

Energy: the currency of physics

A battery, a stretched spring and warm water all store **energy**. Energy can be transferred and stored, but never created or destroyed. This reference covers **AQA GCSE Physics 8463, topic 4.1 Energy**.

- Each paper is 100 marks and 1 h 45 min; energy ideas occur across both papers.
- AQA currently supplies a **Physics Equations Sheet**. Check your series' insert; practise choosing and rearranging equations and converting units.
- Show the equation, substitution and answer with units. Follow the question's precision instructions; marks depend on the question and scheme.

Energy stores and systems

A **system** is an object, or a group of objects, that you choose to think about. When a system changes, energy moves between **energy stores**. The stores you must name are:

Store	What it means	Example
kinetic	energy of a moving object	a rolling ball
gravitational potential	energy stored by an object above the ground	water behind a dam
elastic potential	energy stored in a stretched or compressed spring	a drawn bow
thermal (internal)	energy in a hot object	warm soup
chemical	energy stored in bonds	food, petrol, batteries
nuclear	energy stored in an atomic nucleus	uranium fuel
electrostatic	energy stored by separated charges	a charged cloud
magnetic	energy associated with interacting magnets	magnets attracting or repelling

Use the store name requested, such as thermal, gravitational potential or elastic potential. The June 2024 scheme accepts certain symbols in particular parts; this is not a rule that every symbol is accepted in every naming question.

Eight energy stores: examples in chosen systems

kinetic moving ball	gravitational potential raised water	elastic potential stretched spring	thermal warm water
chemical food or fuel	nuclear atomic nuclei	electrostatic separated charges	magnetic interacting magnets

Heating, mechanical work and electrical work transfer energy; they are not stores.

Say which store fills and which store empties.

Describing a change

Energy leaves one store and enters another. Say both halves. Practise these situations, which the specification names:

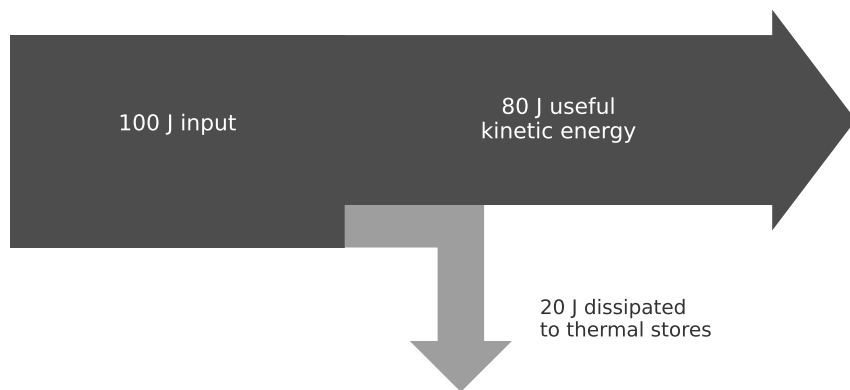
- **An object projected upwards:** the kinetic store decreases and the gravitational potential store of the object–Earth system increases. For a vertical launch, speed is zero at the highest point.
- **A moving object hitting an obstacle:** kinetic store empties; thermal stores of the object and the obstacle increase; sound can carry energy away.
- **An object accelerated by a constant force:** a source store (for example, the chemical store of a battery) decreases; work transfers energy to the vehicle's kinetic store. Electrical work is a transfer pathway, not an electrical store.
- **A vehicle slowing down:** kinetic store empties; thermal store of the brakes fills.
- **Bringing water to the boil in an electric kettle:** chemical energy in the power station's fuel (or another resource) ends in the thermal store of the water.

Energy can enter a system three ways: by **heating** (a temperature difference drives it), by **work done by forces** (a force moves something), and by **work done when a current flows** (an electrical device transfers energy). Electricity is covered in topic 4.2.

Sankey diagrams

A **Sankey diagram** shows energy on a common scale. The width of each arrow is drawn in proportion to the energy it carries. The left arrow is the input; it splits into a useful output and wasted outputs.

