time a particle or ray passes through, which the counter registers as one "count." The **count rate** (counts per unit time) recorded is used as a measure of the activity of a source.

Even with no radioactive source nearby, a GM tube will still register a low, steady count rate — this is **background radiation**, present everywhere in the environment.

Natural sources	Artificial (man-made) sources
Radon gas (seeps from rocks and soil into buildings; usually the single largest natural contributor)	Medical procedures: diagnostic X-rays and radiotherapy treatment
Cosmic rays from space (more intense at high altitude, e.g. in aircraft)	Nuclear industry: waste processing, fuel reprocessing
Rocks and soil (contain naturally radioactive elements, e.g. uranium, thorium, potassium-40)	Fallout from historical nuclear weapons testing or accidents
Food and drink, and the human body itself (trace natural radioisotopes such as potassium-40)	Occupational sources (e.g. industrial radiography)

Sources of background radiation. In most places, natural sources make up the large majority of a person's typical background dose (radon gas is usually the biggest single contributor); of the artificial sources, medical procedures are typically the largest.

(!) Lỗi thường gặp: Whenever the activity of a source is measured with a detector, the reading always includes background radiation *as well as* radiation from the source itself. Before applying any half-life calculation (or comparing activities), the background count rate — measured with the source removed (or far away) — must first be **subtracted** from every reading. Forgetting this step is one of the most common errors in half-life questions: always correct for background *before* working with $N = N_0 \left(\frac{1}{2}\right)^n$.

Ví dụ 3 · Correcting a count rate for background

A GM tube placed near a radioactive source reads 45 counts/min. With the source removed, the same tube reads 15 counts/min (background). Find the count rate due to the source alone.

Corrected count rate $= 45 - 15 = \boxed{30\,\text{counts/min}}$.

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Ống đếm Geiger-Müller (GM) phát hiện bức xạ nhờ hiện tượng ion hóa chất khí bên trong ống, mỗi hạt/tia đi qua tạo ra một xung đếm. Ngay cả khi không có nguồn phóng xạ nào gần đó, máy đếm vẫn ghi nhận một tốc độ đếm nền thấp gọi là **phông phóng xạ nền** (background radiation), đến từ các nguồn tự nhiên (khí radon, tia vũ trụ, đất đá, thực phẩm) và nhân tạo (y tế, công nghiệp hạt nhân). Trước khi tính toán chu kỳ bán rã, luôn phải **trừ đi phông nền** khỏi số đếm đo được.

5.3 Types of Nuclear Radiation

Unstable nuclei can emit three distinct types of nuclear radiation.

Alpha (α) particle: a helium nucleus, ${}^{4}_{2}$He — 2 protons and 2 neutrons bound together, charge $+2$. Being relatively large, slow-moving and heavily charged, alpha particles interact strongly with matter: they are **strongly ionising** (they knock electrons off many atoms along their path) but, because they lose energy so quickly through all this ionising, they have a very short **range** — only a few centimetres in air — and are stopped completely by a single sheet of paper or the outer dead layer of human skin.
Beta (β) particle: a fast-moving **electron**, ejected from the nucleus itself (not from the electron shells) when a neutron converts into a proton. Beta particles are much lighter and faster than alpha particles, and carry charge -1. They are **moderately ionising** and moderately penetrating — able to travel roughly a metre through air, but stopped by a few millimetres of aluminium.
Gamma (γ) ray: a high-frequency, high-energy **electromagnetic wave** emitted from the nucleus, carrying **no charge and no mass**. Gamma rays are **weakly ionising** (they interact only occasionally with atoms) but are, for exactly that reason, the **most penetrating** — travelling large distances through air and requiring several centimetres of lead or a thick layer of concrete to reduce their intensity substantially (gamma radiation is never completely "stopped," only reduced).

Radiation	Nature	Range in air	Ionising power	Stopped by / penetrating power
α	Helium nucleus ($2p + 2n$), charge $+2$	Few cm	Strong (highest)	Weakest — sheet of paper, few cm of air
β	Fast electron, charge -1	~1 m	Moderate	A few mm of aluminium
γ	EM wave, no charge, no mass	Very large (inverse-square law)	Weak (lowest)	Strongest — several cm of lead / thick concrete

Comparison of alpha, beta and gamma radiation: range, ionising power and penetrating power.

(!) Lỗi thường gặp: It is easy to muddle up "most ionising" with "most penetrating," but for these three radiations they run in **opposite** order. **Alpha is the most strongly ionising, yet the least penetrating** (stopped by paper) — precisely *because* it loses its energy so rapidly through intense ionisation over a very short distance. **Gamma is the least ionising, yet the most penetrating** — because it interacts with matter only rarely. Never assume "more ionising" means "more penetrating": for nuclear radiation, it is the reverse.

5.3.1 Behaviour in Electric and Magnetic Fields

Because alpha and beta particles are charged, both are deflected by electric and magnetic fields; gamma rays, having no charge, are undeflected by either.

Radiation	Electric field (between charged plates)	Magnetic field
α	Deflects toward the **negative** plate (positive charge); deflection is **small**, because the alpha particle is relatively massive	Deflects, but by a **smaller** amount than beta, for the same reason (large mass)
β	Deflects toward the **positive** plate (negative charge) — **opposite** direction to alpha; deflection is **large**, because the electron's mass is tiny	Deflects **strongly**, in the **opposite** direction to alpha (opposite sign of charge)
γ	**No** deflection (uncharged)	**No** deflection (uncharged)

Deflection of alpha, beta and gamma radiation in electric and magnetic fields: direction is set by the sign of the charge, while the amount of deflection (for the same field and similar speed) is larger for smaller mass.

Ví dụ 4 · Deflection of radiation in a magnetic field

A beam containing alpha, beta and gamma radiation passes through a strong magnetic field directed into the page. Describe and explain what would be observed for each type.

Alpha: deflected to one side (the direction given by the force on a moving positive charge in that field) — the deflection is relatively **small** because the alpha particle has a comparatively large mass.
Beta: deflected to the **opposite** side from the alpha particles, because it carries the **opposite** sign of charge (negative). Its deflection is considerably **larger** than the alpha particle's, since a beta particle (an electron) has a far smaller mass, so a similar-sized magnetic force produces a much greater curvature in its path.
Gamma: travels straight through, **undeflected**, since it carries no charge and therefore experiences no magnetic force.

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Alpha (hạt nhân heli, $2p + 2n$) mang điện tích $+2$, **ion hóa mạnh nhất** nhưng **xuyên thấu kém nhất** (một tờ giấy cũng chặn được). Beta (electron nhanh) mang điện tích -1, ion hóa và xuyên thấu ở mức trung bình (cần vài mm nhôm để chặn). Gamma (sóng điện từ) không mang điện, **ion hóa yếu nhất** nhưng **xuyên thấu mạnh nhất** (cần chì dày hoặc bê tông dày mới giảm đáng kể). Trong điện trường/từ trường: alpha và beta lệch về hai phía **ngược nhau** (do điện tích trái dấu), beta lệch **nhiều hơn** alpha (do khối lượng electron rất nhỏ); gamma **không bị lệch** vì không mang điện.

5.4 Half-Life and Radioactive Decay

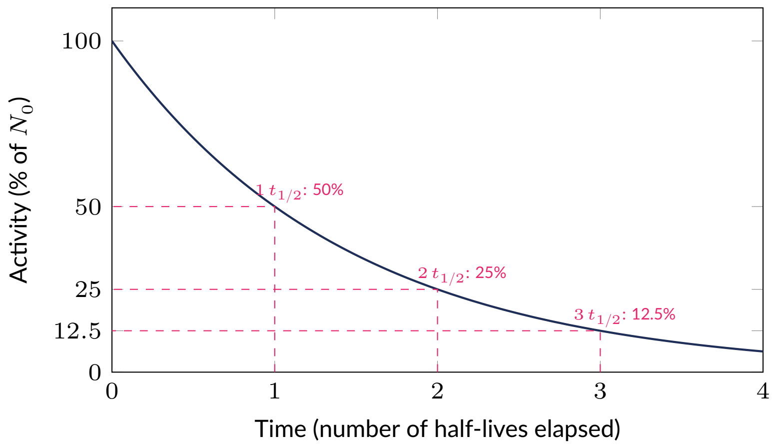
Because the decay of any individual nucleus is random, it is meaningless to ask "how long until this atom decays?" Instead, radioactive decay is described statistically using **half-life**.

Half-life ($t_{1/2}$) is the time taken for **half** of the undecayed nuclei in a sample to decay — equivalently, the time taken for the **activity** (or measured count rate) of a sample to fall to **half** of its original value. Half-life is a fixed, characteristic property of a given radioactive isotope, completely unaffected by the amount of the sample present, its temperature, or its chemical state.

After n whole half-lives, the number of undecayed nuclei (or the activity, or the corrected count rate) remaining is given by:

$$N = N_0\left(\frac{1}{2}\right)^n$$

where N_0 is the initial value and n is the number of half-lives that have elapsed ($n = \dfrac{\text{total elapsed time}}{t_{1/2}}$). At IGCSE level, calculations are restricted to **whole numbers of half-lives**; if a problem gives a time that is *not* a whole-number multiple of the half-life, the appropriate remaining activity must instead be read directly off a decay graph (interpolating between the plotted curve's values), rather than using non-integer powers of $\frac{1}{2}$.



A radioactive decay curve: activity falls exponentially, halving after every successive half-life ($100\% \to 50\% \to 25\% \to 12.5\% \to$ ...). The curve never quite reaches zero, but after only a few half-lives the remaining activity becomes very small.

(!) Lỗi thường gặp: Half-life is **not** the time for a sample to decay completely — it is only the time for the activity (or the number of undecayed nuclei) to fall to **half**. After one half-life, 50% remains (not 0%); after two half-lives, 25% remains (not 100% decayed after "two halves"); the amount remaining keeps halving indefinitely and, mathematically, never reaches exactly zero.

Ví dụ 5 · Finding half-life from initial and final activity

The count rate from a radioactive source falls from 800 counts/min to 100 counts/min over 24 days. Find the half-life of the source.

Ratio of activities: $\dfrac{800}{100} = 8 = 2^3$, so $n = 3$ half-lives have elapsed in 24 days.

$t_{1/2} = \dfrac{24}{3} = \boxed{8.0\,\text{days}}$.

Ví dụ 6 · Activity remaining after a given number of half-lives

A sample has an initial activity of 960 Bq and a half-life of 4.0 days. Find its activity after 16 days.

Number of half-lives: $n = \dfrac{16}{4.0} = 4$.

$N = N_0\left(\dfrac{1}{2}\right)^4 = 960 \times \dfrac{1}{16} = \boxed{60\,\text{Bq}}$.

Ví dụ 7 · Combining background subtraction with half-life

A detector placed near a radioactive source reads 340 counts/min; with the source removed, background alone reads 20 counts/min. The source has a half-life of 6.0 minutes. Find the *total* reading the detector would show after 18 minutes (assuming background stays constant).

Step 1 — subtract background: corrected initial activity $= 340 - 20 = 320$ counts/min.

Step 2 — apply half-life: $n = \dfrac{18}{6.0} = 3$ half-lives, so corrected activity after 18 min $= 320 \times \left(\dfrac{1}{2}\right)^3 = \dfrac{320}{8} = 40$ counts/min.

Step 3 — add background back on (since the detector always measures source + background together): total reading $= 40 + 20 = \boxed{60\,\text{counts/min}}$.

Ví dụ 8 · Choosing a suitable half-life and radiation type for an application

(a) A radioactive tracer is to be injected into a patient to monitor blood flow using an external detector. Explain why the tracer should have a **short** half-life and be a **gamma** emitter.

(b) A source is needed to sterilise medical equipment by killing bacteria, where the source must last for years without needing frequent replacement and must penetrate through packaging. Explain why a long-half-life **gamma** emitter (such as cobalt-60) is appropriate, rather than a short-half-life source.

(a) A **short half-life** means the tracer's activity — and therefore the patient's radiation dose — decays away quickly once the scan is complete, minimising the total radiation dose received. It must be a **gamma** emitter (not alpha or beta) because gamma radiation is by far the most penetrating type, able to pass out through the patient's body and reach an external detector; alpha and beta radiation would be almost entirely absorbed within the tissue, delivering unnecessary ionising damage internally without ever reaching the detector.

(b) For sterilisation, the source needs to keep emitting strongly over a long working lifetime (years) without being replaced constantly, so a **long half-life** (cobalt-60 has a half-life of about 5.3 years) is appropriate — its activity barely falls over the timescale it is used. It must also be a **gamma** emitter because gamma rays can penetrate packaging and equipment to kill bacteria and micro-organisms throughout, whereas alpha or beta radiation would be stopped at or near the surface and could not sterilise the interior.

5.4.1 Radiocarbon Dating (Application)

Living organisms continuously exchange carbon with their environment, keeping a roughly constant proportion of radioactive carbon-14 (alongside stable carbon-12) in their tissues. Once an organism dies, it stops exchanging carbon, and the carbon-14 already present simply decays away with its characteristic half-life (about 5730 years) while the carbon-12 amount stays fixed. Measuring the remaining fraction of carbon-14 activity (compared to a living sample) therefore allows the age of some organic remains to be estimated.

Ví dụ 9 · Radiocarbon dating calculation

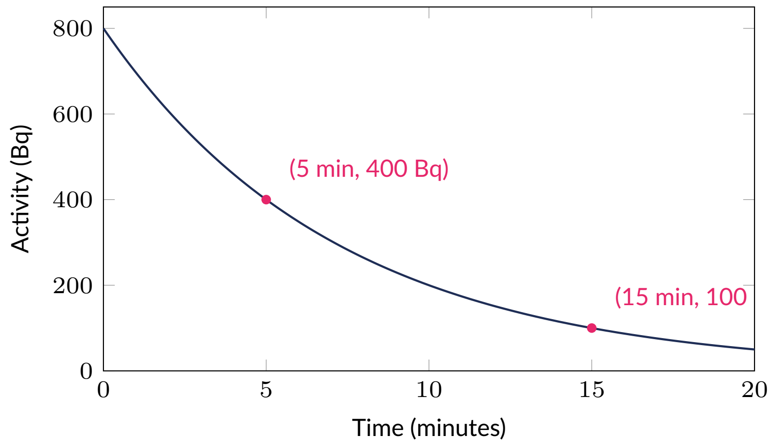
A fragment of ancient wood is found to have a carbon-14 activity equal to 25% of that of an equivalent freshly-cut sample. The half-life of carbon-14 is 5730 years. Estimate the age of the wood.

$25\% = \frac{1}{4} = \left(\frac{1}{2}\right)^2$, so $n = 2$ half-lives have elapsed.

Age $= 2 \times 5730 = \boxed{11460 \text{ years (about } 11500 \text{ years)}}$.

Ví dụ 10 · Deducing half-life directly from a decay graph

The graph below shows the (background-corrected) activity of a radioactive sample plotted against time; the half-life is *not* stated directly and must be read from the curve. Two points have been marked on the curve: at $t = 5$ minutes the activity is 400 Bq; at $t = 15$ minutes the activity is 100 Bq. Use these two readings to find the half-life of the sample.



A decay curve with two points read directly off it, used to deduce the half-life graphically without it being given directly.

Reasoning: between $t = 5$ min and $t = 15$ min, the activity falls by a factor of $\frac{400}{100} = 4 = 2^2$, so exactly **2 half-lives** must have elapsed between these two readings.
Elapsed time between the two readings $= 15 - 5 = 10$ minutes, and this equals $2\,t_{1/2}$.

$t_{1/2} = \frac{10}{2} = \boxed{5.0 \text{ minutes}}$.

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VN Có thể tìm chu kỳ bán rã trực tiếp từ đồ thị phân rã mà không cần biết giá trị ban đầu N_0 và không cần đề bài cho sẵn chu kỳ bán rã: chỉ cần đọc hai điểm bất kỳ trên đường cong (ví dụ 400 Bq tại $t = 5$ phút và 100 Bq tại $t = 15$ phút), tính tỉ số độ phóng xạ giữa hai điểm đó ($400/100 = 4 = 2^2$, tức 2 chu kỳ bán rã), rồi lấy khoảng thời gian giữa hai điểm chia cho số chu kỳ bán rã đó để ra $t_{1/2}$.

5.4.2 Half-Lives in Practice: A Comparison

Real radioisotopes span an enormous range of half-lives, from a few hours to billions of years, and the half-life needed for a given application depends entirely on the timescale over which that application operates.

Isotope	Half-life	Typical use (why this half-life suits it)
Technetium-99m	≈ 6 hours	Medical tracer (imaging organs/blood flow) — decays away almost completely within a day or two, minimising the patient's long-term radiation dose
Iodine-131	≈ 8 days	Diagnosing/treating thyroid conditions — long enough to remain active throughout a multi-day procedure, short enough to clear from the body within a few weeks
Cobalt-60	≈ 5.3 years	Radiotherapy source / sterilisation — long enough that the source need not be replaced often, while still emitting strongly enough to be useful
Americium-241	≈ 432 years	Smoke detectors — a long half-life means sensitivity barely declines over the working lifetime of the detector
Carbon-14	≈ 5730 years	Radiocarbon dating of formerly-living material, over timescales of thousands of years
Uranium-238	$\approx 4.5 \times 10^9$ years	Dating rocks and estimating the age of the Earth, over geological (billions-of-years) timescales

Approximate half-lives of some important real radioisotopes and why each is suited to its particular application.

As a general rule: an application that needs an isotope's activity to **fall away quickly** once it has served its purpose (so as to minimise dose to people, e.g. a medical tracer) calls for a **short** half-life; an application that needs a source to keep working reliably over a **long working lifetime** without replacement (e.g. a smoke detector) or that is dating material over a very long timescale (e.g. rocks, fossils) calls for a **long** half-life.

VN **GIẢI THÍCH TIẾNG VIỆT**

Các đồng vị phóng xạ có chu kỳ bán rã rất khác nhau, từ vài giờ đến hàng tỉ năm, và mỗi ứng dụng phù hợp với một khoảng chu kỳ bán rã nhất định: Tc-99m (≈6 giờ) dùng làm chất đánh dấu y tế; I-131 (≈8 ngày) dùng chẩn đoán/điều trị tuyến giáp; Co-60 (≈5,3 năm) dùng xạ trị/tiệt trùng; Am-241 (≈432 năm) dùng đầu báo khói; C-14 (≈5730 năm) dùng định tuổi carbon; U-238 (≈4,5 tỉ năm) dùng định tuổi đá/địa chất. Nguyên tắc chung: ứng dụng cần đồng vị "biến mất nhanh" sau khi dùng xong (để giảm liều nhiễm xạ) cần chu kỳ bán rã **ngắn**; ứng dụng cần nguồn hoạt động ổn định lâu dài hoặc định tuổi trên thang thời gian rất dài cần chu kỳ bán rã **dài**.

VN **GIẢI THÍCH TIẾNG VIỆT**

Chu kỳ bán rã ($t_{1/2}$) là thời gian để số hạt nhân chưa phân rã (hoặc độ phóng xạ, tốc độ đếm) giảm còn **một nửa**. Sau n chu kỳ bán rã: $N = N_0(1/2)^n$. Ở chương trình IGCSE, chỉ tính với số chu kỳ bán rã **nguyên** (1, 2, 3,...); nếu thời gian không chia hết cho chu kỳ bán rã, phải đọc giá trị trực tiếp từ đồ thị phân rã. Khi làm bài, luôn: (1) trừ phông nền trước, (2) rồi mới áp dụng công thức chu kỳ bán rã, (3) cộng lại phông nền nếu đề hỏi "số đếm tổng cộng" máy sẽ hiển thị. Chu kỳ bán rã ngắn phù hợp với chất đánh dấu y tế (giảm liều nhiễm xạ cho bệnh nhân); chu kỳ bán rã dài phù hợp với đầu báo khói hoặc định tuổi vật liệu.

5.5 Nuclear Equations (Supplement)

(Supplement) When a nucleus decays, the transformation can be written as a nuclear equation, similar in form to a chemical equation, but balancing nucleons instead of atoms.

Rules for balancing nuclear equations

(Supplement) In any nuclear equation, **both** of the following must balance across the whole equation (left-hand side total = right-hand side total):

- the **mass (nucleon) numbers**, A — the top numbers;
- the **proton numbers**, Z — the bottom numbers.

Alpha decay: the nucleus emits an alpha particle, ${}^{4}_{2}\text{He}$. The mass number decreases by 4 and the proton number decreases by 2:

$$ {}^{A}_{Z}\text{X} \rightarrow {}^{A-4}_{Z-2}\text{Y} + {}^{4}_{2}\text{He} $$

Beta decay: inside the nucleus, a **neutron converts into a proton**, emitting a fast electron (the beta particle) which leaves the nucleus:

$$ {}^{1}_{0}\text{n} \rightarrow {}^{1}_{1}\text{p} + {}^{0}_{-1}e $$

This means the mass number is **unchanged** (a neutron becomes a proton, so nucleon count stays the same) while the proton number **increases by 1** (one more proton than before, and correspondingly one fewer neutron):

$$ {}^{A}_{Z}\text{X} \rightarrow {}^{A}_{Z+1}\text{Y} + {}^{0}_{-1}e $$

(!) Lỗi thường gặp: A nuclear equation must balance **both** the mass numbers (A) **and** the proton numbers (Z) on both sides — checking only one of the two is a common and serious mistake. Always add up the top numbers on each side and check they match, then separately add up the bottom numbers on each side and check *those* match too.

Ví dụ 11 · Alpha decay: uranium-238

Write the balanced nuclear equation for the alpha decay of uranium-238, ${}^{238}_{92}\text{U}$.

