Course notes

International Baccalaureate · IB Diploma · Physics · HL

IB IB Diploma · Physics · HL: teaching notes

Version: First assessment 2025

These notes cover selected topics of the course; they are not the whole specification.

Assessment and course boundaries

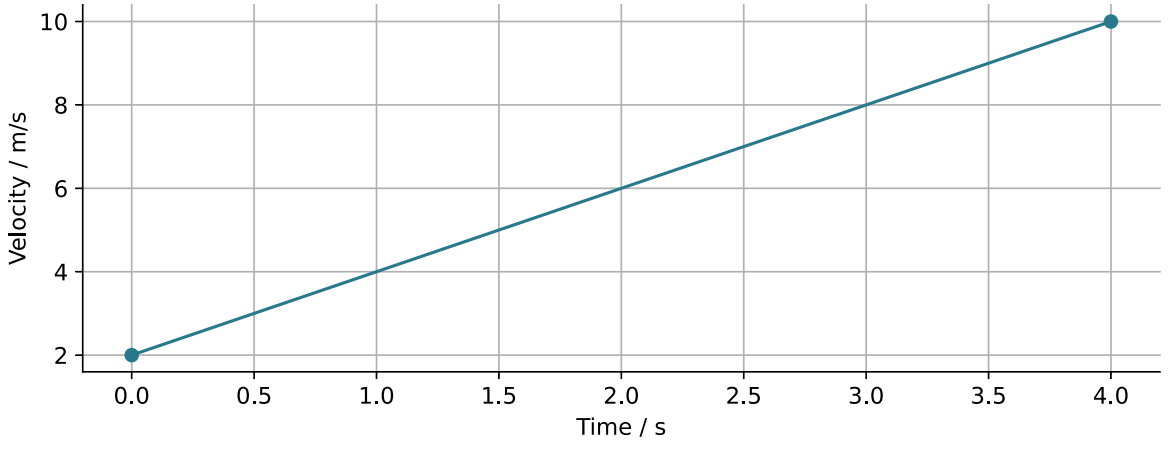
- Use themes A–E and no old optional-topic model.
- SL excludes A.4, A.5, B.4, D.4 and E.2. A.2, B.5, C.1/C.3/C.5, D.1/D.2 and E.1/E.3 include additional HL scope.
- SL Paper 1: 1.5 h, Paper 2: 1.5 h; HL: 2 h, 2.5 h. Papers weigh 36% and 44%; individual investigation 20%, 3,000 words.
- A clean current Physics data booklet and calculator are available in examinations; the booklet itself remains an acquisition item.
- Practical work 40 h plus collaborative sciences project 10 h and investigation 10 h.

Motion graphs and acceleration

Official-unit focus: A.1 Kinematics

A speedometer gives a reading at one moment. A journey average can hide stops and rapid changes in speed.

Displacement includes direction; distance counts total path length. Velocity is change in displacement per time. Acceleration is change in velocity per time.



The gradient of a displacement-time graph is velocity. The area under a velocity-time graph gives displacement. A constant-acceleration formula is valid only when its assumption is justified.

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Choose a positive direction and state it. Use a light gate or video with a known scale and frame interval for repeatable motion measurements. Avoid assuming hand timing is exact over very short intervals.

■ Checked worked case

Known: velocity rises uniformly from 2 to 10 metres per second in 4 s. a = (v-u)/t. a = (10-2)/4 = 2 metres per second squared. Displacement is trapezium area: s = (u+v)t/2 = (2+10)×4/2 = 24 m.

■ Common error

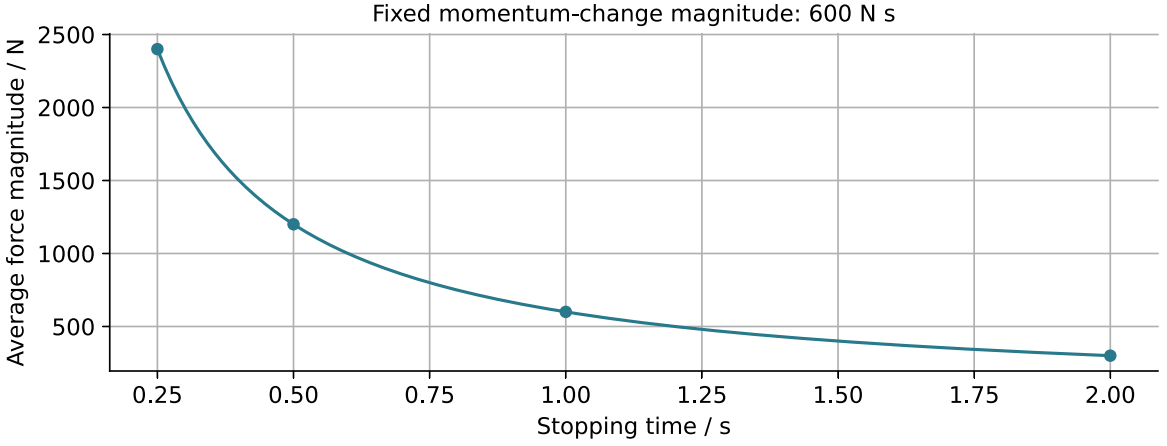
Negative velocity indicates direction under the chosen sign convention; it does not necessarily mean slowing down.

Forces, momentum and safe stopping

Official-unit focus: A.2 Forces and momentum

A passenger continues moving when a vehicle brakes. The seat belt provides the force needed to change the passenger momentum.

Resultant force causes acceleration, not motion itself. Momentum is mass multiplied by velocity. For an isolated system, total momentum is conserved even when kinetic energy is not.



Impulse equals momentum change. Increasing stopping time for the same momentum change reduces average force. Identify external forces before applying momentum conservation.

Draw a free-body diagram containing only forces on the selected object. For spring measurements, add loads in steps within the elastic range and measure extension from the unloaded position.

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■ Checked worked case

Known: a 60 kg passenger slows from 10 to 0 metres per second in 0.50 s. $\Delta p = m(v-u) = 60(0-10) = -600$ kg metres per second. Average $F = \Delta p/\Delta t = -600/0.50 = -1{,}200$ N. The sign shows the force opposes the initial motion.

■ Common error

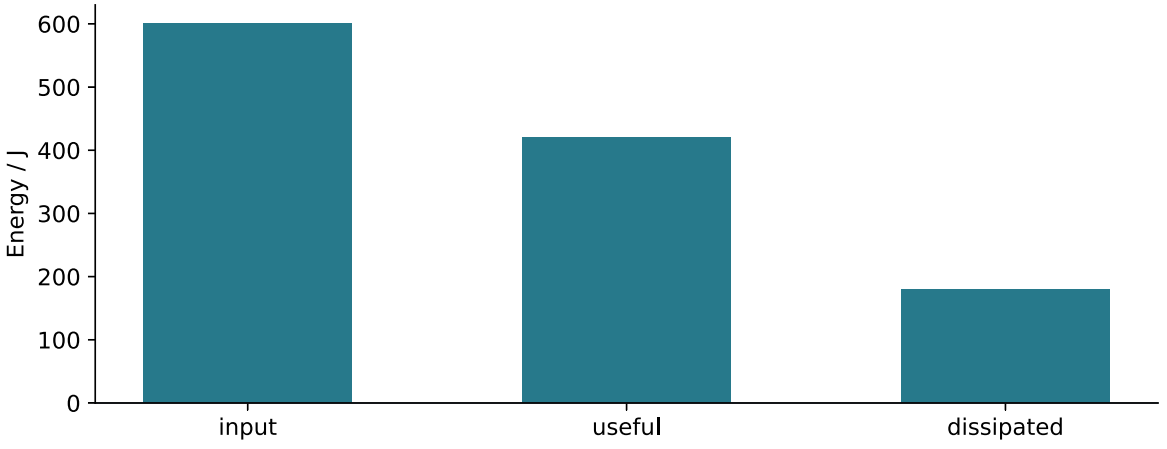
Balanced forces do not require the object to be at rest. Mass and weight have different units and meanings.