Motor model: arrow shaft widths show energy



Width, not length, shows the energy.

- The total width out always equals the width in. Energy is conserved.
- “Wasted” energy is not destroyed. It is stored in less useful ways, usually thermal.

■ Guided practice: naming stores and conserving energy

Starter – teacher-written. A motor transfers 60 J in 3.0 s. What is its power?

Worked reasoning. Power is the rate of energy transfer. The equation is $P = E/t$. Substituting gives $P = E/t = 60 \text{ J}/(3.0 \text{ s}) = 20 \text{ W}$. This means 20 joules each second; it does not establish efficiency or useful output.

Exam transfer – adapted from AQA June 2024 Paper 1H Q01.1, Q01.2 and Q06.1. Name the increasing store when water is heated, water is raised into a reservoir, and bungee cords are stretched. Try before checking: thermal/internal, gravitational potential, elastic potential. Explain each name using the temperature, height or extension change. Electrical work may transfer energy into these systems, but electrical is not an energy store.

Teacher-written motor balance. Input is 100 J and useful kinetic energy is 80 J. All the remainder reaches thermal stores. Calculate this remainder and draw proportional Sankey arrows before checking the diagram.

Worked reasoning. Conservation gives $E_{\text{dissipated}} = E_{\text{input}} - E_{\text{useful}}$. Substitution gives $E_{\text{dissipated}} = E_{\text{input}} - E_{\text{useful}} = 100 \text{ J} - 80 \text{ J} = 20 \text{ J}$. Input/useful/dissipated shaft widths have ratio $100:80:20 = 5:4:1$. Energy is conserved; the dissipated part is less useful, not destroyed. Arrow lengths and arrowhead sizes do not represent energy.

Calculating changes in energy

Choose the equation for the store that changes. Use mass in kg, speed in m/s, extension and height change in m, and the question’s gravitational field strength g in N/kg.

$$E_k = \frac{1}{2}mv^2 \quad E_e = \frac{1}{2}ke^2 \quad E_p = mgh$$

- E_k **kinetic energy** in J; m mass in kg; v speed in m/s.
- E_e **elastic potential energy** in J; k **spring constant** in N/m; e **extension** in m.
- E_p **gravitational potential energy** in J; h height increase in m; g **gravitational field strength** in N/kg.

Two warnings the exam tests:

- **Extension is the change in length:** stretched length minus original length. A “7.5 m extension” already means the extra length.
- $E_e = \frac{1}{2}ke^2$ needs the **limit of proportionality** not exceeded: below it, doubling the extension quadruples the stored energy.

Teacher-written practice – extension and units. A proportional spring is 10 cm long unstretched and 22 cm long stretched, with $k = 50 \text{ N/m}$. Find the extension and stored energy; predict the effect of doubling this extension while the spring remains proportional.

Worked reasoning. $e = L - L_0 = 22 \text{ cm} - 10 \text{ cm} = 12 \text{ cm} = 0.12 \text{ m}$. Then $E_e = \frac{1}{2}ke^2 = \frac{1}{2} \times 50 \text{ N/m} \times (0.12 \text{ m})^2 = 0.36 \text{ J}$. Doubling extension gives $E_{e,2} = \frac{1}{2}k(2e)^2 = 4E_e = 4 \times 0.36 \text{ J} = 1.44 \text{ J}$.

Teacher-written worked example. A 0.020 kg toy plane is launched horizontally by a proportional spring with $k = 50 \text{ N/m}$ and extension $e = 0.12 \text{ m}$. The spring relaxes to its natural length. Assume no height change and all released elastic energy becomes the plane’s kinetic energy. Find the ideal launch speed.