Alpha decay: $A \to A - 4 = 238 - 4 = 234$; $\quad Z \to Z - 2 = 92 - 2 = 90$ (proton number 90 is thorium, Th).

$$ {}^{238}_{92}\text{U} \rightarrow {}^{234}_{90}\text{Th} + {}^{4}_{2}\text{He} $$

Check: mass numbers $234 + 4 = 238$ ✓; proton numbers $90 + 2 = 92$ ✓.

Ví dụ 12 · Alpha decay: radium-226

Write the balanced nuclear equation for the alpha decay of radium-226, ${}^{226}_{88}\text{Ra}$.

$A \to 226 - 4 = 222$; $Z \to 88 - 2 = 86$ (proton number 86 is radon, Rn).

$$^{226}_{88}\text{Ra} \to {}^{222}_{86}\text{Rn} + {}^{4}_{2}\text{He}$$

Check: $222 + 4 = 226$ ✓; $86 + 2 = 88$ ✓.

Ví dụ 13 · Beta decay: carbon-14

Write the balanced nuclear equation for the beta decay of carbon-14, $^{14}_{6}$C.
Beta decay: A unchanged, $= 14$; $Z \to Z + 1 = 6 + 1 = 7$ (proton number 7 is nitrogen, N).

$$^{14}_{6}\text{C} \to {}^{14}_{7}\text{N} + {}^{0}_{-1}e$$

Check: $14 = 14$ ✓; $6 = 7 + (-1) = 6$ ✓.

Ví dụ 14 · Beta decay: cobalt-60

Write the balanced nuclear equation for the beta decay of cobalt-60, $^{60}_{27}$Co (a source widely used in radiotherapy and sterilisation).
Beta decay: A unchanged, $= 60$; $Z \to 27 + 1 = 28$ (proton number 28 is nickel, Ni).

$$^{60}_{27}\text{Co} \to {}^{60}_{28}\text{Ni} + {}^{0}_{-1}e$$

Check: $60 = 60$ ✓; $27 = 28 + (-1) = 27$ ✓.

Ví dụ 15 · Alpha decay: plutonium-239

(Supplement) Plutonium-239, $^{239}_{94}$Pu, used as a fuel in some nuclear reactors, undergoes alpha decay. Write the balanced nuclear equation (proton number 92 is uranium, U).
Alpha decay: $A \to A - 4 = 239 - 4 = 235$; $Z \to Z - 2 = 94 - 2 = 92$ (proton number 92 is uranium, U).

$$^{239}_{94}\text{Pu} \to {}^{235}_{92}\text{U} + {}^{4}_{2}\text{He}$$

Check: mass numbers $235 + 4 = 239$ ✓; proton numbers $92 + 2 = 94$ ✓.

VN **GIẢI THÍCH TIẾNG VIỆT**

(Supplement) Plutonium-239 ($^{239}_{94}$Pu) phân rã alpha thành uranium-235 ($^{235}_{92}$U) và một hạt alpha ($^{4}_{2}$He): số khối giảm 4 (239 → 235), số proton giảm 2 (94 → 92) — hai vế đều cân bằng.

VN **GIẢI THÍCH TIẾNG VIỆT**

(Supplement) Phương trình hạt nhân phải cân bằng **cả** số khối A **và** số proton Z ở hai vế. Phân rã alpha: phát ra $^{4}_{2}$He, số khối giảm 4, số proton giảm 2. Phân rã beta: một neutron biến thành một proton và phát ra electron $^{0}_{-1}e$, số khối giữ nguyên, số proton tăng 1. Ví dụ: U-238 → Th-234 + He-4 (phân rã alpha); Ra-226 → Rn-222 + He-4 (phân rã alpha); C-14 → N-14 + electron (phân rã beta); Co-60 → Ni-60 + electron (phân rã beta).

5.6 Uses and Hazards of Radioactive Emissions

5.6.1 Medical Uses

Diagnosis (tracers): a small quantity of a radioisotope emitting **gamma** radiation (so it can escape the body and be detected externally) with a **short half-life** (so the dose to the patient falls away quickly) is injected or swallowed, and its path or concentration is followed with an external detector — used, for example, to study blood flow, kidney function, or locate tumours.
Radiotherapy: carefully targeted, high-intensity **gamma** (or sometimes beta) radiation from a source such as cobalt-60 is aimed at cancerous tissue to kill or damage cancer cells; healthy surrounding tissue is protected as far as possible by careful focusing/shielding and rotating the source or patient so the beam always converges on the tumour from different angles.

5.6.2 Industrial and Other Uses

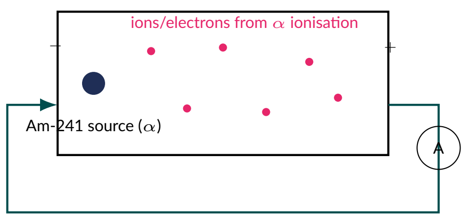
Thickness gauging: a **beta** source is placed on one side of a continuous sheet of material (e.g. paper, plastic, metal foil) as it is manufactured, with a detector on the other side; beta radiation is partly absorbed by the material, so the detector reading changes with thickness — if the sheet becomes too thick, less beta radiation gets through (detector reading falls), and rollers automatically adjust to correct it. (Alpha would be completely stopped even by a very thin sheet, giving no useful information about small thickness changes; gamma would pass through almost unaffected, giving too little sensitivity.)
Smoke detectors: a very weak **alpha** source (typically americium-241) ionises the air in a small chamber, allowing a small, steady current to flow; smoke particles entering the chamber absorb the alpha radiation and disrupt this ionisation, reducing the current and triggering the alarm. A **long half-life** is used so the detector's sensitivity does not noticeably decline over its working lifetime.
Sterilisation: a strong **gamma** source (e.g. cobalt-60) irradiates medical instruments or food, killing bacteria and other micro-organisms; gamma is used because it penetrates deeply enough to sterilise the entire object, including sealed packaging, without the item ever needing to be opened.
Radiocarbon dating (discussed above): uses the known half-life of carbon-14 to estimate the age of formerly-living material.

5.6.3 Smoke Detectors: How the Ionisation Chamber Works (Application)

A household ionisation smoke detector contains a small sensing chamber with two electrodes connected across a small voltage source, and a tiny, extremely weak alpha source (typically americium-241) positioned so that its radiation continuously passes across the gap of air between the electrodes.

Normal operation (no smoke): alpha particles continuously ionise the air molecules in the gap, knocking electrons off them to create a steady population of positive ions and free electrons. Under the small potential difference applied across the electrodes, these charged particles are pulled toward the oppositely-charged electrode, allowing a small, steady **current** to flow continuously through the circuit — this steady current is the detector's "normal, all-clear" signal.

When smoke enters the chamber: smoke particles are relatively large, and they readily absorb alpha particles and attach to the ions produced, both reducing the rate at which fresh ions are created and removing existing ions/electrons from the gap before they can reach the electrodes. This causes the current flowing through the circuit to **fall** measurably. The alarm's circuitry is designed to detect this drop in current, once it falls below a set threshold, and sound the alarm.



A household ionisation smoke detector: a weak alpha source continuously ionises air between two electrodes inside a small chamber, maintaining a small steady current through the external circuit (measured by the ammeter, A). Smoke particles entering the chamber absorb alpha radiation and remove ions, reducing the current and triggering the alarm circuit.

GIẢI THÍCH TIẾNG VIỆT

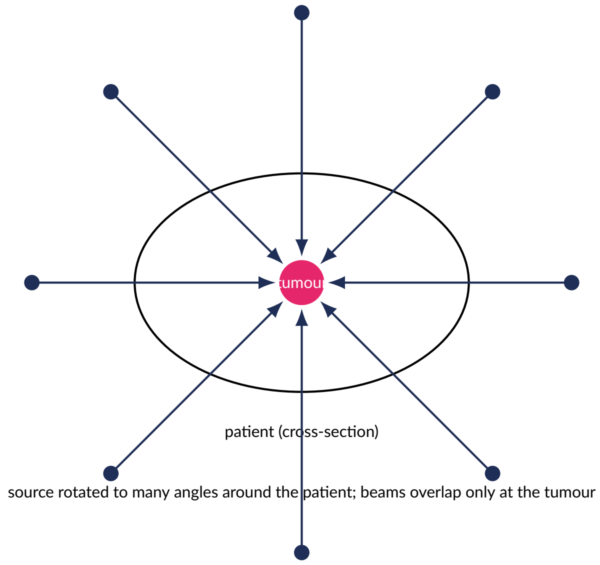
VN Đầu báo khói ion hóa có một buồng cảm biến nhỏ chứa nguồn alpha rất yếu (thường là americium-241) đặt sao cho bức xạ của nó chiếu qua khe hở không khí giữa hai điện cực. Bình thường, hạt alpha liên tục ion hóa không khí trong khe hở, tạo ra các ion dương và electron tự do di chuyển về hai điện cực dưới tác dụng của hiệu điện thế nhỏ, tạo ra một dòng điện nhỏ, ổn định chạy trong mạch — đây là tín hiệu "bình thường, không có cháy". Khi có khói lọt vào buồng, các hạt khói (khá lớn) hấp thụ hạt alpha và các ion, làm giảm số ion đến được điện cực, khiến dòng điện trong mạch **giảm xuống** một cách rõ rệt. Mạch điện được thiết kế để phát hiện sự sụt giảm dòng điện này (khi nó giảm quá một ngưỡng nhất định) và kích hoạt chuông báo động.

(!) Lỗi thường gặp: It is a common misconception that alpha sources are inherently "safer" than beta or gamma sources. In reality, alpha sources are only safe to handle **externally** because alpha particles are stopped by the outer dead layer of skin or by a few centimetres of air, so they cannot reach living tissue from outside the body. If an alpha source is instead **inhaled or ingested**, it becomes extremely hazardous — all of its intensely ionising radiation is then released directly onto living cells inside the body, with none of it wasted or blocked before reaching them, causing far more localised biological damage than an external alpha source of the same activity ever could. This is exactly why a smoke detector's tiny alpha source is permanently sealed inside the device rather than left exposed, and why radioactive sources of any type must never be handled in ways that risk inhalation or ingestion.

5.6.4 External Beam Radiotherapy and Gamma-Emitting Tracers (Application)

External beam radiotherapy directs a high-intensity beam of gamma radiation from a source such as cobalt-60, collimated (narrowed and focused), toward a tumour inside the patient's body. A single, fixed beam angle would deliver its full dose along the entire straight-line path it travels — damaging the healthy tissue it passes through, both before and after reaching the tumour, in addition to the tumour itself. To reduce this collateral damage, the source (or, equivalently, the patient) is slowly **rotated** around the tumour during treatment, so that beams enter the body from many different angles and directions.

Each individual beam path, entering from a different angle, passes through a different region of healthy tissue *only once* on its way to the tumour, delivering a relatively low dose to that particular region of healthy tissue. However, because the **tumour itself lies at the point where all of these different beam paths cross**, it receives the combined, overlapping dose from every single beam angle — a much larger cumulative dose than any one path of healthy tissue receives on its own. The net effect of rotating the source is to **concentrate** a high, destructive dose specifically at the tumour, while **spreading** the incidental dose to healthy tissue thinly across a much larger surrounding volume, minimising damage to any one region of healthy tissue.



External beam radiotherapy: a gamma source is rotated around the patient (or the patient rotated relative to a fixed source) so that beams converge on the tumour from many different angles. Healthy tissue along any single path receives only a low dose, but the tumour — where every path overlaps — receives a much higher cumulative dose.

Medical tracers use a different strategy: rather than irradiating from outside, a small quantity of a gamma-emitting radioisotope is introduced *into* the body (injected or swallowed) and tracked using an external detector (a gamma camera) as it moves through, or accumulates in, a particular organ or tissue. A widely used example is **technetium-99m**, with a half-life of about 6 hours.

Why gamma, not alpha or beta? The tracer must emit radiation capable of travelling out of the patient's body to reach an external detector. Alpha and beta radiation are both absorbed within only millimetres to centimetres of tissue, so they would never escape the body to be detected — they would only deliver unnecessary, purely destructive ionising dose internally, with no diagnostic benefit whatsoever. Gamma radiation, being weakly ionising and highly penetrating, can pass out of the body largely intact and be picked up by an external detector, while depositing comparatively little damaging ionisation within the tissue it passes through.

Why a short half-life? A short half-life means the tracer's activity decays away substantially within hours to a few days of the scan being completed — minimising the total radiation dose accumulated by the patient over time, since a source with a long half-life would continue irradiating the patient's body long after the diagnostic information had already been obtained, for no further benefit. The half-life must not be *too* short, however: it needs to remain active for long enough to be manufactured, transported, administered to the patient, and for the scan itself to be completed.

VN **GIẢI THÍCH TIẾNG VIỆT**

Trong xạ trị chiếu ngoài (external beam radiotherapy), nguồn gamma (ví dụ Co-60) được xoay quanh khối u (hoặc bệnh nhân được xoay) để các chùm tia đi vào cơ thể từ nhiều góc khác nhau. Mỗi đường đi chỉ chiếu qua một vùng mô lành đúng một lần với liều thấp, nhưng khối u — nơi tất cả các đường đi giao nhau — nhận được liều tổng hợp từ mọi góc, tức liều tại khối u cao hơn hẳn liều tại bất kỳ vùng mô lành nào. Chất đánh dấu y tế (ví dụ technetium-99m, chu kỳ bán rã khoảng 6 giờ) được đưa vào cơ thể và theo dõi bằng máy dò gamma bên ngoài. Phải dùng tia **gamma** (không phải alpha/beta) vì gamma xuyên ra khỏi cơ thể để máy dò bên ngoài phát hiện được, trong khi alpha/beta bị hấp thụ ngay trong cơ thể mà không mang lại lợi ích chẩn đoán nào. Phải dùng chu kỳ bán rã **ngắn** để giảm tổng liều nhiễm xạ của bệnh nhân theo thời gian, nhưng không được quá ngắn vì cần đủ thời gian để sản xuất, vận chuyển, tiêm/uống và hoàn thành việc chụp ảnh.

5.6.5 Hazards and Precautions

Ionising radiation can damage living cells: it can break chemical bonds within molecules (including DNA), potentially killing cells outright, or causing **mutations** that may lead to **cancer** if the damaged cell survives and divides abnormally. The degree of biological harm depends on the type of radiation, the dose received, and whether the source is outside the body or has been inhaled/ingested (once inside the body, even a weakly-penetrating but strongly-ionising alpha source can cause severe localised damage, since none of its radiation is wasted escaping the body).

Precautions when handling radioactive sources:

- **Shielding** — using an appropriate barrier (lead for gamma, thick material for beta) to absorb radiation before it reaches the body.
- **Distance** — radiation intensity falls off rapidly with distance from a source (following an inverse-square law for point sources), so handling sources with tongs and standing well back significantly reduces dose.
- **Minimising exposure time** — the total dose received increases with the time spent near a source, so exposure time should always be kept as short as reasonably possible.
- **Protective clothing and equipment** — lead aprons, gloves, and monitoring badges (film badges/dosimeters) to track the cumulative dose received by workers.
- **Safe storage and disposal** — sources are kept in shielded, clearly labelled containers when not in use, and radioactive waste is stored securely (sometimes for very long periods, matching the half-life of the waste) to prevent contamination of the environment.

Ví dụ 16 · Reasoning about radiation choice for an application

A factory produces thin plastic sheeting and needs to continuously monitor its thickness as it is rolled out. Explain why a beta source, rather than an alpha or gamma source, is the appropriate choice.

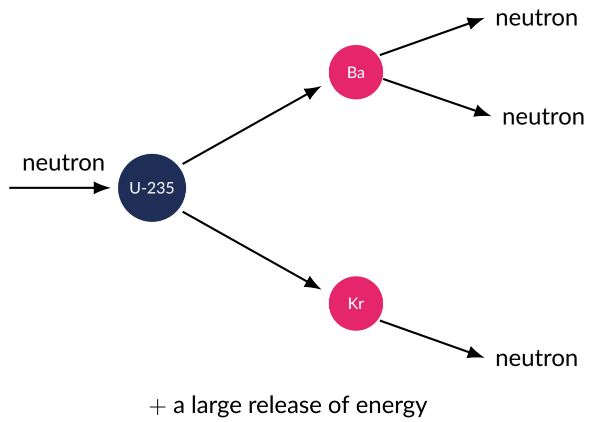
An **alpha** source would be completely absorbed even by the thinnest sheet (or by the air gap itself), so the detector reading would always be zero regardless of thickness — giving no useful information. A **gamma** source would pass through the thin plastic almost unaffected regardless of small changes in thickness, so the detector reading would barely change — again giving too little sensitivity to detect thickness variations. A **beta** source is partially absorbed by a thickness of material in this range, so the detector reading changes measurably (and roughly proportionally) as the sheet's thickness varies — making beta radiation the appropriate, sensitive choice for this thickness-gauging application.

VN **GIẢI THÍCH TIẾNG VIỆT**

Bức xạ ion hóa có thể phá vỡ liên kết hóa học trong tế bào (kể cả ADN), gây chết tế bào hoặc **đột biến** dẫn đến ung thư. Biện pháp phòng tránh: **che chắn** (shielding), giữ **khoảng cách** xa nguồn, giảm **thời gian tiếp xúc**, mặc **trang phục bảo hộ**, và **lưu trữ/xử lý** chất thải phóng xạ an toàn. Ứng dụng: chất đánh dấu y tế và xạ trị dùng gamma; đo độ dày công nghiệp dùng beta; đầu báo khói dùng alpha (chu kỳ bán rã dài); tiệt trùng dùng gamma (xuyên qua được bao bì).

5.6.6 Nuclear Fission (Supplement)

(Supplement) **Nuclear fission** is the splitting of a large, unstable nucleus (such as uranium-235) into two smaller nuclei, after it absorbs a slow-moving neutron. Fission releases a very large amount of energy (far more per reaction than any chemical process), along with two or three additional neutrons.



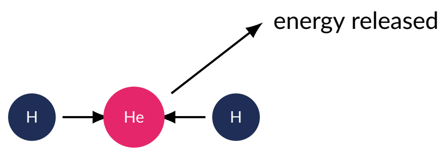
Nuclear fission: a slow neutron is absorbed by a large unstable nucleus (e.g. uranium-235), which splits into two smaller nuclei plus two or three more neutrons and a large release of energy. Each released neutron can go on to split a further nucleus, sustaining a **chain reaction**.

(Supplement) Because each fission event releases *more* neutrons than it absorbed, those neutrons can go on to trigger fission in further nuclei, which release still more neutrons — a self-sustaining **chain reaction**. In a nuclear power station, this chain reaction is controlled (kept steady rather than escalating) inside a reactor:

- **Fuel rods** — contain the fissile material (e.g. enriched uranium-235) where fission takes place.
- **Moderator** (e.g. graphite or water) — slows down the fast neutrons released by fission to the slower speeds needed to efficiently trigger further fission.
- **Control rods** (e.g. boron or cadmium) — absorb a controllable proportion of the free neutrons; lowering them further into the reactor slows the reaction (fewer neutrons available to cause further fission), raising them speeds it up, allowing the chain reaction's rate to be kept steady and safe.
- **Coolant** — a fluid that carries heat away from the reactor core, ultimately used to boil water into steam that drives turbines and generators to produce electricity.

5.6.7 Nuclear Fusion (Supplement)

(Supplement) **Nuclear fusion** is the joining together of two light nuclei (such as isotopes of hydrogen) to form a single heavier nucleus, releasing a large amount of energy in the process. Fusion is the process that powers the **Sun** and other stars.



Nuclear fusion: two light nuclei (e.g. hydrogen isotopes) combine, under extremely high temperature and pressure, to form a heavier nucleus (e.g. helium), releasing energy. This is the process that powers the Sun and other stars.

(Supplement) Because both fusing nuclei carry positive charge, they strongly **repel** each other electrostatically; fusion can only occur if the nuclei collide with enough energy to overcome this repulsion and get close enough for the (very short-range) strong nuclear force to bind them together. This requires **extremely high temperature and pressure** — conditions found naturally in the cores of stars, but very difficult to create and sustain artificially. Despite decades of research, nuclear fusion has **not yet been harnessed as a commercially viable power source** on Earth, though it remains an active area of energy research (in contrast to nuclear fission, which has been used commercially in power stations for decades).

VN GIẢI THÍCH TIẾNG VIỆT

(Supplement) Phân hạch hạt nhân (fission): một hạt nhân lớn, không bền (ví dụ U-235) hấp thụ neutron chậm rồi vỡ thành hai hạt nhân nhỏ hơn, giải phóng thêm 2–3 neutron và một lượng năng lượng lớn; các neutron này tiếp tục gây phân hạch cho các hạt nhân khác, tạo **phản ứng dây chuyền**. Trong lò phản ứng hạt nhân: thanh nhiên liệu chứa vật liệu phân hạch; chất làm chậm (moderator) làm chậm neutron; thanh điều khiển (control rods) hấp thụ neutron để kiểm soát tốc độ phản ứng; chất làm mát (coolant) mang nhiệt ra ngoài để sinh điện. Nhiệt hạch hạt nhân (fusion): hai hạt nhân nhẹ kết hợp thành một hạt nhân nặng hơn, giải phóng năng lượng — đây là quá trình cấp năng lượng cho Mặt Trời và các ngôi sao; cần nhiệt độ và áp suất cực cao để thắng lực đẩy tĩnh điện giữa các hạt nhân, và con người chưa khai thác được thương mại trên Trái Đất.

5.7 Practice Problems

Bài tập luyện tập

State the number of protons, neutrons and electrons (neutral atom) in the nuclide $^{131}_{53}$I (iodine-131).

Lời giải chi tiết

Protons $= Z = \boxed{53}$. Neutrons $= A - Z = 131 - 53 = \boxed{78}$. Electrons (neutral atom) $= Z = \boxed{53}$.