Energy stores, work and efficiency

Official-unit focus: A.3 Work, energy and power

A motor can transfer some input energy to lifting and the rest to heating. Useful output is part of the total energy transfer.

Work done by a constant force parallel to displacement is force multiplied by distance. Kinetic energy depends on speed squared. Energy is conserved when all transfers and stores are included.



Define the system and useful output before calculating efficiency. Doubling speed quadruples kinetic energy at constant mass. Power describes transfer per time, not total energy.

Measure a lifting height and load, time the lift, and record electrical input with suitable instruments. Repeat trials and account for heating or friction as transfers, not missing energy.

■ Checked worked case

Known: a device receives 600 J and transfers 420 J usefully. Efficiency = useful output / total input. Efficiency = 420/600 = 0.70 = 70%. Over 3 s, useful power = useful energy/time = 420/3 = 140 W.

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■ Common error

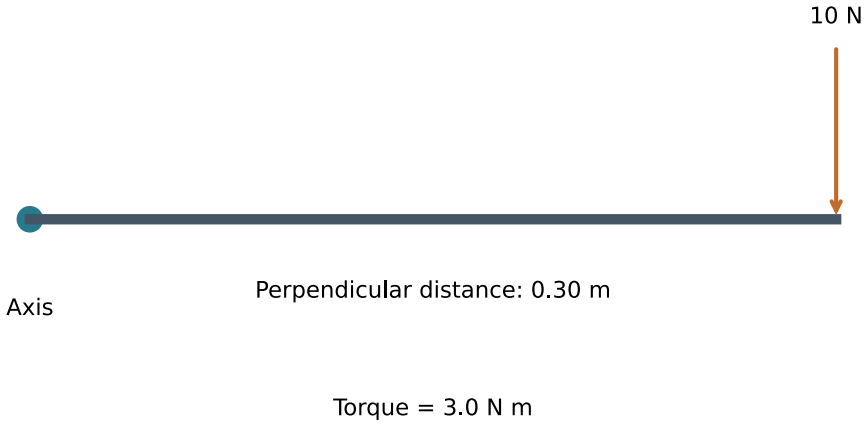
Efficiency cannot exceed 100% for a properly defined energy balance. Energy dissipated by heating is still conserved.

Rigid bodies and rotational dynamics

Official-unit focus: A.4 Rigid body mechanics

A door is easier to open when pushed near its outer edge. Force size alone does not determine the turning effect.

Torque depends on force and perpendicular distance from the axis. Moment of inertia describes resistance to angular acceleration and depends on mass distribution about a stated axis.



For a rigid body about a fixed axis, net torque equals moment of inertia multiplied by angular acceleration. Rotational kinetic energy depends on angular speed squared. Angular momentum is conserved when net external torque is zero.

Draw the pivot, force direction and perpendicular lever arm. Do not use the sloping distance from pivot to force point unless it is perpendicular to the force. For experiments, keep rotating parts guarded and loads secure.

■ Checked worked case

Known: a 10 N perpendicular force acts 0.30 m from an axis. Torque = force × perpendicular distance = $10 \times 0.30 = 3.0$ N m. If moment of inertia is 0.60 kg square metres, angular acceleration = torque/inertia = $3.0/0.60 = 5.0$ radians per second squared.

■ Common error

Torque has unit N m but is a turning effect, not an energy store. Moment of inertia changes if the same mass moves farther from the axis.

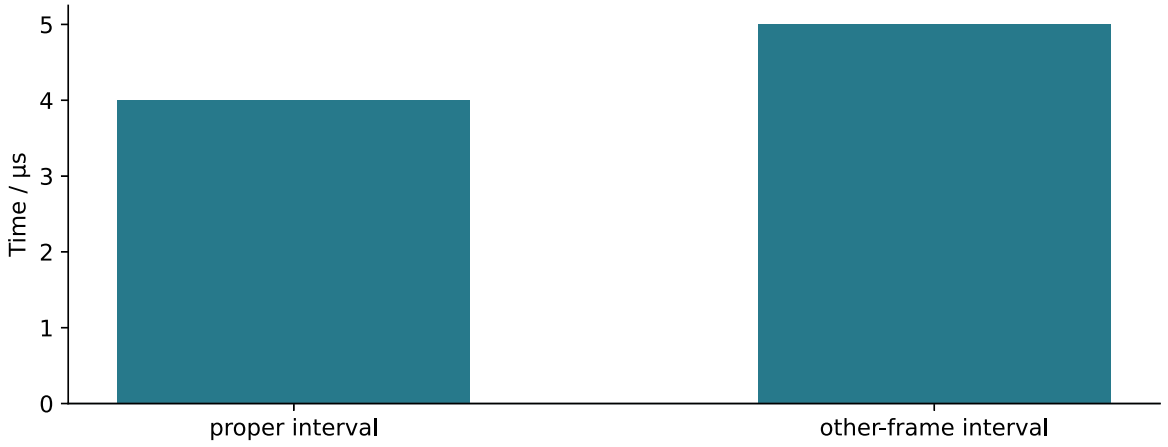
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Relativity and measuring events

Official-unit focus: A.5 Galilean and special relativity

Two observers can assign different times between the same events. A clock reading has meaning only when the frame and events are specified.

In special relativity, inertial observers measure the same vacuum light speed. Time dilation compares proper time measured where two events occur at one place with the interval in another inertial frame.



The Lorentz factor is 1 divided by the square root of 1 minus speed squared over light speed squared. Galilean velocity addition is an approximation for speeds much smaller than light speed.

Label which frame measures proper time or proper length before substituting. Use event coordinates consistently. Do not combine lengths from one frame with time intervals from another without transformation.

■ Checked worked case

Known: $v = 0.60c$ and proper time is 4.0 microseconds. $\gamma = 1/\sqrt{(1-v^2/c^2)} = 1/\sqrt{(1-0.60^2)} = 1.25$. $\Delta t = \gamma \Delta t_0 = 1.25 \times 4.0 = 5.0$ microseconds in the stated second frame.

■ Common error

Time dilation is not an instrument fault. Proper length is measured in the object rest frame; a contracted length is measured in a frame where it moves.

Thermal measurements and particle models

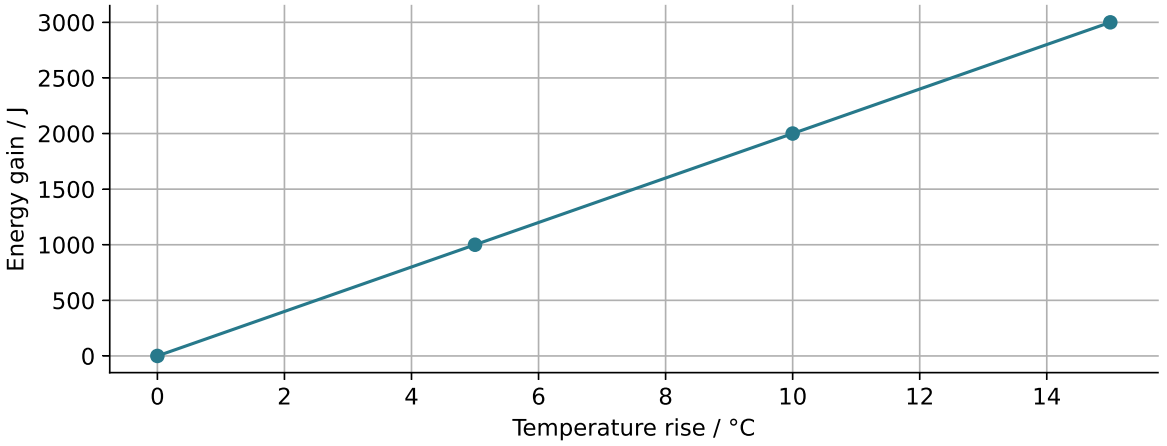
Official-unit focus: B.1 Thermal energy transfers

Two equal masses receive the same energy but show different temperature rises. Material properties determine how energy transfer changes temperature.