- Known: spring data and mass. At launch the elastic store empties into the kinetic store. For maximum speed, assume all of it arrives.

$$E_e = \frac{1}{2}ke^2 = \frac{1}{2} \times 50 \text{ N/m} \times (0.12 \text{ m})^2 = 0.36 \text{ J}$$

- Why $E_k = E_e$: the stated ideal model excludes energy transferred to other stores. In a real launch, thermal transfers can leave less kinetic energy and a lower speed.

$$E_k = \frac{1}{2}mv^2 \quad \Rightarrow \quad v = \sqrt{\frac{2E_k}{m}} = \sqrt{\frac{2 \times 0.36 \text{ J}}{0.020 \text{ kg}}} = 6.0 \text{ m/s}$$

- Check: unit is m/s because $\sqrt{\text{J/kg}} = \sqrt{\text{m}^2/\text{s}^2}$.

■ Exam transfer: two cords and height

Adapted from AQA June 2024 Paper 1H Q06.2–06.3. A 240 kg pod is released upwards by two cords behaving as springs, each with $k = 735 \text{ N/m}$ and extension 8.0 m. Calculate the ideal height gain ($g = 9.8 \text{ N/kg}$), assuming all initial elastic energy becomes gravitational potential energy. Explain why the actual height is lower.

- Known: two identical cords, so the stored energy doubles.

$$E_{e,1} = \frac{1}{2}ke^2 = \frac{1}{2} \times 735 \text{ N/m} \times (8.0 \text{ m})^2 = 23\,520 \text{ J}$$

$$E_{e,\text{total}} = 2E_{e,1} = 2 \times 23\,520 \text{ J} = 47\,040 \text{ J}$$

- In this ideal model all initial elastic energy becomes gravitational potential energy at the highest point, where vertical speed is zero:

$$E_p = mgh \quad \Rightarrow \quad h = \frac{E_p}{mg} = \frac{47\,040 \text{ J}}{240 \text{ kg} \times 9.8 \text{ N/kg}} = 20 \text{ m}$$

- Air resistance opposes the upward motion. Some initial elastic energy is transferred to the surroundings instead of increasing gravitational potential energy, so the actual height gain is smaller. “Energy is wasted” alone does not explain the transfer; energy is conserved.

Keep the physical assumption and each calculation stage visible; the allocation of marks depends on the particular question.

Energy changes in systems: specific heat capacity

Warm an object and its thermal store grows. The energy needed depends on the mass, the material, and the temperature rise:

$$\Delta E = mc\Delta\theta$$

- ΔE change in thermal energy in J; m mass in kg; $\Delta\theta$ temperature change in $^{\circ}\text{C}$.
- c **specific heat capacity** in $\text{J/kg } ^{\circ}\text{C}$: the energy needed to raise the temperature of **one kilogram** of a substance by **one degree Celsius**.

For equal masses gaining equal thermal energy, a material with higher c has a smaller temperature rise. Water has c about $4200 \text{ J/kg } ^{\circ}\text{C}$; copper about $385 \text{ J/kg } ^{\circ}\text{C}$. A spoon’s heating rate also depends on its mass and energy transfer through contact; specific heat capacity alone does not establish the rate.

Teacher-written worked example. A 2.0 kg metal block gains 26 kJ (26 000 J) of thermal energy. The block’s temperature rises from 22°C to 50°C . Find c .

- Known: energy, mass, and temperatures. The temperature *change* is what enters the equation: $\Delta\theta = 50 - 22 = 28^{\circ}\text{C}$.

$$c = \frac{\Delta E}{m\Delta\theta} = \frac{26\,000 \text{ J}}{2.0 \text{ kg} \times 28^{\circ}\text{C}} = 464 \text{ J/kg } ^{\circ}\text{C} \approx 460 \text{ J/kg } ^{\circ}\text{C}$$

- Check: J divided by $(\text{kg} \times ^{\circ}\text{C})$ gives $\text{J/kg } ^{\circ}\text{C}$.

Keep units consistent: 10.5 kJ must become 10 500 J; a time in minutes must become seconds; a mass in grams must become kg; a power in kW must become W. Write the conversion as its own line.

■ Exam transfer: rearranging for temperature change

Adapted from AQA June 2024 Paper 1H Q08.3. Air gains 0.0130 J; its mass is $2.60 \times 10^{-8} \text{ kg}$ and $c = 1.01 \text{ kJ/kg } ^{\circ}\text{C}$. Find the temperature change before checking.