Bài tập luyện tập

Which type of nuclear radiation is stopped completely by a single sheet of paper?

(A) Alpha
(B) Beta
(C) Gamma
(D) All three

Lời giải chi tiết

Alpha particles are strongly ionising and lose their energy over a very short range, so they are stopped by a sheet of paper (or a few cm of air). **(A).**

Bài tập luyện tập

A radioactive source has an activity of 640 Bq and a half-life of 5.0 minutes. Find its activity after 20 minutes.

Lời giải chi tiết

$n = \dfrac{20}{5.0} = 4$ half-lives. $\quad N = 640 \times \left(\dfrac{1}{2}\right)^4 = \dfrac{640}{16} = \boxed{40\,\text{Bq}}$.

Bài tập luyện tập

(Supplement) Americium-241, ${}^{241}_{95}\text{Am}$, used in smoke detectors, undergoes alpha decay. Write the balanced nuclear equation, identifying the daughter nuclide (proton number 93 is neptunium, Np).

Lời giải chi tiết

$A \to 241 - 4 = 237; \quad Z \to 95 - 2 = 93.$

$${}^{241}_{95}\text{Am} \to \boxed{{}^{237}_{93}\text{Np}} + {}^{4}_{2}\text{He}$$

Check: $237 + 4 = 241\ \checkmark; \quad 93 + 2 = 95\ \checkmark$.

Bài tập luyện tập

A GM tube reads 260 counts/min near a source; with the source removed it reads 20 counts/min (background). The source's half-life is 4.0 minutes. Find the *total* reading the detector would show after 12 minutes.

Lời giải chi tiết

Corrected initial activity $= 260 - 20 = 240$ counts/min. $\quad n = \dfrac{12}{4.0} = 3.$

Corrected activity after 12 min $= 240 \times \left(\dfrac{1}{2}\right)^3 = \dfrac{240}{8} = 30$ counts/min.

Total reading $= 30 + 20 = \boxed{50\,\text{counts/min}}$.

Bài tập luyện tập

Lead has two stable isotopes: lead-206 and lead-208 ($Z = 82$ for both). Find the number of neutrons in each, and confirm they are isotopes of the same element.

Lời giải chi tiết

Lead-206: neutrons $= 206 - 82 = \boxed{124}$. Lead-208: neutrons $= 208 - 82 = \boxed{126}$.
Both have the **same proton number** ($Z = 82$, so both are lead) but a **different number of**

neutrons — this is the definition of isotopes.

Bài tập luyện tập

Explain why it is impossible to predict exactly when a particular radioactive nucleus will decay, yet the activity of a large sample of the same isotope follows a smooth, predictable decay curve.

Lời giải chi tiết

Radioactive decay is a **random** process at the level of an individual nucleus: every undecayed nucleus has the same, constant probability of decaying in a given time interval, with no way to know in advance which nucleus (or when) will decay next. However, a real sample contains an enormous number of nuclei, and although each one decays at a random moment, statistically the *proportion* decaying in a given time interval is highly predictable when averaged over so many nuclei — just as tossing a huge number of coins gives an unpredictable result for any single coin but a very predictable overall fraction of heads. This is why the half-life and the overall decay curve are precise and repeatable, even though the underlying process is random.

Bài tập luyện tập

Which type of nuclear radiation is *not* deflected by a magnetic field?

(A) Alpha

(B) Beta

(C) Gamma

(D) Both alpha and beta

Lời giải chi tiết

Gamma radiation carries no charge, so it experiences no force in a magnetic field and travels straight through undeflected. **(C)**.

Bài tập luyện tập

A radioactive sample's activity falls from 960 Bq to 30 Bq over 24 hours. Find its half-life.

Lời giải chi tiết

Ratio: $\dfrac{960}{30} = 32 = 2^5$, so $n = 5$ half-lives have elapsed in 24 hours.

$t_{1/2} = \dfrac{24}{5} = \boxed{4.8 \text{ hours}}$.

Bài tập luyện tập

(Supplement) Strontium-90, $^{90}_{38}\mathrm{Sr}$, undergoes beta decay. Write the balanced nuclear equation, identifying the daughter nuclide (proton number 39 is yttrium, Y).

Lời giải chi tiết

A unchanged $= 90$; $Z \to 38 + 1 = 39$.

$$^{90}_{38}\mathrm{Sr} \to \boxed{^{90}_{39}\mathrm{Y}} + {}^{0}_{-1}e$$

Check: $90 = 90$ ✓; $38 = 39 + (-1) = 38$ ✓.

Bài tập luyện tập

Which of the following is a *natural* source of background radiation?

(A) Radon gas
(B) Medical X-rays
(C) Nuclear waste
(D) Radiotherapy treatment

Lời giải chi tiết

Radon gas seeps naturally from rocks and soil and is typically the largest natural contributor to background radiation. **(A)**.

Bài tập luyện tập

Explain why a radioactive tracer used for medical imaging should have both a **short** half-life and emit **gamma** radiation.

Lời giải chi tiết

A short half-life means the tracer's activity (and the patient's radiation dose) falls away quickly once the scan is complete, minimising the total dose received. Gamma radiation is used because it is the most penetrating type, able to pass out of the patient's body and be detected externally; alpha or beta radiation would instead be absorbed within the body, causing unnecessary internal ionising damage while never reaching an external detector.

Bài tập luyện tập

What fraction of a radioactive sample's original activity remains after exactly 3 half-lives?

(A) $1/8$
(B) $1/6$
(C) $1/3$
(D) $3/8$

Lời giải chi tiết

$\left(\frac{1}{2}\right)^3 = \frac{1}{8}$. **(A)**.

Bài tập luyện tập

A sample contains 800 Bq of a radioisotope with a half-life of 2.0 years. Find its activity after 8.0 years.

Lời giải chi tiết

$$n = \frac{8.0}{2.0} = 4. \quad N = 800 \times \left(\frac{1}{2}\right)^4 = \frac{800}{16} = \boxed{50\,\text{Bq}}.$$

Bài tập luyện tập

Rank alpha, beta and gamma radiation in order of *increasing* penetrating power.

Lời giải chi tiết

$\boxed{\alpha < \beta < \gamma}$ — alpha is stopped by paper, beta by a few mm of aluminium, and gamma needs thick lead or concrete to reduce it substantially.

Bài tập luyện tập

An atom has 7 protons and 7 neutrons in its nucleus. State its mass number and identify the element (proton number 7 is nitrogen).

Lời giải chi tiết

Mass number $A = 7 + 7 = \boxed{14}$. Since $Z = 7$, the element is $\boxed{\text{nitrogen (N-14)}}$.

Bài tập luyện tập

Explain, in terms of ionisation, why alpha particles have a much shorter range in air than beta particles or gamma rays.

Lời giải chi tiết

Alpha particles are large, slow-moving and carry a relatively big charge $(+2)$, so they interact very strongly with the atoms they pass, knocking electrons off a great many of them (strong ionisation) over a very short distance. Each ionisation event costs the alpha particle some of its kinetic energy, so it loses essentially all its energy — and stops — within only a few centimetres of air. Beta and (especially) gamma radiation ionise far less often per unit distance travelled, losing energy much more slowly, so they can travel much further before being absorbed.

Bài tập luyện tập

Uranium has two important isotopes: uranium-235 and uranium-238 (both $Z = 92$). Find the number of neutrons in each, and state which isotope is used as nuclear fuel.

Lời giải chi tiết

U-235: neutrons $= 235 - 92 = \boxed{143}$. U-238: neutrons $= 238 - 92 = \boxed{146}$.
Uranium-235 is the isotope capable of sustaining a fission chain reaction and is used as nuclear fuel.

Bài tập luyện tập

In beta decay, what happens to the proton number Z and the mass number A of the decaying nucleus?

(A) Z increases by 1; A unchanged

(B) Z unchanged; A decreases by 4

(C) Z decreases by 2; A decreases by 4

(D) Z increases by 1; A increases by 1

Lời giải chi tiết

In beta decay a neutron converts to a proton, so Z increases by 1 while the total nucleon count (A) is unchanged. **(A)**.

Bài tập luyện tập

(Supplement) Thorium-232, ${}^{232}_{90}\text{Th}$, undergoes alpha decay. Find the mass number and proton number of the daughter nuclide, and identify the element (proton number 88 is radium).

Lời giải chi tiết

$A \to 232 - 4 = 228; \quad Z \to 90 - 2 = 88.$

$${}^{232}_{90}\text{Th} \to \boxed{{}^{228}_{88}\text{Ra}} + {}^{4}_{2}\text{He}$$

Check: $228 + 4 = 232$ ✓; $88 + 2 = 90$ ✓.

Bài tập luyện tập

Smoke detectors typically use americium-241, an alpha emitter with a long half-life (about 432 years). Explain why an alpha source is suitable for this purpose, and why a long half-life is chosen.

Lời giải chi tiết

An **alpha** source is used because alpha particles are strongly ionising over a very short range, which is exactly what is needed to ionise the small volume of air inside the detector's sensing chamber and maintain a small steady current, without needing to escape the device (unlike gamma, which would mostly pass straight through without ionising the air) and without the health/shielding concerns of a more penetrating source. A **long half-life** is chosen so that the source's activity — and hence the detector's sensitivity — does not noticeably decline over the working lifetime of the smoke detector, avoiding the need for frequent replacement.

Bài tập luyện tập

A patient is injected with a radioactive tracer of activity 12 MBq and half-life 6.0 hours. Find the activity remaining (ignoring biological removal) after 24 hours.

Lời giải chi tiết

$$n = \frac{24}{6.0} = 4. \quad N = 12 \times \left(\frac{1}{2}\right)^4 = \frac{12}{16} = \boxed{0.75\text{ MBq}}.$$

Bài tập luyện tập

Which of the following correctly defines isotopes?

(A) Atoms of the same element with the same proton number but different neutron numbers

(B) Atoms of different elements with the same neutron number

(C) Atoms with the same mass number but different proton numbers

(D) Atoms with the same number of electrons but different protons

Lời giải chi tiết

Isotopes are atoms of the same element (same Z) with different numbers of neutrons (different A). **(A)**.

Bài tập luyện tập

State three precautions that should be taken by a worker who regularly handles radioactive sources in a laboratory.

Lời giải chi tiết

Any three of: **shielding** (using lead or other absorbing material between the source and the body); handling sources with tongs and keeping as much **distance** as possible from the source; keeping **exposure time** as short as possible; wearing **protective clothing** (e.g. lead apron, gloves) and a film badge/dosimeter to monitor cumulative dose; storing sources securely in shielded, labelled containers when not in use.

Bài tập luyện tập

(Supplement) A nuclide has 86 protons and 136 neutrons. (a) Write its nuclide notation and identify the element (proton number 86 is radon). (b) If it undergoes alpha decay, write the balanced nuclear equation for the products (proton number 84 is polonium).

Lời giải chi tiết

(a) $A = 86 + 136 = 222$, so the nuclide is $\boxed{{}^{222}_{86}\text{Rn}}$ (radon-222).
(b) Alpha decay: $A \to 222 - 4 = 218$; $Z \to 86 - 2 = 84$.

$${}^{222}_{86}\text{Rn} \to \boxed{{}^{218}_{84}\text{Po}} + {}^{4}_{2}\text{He}$$

Check: $218 + 4 = 222$ ✓; $84 + 2 = 86$ ✓.

Bài tập luyện tập

Explain why IGCSE half-life calculations are restricted to whole numbers of half-lives, and describe how a question involving a "non-whole" number of half-lives could still be answered.

Lời giải chi tiết

The formula $N = N_0\left(\frac{1}{2}\right)^n$ is straightforward to evaluate by hand only when n is a whole number (repeated halving); for a non-integer n, evaluating $\left(\frac{1}{2}\right)^n$ requires methods (such as logarithms) that go beyond the IGCSE syllabus. If a problem gives an elapsed time that is not an exact whole-number multiple of the half-life, the appropriate remaining activity should instead be found by **reading it directly off a plotted decay curve** (interpolating between the smooth exponential curve's values at the given time), rather than by calculating a non-integer power of $\frac{1}{2}$.

Bài tập luyện tập

A GM tube reads 164 counts/min near a source; with the source removed it reads 4 counts/min (background). The source's half-life is 20 minutes. Find the *total* reading the detector would show after 60 minutes.

Lời giải chi tiết

Corrected initial activity $= 164 - 4 = 160$ counts/min. $\quad n = \dfrac{60}{20} = 3.$

Corrected activity after 60 min $= 160 \times \left(\dfrac{1}{2}\right)^3 = \dfrac{160}{8} = 20$ counts/min.

Total reading $= 20 + 4 = \boxed{24\,\text{counts/min}}$.

Bài tập luyện tập

Which particle has a mass number of 4 and a proton number of 2?

(A) An alpha particle (helium nucleus)
(B) A beta particle (electron)
(C) A gamma ray
(D) A neutron

Lời giải chi tiết

$A = 4$, $Z = 2$ describes a helium nucleus, ${}^4_2$He — the alpha particle. **(A)**.

Bài tập luyện tập

(Supplement) Explain, in terms of a chain reaction, how a nuclear reactor's control rods keep the fission reaction steady rather than allowing it to escalate uncontrollably.

Lời giải chi tiết

Each fission event releases two or three neutrons, more than the one absorbed to trigger it; if left unchecked, these extra neutrons would go on to cause more and more fission events at an ever-increasing rate (a runaway chain reaction). **Control rods** (made of a material such as boron or cadmium that readily absorbs neutrons) are inserted into the reactor core to remove some of these free neutrons before they can cause further fission. Lowering the control rods further into the core absorbs more neutrons, slowing the reaction; raising them absorbs fewer, speeding it up — by adjusting their position, operators keep exactly enough neutrons free to sustain a steady, controlled rate of fission (releasing a steady amount of energy) rather than an escalating one.

Bài tập luyện tập

(Supplement) Explain why nuclear fusion requires extremely high temperature and pressure to occur, and state one reason it has not yet been harnessed as a commercial power source on Earth.

Lời giải chi tiết

The nuclei that need to fuse are both positively charged, so they strongly **repel** each other electrostatically as they approach. Extremely high temperature (giving the nuclei very large kinetic energy/speed) and high pressure (packing nuclei close together, increasing collision frequency) are needed so that some collisions are energetic enough to overcome this electrostatic repulsion and bring the nuclei close enough for the short-range strong nuclear force to bind them together. On Earth, sustaining the enormous temperatures and pressures required (comparable to conditions in the core of a star), while also containing the resulting extremely hot plasma safely and extracting more energy than is put in, has proven immensely difficult — so despite decades of research, fusion has not yet been achieved as a viable, continuous commercial power source (unlike fission, already used in power stations).

Bài tập luyện tập

A student measures the count rate near a radioactive source and forgets to subtract the background count rate before calculating the source's half-life from the data. Explain what effect this error would have on the calculated half-life.

Lời giải chi tiết

Since background radiation stays roughly constant over time (it does not decay away), failing to subtract it means every reading used in the calculation is too high by the same fixed amount. Because this constant background makes the readings decrease by a *smaller* proportion between measurements than the source's activity alone actually does (the ratio of readings is closer to 1 than it should be), the calculated ratio between successive readings will be too small, making the apparent number of half-lives elapsed too small — so the calculated half-life will come out **longer (an overestimate)** than the true half-life of the source.

Bài tập luyện tập

A radioactive isotope has an activity of 500 Bq. After 3 half-lives, what is its activity?

(A) 62.5 Bq
(B) 166.7 Bq
(C) 125 Bq
(D) 250 Bq

Lời giải chi tiết

$N = 500 \times \left(\frac{1}{2}\right)^3 = \frac{500}{8} = 62.5$ Bq. **(A).**

Bài tập luyện tập

Explain why a person standing several metres from a gamma source receives a significantly smaller radiation dose than someone standing right next to it, even though both are exposed for the same length of time.

Lời giải chi tiết

Radiation from a small (point-like) source spreads out in all directions as it travels, so the same total amount of radiation is spread over an ever-larger area the further it travels from the source — the intensity therefore falls off rapidly with distance (following an inverse-square-type relationship). Standing several metres away means the radiation has spread out over a much larger area than right next to the source, so a far smaller fraction of it reaches and passes through the more distant person's body in the same time, giving them a substantially smaller radiation dose.

Bài tập luyện tập

Explain, in terms of ionisation and current, what happens inside a smoke detector's ionisation chamber when smoke enters the chamber, and how this triggers the alarm.

Lời giải chi tiết

Normally, the weak alpha source inside the chamber continuously ionises the air between the two electrodes, producing a steady supply of ions and free electrons that are drawn to the electrodes, maintaining a small, steady current in the circuit. When smoke particles enter the chamber, they absorb alpha particles and attach to the ions produced, reducing the number of ions that reach the electrodes. This causes the current flowing through the circuit to **fall**. The alarm circuit is designed to detect this drop in current and, once it falls below a set threshold, sound the alarm.

Bài tập luyện tập

During external beam radiotherapy, why is the gamma source (or the patient) rotated during treatment, rather than firing a single fixed beam continuously from one direction?

(A) So that the dose is concentrated at the tumour (where all beam paths overlap) while the dose to any single region of healthy tissue is kept low

(B) So that the total treatment time is reduced

(C) So that a weaker source can be used without needing any shielding

(D) So that only alpha radiation reaches the tumour

Lời giải chi tiết

Rotating the source (or patient) means each beam path passes through a different region of healthy tissue only once, delivering a low dose there, but every path converges on the tumour, so the tumour receives the combined, much larger dose from all paths overlapping. **(A)**.

Bài tập luyện tập

Which combination of properties makes technetium-99m suitable for use as a medical tracer, tracked using an external gamma camera?

(A) Long half-life and alpha emission

(B) Short half-life and gamma emission

(C) Long half-life and beta emission

(D) Short half-life and alpha emission

Lời giải chi tiết

Gamma emission is needed so the radiation can escape the patient's body and be detected externally (alpha and beta would simply be absorbed inside the body, delivering dose with no diagnostic benefit). A short half-life is needed so the tracer's activity — and the patient's radiation dose — falls away quickly once the scan is complete. **(B)**.

Bài tập luyện tập

The table below shows how the (background-corrected) activity of a radioactive sample changes with time.

Time (min)	0	10	20
Activity (Bq)	640	320	160

Use the data in the table to find the half-life of the sample.

Lời giải chi tiết

From $t = 0$ to $t = 10$ min, activity falls from 640 to 320 Bq — a factor of 2, so 10 minutes corresponds to 1 half-life. (Check: from $t = 10$ to $t = 20$ min, activity falls from 320 to 160 Bq — again a factor of 2 over the same 10 minutes, confirming a consistent half-life.)
$t_{1/2} = \boxed{10 \text{ minutes}}$.

Bài tập luyện tập

(Supplement) Potassium-40, ${}^{40}_{19}\text{K}$, found naturally in rocks, soil and the human body, undergoes beta decay. Write the balanced nuclear equation for this decay, identifying the daughter nuclide (proton number 20 is calcium, Ca).

Lời giải chi tiết

Beta decay: A unchanged $= 40$; $\quad Z \to 19 + 1 = 20.$

$${}^{40}_{19}\text{K} \to \boxed{{}^{40}_{20}\text{Ca}} + {}^{0}_{-1}e$$

Check: $40 = 40$ ✓; $\;19 = 20 + (-1) = 19$ ✓.

Bài tập luyện tập

A company wants to develop a new radioactive tracer for imaging blood flow in hospital patients using an external gamma camera. A detector placed near a candidate source reads 280 counts/min; with the source removed, background alone reads 24 counts/min. The source has a half-life of 12 minutes.
(a) Find the corrected (source-only) count rate.
(b) Find the total reading the detector would show after 36 minutes (assume background stays constant).
(c) Based on its half-life and the reasoning used for medical tracers, explain briefly whether this source's half-life is suitable for a same-day hospital imaging procedure.

Lời giải chi tiết

(a) Corrected count rate $= 280 - 24 = \boxed{256 \text{ counts/min}}$.
(b) $n = \dfrac{36}{12} = 3$ half-lives. Corrected activity after 36 min $= 256 \times \left(\dfrac{1}{2}\right)^3 = \dfrac{256}{8} = 32$ counts/min. Total reading $= 32 + 24 = \boxed{56 \text{ counts/min}}$.
(c) A half-life of only 12 minutes is far **too short** to be realistic for a hospital tracer: the activity would fall to a small fraction of its starting value within the time needed simply to prepare,

inject and begin imaging the patient, leaving too little activity for a useful scan. A practical tracer (such as technetium-99m, half-life about 6 hours) needs a half-life long enough to survive preparation, administration and the full scan, while still being short enough to decay away and minimise the patient's dose soon afterwards.

Bài tập luyện tập

A hospital needs to choose a suitable radioactive source for three different tasks: (i) a tracer for imaging kidney function, tracked with an external detector; (ii) sterilising packaged surgical instruments without opening the packaging; (iii) a source to calibrate a detector reliably over several years without needing frequent replacement. For each task, state whether alpha, beta or gamma radiation is required, and whether a short or long half-life is more appropriate, giving a reason in each case.

Lời giải chi tiết

(i) **Gamma**, **short** half-life — gamma escapes the body to reach an external detector, while alpha or beta would be absorbed internally with no diagnostic benefit; a short half-life minimises the patient's radiation dose once the scan is complete.
(ii) **Gamma** — it penetrates sealed packaging to sterilise the entire contents without the item needing to be opened; alpha or beta would be stopped at or near the surface of the packaging.
(iii) A **long** half-life — this ensures the source's activity does not noticeably decline over the years it is used, keeping calibration readings consistent over time (the specific type of radiation matters less here than the requirement for a stable, long-lasting activity).