Specific heat capacity is energy needed to raise the temperature of unit mass by one

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degree. Specific latent heat relates energy to change of state without temperature change for the idealized process.



Temperature relates to particle motion in a model; internal energy includes kinetic and potential contributions. During a change of state, energy can change particle arrangements rather than temperature.

Measure mass, electrical input and temperature change for an insulated block. Ensure the temperature sensor has good contact, allow time for equilibration, and consider energy transferred to the surroundings.

■ Checked worked case

Known: a 0.50 kg block gains 2,000 J and rises 10 °C. Use $E = mc\Delta T$. Rearranging gives $c = E/(m\Delta T)$. $c = 2{,}000/(0.50\times10) = 400$ J per kilogram per degree. Heat loss would make the value inferred from electrical input too large.

■ Common error

A flat section of a heating curve can show a phase change, not absence of energy transfer. Do not substitute temperature for a temperature difference in $E = mc\Delta T$.

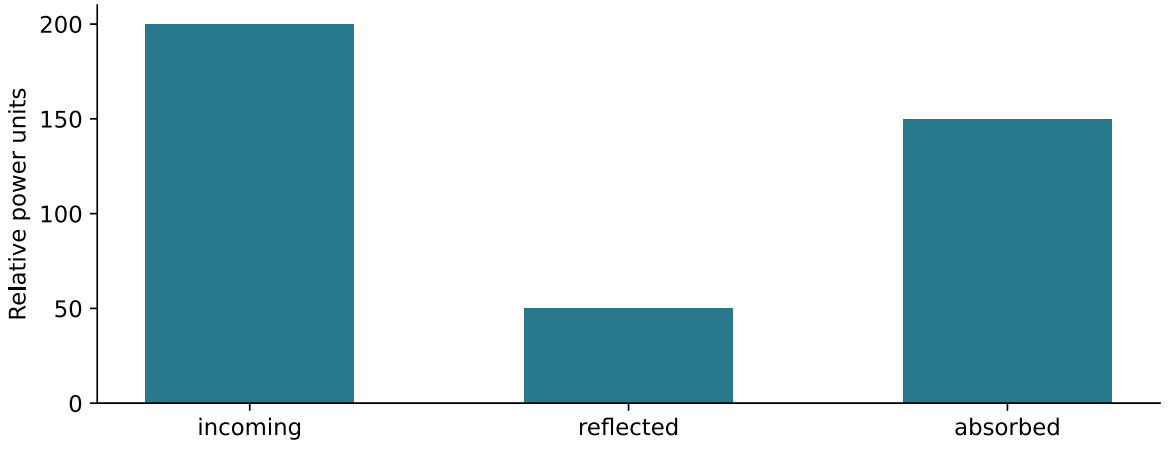
Climate evidence, energy budgets and policy

Official-unit focus: B.2 Greenhouse effect

One cold day does not disprove a warming climate. Weather describes short-term conditions; climate describes distributions over longer times and regions.

The Earth energy balance includes incoming solar radiation, reflection, absorption and outgoing infrared radiation. Greenhouse gases absorb and emit infrared radiation. Feedback can alter the response to an initial forcing.

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Distinguish mitigation, which addresses drivers, from adaptation, which reduces harm from impacts. A policy assessment needs evidence about effectiveness, cost, equity and uncertainty; one criterion is not the entire decision.

Compare multi-year data using consistent baselines. State the region, timescale and uncertainty. At HL, connect a management decision to law, economics and ethics rather than treating these lenses as extra definitions only.

■ Checked worked case

Known: a surface receives 200 power units and reflects 50. Absorbed input = incoming-reflected = 200-50 = 150. Reflected fraction = 50/200 = 0.25 = 25%. A change in reflectivity alters the absorbed budget under this model.

■ Common error

The greenhouse effect is not the same process as ozone depletion. A carbon footprint estimate depends on its system boundary.

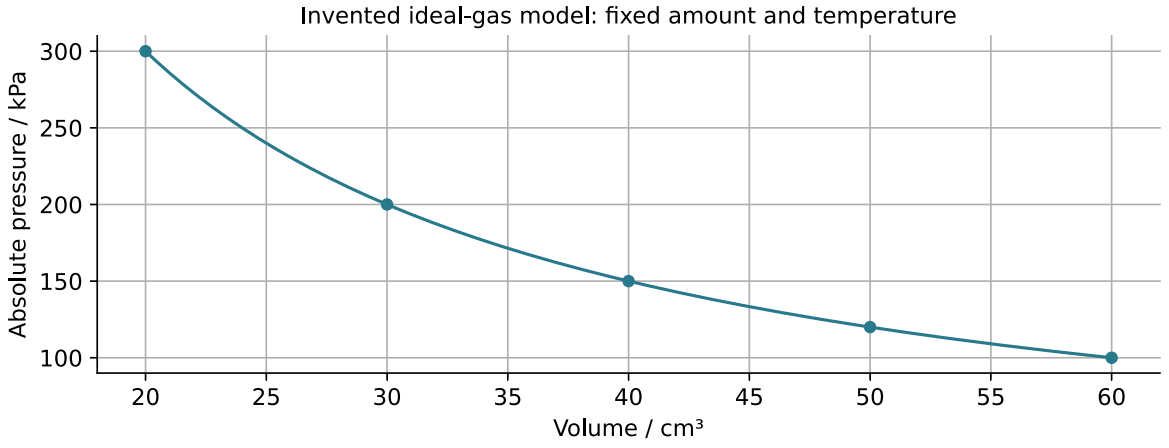
Gas models and absolute temperature

Official-unit focus: B.3 Gas laws

A sealed gas container changes pressure when heated. Celsius ratios cannot predict the pressure change because the gas model uses absolute temperature.

In a gas model, particles move randomly and pressure results from momentum transfer at walls. The ideal gas equation connects pressure, volume, amount and absolute temperature.

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At fixed amount and volume, pressure is proportional to kelvin temperature. At fixed temperature and amount, pressure is inversely proportional to volume. State which quantities are fixed before choosing a relationship.

Use approved apparatus with a temperature range and pressure limit set by the teacher. Allow thermal equilibrium and record pressure against kelvin temperature. Never heat an improvised sealed vessel.

■ Checked worked case

Known: pressure is 100 kPa at 300 K, with fixed volume and amount. At 330 K, p2/p1=T2/T1. p2=p1 T2/T1=100×330/300=110 kPa. A 30 °C rise is a 30 K change, but the temperature ratio must use kelvin.

■ Common error

An ideal gas is a model with conditions of validity. Celsius zero is not zero molecular motion, and internal energy is not determined by pressure alone.