- Convert $c = 1.01 \text{ kJ/(kg } ^{\circ}\text{C)} = 1010 \text{ J/(kg } ^{\circ}\text{C)}$.
- Rearrange $\Delta E = mc\Delta\theta$ to $\Delta\theta = \Delta E/(mc)$.

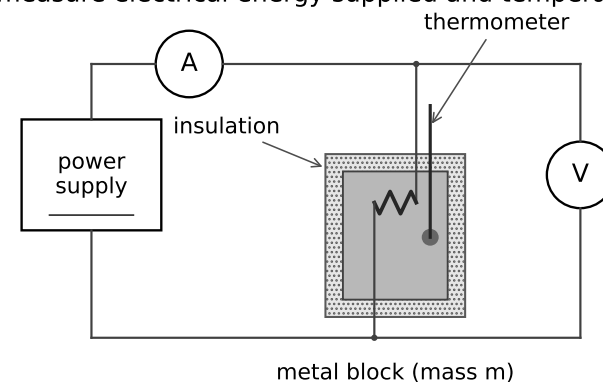
$$\Delta\theta = \frac{\Delta E}{mc} = \frac{0.0130 \text{ J}}{2.60 \times 10^{-8} \text{ kg} \times 1010 \text{ J/(kg } ^{\circ}\text{C)}} \approx 495^{\circ}\text{C}$$

- This is the rise, not the final reading; finding final temperature also needs the initial temperature.

■ Required practical 1: specific heat capacity

You must know this investigation from memory – the exam asks you to describe or evaluate it at a desk.

RP1: measure electrical energy supplied and temperature rise



The block is lagged to reduce transfer to the surroundings; supplied electrical energy is not automatically all gained by the block.

Method:

1. Measure the mass m of the metal block with a balance.

- Put a little water in the thermometer hole for good thermal contact, and insert the heater and thermometer.
- Record the starting temperature. Switch on the power supply.
- Record the current I and potential difference V , and the time t for which the heater runs. The heater power is $P = VI$ (given in topic 4.2; some questions just give you P).
- The energy supplied is $\Delta E = Pt$.
- Record temperature at regular intervals and calculate supplied energy for each time. Plot temperature against supplied energy; the initial part may curve because of thermal lag.
- Calculate $c = \frac{\Delta E}{m\Delta\theta}$.

Measurement reasoning:

- Insulate the block** (lagging) to reduce energy transferred to the surroundings. If some supplied energy heats the surroundings, using all the supplied energy as the block's thermal-energy increase overestimates c .
- Wait for the thermometer to settle before reading the starting temperature (thermal contact takes time).
- Use the straight region of temperature against supplied energy after the initial thermal lag. In the ideal model its gradient is $1/(mc)$. Repeats help assess variation but do not remove systematic heat loss.
- State how the error changes the measured energy, mass or temperature rise. Poor thermometer contact alone does not establish an error direction; an underestimated temperature rise gives an overestimated c if energy and mass are unchanged.

■ RP1 error check: calculate before predicting

Teacher-written. A 1.0 kg block gains 6000 J and warms by 12 °C. Calculate its c . A student records only a 10 °C rise with the same energy and mass. Calculate the resulting estimate and explain the direction of the error.

$$c = \frac{E}{m\Delta\theta} = \frac{6000 \text{ J}}{1.0 \text{ kg} \times 12^\circ\text{C}} = 500 \text{ J}/(\text{kg } ^\circ\text{C})$$

$$c_{\text{measured}} = \frac{E}{m\Delta\theta_{\text{measured}}} = \frac{6000 \text{ J}}{1.0 \text{ kg} \times 10^\circ\text{C}} = 600 \text{ J}/(\text{kg } ^\circ\text{C})$$

The smaller recorded rise gives a smaller denominator and an overestimate of c . Diagnose the recorded temperature change; do not assign an error direction from “poor contact” alone.