Bài tập luyện tập

A decay graph shows that a sample's activity falls from 500 Bq at $t = 0$ to 125 Bq at $t = 18$ minutes. What is the half-life of the sample?

(A) 6.0 minutes
(B) 9.0 minutes
(C) 18 minutes
(D) 4.5 minutes

Lời giải chi tiết

$\frac{500}{125} = 4 = 2^2$, so $n = 2$ half-lives elapse in 18 minutes. $t_{1/2} = \frac{18}{2} = 9.0$ minutes. **(B)**.

CAMBRIDGE IGCSE • Unit 6

Space Physics

Mục tiêu Unit: Mặt Trời và Hệ Mặt Trời (nhiệt hạch, các hành tinh trong/ngoài, vành đai tiểu hành tinh, sao chổi, mặt trăng); lực hấp dẫn giữ các thiên thể trên quỹ đạo, mối quan hệ giữa bán kính – chu kỳ – tốc độ quỹ đạo (Supplement: công thức $v = 2\pi r/T$); vệ tinh nhân tạo (quỹ đạo địa tĩnh và quỹ đạo cực/thấp); (Supplement) vòng đời của các ngôi sao, phân loại sao theo độ sáng & nhiệt độ/màu sắc; thiên hà, năm ánh sáng, dịch chuyển đỏ, định luật Hubble và thuyết Big Bang.

6.1 The Sun and the Solar System

6.1.1 The Sun: a Star Powered by Nuclear Fusion

The Sun is an ordinary **star**: a huge ball of extremely hot gas (mostly hydrogen, with some helium) that generates its own light and heat, unlike a planet or moon, which merely *reflects* light from a star. The Sun is by far the largest and most massive object in the Solar System, and its gravitational pull is what holds every planet, dwarf planet, asteroid, comet and moon in orbit around it.

Nuclear fusion in the Sun's core

Deep in the Sun's core, the temperature and pressure are so extreme that hydrogen nuclei are forced together and fuse to form helium nuclei. This process, **nuclear fusion**, releases an enormous amount of energy (a small amount of mass is converted directly into a very large amount of energy). This energy is what makes the Sun hot and luminous, radiating light and heat outward through space, including the small fraction that reaches Earth and drives our weather, seasons, and the vast majority of life-supporting energy on our planet. The Sun has been fusing hydrogen into helium for about 4.6 billion years and has enough hydrogen fuel to continue doing so, essentially unchanged, for several billion years more.

VN GIẢI THÍCH TIẾNG VIỆT

Mặt Trời là một ngôi sao bình thường – một khối khí cực nóng tự phát ra ánh sáng, khác với hành tinh hay mặt trăng chỉ phản chiếu ánh sáng. Trong lõi Mặt Trời, các hạt nhân hydro bị ép lại với nhau trong điều kiện nhiệt độ và áp suất cực cao, xảy ra phản ứng **nhiệt hạch (nuclear fusion)**: hydro hợp nhất thành heli, giải phóng năng lượng khổng lồ khiến Mặt Trời nóng và sáng. Quá trình này đã diễn ra khoảng 4,6 tỉ năm và còn tiếp diễn thêm vài tỉ năm nữa.

Key facts about the Sun: surface temperature $\approx 5500\,^\circ$C; core temperature ≈ 15 million $^\circ$C (needed to sustain hydrogen fusion); diameter about 109 times Earth's diameter, and volume enough to fit over a million Earths inside it. The Sun alone makes up about 99.8% of *all* the mass in the entire Solar System – which is exactly why its gravity dominates the motion of every planet, dwarf planet, asteroid, comet and moon within it.

The eventual future of the Sun

Applying the star life-cycle stages described later in this chapter to our own Sun: in roughly 5 billion years, once the hydrogen fuel in the Sun's core becomes depleted, the Sun will leave the main sequence and swell into a **red giant** – large enough that it will engulf Mercury and Venus, and possibly reach as far as Earth's present orbit. Eventually its outer layers will drift away into space as a **planetary nebula**, leaving behind an Earth-sized, extremely dense core: a **white dwarf**, which will then cool and dim for a very long time. Because the Sun is a medium-mass star, it will never become massive enough to undergo a supernova, and will never form a neutron star or black hole.

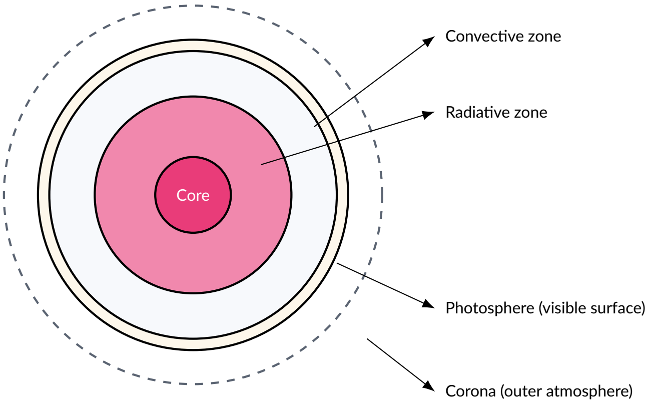
6.1.2 The Structure of the Sun (Supplement)

Although the Sun appears from Earth as a single glowing disc, it is actually organised into several distinct internal layers, each playing a different role in carrying the energy released by nuclear fusion outward from the core into space.

(Supplement) From core to corona: the Sun's internal layers

- **Core:** the innermost region, where the temperature ($\approx$ 15 million $^\circ$C) and pressure are extreme enough to sustain the hydrogen fusion described earlier in this chapter. Essentially all of the Sun's energy originates here.
- **Radiative zone:** surrounding the core, energy travels outward mainly as radiation. The material here is so dense that radiation is repeatedly absorbed and re-emitted in random directions, so it can take many thousands of years to work its way through this zone, even though radiation itself always travels at the speed of light.
- **Convective zone:** closer to the surface, where the gas is cooler and less dense, energy is instead carried the rest of the way outward mainly by **convection**: hot plasma physically rises toward the surface in large circulating currents, cools, and sinks back down again.
- **Photosphere:** the visible "surface" of the Sun, and the layer from which almost all of the light and heat detected on Earth is actually emitted. It is not a solid surface – it is simply the layer of gas thin enough for light generated deeper inside to finally escape freely into space.
- **Corona and solar wind:** beyond the photosphere lies the Sun's faint, extremely hot outer atmosphere, the **corona**, ordinarily visible from Earth only during a total solar eclipse. The corona continuously releases a stream of charged particles into space, called the **solar wind**, which travels throughout the Solar System (and is one cause of the auroras seen near Earth's poles, where it interacts with Earth's magnetic field).

Every layer beyond the core exists only because of the continuous energy supplied by fusion in the core: without that energy source, the Sun could not maintain the outward pressure needed to balance its own gravity, and it would instead collapse.



(Supplement) Simplified cross-section of the Sun's internal structure (schematic, **not to scale**): fusion energy generated in the core travels outward through the radiative zone (as radiation) and the convective zone (as circulating hot plasma), before being emitted into space from the visible photosphere; the corona is the Sun's much fainter, extremely hot outer atmosphere.

GIẢI THÍCH TIẾNG VIỆT

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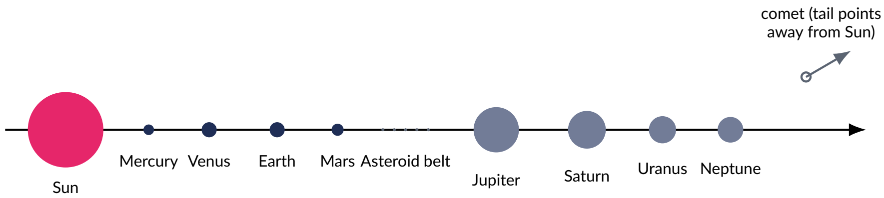
Mặt Trời gồm nhiều lớp: **lõi (core)** là nơi xảy ra phản ứng nhiệt hạch hydro thành heli ở nhiệt độ và áp suất cực cao; **vùng bức xạ (radiative zone)** truyền năng lượng ra ngoài chủ yếu bằng bức xạ nhưng rất chậm vì bị hấp thụ và phát lại liên tục; **vùng đối lưu (convective zone)** truyền năng lượng bằng dòng đối lưu của plasma nóng dâng lên rồi hạ xuống; **quang cầu (photosphere)** là "bề mặt" nhìn thấy được, nơi phát ra hầu hết ánh sáng và nhiệt ta quan sát trên Trái Đất; và **nhật hoa (corona)** là khí quyển ngoài cùng, cực nóng nhưng rất loãng, chỉ thấy rõ khi nhật thực toàn phần, liên tục phát ra **gió Mặt Trời**. Mọi lớp bên ngoài lõi tồn tại được đều nhờ năng lượng liên tục sinh ra từ phản ứng nhiệt hạch trong lõi.

6.1.3 Structure of the Solar System

The Solar System is the Sun together with everything held in orbit around it by gravity. Moving outward from the Sun:

- **Four inner, rocky (terrestrial) planets**: Mercury, Venus, Earth, Mars – small, dense, solid-surfaced worlds close to the Sun.
- The **asteroid belt**: a region between the orbits of Mars and Jupiter containing millions of small rocky bodies (asteroids) too small and too numerous to have combined into a single planet.
- **Four outer, gas/ice giant planets**: Jupiter, Saturn, Uranus, Neptune – much larger, lower-density worlds made mostly of gas (Jupiter, Saturn) or icy/rocky material beneath a thick gas envelope (Uranus, Neptune), each with prominent ring systems and many moons.
- **Dwarf planets**, such as Pluto (orbiting beyond Neptune) – objects that orbit the Sun and are roughly spherical, but have not cleared other debris from their orbital path, so are not classed as full planets.
- **Comets**: lumps of ice, dust and rock on highly elongated (elliptical) orbits that can carry them from close to the Sun out to the far edges of the Solar System and back. As a comet approaches the Sun, heat vaporises some of its ice, releasing gas and dust that form a glowing **tail**, which always points *away* from the Sun (pushed outward by the solar wind and radiation pressure) regardless of the comet's direction of travel.
- **Moons (natural satellites)**: bodies that orbit a planet rather than the Sun directly, held in orbit by the gravitational attraction of that planet. Mercury and Venus have none; Earth has one (the Moon); Mars has two small moons; the giant planets each have dozens.



The Solar System in order outward from the Sun (schematic, **not to scale**): four small rocky inner planets, the asteroid belt, then four much larger gas/ice giant outer planets; a comet on a highly elliptical orbit is shown developing a tail as it nears the Sun.

Property	**Terrestrial (inner) planets**	**Gas/ice giant (outer) planets**
Composition	Rock and metal; solid surface	Mostly hydrogen/helium gas (Jupiter, Saturn), or icy/rocky material under a thick gas envelope (Uranus, Neptune), around a small core
Density	High (≈ 4000–$5500\,\mathrm{kg/m^3}$)	Low (≈ 700–$1700\,\mathrm{kg/m^3}$)
Size	Small diameter (≈ 5000–$13000\,\mathrm{km}$)	Large diameter (≈ 51000–$143000\,\mathrm{km}$)
Moons	Few or none (Mercury, Venus: 0; Earth: 1; Mars: 2)	Many (dozens each)
Rings	None	All four have ring systems
Distance from Sun	Close (within the asteroid belt)	Far (beyond the asteroid belt)

Terrestrial planets are small, dense and rocky with solid surfaces; gas/ice giants are large, low-density, and made mostly of gas or ice around a small core.

(Supplement) **Exoplanets:** planets are not unique to our Solar System – thousands of **exoplanets** (planets orbiting stars other than the Sun) have now been detected, often too faint to be seen directly, but revealed indirectly through their gravitational effect on their host star (a very slight, regular “wobble” in the star’s position or velocity) or through the tiny, regular dip in a star’s brightness as a planet passes in front of it. The existence of exoplanets confirms that the same gravitational principles that hold our own Solar System together – and the same relationship between orbital radius, period and speed – apply throughout the universe, wherever a planet orbits a star.

VN **GIẢI THÍCH TIẾNG VIỆT**

Hệ Mặt Trời gồm Mặt Trời và mọi thiên thể quay quanh nó nhờ lực hấp dẫn: 4 hành tinh đá nhỏ gần Mặt Trời (Sao Thủy, Sao Kim, Trái Đất, Sao Hỏa), vành đai tiểu hành tinh, rồi 4 hành tinh khí/băng khổng lồ (Sao Mộc, Sao Thổ, Sao Thiên Vương, Sao Hải Vương), các hành tinh lùn (như Sao Diêm Vương), sao chổi (quỹ đạo elip rất dẹt, đuôi luôn hướng ra xa Mặt Trời), và các mặt trăng (vệ tinh tự nhiên) quay quanh hành tinh. Hành tinh đá đặc, nhỏ, có bề mặt rắn; hành tinh khí khổng lồ có kích thước lớn nhưng mật độ thấp, chủ yếu là khí. Trong khoảng 5 tỉ năm nữa, Mặt Trời sẽ trở thành sao khổng lồ đỏ (có thể nuốt chửng Sao Thủy, Sao Kim) rồi thành sao lùn trắng – vì là sao khối lượng trung bình nên sẽ không bao giờ nổ siêu tân tinh. Các **ngoại hành tinh** (exoplanet) quay quanh những ngôi sao khác cũng tuân theo cùng quy luật hấp dẫn và mối quan hệ bán kính–chu kỳ–tốc độ như trong Hệ Mặt Trời của chúng ta.

A closer look at moons and small bodies: several moons are worlds of scientific interest in their own right. **Io** (a moon of Jupiter) is the most volcanically active body in the Solar System, heated internally by the constantly changing gravitational pull of Jupiter and neighbouring moons (tidal heating). **Europa** (also a moon of Jupiter) is thought to hide a liquid-water ocean beneath its icy surface, making it a prime target in the search for life beyond Earth. **Titan** (a moon of Saturn) has a thick atmosphere and lakes of liquid methane on its surface. **Saturn's rings** are made of countless small chunks of ice and rock, all independently orbiting Saturn together as a flat disc. Beyond Neptune lies the **Kuiper Belt**, a disc of icy bodies (including Pluto) that supplies many of the comets seen from Earth; far beyond that, the roughly spherical **Oort Cloud** is thought to be the source of comets on extremely long, wide orbits, taking thousands of years to return. Pluto was reclassified from a "planet" to a **dwarf planet** by the International Astronomical Union in 2006, because although it orbits the Sun and is roughly spherical, it has *not* gravitationally cleared its orbital neighbourhood of other similarly sized bodies – one of three criteria now required for full planet status. **Uranus** is also unusual: its axis of rotation is tilted by about $98°$, so it essentially rotates "on its side" compared with the other planets – most likely the result of an ancient, giant collision early in the Solar System's history.

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Một số mặt trăng đáng chú ý: **Io** (mặt trăng Sao Mộc) là thiên thể núi lửa hoạt động mạnh nhất Hệ Mặt Trời do lực hấp dẫn thay đổi liên tục từ Sao Mộc và các mặt trăng lân cận (nung nóng thủy triều); **Europa** được cho là có đại dương nước lỏng dưới lớp băng bề mặt; **Titan** (mặt trăng Sao Thổ) có khí quyển dày và hồ khí mê-tan lỏng. Vành đai Sao Thổ gồm vô số mảnh băng đá nhỏ. Ngoài quỹ đạo Sao Hải Vương là **Vành đai Kuiper** (nguồn gốc nhiều sao chổi) và xa hơn nữa là **Đám mây Oort**. Sao Diêm Vương bị xếp lại thành **hành tinh lùn** năm 2006 vì chưa "dọn sạch" quỹ đạo của nó khỏi các thiên thể khác cùng kích cỡ.

6.1.4 Natural Satellites: The Moon

The Moon is Earth's only natural satellite, held in orbit by Earth's gravitational pull acting as a centripetal force – the same principle described throughout this chapter for any orbiting body. Measured relative to the distant stars, the Moon completes one full orbit of Earth (its **sidereal orbital period**) in about 27.3 days.

Property of the Moon	Approximate value
Diameter	3.47×10^6 m (≈ 3474 km; about a quarter of Earth's diameter)
Mean distance from Earth	3.84×10^8 m (≈ 384000 km)
Orbital period (sidereal)	≈ 27.3 days ($\approx 2.36 \times 10^6$ s)
Mean orbital speed	≈ 1.0 km/s

Basic orbital and physical data for the Moon, Earth's only natural satellite.

The Moon and ocean tides: the Moon's gravitational pull on Earth is not perfectly uniform – it is slightly stronger on the side of Earth facing the Moon than on the far side. This difference in pull stretches Earth's oceans very slightly, producing two tidal bulges of water roughly aligned with the Earth–Moon line. As Earth rotates underneath these bulges once approximately every 24 hours, most coastal locations pass through both bulges, experiencing two high tides (and two low tides) per day. The Sun's gravity contributes to this effect too, though less strongly than the Moon's (despite the Sun's far greater mass, its much greater distance makes the *difference* in its pull across the Earth much smaller than the Moon's): when the Sun and Moon line up (at new moon and full moon) their combined pull produces unusually large "spring" tides, while at other points in the Moon's orbit their effects partly cancel, producing smaller "neap" tides.

(!) Lỗi thường gặp: The Moon's regularly changing appearance from Earth – from new moon, through crescent, quarter and gibbous phases, to full moon and back again – is caused simply by the **changing relative positions** of the Moon, Earth and Sun as the Moon orbits Earth, which changes how much of the Moon's permanently sunlit half is visible from Earth at any given time. This is entirely different from a **lunar eclipse**, in which Earth passes directly between the Sun and the Moon so that Earth's shadow falls on the Moon – a much rarer event that only occurs on the relatively few occasions when the Sun, Earth and Moon become closely aligned, not every month.

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Mặt Trăng là vệ tinh tự nhiên duy nhất của Trái Đất, được giữ trên quỹ đạo nhờ lực hấp dẫn của Trái Đất đóng vai trò lực hướng tâm. Chu kỳ quỹ đạo (so với các ngôi sao ở xa) khoảng $27,3$ ngày. Lực hấp dẫn của Mặt Trăng tác dụng không đều lên Trái Đất (mạnh hơn ở phía gần, yếu hơn ở phía xa) tạo ra hai chỗ phình nước đại dương, và khi Trái Đất tự quay quanh trục (khoảng 24 giờ), hầu hết các vùng ven biển sẽ đi qua cả hai chỗ phình này, tạo ra hai lần thủy triều cao và hai lần thủy triều thấp mỗi ngày. Mặt Trời cũng góp phần (yếu hơn Mặt Trăng); khi Mặt Trời và Mặt Trăng thẳng hàng (trăng non/trăng tròn) sẽ có thủy triều cường (spring tide) lớn hơn bình thường. **Lưu ý:** các pha của Mặt Trăng là do vị trí tương đối giữa Mặt Trăng–Trái Đất–Mặt Trời thay đổi, **không phải** do bóng của Trái Đất – đó là hiện tượng nguyệt thực (lunar eclipse), hiếm gặp hơn nhiều.

6.1.5 Escape of Gravity's Grip: Why Some Planets Keep an Atmosphere and Others Don't (Supplement, qualitative)

Whether a planet or moon can hold on to a gas atmosphere over billions of years depends on a competition between two factors: how strongly its gravity pulls on gas particles at its surface (which depends mainly on its **mass** – a more massive body produces a stronger surface gravitational field, and so requires a gas particle to reach a higher speed, called the **escape speed**, before it can escape into space), and how fast its gas particles are actually moving (which depends on **temperature** – hotter gas particles move faster, on average, and lighter gas particles such as hydrogen and helium naturally move fastest of all at any given temperature). A body can only retain a gas over long timescales if the typical speed of that gas's particles stays well below the body's escape speed. The **Moon** has only about $1/80$ of Earth's mass, giving it weak surface gravity and a low escape speed; even without being especially hot, this low escape speed has allowed almost all of its original gas to leak away into space over billions of years, leaving the Moon with essentially no atmosphere today. **Earth**, being far more massive, has a much higher escape speed and so can retain even relatively light gases such as nitrogen and oxygen. **Venus**, of broadly similar mass and size to Earth, is much hotter at its surface, yet its high escape speed (from its Earth-like mass) is still more than enough to retain an extremely thick atmosphere. **Mercury**, by contrast, combines both a small mass (low escape speed) *and* high daytime surface temperatures, and so retains essentially no atmosphere at all.

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Việc một hành tinh/mặt trăng có giữ được khí quyển hay không phụ thuộc vào **cả hai** yếu tố: lực hấp dẫn bề mặt (phụ thuộc khối lượng – khối lượng càng lớn thì tốc độ thoát (escape speed) cần thiết để hạt khí thoát ra ngoài không gian càng cao), và nhiệt độ (nhiệt độ càng cao thì hạt khí chuyển động càng nhanh, đặc biệt các khí nhẹ như hydro, heli). Mặt Trăng có khối lượng chỉ bằng khoảng 1/80 Trái Đất nên lực hấp dẫn yếu, tốc độ thoát thấp, khiến gần như toàn bộ khí đã thoát ra ngoài không gian dù Mặt Trăng không quá nóng. Trái Đất có khối lượng lớn hơn nhiều nên giữ được khí quyển; Sao Kim (khối lượng gần bằng Trái Đất) vẫn giữ được khí quyển rất dày dù rất nóng; còn Sao Thủy vừa nhỏ (hấp dẫn yếu) vừa rất nóng nên gần như không có khí quyển.

6.2 Gravity, Orbits and Orbital Speed

Gravity is the force that keeps every planet in orbit around the Sun, every moon in orbit around its planet, and every artificial satellite in orbit around Earth. In a stable orbit, the gravitational pull acts as a **centripetal force**: it constantly acts toward the centre of the orbit, continuously changing the *direction* of the orbiting body's velocity (keeping it moving in a curved path) without ever needing to change its speed or do net work on it – this is why an orbiting body does not need an engine running to "keep it moving".