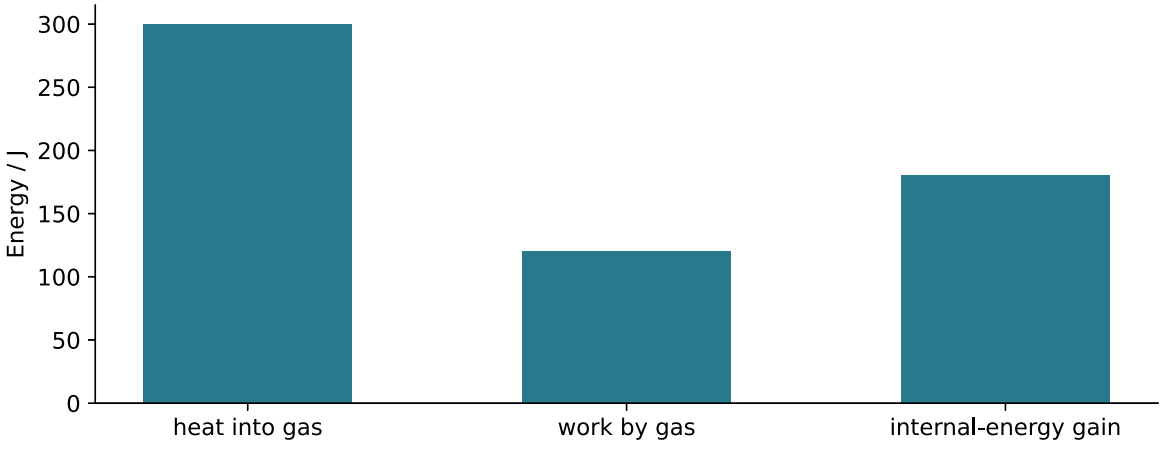
Thermodynamic systems and energy accounts

Official-unit focus: B.4 Thermodynamics

Compressing a gas can warm it even without a heater. Work is another path for energy transfer into the system.

Internal energy is a property of the chosen system. Heat and work describe energy transfer across its boundary. For an ideal monatomic gas, internal energy depends on temperature and amount.

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State a sign convention before using the first law. Here change in internal energy equals heat into the system minus work done by the system. Expansion work can reduce internal energy when no heat enters.

Identify whether a process is isothermal, adiabatic or at constant volume. On a pressure-volume graph, area under the process curve gives work done by the gas. The path matters for work even when endpoints match.

■ Checked worked case

Known: gas gains 300 J by heating and does 120 J of work. With $\Delta U = Q - W$, $\Delta U = 300 - 120 = 180$ J. For adiabatic compression, $Q = 0$ and work done by the gas is negative, so ΔU is positive.

■ Common error

Adiabatic does not mean constant temperature. Use the stated sign convention; some courses write work done on the gas with the opposite sign.

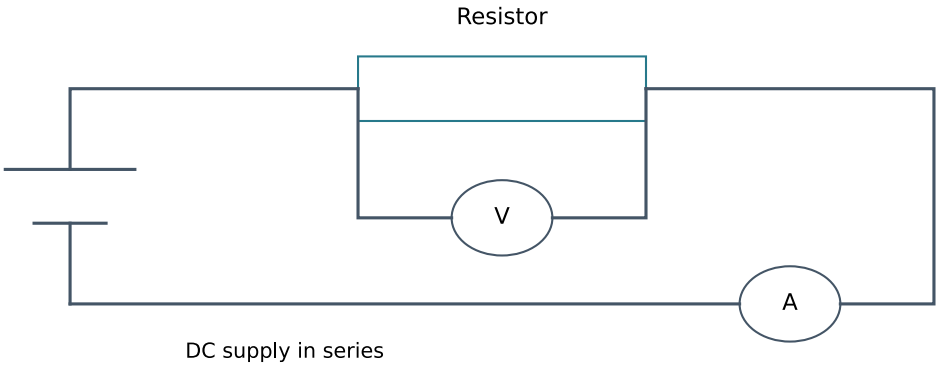
Current, potential difference and resistance

Official-unit focus: B.5 Current and circuits

A lamp becomes dimmer when another is added in series. Current and energy transfer depend on the whole circuit, not only one lamp.

Current is charge passing per time. Potential difference is energy transferred per charge. Resistance is potential difference divided by current for a stated operating point.

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Ammeter in series; voltmeter across resistor

Current is the same through components in series. Potential differences add around the series path. In parallel, branches share the same potential difference, while branch currents sum at a junction.

Place an ammeter in series and a voltmeter in parallel. For an I-V investigation, change voltage in steps, reverse polarity when appropriate and limit current to reduce heating.

■ Checked worked case

Known: a resistor has 6.0 V across it and carries 0.30 A. Use $R = V/I$. $R = 6.0/0.30 = 20$ ohms. Power $= VI$. Power $= 6.0 \times 0.30 = 1.8$ W. These quantities describe the same operating point.

■ Common error

Current is not used up by a lamp. A filament heats up, so its resistance need not remain constant as voltage changes.

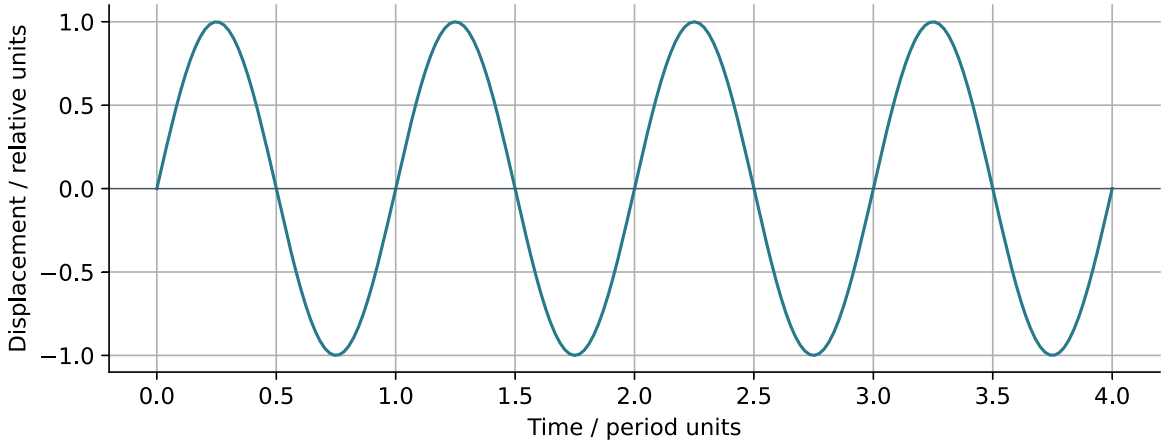
Oscillation, resonance and phase

Official-unit focus: C.1 Simple harmonic motion; C.4 Standing waves and resonance

A swing gains a large amplitude when pushes arrive with the right timing. The forcing frequency and damping help determine the response.

Simple harmonic motion has acceleration proportional to displacement and directed toward equilibrium. Period is time per cycle; frequency is its reciprocal. Damping transfers energy away from the oscillating system.

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Velocity is greatest near equilibrium for ideal SHM, while acceleration magnitude is greatest at extreme displacement. Resonance can occur near the natural frequency under periodic driving, with amplitude limited by damping.

Measure time for several complete oscillations and divide. Define a cycle consistently and use a small displacement when the model requires it. Keep pendulum paths clear and record damping effects rather than assuming perfect motion.

■ Checked worked case

Known: 20 cycles take 32 s. T=total time/cycles=32/20=1.6 s. Frequency=1/T=1/1.6=0.625 Hz. A shorter total timing interval would make reaction-time error a larger fraction of the measurement.

■ Common error

Not every repeated motion is SHM. A force proportional to displacement but directed away from equilibrium does not produce SHM.