Power

Two motors can lift the same load through the same height. The faster one is more **powerful**. **Power** is the rate of energy transfer, or the rate of doing work:

$$P = \frac{E}{t} \quad P = \frac{W}{t}$$

- P power in W; E energy transferred in J; W **work done** in J; t time in s.
- An energy transfer of 1 J per second is a power of 1 **watt**, W.

Conversions to keep at hand: 1 kW = 1000 W, 1 MW = 10^6 W, 1 GW = 10^9 W, 1 kJ = 1000 J, 1 MJ = 10^6 J.

Teacher-written worked example. A 60.0 kg athlete climbs a vertical height of 175 cm in 1.40 s ($g = 9.8 \text{ N/kg}$). Find the average useful power associated with gravitational potential gain.

- Known: mass, height, time. Height must be converted: 175 cm = 1.75 m.
- Her gain of gravitational potential energy is the useful energy transferred.

$$E_p = mgh = 60.0 \text{ kg} \times 9.8 \text{ N/kg} \times 1.75 \text{ m} = 1029 \text{ J}$$

- Power divides energy by time in seconds.

$$P = \frac{E_p}{t} = \frac{1029 \text{ J}}{1.40 \text{ s}} = 735 \text{ W}$$

- Check: this is the rate of gravitational potential gain, not total chemical-energy transfer. Heating and other transfers mean more chemical energy is transferred than the useful gain.

An energy transfer stated per second is already a power: 0.343 J of gravitational potential energy gained each second is 0.343 W of useful power. A value per second is not automatically useful output; read which transfer is described.

■ Power comparison and exam transfer

Teacher-written practice. Motors A and B each lift 20 kg through 2.0 m ($g = 10 \text{ N/kg}$). A takes 2.0 s; B takes 4.0 s. Find their useful power outputs before checking.

$$E_p = mgh = 20 \text{ kg} \times 10 \text{ N/kg} \times 2.0 \text{ m} = 400 \text{ J}$$

$$P_A = \frac{E_p}{t_A} = \frac{400 \text{ J}}{2.0 \text{ s}} = 200 \text{ W}$$

$$P_B = \frac{E_p}{t_B} = \frac{400 \text{ J}}{4.0 \text{ s}} = 100 \text{ W}$$

A transfers the same useful energy in half the time: twice the useful power. Efficiency cannot be compared without input data.

Adapted from AQA June 2024 Paper 1H Q02.2–02.3. A power station has output 500 MW. Find its energy output in 3600 s, in joules. Here $P = 500 \text{ MW} = 5.00 \times 10^8 \text{ W}$, and $P = E/t$ rearranges to $E = Pt$.

$$E = Pt = 5.00 \times 10^8 \text{ W} \times 3600 \text{ s} = 1.8 \times 10^{12} \text{ J}$$

The unit check is watts times seconds equals joules. Output alone does not determine efficiency.

Conservation and dissipation of energy

Energy can be transferred usefully, stored, or dissipated, but never created or destroyed. Dissipated energy is stored in less useful ways. It is often called “wasted”, but it still exists – usually spread into thermal stores of the surroundings.

- For this energy balance, a **closed system** exchanges no energy with its outside, so its total energy does not change. Name the objects included: gravitational potential energy belongs to the object–Earth interaction, not the ball alone. An ideal fall with negligible resistance transfers gravitational potential energy to kinetic energy; a vacuum by itself does not define the system boundary.

■ Follow energy through a fall and impact

Teacher-written model. Include a ball, Earth, floor and nearby surroundings. Assume no energy crosses this system’s boundary and ignore air resistance during the fall. The ball starts at rest with 20 J of gravitational potential energy relative to the floor. When that store is 5 J, what is the kinetic energy? After impact and settling, where is the energy?

Stage	Gravitational / J	Kinetic / J	Thermal gain / J
Start	20	0	0
During fall	5	15	0
After settling	0	0	20

Each row totals 20 J. After impact, energy is spread into thermal stores in this simplified model; sound may carry energy within the chosen surroundings before dissipating. Counting the ball alone gives a different system, which can exchange energy with the Earth and floor. Energy that leaves one object has not disappeared.