(!) Lỗi thường gặp: Gravity provides the centripetal force that keeps a satellite (or planet, or moon) on its curved path – it does *not* "run out" or get used up over time, and a stable orbit does not require any engine thrust to be maintained. Many students incorrectly think satellites need constant propulsion to stay up; in reality, once in a stable orbit with the right speed, gravity alone maintains the orbit indefinitely (real satellites eventually need small corrections only because of tiny disturbances like atmospheric drag at very low altitudes, not because gravity itself weakens with time).

Gravitational field strength decreases as distance from the attracting body increases: the closer you are to the Sun (or to a planet), the stronger the gravitational pull you feel; the farther away, the weaker the pull. (At IGCSE you are not required to use an inverse-square-law formula for this – only the qualitative trend that **greater distance means weaker gravitational field strength** needs to be understood and applied.)

Orbital radius, period and speed: because the Sun's gravitational pull is weaker at greater distances, a planet farther from the Sun needs a lower orbital speed to stay in a stable orbit – and it also has a much longer path to travel around the Sun. Both effects act in the same direction, so: **the larger the orbital radius, the longer the orbital period, and the slower the orbital speed.** Mercury, the closest planet to the Sun, completes an orbit in only about 88 days, moving very fast; Neptune, the most distant major planet, takes about 165 *years* to complete one orbit, moving far more slowly. The same radius–period–speed relationship applies to moons orbiting planets and to artificial satellites orbiting Earth.

(!) Lỗi thường gặp: A very common confusion is getting the direction of the radius–period–speed relationship backwards, or assuming only *one* of period or speed changes with radius. In fact **both** change together in a consistent pattern: a **smaller** orbital radius always goes with a **shorter** period *and* a **faster** orbital speed (e.g. a low-Earth-orbit satellite, only a few hundred km up, orbits in about 90 minutes at roughly 7.7 km/s); a **larger** orbital radius always goes with a **longer** period *and* a **slower** speed (e.g. Neptune, 30 times farther from the Sun than Earth, takes 165 years to orbit at only about 5.4 km/s). Do not assume that being closer means "less distance to travel so it must be slower" – the opposite is true, because the stronger nearby gravity demands a faster speed to maintain a stable circular path.

(Supplement) For a body moving at constant speed around a circular orbit of radius r with orbital period T, the orbital speed is

$$v = \frac{2\pi r}{T}$$

(the circumference of the orbit, $2\pi r$, divided by the time taken to complete one full orbit).

Ví dụ 1 · Earth's orbital speed around the Sun

(Supplement) Earth orbits the Sun at a mean radius $r = 1.5 \times 10^{11}$ m, completing one orbit in $T = 3.15 \times 10^7$ s (one year). Find Earth's orbital speed.

$$v = \frac{2\pi r}{T} = \frac{2\pi(1.5 \times 10^{11})}{3.15 \times 10^7} = \frac{9.42 \times 10^{11}}{3.15 \times 10^7} \approx 2.99 \times 10^4\,\text{m/s} \approx 30\,\text{km/s}.$$

Ví dụ 2 · Mercury's orbital speed

(Supplement) Mercury orbits the Sun at a mean radius $r = 5.8 \times 10^{10}$ m, with a period $T = 88$ days. Find Mercury's orbital speed, in m/s.

First convert T to seconds: $T = 88 \times 24 \times 3600 = 7.6 \times 10^6$ s (to 2 s.f.).

$$v = \frac{2\pi r}{T} = \frac{2\pi(5.8 \times 10^{10})}{7.6 \times 10^6} = \frac{3.64 \times 10^{11}}{7.6 \times 10^6} \approx 4.8 \times 10^4\,\text{m/s} \approx 48\,\text{km/s}.$$

Mercury – much closer to the Sun and with a much shorter period than Earth – orbits noticeably *faster* than Earth, exactly as the radius–period–speed relationship predicts.

Ví dụ 3 · Neptune's orbital speed

(Supplement) Neptune orbits the Sun at a mean radius $r = 4.5 \times 10^{12}$ m, with a period $T = 165$ years. Find Neptune's orbital speed, in m/s.

Convert T to seconds (using 1 year $\approx 3.15 \times 10^7$ s): $T = 165 \times 3.15 \times 10^7 \approx 5.2 \times 10^9$ s.

$$v = \frac{2\pi r}{T} = \frac{2\pi(4.5 \times 10^{12})}{5.2 \times 10^9} = \frac{2.83 \times 10^{13}}{5.2 \times 10^9} \approx 5.4 \times 10^3\,\text{m/s} \approx 5.4\,\text{km/s}.$$

Neptune – 30 times farther from the Sun than Earth, with a period 165 times longer – orbits far more slowly than Earth or Mercury, again consistent with the radius–period–speed relationship.

Planet	Mean orbital radius	Orbital period
Mercury	0.39 AU	88 days (≈ 0.24 yr)
Venus	0.72 AU	225 days (≈ 0.62 yr)
Earth	1.00 AU	365 days (1.0 yr)
Mars	1.52 AU	687 days (≈ 1.9 yr)
Jupiter	5.2 AU	11.9 yr
Saturn	9.5 AU	29.5 yr
Uranus	19.2 AU	84 yr
Neptune	30.1 AU	165 yr

Orbital radius (in astronomical units, AU, where 1 AU $\approx 1.5 \times 10^{11}$ m is the mean Earth–Sun distance) and orbital period for the eight planets. As radius increases, period increases far more than the radius alone would suggest – a consequence of orbital speed *also* decreasing with radius.

Planet	Type	Known moons (approx.)	Notable feature
Mercury	Terrestrial	0	Smallest planet; huge day–night temperature swing
Venus	Terrestrial	0	Thick CO_2 atmosphere; hottest planet surface
Earth	Terrestrial	1	Only known planet with life
Mars	Terrestrial	2	Largest volcano and canyon in the Solar System
Jupiter	Gas giant	90+	Largest planet; Great Red Spot storm
Saturn	Gas giant	140+	Most extensive, visible ring system
Uranus	Ice giant	25+	Axis tilted $\approx 98^{\circ}$ (rotates "on its side")
Neptune	Ice giant	14+	Strongest winds measured of any planet

Quick-reference facts for the eight planets (moon counts are approximate and continue to be revised as more small moons are discovered).

Ví dụ 4 · Comparing orbital period and speed at two radii

A newly discovered planet, Planet X, orbits the same star as Earth-like Planet Y, at a much greater orbital radius than Planet Y. State, with reasoning, how Planet X's orbital period and orbital speed compare with Planet Y's.

Since Planet X is farther from the star, the star's gravitational pull on it is **weaker**, so Planet X needs a **lower orbital speed** to remain in a stable orbit. Planet X also has a much **longer path** (larger circumference) to travel around the star. Both effects combine, so Planet X has a **longer orbital period** than Planet Y, and a **slower orbital speed** than Planet Y – the same pattern seen between, for example, Mercury and Neptune in our own Solar System.

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Lực hấp dẫn đóng vai trò lực hướng tâm giữ hành tinh/mặt trăng/vệ tinh trên quỹ đạo, luôn hướng vào tâm quỹ đạo và không hề "cạn kiệt" theo thời gian. Độ mạnh trường hấp dẫn giảm khi khoảng cách tăng (chỉ cần hiểu xu hướng định tính). Bán kính quỹ đạo càng lớn thì chu kỳ quỹ đạo càng dài và tốc độ quỹ đạo càng chậm – ví dụ Sao Thủy (gần Mặt Trời) quay hết 88 ngày, trong khi Sao Hải Vương (xa Mặt Trời) mất tới 165 năm. Công thức (Supplement) $v = 2\pi r/T$ tính tốc độ quỹ đạo từ chu vi quỹ đạo $2\pi r$ chia cho chu kỳ T.

Why astronauts appear weightless in orbit

A common misconception is that astronauts aboard the International Space Station (ISS) are weightless because there is no gravity at that altitude. This is *not* true: at the ISS's altitude (only a few hundred km above Earth's surface – tiny compared with Earth's radius of about 6400 km), Earth's gravitational field strength is only slightly less than at the surface, so the astronauts still have almost their full weight acting on them. The real reason they *appear* weightless is that the ISS – and everything inside it, including the astronauts – is continuously **falling freely** toward Earth under gravity, while also moving forward fast enough that the curve of its fall matches the curvature of the Earth below. This is exactly what an orbit is. Because the astronaut and the spacecraft are falling at the *same* rate, there is no contact (normal) force between the astronaut and the floor – and it is precisely that contact force we perceive as "weight" in everyday life. Hence the sensation of weightlessness, even though gravity itself has certainly not disappeared.

Ví dụ 5 · A comet's changing orbital speed

A comet follows a highly elliptical orbit around the Sun, rather than a circular one. State, with reasoning, at which point in its orbit the comet moves fastest, and at which point it moves slowest.

The comet moves **fastest** at its closest approach to the Sun (called **perihelion**), where the Sun's gravitational pull on it is strongest. It moves **slowest** at its farthest point from the Sun (called **aphelion**), where the pull is weakest. This is the same radius–speed relationship seen for planets in circular orbits, applied instead to a single body whose distance from the Sun continuously changes as it travels around one elliptical orbit.

VN **GIẢI THÍCH TIẾNG VIỆT**

Phi hành gia trên Trạm Vũ trụ Quốc tế (ISS) **không** phải ở trạng thái không trọng lực vì hết lực hấp dẫn – ở độ cao đó, trường hấp dẫn của Trái Đất chỉ yếu đi một chút so với mặt đất. Cảm giác "không trọng lượng" thực ra là do phi hành gia và trạm vũ trụ đang **rơi tự do** cùng tốc độ quanh Trái Đất (đây chính là bản chất của quỹ đạo), nên không có lực tiếp xúc giữa người và sàn tàu – chính lực tiếp xúc đó mới tạo ra cảm giác "trọng lượng" hằng ngày. Với sao chổi trên quỹ đạo elip, tốc độ nhanh nhất khi ở gần Mặt Trời nhất (perihelion) và chậm nhất khi ở xa Mặt Trời nhất (aphelion), do lực hấp dẫn mạnh/yếu tương ứng.

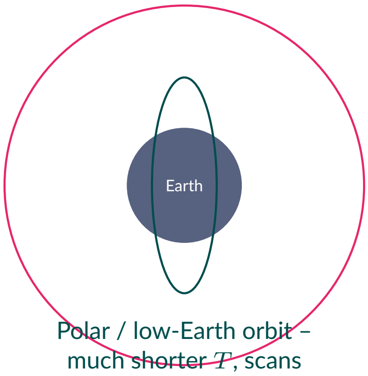
6.3 Artificial Satellites

An **artificial satellite** is any human-made object placed into orbit, typically around Earth. Like natural satellites (moons), artificial satellites are held in orbit purely by gravity acting as a centripetal force; different applications call for very different orbits.

Geostationary orbit: a satellite in geostationary orbit has an orbital period of exactly 24 hours and orbits directly above the **equator**, in the same direction as Earth's rotation. Because its period exactly matches Earth's rotation period, the satellite appears to stay fixed above the *same* point on Earth's surface at all times, as seen from the ground. This makes geostationary orbits ideal for **communications satellites** (a satellite dish on the ground can point at a single fixed spot in the sky) and for **weather satellites** monitoring the same region of Earth continuously. Geostationary orbits require a large orbital radius (about 4.2×10^7 m from Earth's centre, roughly 36000 km above the surface).

(!) Lỗi thường gặp: A satellite is *not* geostationary just because it is "high up" – geostationary status requires **both** an orbital period of exactly 24 hours **and** an orbit directly above the equator. A satellite at the right altitude but tilted at an angle to the equator, or at the wrong altitude even if above the equator, will not stay above a fixed point on Earth's surface. The 24-hour period is fixed by the specific orbital radius that geostationary orbits require – you cannot simply choose any high orbit and call it geostationary.

Low-Earth orbit (LEO) / polar orbit: satellites much closer to Earth's surface (a few hundred to a few thousand km up) have a much **shorter** orbital period (often 90–100 minutes) because of their smaller orbital radius. Many are placed in **polar orbits**, passing over (or near) the North and South poles on each orbit; because Earth rotates underneath the satellite's orbital plane, a polar-orbiting satellite passes over a *different* strip of the Earth's surface on each successive orbit, eventually scanning the *entire* globe over the course of a day. This makes low-Earth/polar orbits ideal for **Earth-imaging and environmental-monitoring satellites** (e.g. mapping, reconnaissance, tracking deforestation or ice cover) and for satellites like the International Space Station.



A geostationary orbit (large radius, $T = 24$ h, directly above the equator) keeps a satellite fixed over one point on Earth. A polar/low-Earth orbit (small radius, short period) passes over different strips of the globe on successive orbits.

Feature	Geostationary orbit	Low-Earth / polar orbit
Orbital radius	Very large ($\approx 4.2 \times 10^7$ m from Earth's centre)	Small (a few hundred to a few thousand km altitude)
Orbital period	Exactly 24 hours	Short (often 90–100 minutes)
Position relative to ground	Fixed above one point (above the equator)	Sweeps over a different strip of Earth each orbit
Typical uses	Communications, broadcast television, weather monitoring of one region	Earth imaging, environmental monitoring, the ISS

Comparing the two main categories of Earth-orbiting satellite discussed in this section.

Ví dụ 6 · Orbital speed of a geostationary satellite

(Supplement) A geostationary satellite orbits at radius $r = 4.2 \times 10^7$ m with period $T = 24$ hours. Find its orbital speed.

$T = 24 \times 3600 = 86400$ s.

$$v = \frac{2\pi r}{T} = \frac{2\pi(4.2 \times 10^7)}{86400} = \frac{2.64 \times 10^8}{86400} \approx 3.1 \times 10^3 \text{ m/s} \approx 3.1 \text{ km/s}.$$

Ví dụ 7 · Orbital speed of a low-Earth-orbit satellite

(Supplement) A satellite in low-Earth orbit has radius $r = 7.0 \times 10^6$ m and period $T = 5.8 \times 10^3$ s (about 97 minutes). Find its orbital speed.

$$v = \frac{2\pi r}{T} = \frac{2\pi(7.0 \times 10^6)}{5.8 \times 10^3} = \frac{4.40 \times 10^7}{5.8 \times 10^3} \approx 7.6 \times 10^3\,\text{m/s} \approx 7.6\,\text{km/s}.$$

Notice this is much faster than the geostationary satellite in the previous example – consistent with its much smaller orbital radius.

Ví dụ 8 · Choosing the right satellite orbit

A television broadcasting company wants a satellite that a household satellite dish can point at permanently, without needing to track its motion across the sky. State which type of orbit is suitable, and explain why.

A **geostationary orbit** is suitable. Because a geostationary satellite has a 24-hour period and orbits directly above the equator (matching Earth's own rotation), it remains above the *same* point on Earth's surface at all times – so a satellite dish can be fixed permanently in one direction without needing to track the satellite's motion across the sky, unlike a low-Earth-orbit satellite, which would rise and set within minutes.

A third category: navigation satellites. Global positioning systems (such as GPS) use a whole **constellation** of satellites (typically around 24–32) in **medium-Earth orbit** – higher than a typical low-Earth orbit but much lower than geostationary orbit, with a period of about 12 hours. Using many satellites spread around several orbital planes ensures that a receiver on the ground can always detect signals from several satellites simultaneously, however the constellation is arranged, allowing its position to be calculated precisely by comparing the timing of signals from each visible satellite. **Orbital decay:** satellites in *very* low orbits experience a small amount of drag from the thin outer atmosphere, which very gradually removes energy from the orbit and causes the orbital radius to slowly shrink over months or years, eventually causing re-entry unless the satellite periodically boosts itself back up – this is a separate effect from the (constant, ever-present) centripetal role that gravity itself plays in maintaining the orbit.

VN **GIẢI THÍCH TIẾNG VIỆT**

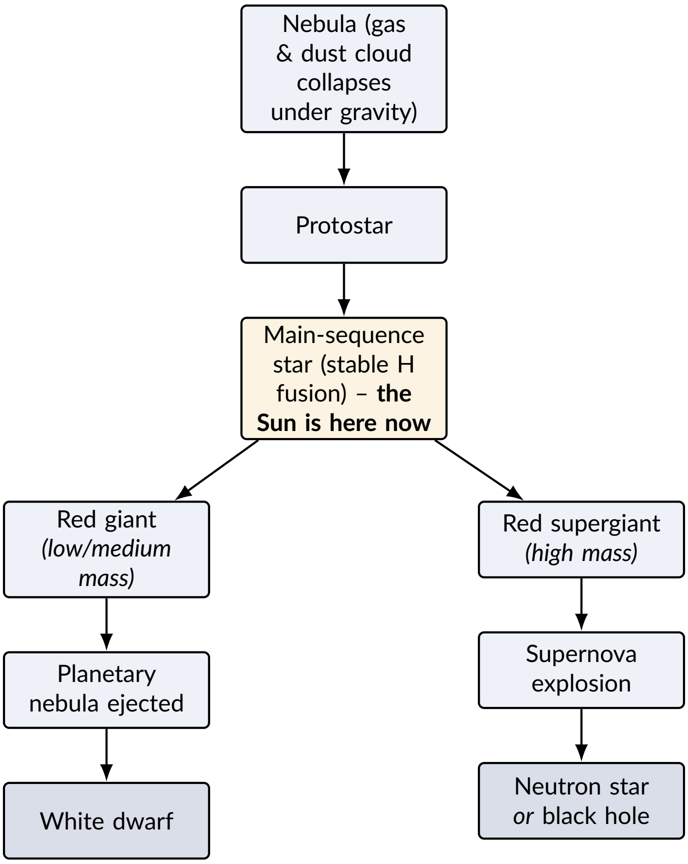
Vệ tinh địa tĩnh (geostationary) có chu kỳ đúng 24 giờ và bay phía trên **xích đạo**, nên luôn ở cố định trên một điểm của Trái Đất – dùng cho truyền hình, viễn thông, quan sát thời tiết một vùng liên tục. Vệ tinh quỹ đạo thấp/quỹ đạo cực (LEO/polar) bay gần Trái Đất hơn nên chu kỳ ngắn hơn nhiều (khoảng 90–100 phút), quét qua các dải khác nhau của Trái Đất sau mỗi vòng – dùng để chụp ảnh, giám sát môi trường, bản đồ toàn cầu. Một vệ tinh chỉ được gọi là địa tĩnh khi thỏa **cả hai** điều kiện: chu kỳ 24h VÀ nằm phía trên xích đạo. Hệ thống định vị GPS dùng một chùm khoảng 24–32 vệ tinh ở quỹ đạo tầm trung (chu kỳ khoảng 12 giờ) để luôn có tín hiệu từ nhiều vệ tinh cùng lúc. Vệ tinh ở quỹ đạo rất thấp có thể bị suy giảm quỹ đạo dần theo thời gian do ma sát với khí quyển mỏng còn sót lại – đây là hiệu ứng khác, không liên quan đến việc lực hấp dẫn "cạn kiệt".

6.4 The Life Cycle of Stars (Supplement)

(Supplement) How a star is born, lives, and dies

A star begins life as a **nebula** – a vast cloud of gas (mostly hydrogen) and dust in space. Gravity pulls the material in the nebula together; as it collapses, it heats up and forms a **protostar**. Once the core becomes hot and dense enough for hydrogen nuclei to fuse into helium, the protostar becomes a stable **main-sequence star**: a star in this long, stable phase generates enough outward pressure from fusion to balance the inward pull of its own gravity, so it neither collapses further nor expands – our Sun is currently a main-sequence star, and has been for about 4.6 billion years. What happens after the main-sequence phase depends on the star's mass:

- **A star of low or medium mass (like the Sun):** once the hydrogen fuel in its core runs low, the core contracts and heats further while the outer layers expand and cool, and the star becomes a **red giant**. Eventually the outer layers are gently blown off into space, forming a glowing shell of gas called a **planetary nebula**, leaving behind a small, extremely dense, hot core called a **white dwarf**, which then slowly cools over billions of years.
- **A star of much greater mass:** such a star swells into an even larger, more luminous **red supergiant**. When its core fuel is exhausted, the core collapses catastrophically while the outer layers are blasted outward in a massive explosion called a **supernova** – briefly outshining an entire galaxy. What remains of the core afterward depends on its mass: a **neutron star** (an incredibly dense, small remnant made almost entirely of neutrons) for a moderately massive remnant, or a **black hole** (a region of space where gravity is so strong that not even light can escape) for the most massive remnants.



(Supplement) The life cycle of a star. Every star begins the same way (nebula → protostar → main sequence); the final stages depend entirely on the star's mass, splitting into a low/medium-mass path (left) and a high-mass path (right).

Ví dụ 9 · Predicting a star's life-cycle path from its mass

(Supplement) A star has a mass about 20 times that of the Sun. Describe the sequence of stages this star is expected to go through over its lifetime.

A star this massive follows the **high-mass path**: it forms from a nebula, becomes a protostar, and then a main-sequence star (fusing hydrogen, just as the Sun does now, but much more rapidly given its far greater mass). Once its core fuel is exhausted it swells into a **red supergiant**, then undergoes a catastrophic core collapse and **supernova** explosion. What remains of the core afterward becomes either a **neutron star** or, since 20 solar masses is a very large initial mass, quite possibly a **black hole**, depending on the exact mass of the collapsed remnant.