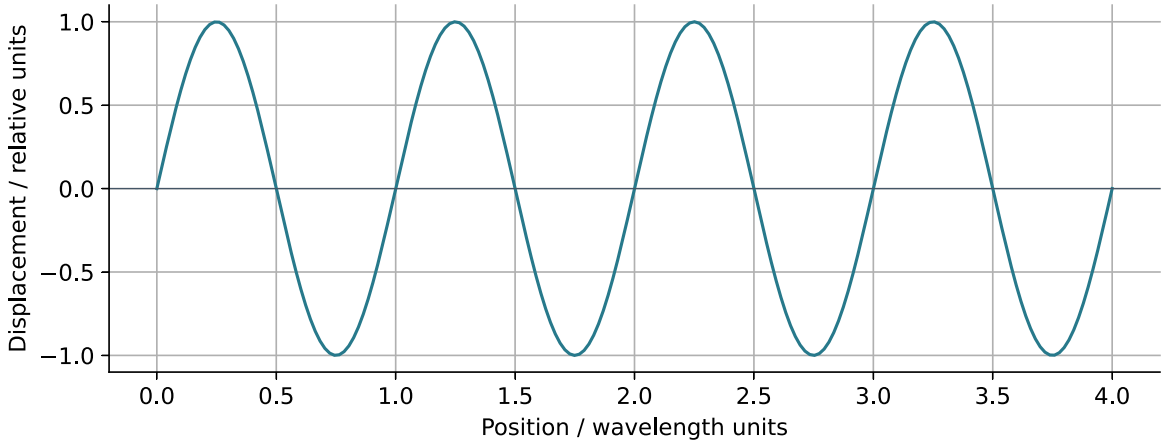
Waves, measurement and refraction

Official-unit focus: C.2 Wave model; C.3 Wave phenomena

A wave can carry energy across water while a floating marker mainly oscillates. Energy transfer and bulk transfer of matter are different.

Frequency is oscillations per time; wavelength is distance between successive points in phase. Wave speed equals frequency multiplied by wavelength. Transverse oscillations are perpendicular to propagation.

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At a boundary, frequency stays fixed by the source. A change of speed changes wavelength. Refraction follows from speed differences; angles are measured from the normal.

Measure several wavelengths and divide to reduce fractional reading uncertainty. Use a ray box with a normal drawn at the boundary. Keep the beam away from eyes and record incident and refracted angles clearly.

■ Checked worked case

Known: frequency 5 Hz and wavelength 0.40 m. Use $v = f\lambda$. $v = 5 \times 0.40 = 2.0$ metres per second. If speed falls to 1.5 metres per second at the same frequency, wavelength $= v/f = 1.5/5 = 0.30$ m.

■ Common error

The wave frequency does not change simply because the medium changes. A longitudinal wave has oscillations parallel to propagation.

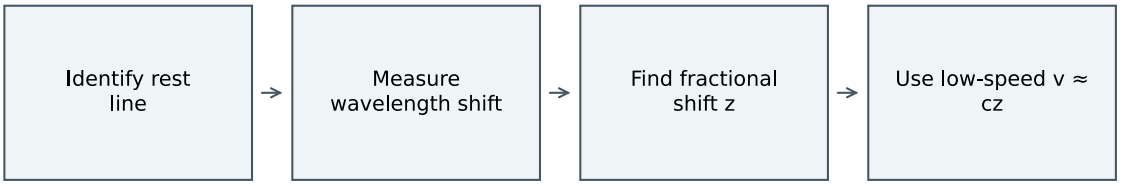
Spectral shifts: a low-speed astronomical estimate

Official-unit focus: C.5 Doppler effect

A recognizable spectral line appears at a longer wavelength in a distant source. Its shift can provide evidence of recession along the line of sight.

Relative source-observer motion changes observed frequency or wavelength. For light at a relative speed much smaller than c, the magnitude of the fractional wavelength shift is approximately v/c. Recession corresponds to longer wavelength, and approach to shorter wavelength.

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Compare a identified line with its laboratory rest wavelength. Use z = (observed−rest)/rest, then v approximately cz in the stated low-speed model. Do not apply this approximation without checking the regime or treating a cosmological redshift as a simple exact velocity.

Use attributed spectra with calibration and line identification. Compare several lines for a consistent shift. State uncertainty and distinguish relative line-of-sight motion from an unmeasured transverse component.

■ Checked worked case

Known: a 500 nm rest line is observed at 501 nm. z = (501−500)/500 = 0.002. With c=3.0×10^8 m/s, v approximately 6.0×10^5 m/s away. The sound-source denominator formula is not the required SL light approximation.

■ Common error

The approximate shift relation does not show that light travels faster from an approaching source. A single unidentified line cannot safely establish a redshift.

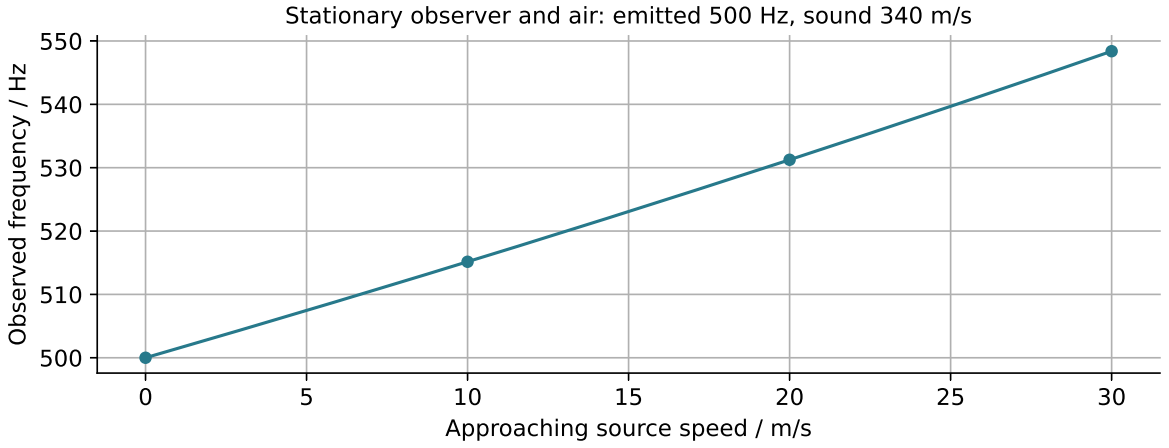
Doppler effect: separate source motion from wave speed

Official-unit focus: C.5 Doppler effect

An approaching sound source is heard at a higher pitch even when the source produces a constant frequency.

Doppler shift arises from relative source-observer motion. A moving source compresses wavefront spacing ahead and increases it behind. For sound in a stationary medium, the wave speed relative to that medium need not change.

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For a source approaching a stationary observer along the line of sight, f observed = f source × v/(v−v source). Recession uses v+v source in the denominator. These are sound-wave models; light requires its appropriate relation.

Use a simulation or recorded data with stated source and observer directions. Draw wavefronts before choosing signs. Avoid demonstrations near moving traffic or unsafe high-volume sources.

■ Checked worked case

Known: source frequency 500 Hz, sound speed 340 m/s, source approaches at 20 m/s. Observed frequency = 500 × 340/(340−20) = 531.25 Hz. The increase is 31.25 Hz; it is not the source frequency changing.

■ Common error

A stationary source and moving observer require the observer-motion relation. Do not use the same denominator formula for every arrangement or import a sound formula into relativity.