■ Explaining a “lower than calculated” answer

Exam questions love this shape: “the real height/speed/temperature is lower than your answer. Explain why.” The credited reasoning:

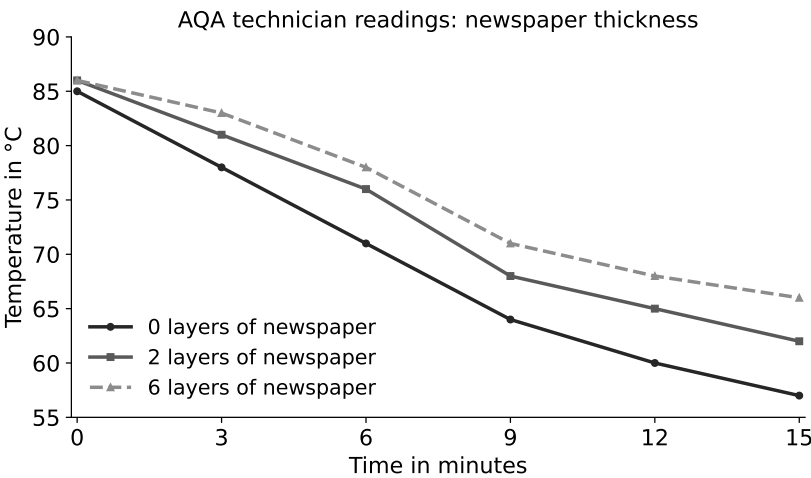
- Name the cause: air resistance, friction between moving parts, or energy transferred to the surroundings by heating.
- State the consequence: some energy from the input store is dissipated into thermal stores instead of the intended store.
- Conclude: so less energy arrives in the useful store.

■ Reducing unwanted energy transfers

- Lubrication** reduces friction between moving parts, so less energy is dissipated by heating.
- Thermal insulation** reduces energy transfer by heating. **Thick walls**, walls made of a material with **low thermal conductivity**, or cavity insulation all slow the cooling of a building.

Compare one factor at a time. With equal wall area, thickness and temperature difference, a higher thermal conductivity gives faster transfer by conduction. With the same material and other conditions, a thicker wall reduces this rate. If both thickness and conductivity change in opposing directions, their descriptions alone do not establish the ranking.

■ Required practical 2 (physics only): thermal insulators



Replotted from the AQA practical handbook’s technician data (PDF page 12, printed page 11). Initial readings are 85 °C for zero layers and 86 °C for the covered runs; check temperature falls and comparison limits.

Investigate the **effectiveness of different materials as thermal insulators**:

1. Put a fixed volume of hot water in a beaker with a lid.
2. Wrap the beaker in one material (bubble wrap, newspaper, foil, cotton wool).
3. Record the temperature as it cools for a fixed time (or the time to fall by a fixed amount).
4. Repeat for equal measured thicknesses and covered areas of different materials; equal layer counts need not give equal thicknesses.
5. Part 2: repeat for different thicknesses (layers) of one material.

Controls: same water volume, starting temperature, beaker, lid, surroundings, covered area and measurement times. Repeat to judge variation. A smaller temperature fall over a fixed time indicates less cooling under those conditions. Keep material fixed when investigating thickness; keep thickness fixed when comparing materials.

■ RP2: interpret recorded readings

The figure uses the AQA practical handbook, PDF page 12. Points are recorded values joined by lines, not a fitted cooling law. In 15 min, the zero-layer run changes from 85 to 57 °C, two layers from 86 to 62 °C, and six layers from 86 to 66 °C. Calculate the falls before checking.

$$\text{fall}_0 = \theta_i - \theta_f = 85^\circ\text{C} - 57^\circ\text{C} = 28^\circ\text{C}$$

$$\text{fall}_2 = \theta_i - \theta_f = 86^\circ\text{C} - 62^\circ\text{C} = 24^\circ\text{C}$$

$$\text{fall}_6 = \theta_i - \theta_f = 86^\circ\text{C} - 66^\circ\text{C} = 20^\circ\text{C}$$

Six layers cool 4 °C less than two layers over the same time, from the same initial temperature. This supports less cooling with greater newspaper thickness here. The zero-layer run starts 1 °C cooler. Subtracting initial temperatures does not remove all effects of unequal starting conditions; standardise them in a fresh investigation. These runs compare thickness, not different materials.