(Supplement) **Mass and main-sequence lifetime:** the more massive a main-sequence star is, the **hotter** it burns and the **faster** it uses up its hydrogen fuel – so, counter-intuitively, the most massive stars actually have the *shortest* main-sequence lifetimes (millions of years, rather than billions), while lower-mass stars burn their fuel far more slowly and can remain on the main sequence for tens of billions of years. **Supernovae and the origin of heavy elements:** the extreme conditions inside a supernova explosion are hot and energetic enough to forge elements heavier than iron (such as gold, silver, and uranium), which ordinary nuclear fusion inside a star cannot produce. These heavy elements are scattered into space by the explosion and can later be incorporated into new nebulae, new stars, new planets – and, ultimately, into the chemical elements that make up living things.

VN GIẢI THÍCH TIẾNG VIỆT

Mọi ngôi sao đều bắt đầu giống nhau: tinh vân (nebula) co lại do hấp dẫn → sao tiền sao (protostar) → sao dãy chính (main sequence, khi phản ứng nhiệt hạch hydro ổn định – Mặt Trời hiện đang ở giai đoạn này). Sau đó, con đường phụ thuộc khối lượng: sao khối lượng thấp/trung bình (như Mặt Trời) → sao khổng lồ đỏ (red giant) → tinh vân hành tinh (planetary nebula) → sao lùn trắng (white dwarf); sao khối lượng lớn hơn nhiều → sao siêu khổng lồ đỏ (red supergiant) → vụ nổ siêu tân tinh (supernova) → sao neutron hoặc lỗ đen (black hole). Sao càng nặng thì cháy càng nhanh, tuổi thọ dãy chính càng **ngắn** (trái với trực giác); các nguyên tố nặng hơn sắt (như vàng, uranium) chỉ được tạo ra trong vụ nổ siêu tân tinh, sau đó phát tán vào không gian để hình thành các ngôi sao, hành tinh – và sự sống – thế hệ sau.

6.5 Classifying Stars: Brightness, Temperature and Colour (Supplement)

(Supplement) Stars can be compared and classified by their **brightness** (how much light they emit, related to both their size and temperature) and their **surface temperature**, which is closely linked to their **colour**: hotter stars appear more **blue-white**, while cooler stars appear more **red**/orange. A very hot, young, massive star may appear blue-white; a cooler, older, lower-mass star (or a red giant/supergiant, whose surface has cooled and expanded) appears distinctly red or orange. Our Sun, a medium-temperature main-sequence star, appears yellow-white. This means colour alone gives useful information about a star's surface temperature, even without any other measurement.

(Supplement) Apparent brightness versus true luminosity: how bright a star *looks* to us from Earth (its **apparent brightness**) depends on *both* how much light it actually emits (its true **luminosity**) *and* how far away it is – a highly luminous star that is very far away can look fainter than a much less luminous star that is nearby, so apparent brightness alone cannot be used to judge a star's true energy output without also knowing its distance. For example: **Betelgeuse** is a red supergiant – enormous and highly luminous, but relatively cool, so it appears distinctly reddish; **Rigel** is a blue-white supergiant – extremely hot and even more luminous than Betelgeuse; **Sirius**, the brightest star in the night sky as seen from Earth, is a fairly ordinary hot white main-sequence star that appears so bright mainly because it is one of the closest stars to us, not because it is exceptionally luminous.

VN GIẢI THÍCH TIẾNG VIỆT

Có thể phân loại sao dựa trên độ sáng và nhiệt độ bề mặt, và nhiệt độ liên hệ chặt chẽ với **màu sắc**: sao càng nóng thì càng có màu **xanh–trắng**, sao càng nguội thì càng có màu **đỏ/cam**. Mặt Trời có nhiệt độ trung bình nên có màu vàng–trắng. Chỉ cần nhìn màu của một ngôi sao cũng có thể ước lượng được nhiệt độ bề mặt của nó. **Độ sáng biểu kiến** (nhìn thấy từ Trái Đất) phụ thuộc vào **cả** độ sáng thực (luminosity) **lẫn** khoảng cách – một ngôi sao rất sáng nhưng ở rất xa có thể trông mờ hơn một ngôi sao gần hơn nhưng kém sáng hơn. Ví dụ: Sao Thiên Lang (Sirius) sáng nhất bầu trời đêm chủ yếu vì nó ở rất gần, không hẳn vì nó cực kỳ sáng.

6.6 Galaxies and the Scale of the Universe

A **galaxy** is a vast collection of billions of stars (together with gas, dust, and the effects of dark matter) held together by their mutual gravitational attraction. Our Sun is just one of **more than** 100 **billion stars** in our own galaxy, the **Milky Way**. Galaxies themselves are enormously far apart, and galaxies are grouped into even larger structures (clusters and superclusters) throughout the observable universe, which contains at least 100 billion galaxies.

Because distances in space are so vast, using metres (or even kilometres) quickly leads to unwieldy numbers. Astronomers instead commonly use the **light-year (ly)** – the distance that light travels through empty space in one year – as a convenient unit of distance for comparing stellar and galactic distances.

(!) Lỗi thường gặp: A light-year is a unit of **distance**, *not* a unit of time – despite containing the word "year". A statement like "Proxima Centauri is 4.2 light-years away" means light takes 4.2 years to travel from there to here; it tells you *how far away* the star is, not how long ago something happened (although, since light takes time to travel, we *do* see that star as it was 4.2 years ago – but the light-year itself remains fundamentally a distance measurement, calculated from a speed multiplied by a time).

Ví dụ 10 · Light-year conversions (both directions)

(a) Calculate the distance of one light-year in metres, using $c = 3.0 \times 10^8$ m/s and 1 year $\approx 3.15 \times 10^7$ s.

1 ly $= c \times t = (3.0 \times 10^8)(3.15 \times 10^7) \approx 9.5 \times 10^{15}$ m.

(b) The star Sirius is about 8.6 light-years from Earth. Express this distance in metres.

Distance $= 8.6 \times (9.5 \times 10^{15}) \approx 8.1 \times 10^{16}$ m.

(c) The star Proxima Centauri is 4.0×10^{16} m from Earth. Express this distance in light-years.

$$\text{Distance in ly} = \frac{4.0 \times 10^{16}}{9.5 \times 10^{15}} \approx 4.2 \text{ light-years.}$$

Types of galaxies and our cosmic neighbourhood: galaxies are broadly classified by shape into **spiral** galaxies (a flattened, rotating disc with curved arms of stars, gas and dust, and a dense central bulge – both the Milky Way and our nearest large neighbour, the Andromeda Galaxy, are spirals), **elliptical** galaxies (a smooth, rounded, football-to-sphere-shaped collection of stars with comparatively little gas or dust left to form new stars), and **irregular** galaxies (with no clear, organised shape). Our Milky Way belongs to a small cluster of around 50 galaxies called the **Local Group**, which includes the Andromeda Galaxy – our Local Group is itself just one small part of the much larger Virgo Supercluster. Interestingly, unlike almost all distant galaxies, **Andromeda shows a blueshift, not a redshift**: it is one of the few galaxies close enough that its motion, under the mutual gravitational pull within the Local Group, is currently bringing it *toward* us rather than away.

VN GIẢI THÍCH TIẾNG VIỆT

Vì khoảng cách trong vũ trụ quá lớn, các nhà thiên văn dùng đơn vị **năm ánh sáng (light-year)** – quãng đường ánh sáng đi được trong một năm – thay vì mét. **Năm ánh sáng là đơn vị đo khoảng cách, không phải đơn vị thời gian**, dù trong tên có chữ "năm". Ngân Hà (Milky Way) của chúng ta chứa hơn 100 tỉ ngôi sao, và Mặt Trời chỉ là một trong số đó. Vũ trụ quan sát được chứa ít nhất 100 tỉ thiên hà. Thiên hà có ba dạng chính: xoắn ốc (spiral, như Ngân Hà và thiên hà Andromeda), elip (elliptical), và không định hình (irregular). Ngân Hà thuộc "Nhóm Địa Phương" (Local Group) gồm khoảng 50 thiên hà; đặc biệt, Andromeda lại dịch chuyển **xanh** (blueshift) vì đang tiến lại gần chúng ta do hấp dẫn trong Nhóm Địa Phương, khác với đa số thiên hà xa hơn đang dịch chuyển đỏ.

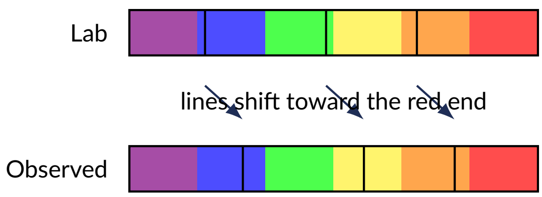
6.7 Redshift, Hubble's Law and the Big Bang (Supplement)

(Supplement) When light from a distant galaxy is analysed, the characteristic pattern of dark lines in its spectrum is found shifted toward the **red** (longer-wavelength) end of the spectrum, compared to the same pattern measured from a source at rest in the laboratory. This is called **redshift**, and it is evidence that the galaxy is moving *away* from us. Measurements show that, in general, the **more distant** a galaxy is, the **greater** its redshift – meaning more distant galaxies are receding *faster*. This observation (that almost all distant galaxies are moving away from us, faster the farther away they are) is one of the key pieces of evidence that the universe as a whole is expanding.

(Supplement) An everyday analogy: the Doppler effect

Redshift is closely related to the everyday **Doppler effect** heard with sound: as an ambulance siren approaches you, the sound waves are compressed, raising the pitch you hear; as it moves away, the sound waves are stretched out, lowering the pitch. Exactly the same principle applies to light waves from a moving source: light from a galaxy moving *away* from us has its wavelengths stretched out, shifting it toward the red (longer-wavelength) end of the spectrum – a redshift; light from a source moving *toward* us would instead be compressed toward the blue (shorter-wavelength) end – a blueshift. This relationship between the light received from galaxies and their motion was discovered observationally in the 1920s by the American astronomer **Edwin Hubble**, whose measurements of galaxy redshifts and distances first revealed that (almost) all distant galaxies are receding from us, laying the observational foundation for the expanding-universe and Big Bang models.

(!) Lỗi thường gặp: Redshift does *not* mean that a galaxy visibly changes colour to red, or that we would literally see it glowing red if we looked at it directly. "Redshift" refers only to a shift of the *specific wavelengths* in a galaxy's spectrum toward the red (long-wavelength) end, compared to a reference spectrum – it is detected by careful spectral analysis, not by the naked-eye colour of the galaxy, and most redshifted galaxies do not appear visibly red-tinted at all.

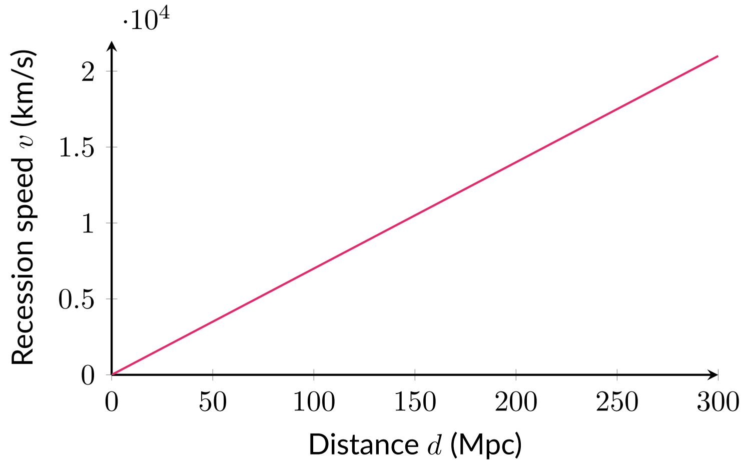


(Supplement) Redshift: the dark spectral lines from a distant, receding galaxy (bottom) are found shifted toward the red end of the spectrum, compared to the same lines measured from a stationary laboratory source (top).

(Supplement) Hubble's law: the recession speed v of a distant galaxy is directly proportional to its distance d from us:

$$v = H_0 d$$

where H_0 is the **Hubble constant**. Because $v = H_0 d$ implies $d = v/H_0$, measuring a galaxy's recession speed (from its redshift) lets astronomers calculate its distance. Hubble's law also allows an estimate of the **age of the universe**: if all galaxies have been receding at their current speeds ever since a single starting point, the age of the universe is approximately $\frac{1}{H_0}$.



(Supplement) Hubble's law: recession speed is directly proportional to distance, giving a straight line through the origin; the gradient of the line equals the Hubble constant H_0 (here 70 km/s/Mpc).

Ví dụ 11 · Using Hubble's law

(Supplement) Take $H_0 = 70\,\text{km/s/Mpc}$ (Mpc = megaparsec, a unit of distance used for galaxies).

(a) A galaxy's recession speed, measured from its redshift, is $v = 3500\,\text{km/s}$. Find its distance.

$d = \dfrac{v}{H_0} = \dfrac{3500}{70} = 50\,\text{Mpc}$.

(b) Another galaxy is measured at a distance of $d = 200\,\text{Mpc}$. Find its expected recession speed.

$v = H_0 d = 70 \times 200 = 14000\,\text{km/s} = 1.4 \times 10^4\,\text{km/s}$.

Ví dụ 12 · Estimating the age of the universe

(Supplement) Using $H_0 = 70\,\text{km/s/Mpc}$, and given that $1\,\text{Mpc} \approx 3.09 \times 10^{19}\,\text{km}$, estimate the age of the universe in years (using 1 year $\approx 3.15 \times 10^7$ s).

First convert H_0 into units of s^{-1}: $H_0 = \dfrac{70\,\text{km/s}}{3.09 \times 10^{19}\,\text{km}} \approx 2.27 \times 10^{-18}\,\text{s}^{-1}$.

Age $\approx \dfrac{1}{H_0} = \dfrac{1}{2.27 \times 10^{-18}} \approx 4.4 \times 10^{17}$ s.

Converting to years: $\dfrac{4.4 \times 10^{17}}{3.15 \times 10^7} \approx 1.4 \times 10^{10}$ years, i.e. $\boxed{\text{approximately } 14 \text{ billion years}}$.

(Supplement) The Big Bang theory: the observation that galaxies are receding from us in every direction, faster the farther away they are, strongly suggests that the entire universe was, in the distant past, concentrated in an extremely hot, dense state, and has been expanding ever since – an event known as the **Big Bang**. A key additional piece of supporting evidence is the **cosmic microwave background (CMB) radiation**: faint microwave radiation detected coming from every direction in space, understood as the cooled, stretched-out remnant of the intense radiation released in the very early, hot, dense universe. The existence, uniformity, and precise properties of this background radiation are strong evidence supporting the Big Bang model over alternative explanations for the universe's origin.

VN GIẢI THÍCH TIẾNG VIỆT

Dịch chuyển đỏ (redshift): vạch quang phổ của thiên hà xa dịch về phía đỏ (bước sóng dài hơn) so với nguồn đứng yên – đây là bằng chứng thiên hà đang chuyển động ra xa chúng ta; thiên hà càng xa thì dịch chuyển đỏ càng lớn (tốc độ lùi ra xa càng nhanh). **Lưu ý:** dịch chuyển đỏ không có nghĩa là thiên hà đổi màu thành đỏ khi nhìn bằng mắt thường – đây chỉ là sự dịch chuyển của các vạch quang phổ cụ thể. **Định luật Hubble:** $v = H_0 d$, dùng để tính khoảng cách hoặc tốc độ lùi ra xa của thiên hà, và ước tính tuổi vũ trụ $\approx 1/H_0$ (khoảng 14 tỉ năm). **Thuyết Big Bang:** vũ trụ từng ở trạng thái cực nóng, cực đặc và đã giãn nở từ đó đến nay; bức xạ nền vi sóng vũ trụ (CMB) là bằng chứng quan trọng ủng hộ thuyết này. Hiện tượng dịch chuyển đỏ tương tự **hiệu ứng Doppler** của âm thanh (còi xe cấp cứu nghe cao hơn khi lại gần, trầm hơn khi ra xa) – nhà thiên văn Edwin Hubble là người phát hiện mối liên hệ này vào thập niên 1920.

Quantity	Approximate value used in this chapter
Speed of light, c	3.0×10^8 m/s
Mean Earth–Sun distance (1 AU)	1.5×10^{11} m
One light-year	$\approx 9.5 \times 10^{15}$ m
Sun's surface / core temperature	$\approx 5500\,^\circ$C / ≈ 15 million $^\circ$C
Stars in the Milky Way	Over 100 billion
Hubble constant, H_0 (example value)	70 km/s/Mpc
Estimated age of the universe, $\approx 1/H_0$	≈ 14 billion years

Key approximate quantities used throughout this chapter's worked examples.

Ví dụ 13 · Venus's orbital speed

(Supplement) Venus orbits the Sun at a mean radius $r = 1.08 \times 10^{11}$ m (0.72 AU), with an orbital period $T = 225$ days. Find Venus's orbital speed, in m/s.

Convert T to seconds: $T = 225 \times 24 \times 3600 = 1.944 \times 10^7$ s.

$$v = \frac{2\pi r}{T} = \frac{2\pi(1.08 \times 10^{11})}{1.944 \times 10^7} = \frac{6.79 \times 10^{11}}{1.944 \times 10^7} \approx 3.5 \times 10^4 \text{ m/s} \approx 35 \text{ km/s}.$$

Venus – closer to the Sun than Earth, but farther than Mercury – orbits faster than Earth (≈ 30 km/s) but slower than Mercury (≈ 48 km/s), exactly as expected from the radius–period–speed relationship.

Ví dụ 14 · Converting an AU distance to metres and to light-years

(Supplement) Saturn orbits the Sun at a mean distance of 9.5 AU, where 1 AU $\approx 1.5 \times 10^{11}$ m (the mean Earth–Sun distance).

(a) Express Saturn's mean distance from the Sun in metres.

$d = 9.5 \times (1.5 \times 10^{11}) = 1.425 \times 10^{12} \approx 1.4 \times 10^{12}$ m.

(b) Using 1 light-year $\approx 9.5 \times 10^{15}$ m (as found earlier in this chapter), express this same distance in light-years.

$$d = \frac{1.425 \times 10^{12}}{9.5 \times 10^{15}} \approx 1.5 \times 10^{-4} \text{ light-years.}$$

This very small result illustrates why astronomers use the AU (not the light-year) for distances *within* a solar system, reserving the much larger light-year for the far greater distances *between* stars and galaxies.

6.8 Practice Problems

Bài tập luyện tập

A newly observed planet orbits its star at a much greater radius than Earth orbits the Sun. Compared with Earth, this planet's orbital period is expected to be:

(A) Shorter, and its orbital speed faster

(B) Longer, and its orbital speed slower

(C) The same, but its orbital speed slower

(D) Longer, but its orbital speed faster

Lời giải chi tiết

A larger orbital radius means a weaker gravitational pull, requiring a lower orbital speed, combined with a much longer path to travel – so both the period is longer *and* the speed is slower. **(B).**

Bài tập luyện tập

(Supplement) A satellite orbits Earth at radius $r = 6.6 \times 10^6$ m with period $T = 5400$ s. Calculate its orbital speed.

Lời giải chi tiết

$$v = \frac{2\pi r}{T} = \frac{2\pi(6.6 \times 10^6)}{5400} = \frac{4.147 \times 10^7}{5400} \approx \boxed{7.7 \times 10^3\,\text{m/s} \approx 7.7\,\text{km/s}}.$$

Bài tập luyện tập

Place the following stages of a very massive star's life cycle in the correct order: (i) supernova, (ii) main-sequence star, (iii) nebula, (iv) neutron star or black hole, (v) red supergiant, (vi) protostar.

(A) iii, vi, ii, v, i, iv
(B) iii, ii, vi, v, i, iv
(C) vi, iii, ii, v, i, iv
(D) iii, vi, ii, i, v, iv

Lời giải chi tiết

The correct sequence is: nebula (iii) → protostar (vi) → main-sequence star (ii) → red supergiant (v) → supernova (i) → neutron star or black hole (iv). **(A).**

Bài tập luyện tập

(Supplement) A galaxy's recession speed, measured from its redshift, is $v = 5600$ km/s. Using $H_0 = 70$ km/s/Mpc, find its distance.

Lời giải chi tiết

$$d = \frac{v}{H_0} = \frac{5600}{70} = \boxed{80\,\text{Mpc}}.$$

Bài tập luyện tập

Proxima Centauri is 4.0×10^{16} m from Earth. Using 1 light-year $\approx 9.5 \times 10^{15}$ m, express this distance in light-years.

Lời giải chi tiết

$$\text{Distance} = \frac{4.0 \times 10^{16}}{9.5 \times 10^{15}} \approx \boxed{4.2\ \text{light-years}}.$$

Bài tập luyện tập

A light-year is a unit of:

(A) Time
(B) Distance
(C) Speed
(D) Mass

Lời giải chi tiết

A light-year is the *distance* light travels in one year – despite containing the word "year", it measures distance, not time. **(B)**.

Bài tập luyện tập

(Supplement) Describe the life cycle of a star with a mass similar to the Sun's, from formation to its final state.

Lời giải chi tiết

The star begins as a **nebula** (a cloud of gas and dust) that collapses under gravity into a **protostar**, which becomes a stable **main-sequence star** once hydrogen fusion begins in its core (this is the stage the Sun is in now). When core hydrogen runs low, the star expands and cools into a **red giant**. Eventually its outer layers are ejected as a **planetary nebula**, leaving behind a small, dense, hot core called a **white dwarf**, which then cools slowly over billions of years.

$\boxed{\text{Nebula} \to \text{protostar} \to \text{main sequence} \to \text{red giant} \to \text{planetary nebula} \to \text{white dwarf}}$

Bài tập luyện tập

(Supplement) Describe the life cycle of a star with a mass much greater than the Sun's, from formation to its final state.

Lời giải chi tiết

As with any star, it begins as a **nebula** → **protostar** → **main-sequence star**. Because of its much greater mass, once its core fuel is exhausted it swells into a **red supergiant**, then its core collapses catastrophically in a **supernova** explosion. The collapsed remnant becomes either a **neutron star** or, for the most massive remnants, a **black hole**.