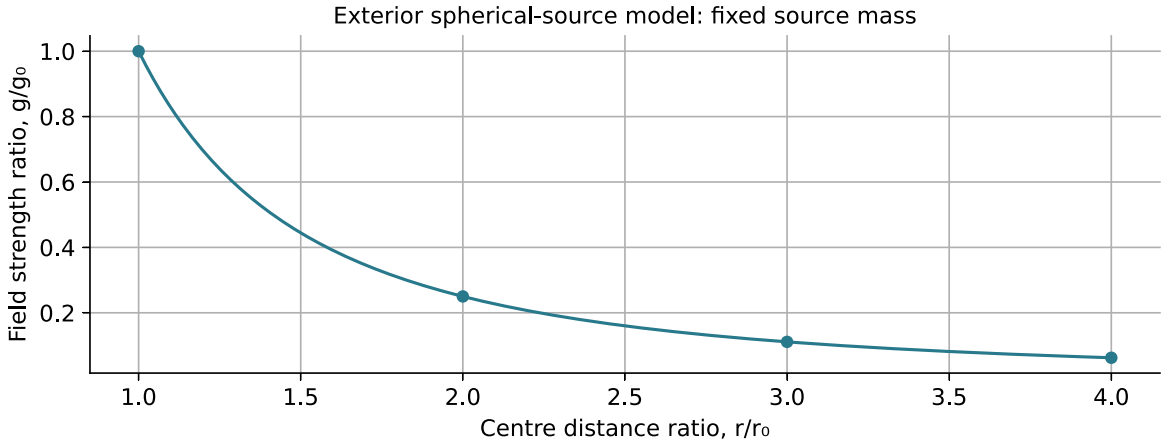
Gravitational fields and orbital motion

Official-unit focus: D.1 Gravitational fields

An orbiting satellite is continuously falling while moving sideways. Being in orbit does not require gravity to vanish.

Gravitational field strength is force per unit mass. A gravitational force can provide the centripetal force for a circular orbit. Field and potential describe different quantities.

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For a point mass or outside a spherical mass, field strength follows an inverse-square distance dependence. Use distance from the centre, not height above the surface alone.

State the circular-orbit approximation and ignore atmospheric drag only when justified. Draw the force toward the central body and velocity tangential to the orbit. Do not add an outward force merely because the path is circular.

■ Checked worked case

Known: field strength is 8 units at distance r from a spherical source. At 2r, $g2/g1=(r/2r)^2=1/4$. $g2=8/4=2$ units. The gravitational force on a fixed test mass decreases in the same ratio.

■ Common error

Weightlessness in an orbiting spacecraft means apparent weight is small in free fall, not that there is no gravitational field.

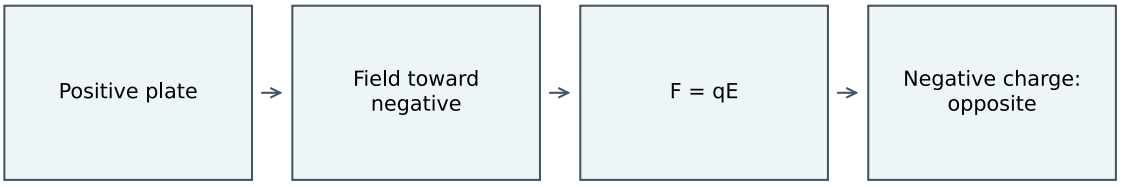
Electric fields: force and a positive test charge

Official-unit focus: D.2 Electric and magnetic fields

A negatively charged particle moves opposite to the direction of the electric field. Field direction is defined using a positive test charge.

Electric field strength is force per unit positive test charge. Like charges repel and unlike charges attract. Field lines point away from positive charges and toward negative charges. Closely spaced lines represent a stronger field within a consistently drawn diagram.

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In a uniform field between ideal parallel plates, E = V/d away from edge effects. The force is F = qE, so its direction reverses for a negative charge. Coulomb force between ideal point charges decreases with separation squared.

Sketch labelled plate polarities, field arrows and the charge before calculating. Convert separation to metres. In school, use simulations or approved low-voltage electrostatic models rather than exposed high-voltage equipment.

■ Checked worked case

Known: plate potential difference is 120 V and separation is 0.020 m. E = V/d = 6,000 V/m. A +2.0 microcoulomb charge experiences F = qE = 0.012 N along the field; a −2.0 microcoulomb charge experiences the same magnitude opposite to it.

■ Common error

Field strength is a vector. Potential difference is energy per charge and is not the same quantity. A field-line drawing is a model, not a set of physical threads.

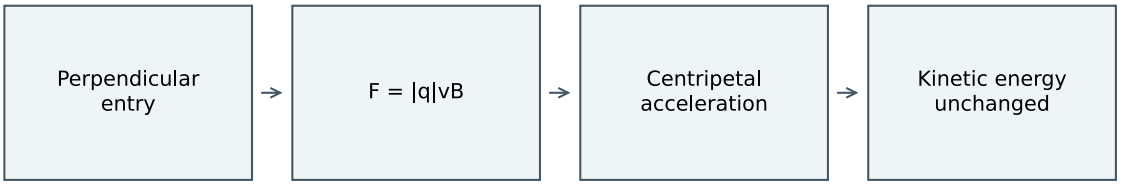
Magnetic forces: turn velocity without increasing speed

Official-unit focus: D.3 Motion in electromagnetic fields

A charged particle curves in a uniform magnetic field. Its direction changes although the magnetic force alone does not increase its kinetic energy.

The magnetic force magnitude is F = |q|vB sinθ. It is perpendicular to velocity and magnetic field, with direction determined by charge sign. For perpendicular entry into a uniform field, it can provide the centripetal force for circular motion.

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Equate magnetic force with mv^2/r to obtain $r = mv/(|q|B)$ for perpendicular motion. A stronger field makes a smaller radius at fixed momentum. Parallel entry gives zero magnetic force in this model.

Draw velocity, field and force as separate arrows using stated into/out-of-page conventions. Use supplied beam data or a simulation. Do not treat a current-carrying wire direction as identical to electron-motion direction.

■ Checked worked case

Known: a particle has $m = 2.0\times10^{-27}$ kg, $v = 3.0\times10^{6}$ m/s, $|q| = 1.0\times10^{-19}$ C and $B = 0.20$ T. $r = mv/(|q|B) = 0.30$ m. The calculation assumes non-relativistic motion and perpendicular entry.

■ Common error

A magnetic force can change momentum direction without doing work. Adding an electric field can change the energy, so conclusions about a magnetic field alone do not cover every combined-field apparatus.

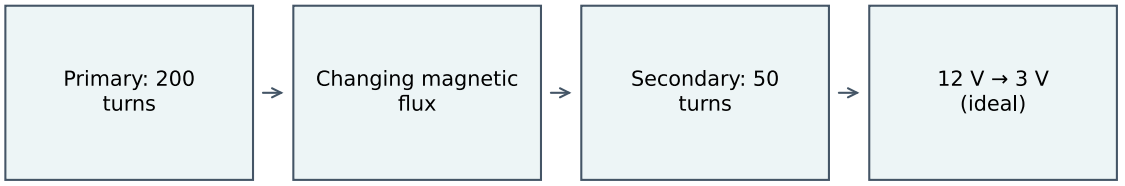
Fields, motors and induction

Official-unit focus: D.4 Induction

A magnet beside a wire does not always produce a current. An induced electromotive force depends on changing magnetic flux linkage.

A field describes a force effect at positions in space. A current-carrying conductor in a magnetic field can experience a force. Electromagnetic induction occurs when magnetic flux linkage changes.

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Changing field strength, coil area, orientation or relative motion can change flux linkage. Lenz law describes an induced effect opposing the change producing it, consistent with energy conservation.

Use a coil and sensitive meter to compare magnet motion in each direction. Record that a stationary arrangement gives no induced signal. Use approved low-voltage supplies for motor demonstrations.