$\boxed{\text{Nebula} \to \text{protostar} \to \text{main sequence} \to \text{red supergiant} \to \text{supernova} \to \text{neutron star/black hole}}$

Bài tập luyện tập

(Supplement) Compared with a cooler star, a much hotter star will generally appear:

(A) More blue-white
(B) More red
(C) Colourless
(D) More yellow, regardless of temperature

Lời giải chi tiết

Hotter stars appear more blue-white; cooler stars appear more red/orange. **(A)**.

Bài tập luyện tập

The Milky Way galaxy contains approximately how many stars?

(A) 100 thousand
(B) 100 million
(C) 100 billion
(D) 100 trillion

Lời giải chi tiết

The Milky Way contains **over 100 billion** stars, of which our Sun is just one. **(C)**.

Bài tập luyện tập

(Supplement) State one piece of observational evidence that supports the Big Bang theory, and briefly explain how it does so.

Lời giải chi tiết

The **cosmic microwave background (CMB) radiation** – faint microwave radiation detected uniformly from every direction in space – is strong supporting evidence. It is understood to be the cooled, stretched-out remnant of the intense radiation released when the universe was extremely hot and dense in its very early history, exactly as predicted if the universe began in a Big Bang and has been expanding (and cooling) ever since. (The observation that distant galaxies show redshift, indicating they are all receding from us, is also acceptable supporting evidence.)

Bài tập luyện tập

(Supplement) As the distance to a galaxy increases, its observed redshift and recession speed:

(A) Both increase
(B) Both decrease
(C) Redshift increases, recession speed decreases
(D) Both stay constant

Lời giải chi tiết

More distant galaxies show greater redshift and greater recession speed – both increase together with distance. **(A)**.

Bài tập luyện tập

The Andromeda galaxy is approximately 2.5 million light-years from Earth. Using 1 light-year $\approx 9.5 \times 10^{15}$ m, express this distance in metres.

Lời giải chi tiết

Distance $= 2.5 \times 10^6 \times 9.5 \times 10^{15} \approx \boxed{2.4 \times 10^{22}\text{ m}}$.

Bài tập luyện tập

A star is measured to be 7.56×10^{16} m from Earth. Using 1 light-year $\approx 9.5 \times 10^{15}$ m, express this distance in light-years.

Lời giải chi tiết

Distance $= \dfrac{7.56 \times 10^{16}}{9.5 \times 10^{15}} = \boxed{8.0 \text{ light-years}}$.

Bài tập luyện tập

(Supplement) A galaxy is measured to be at a distance of $d = 30\,\text{Mpc}$. Using $H_0 = 70\,\text{km/s/Mpc}$, find its expected recession speed.

Lời giải chi tiết

$v = H_0 d = 70 \times 30 = \boxed{2100\,\text{km/s}}$.

Bài tập luyện tập

(Supplement) A polar-orbiting satellite orbits Earth at radius $r = 7.2 \times 10^6$ m with period $T = 6.0 \times 10^3$ s. Find its orbital speed.

Lời giải chi tiết

$$v = \frac{2\pi r}{T} = \frac{2\pi(7.2 \times 10^6)}{6.0 \times 10^3} = \frac{4.524 \times 10^7}{6.0 \times 10^3} \approx \boxed{7.5 \times 10^3\,\text{m/s} \approx 7.5\,\text{km/s}}.$$

Bài tập luyện tập

A weather agency needs a satellite that continuously monitors the same region of Earth's surface, day and night. Which orbit should it use, and why?

Lời giải chi tiết

A **geostationary orbit** should be used. With a 24-hour period directly above the equator, the satellite matches Earth's own rotation and therefore stays fixed above the *same* region at all times, allowing continuous monitoring – a low-Earth/polar-orbiting satellite would instead pass over the region only briefly during each orbit, then move on to view different areas.

Bài tập luyện tập

Explain, in terms of the process occurring in its core, why the Sun is hot and luminous.

Lời giải chi tiết

In the Sun's extremely hot, dense core, hydrogen nuclei are forced together and undergo **nuclear fusion**, combining to form helium nuclei. This process releases an enormous amount of energy, which travels outward through the Sun and radiates into space as light and heat – this is why the Sun (unlike a planet, which only reflects light) is hot and luminous, generating its own light.

Bài tập luyện tập

State one difference in orbit and one difference in appearance between an asteroid and a comet.

Lời giải chi tiết

Orbit: most asteroids follow roughly circular orbits confined to the asteroid belt between Mars and Jupiter, while comets follow highly elongated (elliptical) orbits that can take them from very close to the Sun out to the far edges of the Solar System. **Appearance:** asteroids are solid, rocky bodies with no tail; a comet develops a glowing **tail** of gas and dust (always pointing away from the Sun) as it approaches the Sun and its ice vaporises, whereas asteroids show no such tail.

Bài tập luyện tập

(Supplement) After a supernova, the collapsed core of a very massive star is left over, but is not massive enough to become a black hole. What does it become?

(A) White dwarf
(B) Neutron star
(C) Red giant
(D) Protostar

Lời giải chi tiết

Such a core becomes a **neutron star** – an extremely dense, small remnant made almost entirely of neutrons. (A white dwarf is instead the remnant of a low/medium-mass star, which never undergoes a supernova.) **(B)**.

Bài tập luyện tập

The Moon orbits Earth at a mean radius $r = 3.84 \times 10^8$ m with an orbital period $T = 2.36 \times 10^6$ s (about 27.3 days). (Supplement) Find the Moon's orbital speed.

Lời giải chi tiết

$$v = \frac{2\pi r}{T} = \frac{2\pi(3.84 \times 10^8)}{2.36 \times 10^6} = \frac{2.412 \times 10^9}{2.36 \times 10^6} \approx \boxed{1.0 \times 10^3\,\text{m/s} \approx 1.0\,\text{km/s}}.$$

Bài tập luyện tập

Planet Y orbits a star at exactly twice the orbital radius of Planet Z. Without doing any calculation, state and explain how Planet Y's orbital period and orbital speed compare with Planet Z's.

Lời giải chi tiết

Planet Y, being farther from the star, experiences a **weaker** gravitational pull, so it requires a **slower** orbital speed to remain in a stable orbit; it must also travel around a much **larger** circular path. Both effects mean Planet Y takes **longer** to complete one orbit than Planet Z – i.e. Planet Y has a **longer orbital period** and a **slower orbital speed** than Planet Z.

Bài tập luyện tập

State two differences in physical properties between a terrestrial planet (such as Earth) and a gas giant (such as Jupiter).

Lời giải chi tiết

Any two of: (1) terrestrial planets are made of rock and metal with a solid surface, while gas giants are made mostly of hydrogen and helium gas (or icy/rocky material under thick gas) with no solid surface to stand on; (2) terrestrial planets have much **higher density** than gas giants; (3) terrestrial planets are much **smaller** in diameter than gas giants; (4) gas giants have **ring systems** and many more moons, while terrestrial planets have few or no moons and no rings.

Bài tập luyện tập

(Supplement) A distant galaxy has a recession speed (measured from its redshift) of $v = 4200\,\text{km/s}$. Using $H_0 = 70\,\text{km/s/Mpc}$, find its distance in Mpc, and then express this distance in light-years, given $1\,\text{Mpc} \approx 3.26 \times 10^6$ light-years.

Lời giải chi tiết

Distance: $d = \dfrac{v}{H_0} = \dfrac{4200}{70} = 60\,\text{Mpc}$.

In light-years: $d = 60 \times 3.26 \times 10^6 = 1.956 \times 10^8 \approx \boxed{2.0 \times 10^8 \text{ light-years}}$.

Bài tập luyện tập

(Supplement) Planet A orbits a star at $r = 1.0 \times 10^{11}$ m with period $T = 2.0 \times 10^7$ s. Planet B orbits the same star at $r = 4.0 \times 10^{11}$ m with period $T = 1.6 \times 10^8$ s. Calculate the orbital speed of each planet, and state which planet moves faster.

Lời giải chi tiết

Planet A: $v_A = \dfrac{2\pi(1.0 \times 10^{11})}{2.0 \times 10^7} = \dfrac{6.283 \times 10^{11}}{2.0 \times 10^7} \approx 3.1 \times 10^4\,\text{m/s} = 31\,\text{km/s}$.

Planet B: $v_B = \dfrac{2\pi(4.0 \times 10^{11})}{1.6 \times 10^8} = \dfrac{2.513 \times 10^{12}}{1.6 \times 10^8} \approx 1.6 \times 10^4\,\text{m/s} = 16\,\text{km/s}$.

$\boxed{\text{Planet A (the smaller orbital radius) moves faster}}$ – consistent with the radius–period–speed relationship.

Bài tập luyện tập

(Supplement) Explain why a larger measured value of the Hubble constant, H_0, would lead to a *younger* estimated age for the universe.

Lời giải chi tiết

The estimated age of the universe is approximately $\dfrac{1}{H_0}$ – an inverse relationship. If H_0 is measured to be **larger**, then $\dfrac{1}{H_0}$ becomes **smaller**, giving a **younger** estimated age. (Physically, a larger H_0 means galaxies are, on average, receding faster for a given distance, implying it took *less* time for them to reach their current separations since the Big Bang.)

Bài tập luyện tập

Explain why an artificial satellite in a stable orbit does not need its engines running continuously to stay in orbit.

Lời giải chi tiết

Gravity provides exactly the **centripetal force** needed to continuously change the direction of the satellite's velocity, keeping it on a curved (circular or elliptical) path, without needing to change its speed or do net work on it. As long as the satellite has the correct combination of speed and radius for a stable orbit, gravity alone maintains that orbit indefinitely – gravity does not weaken or "run out" over time, so no continuous engine thrust is required (real satellites only need occasional small corrections due to minor disturbances, such as atmospheric drag at very low altitudes).

Bài tập luyện tập

(Supplement) A geostationary satellite orbits at radius $r = 4.2 \times 10^7$ m. Using the fact that its period must be exactly 24 hours, calculate its orbital speed in m/s.

Lời giải chi tiết

$T = 24 \times 3600 = 86400\,\text{s}$.

$$v = \frac{2\pi r}{T} = \frac{2\pi(4.2 \times 10^7)}{86400} = \frac{2.639 \times 10^8}{86400} \approx \boxed{3.1 \times 10^3\,\text{m/s} \approx 3.1\,\text{km/s}}.$$

Bài tập luyện tập

State whether each of the following is more characteristic of a terrestrial planet or a gas giant: (a) very low density; (b) solid rocky surface; (c) large ring system; (d) high density.

Lời giải chi tiết

(a) Gas giant. (b) Terrestrial planet. (c) Gas giant. (d) Terrestrial planet.

Bài tập luyện tập

(Supplement) A small satellite orbits Earth at radius $r = 1.0 \times 10^7$ m with period $T = 1.0 \times 10^4$ s. Find its orbital speed.

Lời giải chi tiết

$$v = \frac{2\pi r}{T} = \frac{2\pi(1.0 \times 10^7)}{1.0 \times 10^4} = \frac{6.283 \times 10^7}{1.0 \times 10^4} \approx \boxed{6.3 \times 10^3\,\text{m/s} \approx 6.3\,\text{km/s}}.$$

Bài tập luyện tập

Which of the following best describes what a nebula is?

(A) A collapsed stellar core made almost entirely of neutrons

(B) A vast cloud of gas and dust in space that can collapse under gravity to form a star

(C) A region of space where gravity is so strong that light cannot escape

(D) The glowing remnant of an exploded massive star

Lời giải chi tiết

A nebula is a vast cloud of gas and dust; gravity can pull this material together to form a protostar and, eventually, a star. **(B)**.

Bài tập luyện tập

A student claims that a satellite orbiting very high above Earth, but tilted at $45°$ to the equator, is geostationary because it is "far enough away". Explain why this claim is incorrect.

Lời giải chi tiết

Altitude alone does not make an orbit geostationary. A truly geostationary satellite must satisfy **two** conditions simultaneously: it must have an orbital period of exactly 24 hours, *and* it must orbit directly above the **equator** (in the same direction as Earth's rotation). A satellite tilted at $45°$ to the equator will trace out a path that moves north and south relative to the ground as it orbits, even if its period happens to be 24 hours – it will *not* stay fixed above a single point on Earth's surface, so it is not geostationary.

Bài tập luyện tập

State two properties, other than surface temperature, that determine how bright a star appears to an observer on Earth.

Lời giải chi tiết

The apparent brightness of a star, as seen from Earth, depends on its **true luminosity** (the total amount of light energy it actually emits, which itself depends on the star's size and temperature) and its **distance** from Earth – a highly luminous star that is very far away can appear fainter than a much less luminous, but much closer, star.

Bài tập luyện tập

(Supplement) Explain why, of all the galaxies we observe, the Andromeda Galaxy is unusual in showing a *blueshift* rather than a redshift.

Lời giải chi tiết

Almost all distant galaxies show redshift because the overall expansion of the universe is carrying them away from us. Andromeda, however, is a member of our own **Local Group** of galaxies, close enough that the mutual **gravitational attraction** between it and the Milky Way currently dominates over the effect of the universe's expansion – as a result, Andromeda is actually moving **toward** the Milky Way, producing a blueshift instead of a redshift.

Bài tập luyện tập

(Supplement) Explain why the most massive main-sequence stars have *shorter* lifetimes than lower-mass main-sequence stars, even though they contain far more hydrogen fuel to begin with.

Lời giải chi tiết

Although a more massive star does start with more hydrogen fuel, it also burns **far hotter** and fuses hydrogen at a **much faster rate** than a lower-mass star. This much higher rate of fuel consumption more than cancels out the larger fuel supply, so the most massive stars actually use up their core hydrogen, and leave the main sequence, far **sooner** (in millions of years) than lower-mass stars like the Sun (which last billions of years).

Bài tập luyện tập

State one difference between the Kuiper Belt and the Oort Cloud.

Lời giải chi tiết

Any correct difference, such as: the **Kuiper Belt** is a relatively flat, disc-shaped region of icy bodies (including Pluto) just beyond Neptune's orbit, while the **Oort Cloud** is thought to be a much more distant, roughly **spherical** shell of icy bodies surrounding the entire Solar System, far beyond the Kuiper Belt; both are considered source regions for comets, but Oort Cloud comets typically follow far longer, wider orbits than Kuiper Belt comets.

Bài tập luyện tập

(Supplement) A GPS navigation satellite orbits in medium-Earth orbit with a period of about 12 hours – shorter than a geostationary satellite's period, but much longer than a typical low-Earth-orbit satellite's period. Explain why a *single* GPS satellite is not sufficient for a receiver to determine its position, and why a large constellation of satellites is used instead.

Lời giải chi tiết

A single satellite can only tell a receiver its distance from that one satellite, which narrows the receiver's possible location down to a sphere (or, combined with being on Earth's surface, a circle) – not a single unique point. By using signals from **several** satellites simultaneously (a large constellation ensures enough satellites are visible from anywhere on Earth at any time), a receiver can combine multiple distance measurements to pinpoint a single, precise location through triangulation.

Bài tập luyện tập

Explain, in terms of gravity and motion, why astronauts aboard the International Space Station (ISS) experience apparent weightlessness, even though Earth's gravity at that altitude is only slightly weaker than at the surface.

Lời giải chi tiết

The ISS and everything inside it (including the astronauts) are continuously in **free fall** toward Earth under gravity, while also moving forward fast enough that the curve of their fall matches the curvature of the Earth beneath them – this combination of falling and moving forward is exactly what keeps them in orbit. Because the astronauts and the station are falling at the *same* rate, there is no contact (normal) force between an astronaut's body and the floor of the station, and it is precisely this contact force that we normally perceive as "weight". The apparent weightlessness is therefore due to being in continuous free fall together with the spacecraft, not due to an absence of gravity.

Bài tập luyện tập

(Supplement) Explain how elements heavier than iron, such as gold and uranium, are created, and how they eventually become part of new stars and planets.

Lời giải chi tiết

Elements heavier than iron cannot be produced by the nuclear fusion that powers ordinary stars; they require the extreme temperatures and pressures generated during a **supernova** explosion, when a massive star's core catastrophically collapses. The explosion forges these heavy elements and simultaneously scatters them, along with the star's other material, out into space. This ejected material can later become incorporated into new **nebulae**, which may go on to collapse under gravity and form new stars and planetary systems – meaning the heavy elements found in the Earth (and in living things) were originally created inside a star that exploded long before the Solar System formed.

Bài tập luyện tập

Two planets, P and Q, orbit the same star. Planet P has a shorter orbital period than Planet Q. Which planet is closer to the star, and which planet has the higher orbital speed?

(A) P is closer; P has the higher speed

(B) Q is closer; Q has the higher speed

(C) P is closer; Q has the higher speed

(D) Q is closer; P has the higher speed

Lời giải chi tiết

A shorter orbital period goes with a smaller orbital radius (closer to the star) and a faster orbital speed. Since Planet P has the shorter period, **P is closer to the star and P has the higher orbital speed. (A)**.

Bài tập luyện tập

(Supplement) A distant galaxy's spectrum shows a redshift corresponding to a recession speed of $v = 9800\,\mathrm{km/s}$. Using $H_0 = 70\,\mathrm{km/s/Mpc}$, find its distance in Mpc, then convert this distance into metres, given $1\,\mathrm{Mpc} \approx 3.09 \times 10^{22}\,\mathrm{m}$.

Lời giải chi tiết

Distance in Mpc: $d = \dfrac{v}{H_0} = \dfrac{9800}{70} = 140\,\mathrm{Mpc}$.

Distance in metres: $d = 140 \times 3.09 \times 10^{22} = \boxed{4.3 \times 10^{24}\,\mathrm{m}}$.

Bài tập luyện tập

Betelgeuse is a red supergiant star – enormous and highly luminous, yet it appears distinctly reddish rather than blue-white. Explain why.

Lời giải chi tiết

A star's colour depends on its **surface temperature**, not directly on its size or total luminosity: hotter stars appear blue-white, while cooler stars appear red/orange. Although Betelgeuse is enormous and radiates a huge total amount of energy (due to its immense surface area), its outer surface has **expanded and cooled** as part of becoming a red supergiant, giving it a relatively low surface temperature for a star – and hence its distinctly reddish colour.

Bài tập luyện tập

For each of the following, state whether it is generally considered a source of new comets: (a) the asteroid belt; (b) the Kuiper Belt; (c) the Oort Cloud.

Lời giải chi tiết

(a) **No** – the asteroid belt mainly contains rocky asteroids, not icy comets. (b) **Yes** – the Kuiper Belt is a disc of icy bodies beyond Neptune that supplies many comets. (c) **Yes** – the more distant, spherical Oort Cloud is thought to supply comets on extremely long, wide orbits.

Bài tập luyện tập

(Supplement) A galaxy's redshift corresponds to a recession speed of $v = 2800\,\text{km/s}$. Using $H_0 = 70\,\text{km/s/Mpc}$, find its distance in Mpc, then express this distance in light-years, given $1\,\text{Mpc} \approx 3.26 \times 10^6$ light-years.

Lời giải chi tiết

Distance in Mpc: $d = \dfrac{2800}{70} = 40\,\text{Mpc}$.

In light-years: $d = 40 \times 3.26 \times 10^6 = 1.304 \times 10^8 \approx \boxed{1.3 \times 10^8 \text{ light-years}}$.

Bài tập luyện tập

Explain why doubling a satellite's orbital radius does *not* simply double its orbital period.

Lời giải chi tiết

Two effects combine when the orbital radius doubles: the satellite has **twice** the distance (circumference) to travel around its orbit, *and* it must also travel at a **slower** speed than before (because the gravitational pull, and hence the required orbital speed, is weaker at the larger radius). Since the period depends on *both* a larger distance *and* a smaller speed working in the same direction, the orbital period increases by *more* than a factor of two, not simply by a factor of two.

Bài tập luyện tập

Explain why elements heavier than iron, such as gold and uranium, are not produced by the nuclear fusion that powers ordinary stars.

(A) Such fusion reactions absorb energy rather than releasing it, so they do not happen inside ordinary stars

(B) Iron does not exist inside stars

(C) Ordinary stars are not hot enough to fuse hydrogen

(D) Heavy elements can only exist outside of stars

Lời giải chi tiết

Fusing nuclei up to iron releases energy, which is what powers a star; fusing elements *heavier* than iron would actually **absorb** energy rather than release it, so this does not happen during a star's normal life. Elements heavier than iron are instead created only in the extreme, energetic conditions of a supernova explosion. **(A)**.

Bài tập luyện tập

State two defining features of a main-sequence star.

Lời giải chi tiết

Any two of: (1) it is fusing hydrogen into helium in its core; (2) it is in a stable equilibrium, where the outward pressure from fusion balances the inward pull of gravity, so the star's size stays roughly constant; (3) it spends the majority of its lifetime in this stage (our Sun has been on the main sequence for about 4.6 billion years already).

Bài tập luyện tập

Suggest why the four planets closest to the Sun are small and rocky, while the four planets farthest from the Sun are large gas/ice giants.

Lời giải chi tiết

Close to the young Sun, temperatures were too high for ice and light gases to remain solid or condense, so only rock and metal could form solid material there, building small, dense, rocky planets. Farther out, it was cold enough for ice (water, ammonia, methane) to condense as well as rock, giving far more raw material for planets to grow from – these larger rocky/icy cores were then massive enough to gravitationally attract and hold on to huge quantities of surrounding hydrogen and helium gas, growing into the much larger gas/ice giant planets.

Bài tập luyện tập

Not every massive star that undergoes a supernova leaves behind a black hole. Explain what determines whether the collapsed remnant becomes a neutron star or a black hole.