■ Checked worked case

Known: a transformer has 200 primary turns, 50 secondary turns and 12 V primary voltage. For an ideal transformer, Vs/Vp = Ns/Np. Vs = Vp Ns/Np = 12×50/200 = 3.0 V. Real transformers also dissipate energy.

■ Common error

A transformer needs changing magnetic flux; a steady DC input does not provide continuous transformer action. Magnetic field direction is not automatically the direction of force.

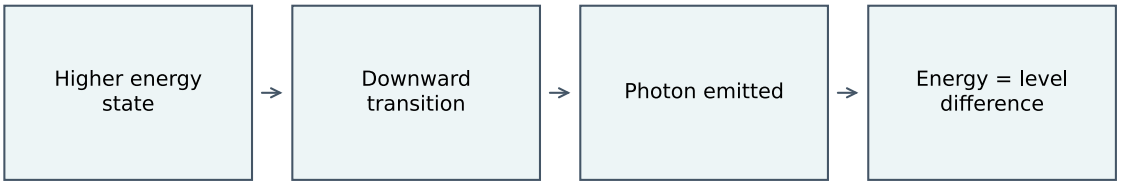
Atomic models and line spectra

Official-unit focus: E.1 Structure of the atom

An excited gas produces separate coloured lines rather than every wavelength. The pattern is evidence for discrete atomic energy differences.

Atoms have a small positive nucleus and electrons. Emission and absorption spectra arise from transitions between discrete energy levels. A photon energy equals the level difference and obeys E = hf.

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An emitted photon corresponds to a transition to a lower energy level. Absorption requires a compatible energy difference. Rutherford scattering supported a small dense nucleus, but that experiment alone did not establish the complete quantum model.

Read a labelled energy-level diagram before calculating. Keep joules and electron-volts distinct and use the given constants. Compare attributed spectra at a common wavelength scale and avoid looking at unsafe light sources.

■ Checked worked case

Known: energy levels are -6.0 and -2.0 eV. A downward transition releases 4.0 eV $= 6.4\times10^{-19}$ J using 1 eV $= 1.6\times10^{-19}$ J. With h $= 6.63\times10^{-34}$ J s, frequency is 9.65×10^{14} Hz.

■ Common error

Negative bound-state energies are relative to a chosen zero; they do not mean a negative photon energy is emitted. A larger downward energy difference gives higher frequency.

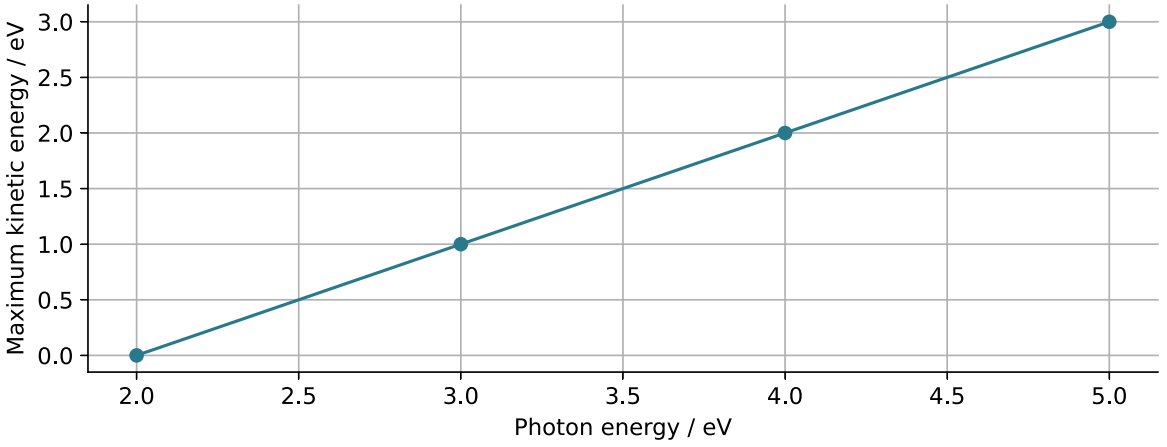
Photons and the photoelectric effect

Official-unit focus: E.2 Quantum physics

Bright low-frequency light can fail to eject electrons while dim higher-frequency light succeeds. Photon energy depends on frequency, not intensity alone.

A photon has energy proportional to frequency. The work function is the minimum energy needed to release an electron from a surface. Above threshold, excess photon energy can become electron kinetic energy.

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Use photon energy = Planck constant × frequency. Maximum kinetic energy = photon energy - work function. Increasing intensity at fixed frequency increases photon arrival rate, not individual photon energy.

Read axes carefully on a stopping-potential or kinetic-energy graph. Identify threshold frequency from the zero-energy intercept. State the metal and experimental conditions because work function is material-specific.

■ Checked worked case

Known: photon energy is 5.0 electronvolts and work function is 2.0 electronvolts. Maximum kinetic energy = photon energy - work function = 5.0 - 2.0 = 3.0 electronvolts. A 1.5 electronvolt photon cannot cause emission from that surface in this model.

■ Common error

Electrons do not accumulate many sub-threshold photons in the elementary single-photon model. Do not confuse photon number with photon energy.

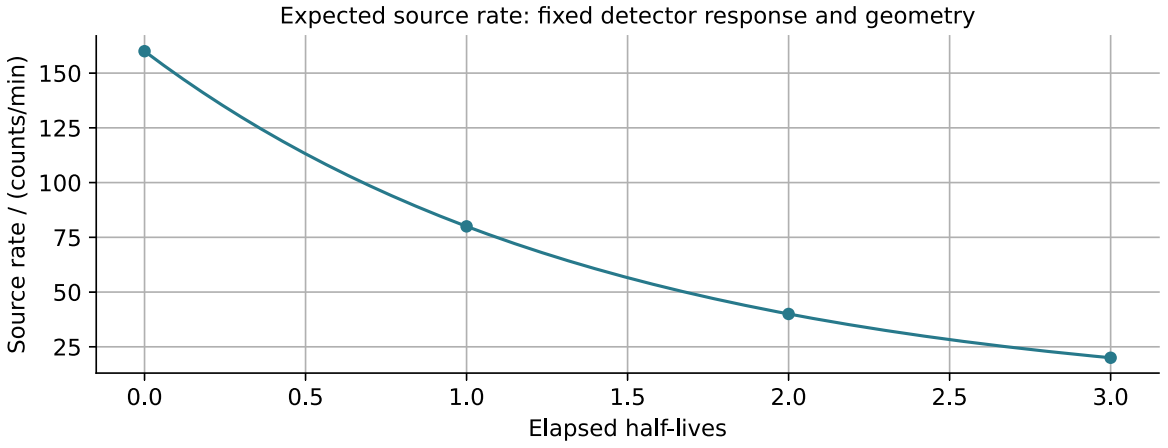
Nuclear changes and radiation evidence

Official-unit focus: E.3 Radioactive decay

A detector records counts even when the classroom source is removed. Background must be considered before attributing every count to the source.

Radioactive decay is spontaneous and random for an individual nucleus. Half-life describes the time for half the undecayed nuclei in a large population to decay, or for background-corrected activity to halve.

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Subtract background counts measured over the same time interval. Distinguish irradiation from contamination. Shielding, distance and reduced exposure time can reduce risk under a school-controlled procedure.

Use teacher-managed sources and the school radiation rules. Record count duration and repeat background measurements. Do not extrapolate a half-life from one nucleus or from uncorrected readings.

■ Checked worked case

Known: measured count rate falls from 100 to 55 counts per minute; background is 10. Source rates are 90 and 45, so one half-life has elapsed. Without subtraction, 55/100 would obscure the exact half in this example.

■ Common error

An irradiated object is not automatically radioactive. A half-life does not predict the exact decay time of one nucleus.

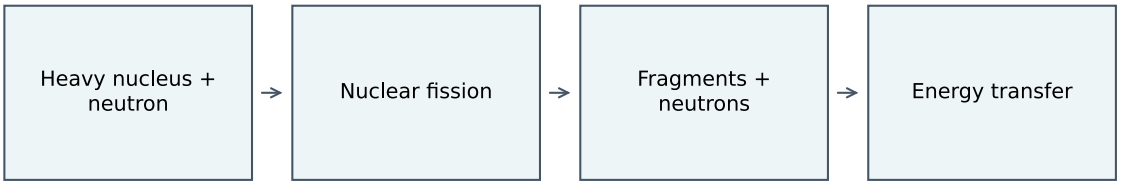
Fission: conserve charge and nucleons, account for energy

Official-unit focus: E.4 Fission

A neutron can trigger a heavy nucleus to split, releasing energy and further neutrons. Whether the process becomes a chain reaction depends on what happens to those neutrons.

In nuclear fission a heavy nucleus splits into lighter nuclei. Proton number and nucleon number balance in a nuclear equation. The total rest mass can decrease; the difference corresponds to released energy through $E = \Delta mc^2$.

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Separate conservation of nucleon number from conservation of total energy. Released neutrons may initiate further fissions, escape or be absorbed. A controlled reactor and an uncontrolled chain reaction have different neutron-management conditions.

Balance a supplied nuclear equation, use the specified mass data and identify the system. Analyse models or published reactor data; this is not a school attempt to produce fission or handle reactor materials.

■ Checked worked case

Known: U-235 absorbs one neutron, forming Ba-141, Kr-92 and three neutrons. Nucleon balance: 235+1 = 141+92+3 = 236. Proton balance: 92 = 56+36. A mass decrease of 2.0×10^{-28} kg corresponds to 1.8×10^{-11} J using c=3.0×10^{8} m/s.

■ Common error

Mass number is not a precise mass in kilograms. Balanced integer labels alone do not calculate the released energy. Radioactive decay and neutron-induced fission are not interchangeable descriptions.

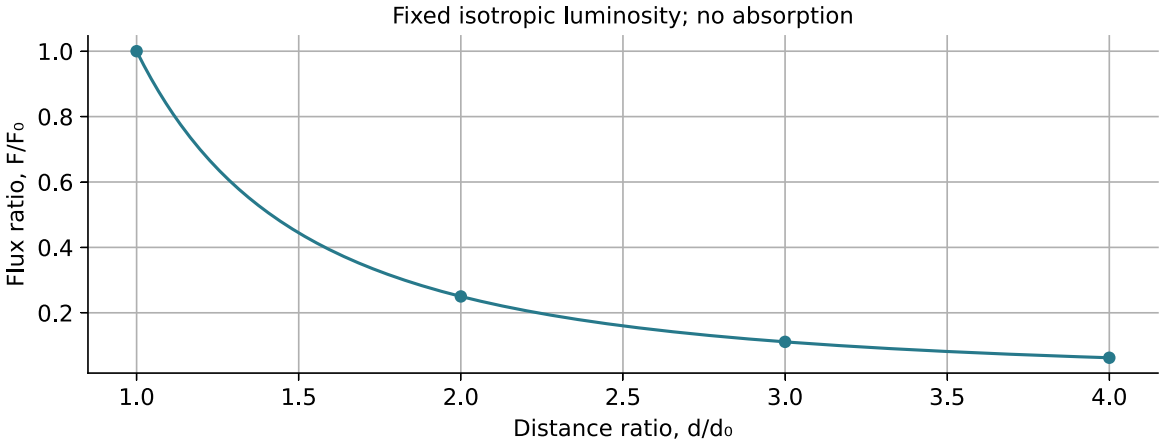
Stars, radiation and scale

Official-unit focus: E.5 Fusion and stars

Two stars can have the same apparent brightness while having different luminosities. Distance changes the flux reaching an observer.

Luminosity is total power emitted; flux is power received per area. A stellar spectrum carries information about surface temperature and composition. Fusion transfers energy as light nuclei combine.

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For isotropic emission without absorption, flux follows an inverse-square relationship with distance. Observed brightness alone therefore cannot establish luminosity.

Keep distance units consistent, identify which quantities are intrinsic to the star, and distinguish observational evidence from a model of stellar evolution. Do not confuse a red giant stage with every possible final remnant.

■ Checked worked case

Known: distance doubles while luminosity remains fixed. Use F proportional to $1/d^2$. Flux ratio $= 1/2^2 = 1/4$. A flux of 12 units becomes 3 units. This assumes no change in absorption or source output.

■ Common error

The Sun is not expected to become a supernova. Redshift can support cosmological expansion; it does not mean every nearby object must move away from every observer.

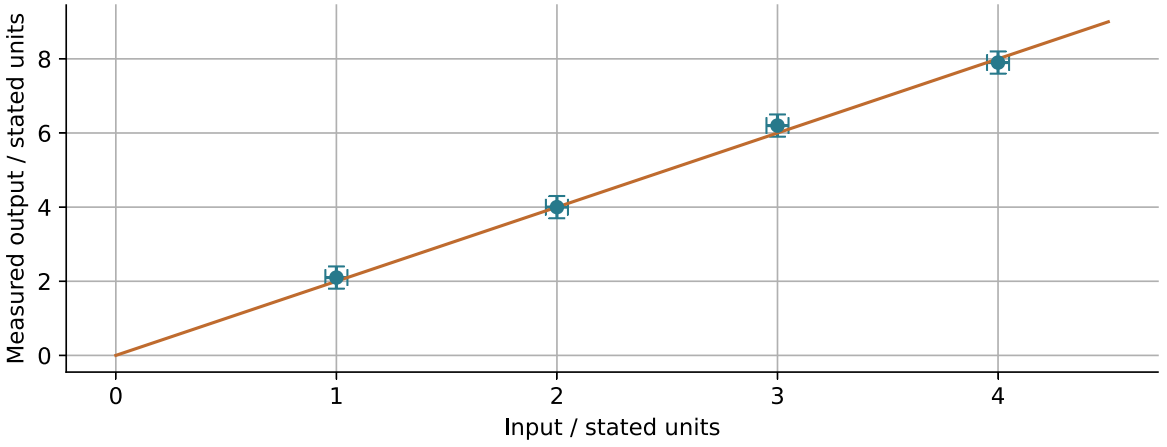
Uncertainty, gradients and model testing

Official-unit focus: Practical Experimental programme

A line passing near every data point is useful, but its gradient can still be uncertain. A graph is evidence for a model within the measurement range.

Random variation makes repeated readings differ. Systematic error shifts results consistently. Absolute uncertainty has the measured unit; relative or percentage uncertainty compares uncertainty with the measured value.

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For a product or quotient, adding fractional uncertainties is a common maximum-uncertainty approximation. For a difference, add absolute uncertainties. A nonzero intercept can reveal an offset or an incomplete model.

Show units on axes and choose a sensible scale. Plot uncertainty bars where justified, draw a best-fit line rather than joining every point, and estimate steepest and shallowest plausible gradients when the course method calls for them.

■ Checked worked case

Known: length = 50.0 mm with uncertainty 1.0 mm. Percentage uncertainty = absolute uncertainty/value $\times 100 = 1.0/50.0 \times 100 = 2.0\%$. For a quotient of two independently measured quantities with maximum percentage uncertainties 2% and 3%, the summed maximum estimate is 5%.

■ Common error

Repeating readings reduces random uncertainty in a mean but does not automatically remove a zero error. Do not quote more decimal places than your measurement can support.

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