Lời giải chi tiết

It depends on the **mass** of the collapsed core left behind after the supernova explosion. If the remnant's mass is below a certain threshold, the collapse is halted by internal forces and it settles as an extremely dense **neutron star**. If the remnant's mass is **above** that threshold, no known force can halt the collapse, and it continues to collapse into a **black hole** – a region where gravity is strong enough that not even light can escape.

Bài tập luyện tập

(Supplement) On a graph of recession speed v against distance d for a set of galaxies (Hubble's law), state what physical quantity is represented by the gradient of the line.

Lời giải chi tiết

The gradient of the v against d graph represents the **Hubble constant**, H_0, since $v = H_0 d$ is the equation of a straight line through the origin with gradient H_0.

Bài tập luyện tập

(Supplement) A moon orbits a gas giant planet at radius $r = 4.2 \times 10^8$ m with period $T = 1.5 \times 10^5$ s. Find its orbital speed.

Lời giải chi tiết

$$v = \frac{2\pi r}{T} = \frac{2\pi(4.2 \times 10^8)}{1.5 \times 10^5} = \frac{2.639 \times 10^9}{1.5 \times 10^5} \approx \boxed{1.8 \times 10^4\ \text{m/s} \approx 18\ \text{km/s}}.$$

Bài tập luyện tập

State the type of orbit (geostationary or low-Earth/polar) that would be most suitable for each application: (a) tracking deforestation across the entire globe over the course of a month; (b) relaying live television broadcasts to a fixed satellite dish.

Lời giải chi tiết

(a) **Low-Earth / polar orbit** – its short period and changing ground track allow it to image different strips of the whole Earth over repeated orbits. (b) **Geostationary orbit** – it stays fixed above one point on Earth, allowing a satellite dish to remain pointed in a single, unchanging direction.

Bài tập luyện tập

Explain, using the terms nebula, gravity, and hydrogen fusion, how a star forms.

Lời giải chi tiết

A **nebula** – a large cloud of gas (mostly hydrogen) and dust – begins to collapse inward under its own **gravity**. As the material falls inward, it heats up, forming a protostar; if enough mass has collapsed together, the core eventually becomes hot and dense enough to trigger **hydrogen fusion** (hydrogen nuclei fusing into helium), at which point the star is born as a stable main-sequence star, with the outward pressure from fusion balancing the continued inward pull of gravity.

Bài tập luyện tập

A student says: "Since Jupiter is much farther from the Sun than Earth, and much more massive than Earth, its orbital speed must be greater than Earth's." Explain what is wrong with this reasoning.

Lời giải chi tiết

The student has confused the effect of a planet's *own* mass with the effect of its *orbital radius*. A planet's own mass does not determine its orbital speed for a given orbital radius (a more massive and a less massive planet at the *same* distance from the Sun would orbit at essentially the same speed). What actually determines orbital speed is **distance from the Sun**: since Jupiter's orbital radius is much *larger* than Earth's, Jupiter's orbital speed is in fact **slower** than Earth's, not faster – consistent with the general rule that larger orbital radius means slower orbital speed.

Bài tập luyện tập

(Supplement) Which layer of the Sun is directly responsible for generating its energy, through nuclear fusion?

(A) The photosphere
(B) The corona
(C) The core
(D) The convective zone

Lời giải chi tiết

Nuclear fusion of hydrogen into helium occurs in the Sun's **core**, where temperature and pressure are extreme enough to sustain it; the other layers (radiative zone, convective zone, photosphere, corona) only carry that energy outward or mark the Sun's visible surface/outer atmosphere. **(C)**.

Bài tập luyện tập

What is the primary cause of Earth's ocean tides?

(A) Earth's rotation alone, with no contribution from the Moon or Sun
(B) The Moon's (and, to a lesser extent, the Sun's) differential gravitational pull on Earth's oceans
(C) Wind patterns produced by uneven solar heating of the atmosphere
(D) Changes in the Moon's phase altering the amount of sunlight reflected onto the oceans

Lời giải chi tiết

Ocean tides are caused by the **Moon's gravitational pull** (with a smaller contribution from the Sun's), which is slightly stronger on the side of Earth nearer the Moon than on the far side, stretching the oceans into two tidal bulges; Earth's rotation beneath these bulges is what produces the regular *timing* of tides, but it is gravity – not rotation alone – that creates the bulges in the first place. **(B)**.

Bài tập luyện tập

Jupiter orbits the Sun at a mean distance of 5.2 AU. Using 1 AU $\approx 1.5 \times 10^{11}$ m, express this distance in metres.

Lời giải chi tiết

$d = 5.2 \times 1.5 \times 10^{11} = \boxed{7.8 \times 10^{11}\ \text{m}}$.

Bài tập luyện tập

Uranus orbits the Sun at a mean distance of 19.2 AU. Using 1 AU $\approx 1.5 \times 10^{11}$ m and 1 light-year $\approx 9.5 \times 10^{15}$ m, express Uranus's mean distance from the Sun in light-years.

Lời giải chi tiết

First convert to metres: $d = 19.2 \times 1.5 \times 10^{11} = 2.88 \times 10^{12}$ m.
Then convert to light-years: $d = \dfrac{2.88 \times 10^{12}}{9.5 \times 10^{15}} \approx \boxed{3.0 \times 10^{-4}\ \text{light-years}}$.

Bài tập luyện tập

(Supplement) An exoplanet orbits its star at radius $r = 2.4 \times 10^{11}$ m with period $T = 3.0 \times 10^{7}$ s. Calculate its orbital speed.

Lời giải chi tiết

$$v = \frac{2\pi r}{T} = \frac{2\pi(2.4 \times 10^{11})}{3.0 \times 10^{7}} = \frac{1.508 \times 10^{12}}{3.0 \times 10^{7}} \approx \boxed{5.0 \times 10^{4}\ \text{m/s} \approx 50\ \text{km/s}}.$$

Bài tập luyện tập

(Supplement) A newly discovered exoplanet orbits its star at a distance of 2.0 AU, completing one orbit in $T = 6.3 \times 10^{7}$ s. Using 1 AU $\approx 1.5 \times 10^{11}$ m: (a) express its orbital radius in metres; (b) calculate its orbital speed.

Lời giải chi tiết

(a) $r = 2.0 \times 1.5 \times 10^{11} = 3.0 \times 10^{11}$ m.
(b) $v = \dfrac{2\pi r}{T} = \dfrac{2\pi(3.0 \times 10^{11})}{6.3 \times 10^{7}} = \dfrac{1.885 \times 10^{12}}{6.3 \times 10^{7}} \approx \boxed{3.0 \times 10^{4}\ \text{m/s} \approx 30\ \text{km/s}}$.

Bài tập luyện tập

(Supplement) A galaxy's recession speed, measured from its redshift, is $v = 7000$ km/s. Using $H_0 = 70$ km/s/Mpc, find its distance in Mpc, then express this distance in light-years and in metres, given 1 Mpc $\approx 3.26 \times 10^{6}$ light-years and 1 light-year $\approx 9.5 \times 10^{15}$ m.

Lời giải chi tiết

Distance in Mpc: $d = \dfrac{v}{H_0} = \dfrac{7000}{70} = 100$ Mpc.

In light-years: $d = 100 \times 3.26 \times 10^6 = 3.26 \times 10^8$ light-years.
In metres: $d = (3.26 \times 10^8) \times (9.5 \times 10^{15}) \approx \boxed{3.1 \times 10^{24}\,\text{m}}$.

Bài tập luyện tập

The Moon's sidereal orbital period is approximately 27.3 days, while a satellite in low-Earth orbit (such as the ISS) has a period of only about 90 minutes. Explain, in terms of orbital radius and gravitational pull, why the Moon's orbital speed is so much slower than the ISS's, even though both are held in orbit purely by Earth's gravity.

Lời giải chi tiết

The Moon orbits at a much **larger radius** from Earth (about 3.84×10^8 m) than the ISS (only a few hundred km up). At this much greater distance, Earth's gravitational pull is much **weaker**, so the Moon needs only a much **lower orbital speed** to remain in a stable orbit than the ISS does. This is the same radius–speed relationship that applies to planets orbiting the Sun: a larger orbital radius always goes with a slower orbital speed (and, correspondingly, a much longer orbital period – days rather than minutes).

Ôn tập nhanh: $g = 10\,$N/kg trừ khi đề cho giá trị khác; trên đồ thị v–t, độ dốc (gradient) = gia tốc và diện tích dưới đồ thị = quãng đường đi được; động lượng và năng lượng được bảo toàn trong va chạm kín (không có ngoại lực/không mất năng lượng ra ngoài); nhiệt độ không đổi trong suốt quá trình chuyển thể (nóng chảy/sôi) dù vẫn cấp nhiệt liên tục; điện trở tương đương của các điện trở mắc song song tính theo quy tắc nghịch đảo $1/R = 1/R_1 + 1/R_2 + \cdots$; trong ba loại bức xạ hạt nhân, hạt alpha xuyên thấu kém nhất còn tia gamma xuyên thấu mạnh nhất; sau n chu kỳ bán rã, số hạt nhân phóng xạ còn lại $N = N_0(1/2)^n$; tốc độ trên quỹ đạo tròn $v = 2\pi r/T$, và bán kính quỹ đạo càng lớn thì chu kỳ càng dài, tốc độ càng chậm.

Đồng hành cùng 8020 English

Cảm ơn bạn đã học cùng bộ giáo trình quốc tế 8020. **Điểm thật · Thầy thật · Kết quả thật** — nhiều học viên chỉ cần 1–2 khoá để đạt kết quả mong muốn.

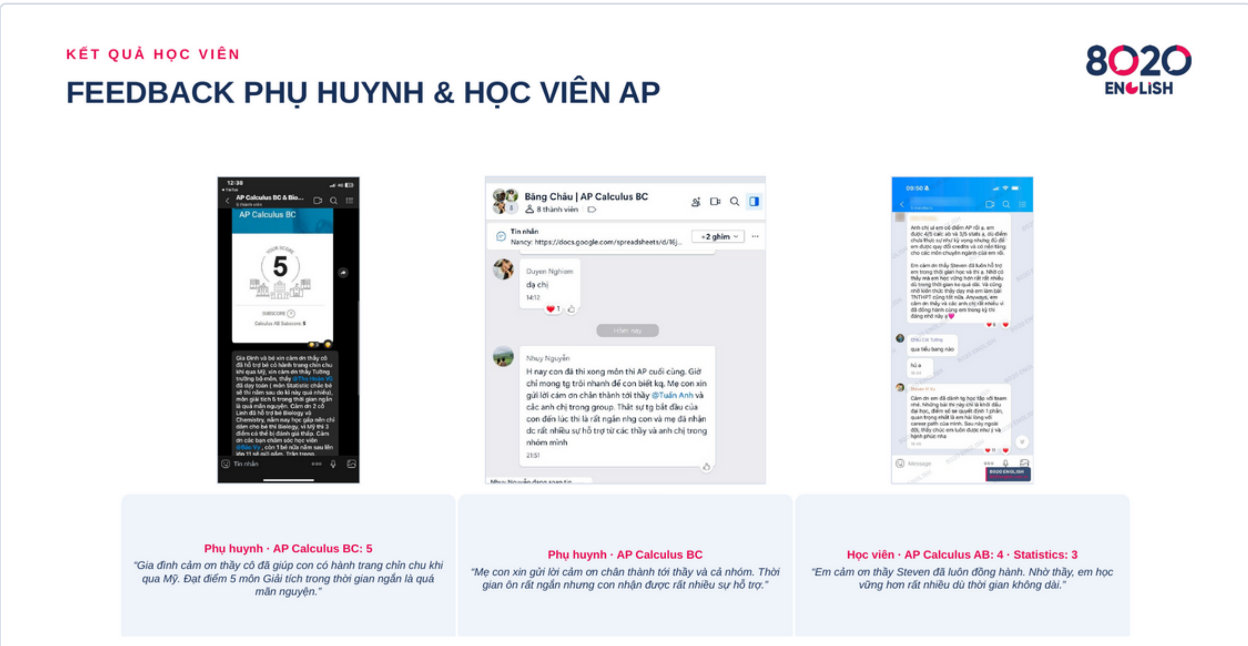
Cảm nhận học viên & phụ huynh

> *“Bạn đã cải thiện được tư duy Writing — kỹ năng từng là nỗi sợ lớn nhất — và cuối cùng đã đậu vào trường top như mong muốn. Thái độ học tập cực kỳ nghiêm túc; ngay cả khi nằm viện vẫn cố gắng học đều đặn.”*
>
> — Phan Thị Thanh Hằng · IELTS Overall 8.5

> *“Cần tất cả kỹ năng trên 7.5 để xét vào trường top 1 Anh Quốc về Y học (chương trình UKFPO của NHS) — và đã đạt mục tiêu sau khi học Writing 1–1.”*
>
> — Trần Hoàng Bảo Ngọc · IELTS Overall 8.0 (Writing 6.0 → 7.5)

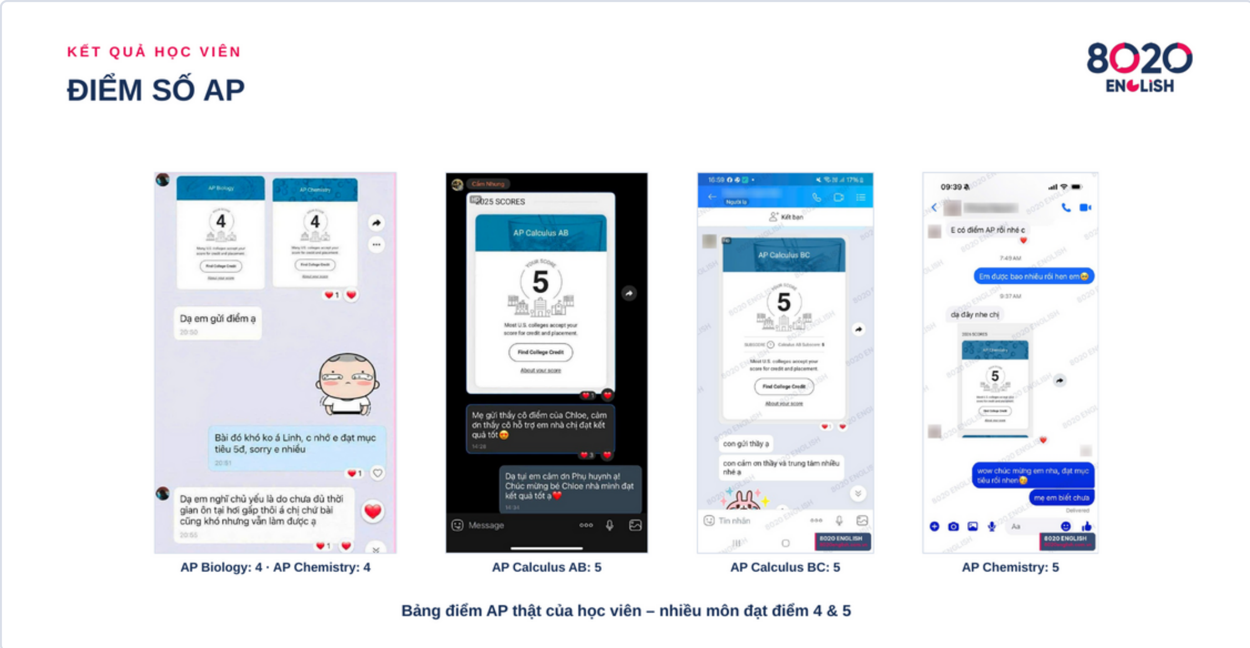
> *“Gia đình và bé xin cảm ơn thầy cô đã giúp con có hành trang chỉn chu khi qua Mỹ. Đạt điểm 5 môn Giải tích trong thời gian ngắn là quá mãn nguyện.”*
>
> — Phụ huynh · AP Calculus BC 5/5

> *“Em cảm ơn thầy đã luôn đồng hành. Nhờ thầy, em học vững hơn rất nhiều dù thời gian ôn không dài.”*
>
> — Học viên · AP Calculus AB 4

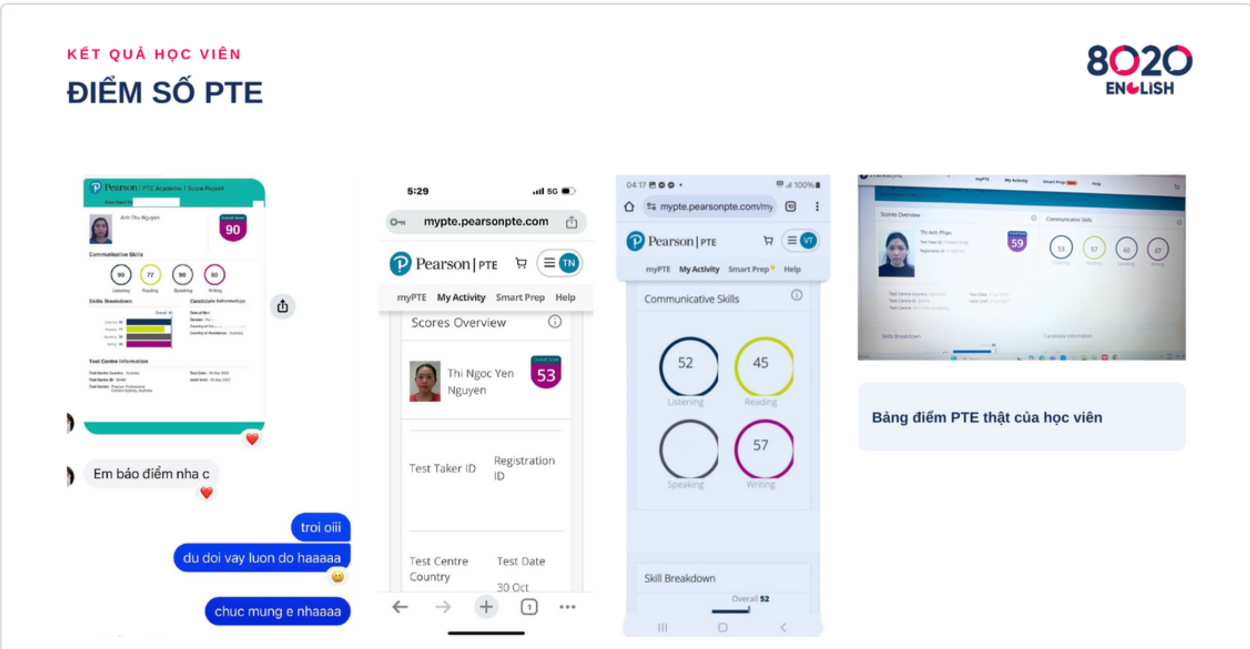


Feedback phụ huynh & học viên AP — nhiều môn đạt điểm 4 & 5

Điểm thi thật của học viên



Bảng điểm AP thật — Calculus AB/BC 5/5 · Biology & Chemistry 4–5 (College Board)

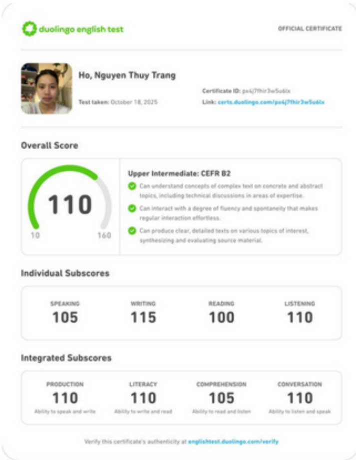


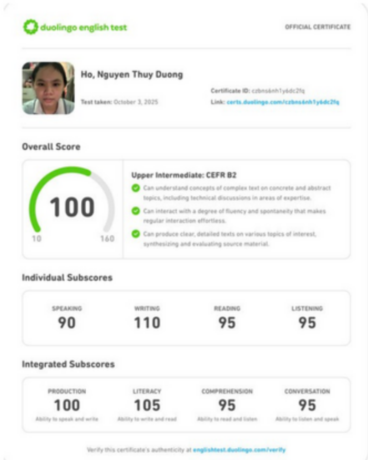
Học viên 8020 — PTE Academic 90

KẾT QUẢ HỌC VIÊN

ĐIỂM SỐ DUOLINGO

8020 ENGLISH





Duolingo English Test – 110 & 100

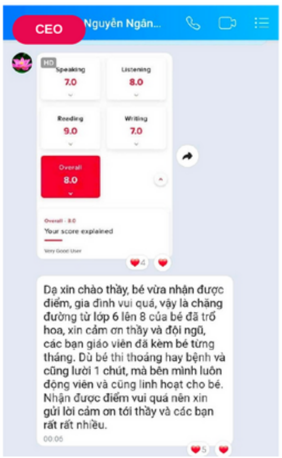
Học viên 8020 — Duolingo English Test 110 & 100

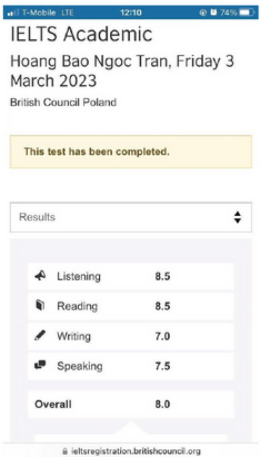
KẾT QUẢ HỌC VIÊN

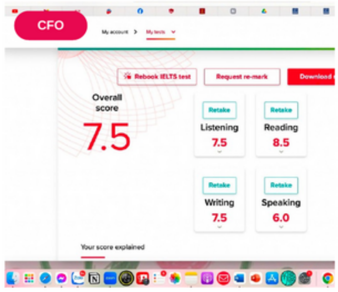
THÀNH TÍCH HỌC VIÊN

8020 ENGLISH

Bảng điểm thi thật – chất lượng được giám sát nghiêm ngặt. Một số học viên chỉ cần 1–2 khóa để đạt kết quả mong muốn.







Học viên 8020 — IELTS 8.0 / 7.5 / 8.5 (báo điểm thật)