Teacher-written evaluation. Water in a beaker covered with 20 mm of cotton starts at 90 °C and finishes at 75 °C after 10 min. Water in a beaker covered with 2 mm of foil starts at 80 °C and finishes at 70 °C. Which material is the better insulator? Explain the limits and improve the method before checking.

Reasoning. Cotton falls $90 - 75 = 15^\circ\text{C}$; foil falls $80 - 70 = 10^\circ\text{C}$. Material, thickness and initial temperature all differ, so neither final readings nor temperature falls isolate the material effect. Use equal measured thickness and covered area, the same starting temperature, water volume, apparatus and surroundings; record at the same times and repeat. Conclude for the tested conditions, taking variation into account.

Efficiency

The fraction of input energy that ends up somewhere useful is the **efficiency** :

$$\text{efficiency} = \frac{\text{useful output energy transfer}}{\text{total input energy transfer}} \quad \text{efficiency} = \frac{\text{useful power output}}{\text{total power input}}$$

- Efficiency can be a **decimal** (0 to 1) or a **percentage** (0 % to 100 %). The exam may ask for either; a decimal above 1 or a percentage above 100 % is impossible – check your answer against this.
- Percentage wasted = 100 % – percentage useful.

Teacher-written worked example. A lamp takes 4.0 W of electrical power and is 0.85 efficient for useful light transfer. Find its useful light power and the remaining power.

- Known: total input and efficiency as a decimal. Rearrange before substituting.

$$\text{useful power} = \text{efficiency} \times \text{total input} = 0.85 \times 4.0 \text{ W} = 3.4 \text{ W}$$

- The remainder is $P_{\text{other}} = P_{\text{input}} - P_{\text{useful}} = 4.0 \text{ W} - 3.4 \text{ W} = 0.6 \text{ W}$. Outputs add to input; no energy is destroyed. Efficiency is a ratio without a unit.

Exam transfer – adapted from AQA June 2024 Paper 1H Q01.3. Method A heats water by 80 °C, storing 33 600 kJ per 100 kg, and wastes 40%; installation is possible anywhere in the question. Method B pumps water uphill by 500 m, storing 490 kJ per 100 kg, wastes 25%, and requires high mountains. Compare useful fractions, useful energy and practical constraints before checking.

- Percentage useful = $100 - 40 = 60\%$.

$$E_{\text{useful}} = \frac{60}{100} \times 33\,600 \text{ kJ} = 20\,160 \text{ kJ}$$

Method B has useful fraction $f_B = 1 - 0.25 = 0.75$ and useful energy $E_{\text{useful,B}} = f_B E_B = 0.75 \times 490 \text{ kJ} = 367.5 \text{ kJ}$. It is more efficient than A (75% versus 60%), but A provides much more useful energy per 100 kg (20 160 kJ versus 367.5 kJ). Explain both quantities, the stated location restriction and the need to insulate heated water. Use numerical evidence alongside the stated constraints.

■ Efficiency: compare a clearly defined useful transfer

Teacher-written. Lifting devices A and B each take 2000 W of electrical input. Their useful mechanical outputs are 1700 W and 1500 W. Find both efficiencies and their difference in percentage points.

$$\eta_A = \frac{P_{\text{useful,A}}}{P_{\text{input,A}}} = \frac{1700 \text{ W}}{2000 \text{ W}} = 0.85 = 85\%$$

$$\eta_B = \frac{P_{\text{useful},B}}{P_{\text{input},B}} = \frac{1500 \text{ W}}{2000 \text{ W}} = 0.75 = 75\%$$

The gap is $85\% - 75\% = 10$ percentage points. A transfers a greater fraction to useful lifting; the ratio's units cancel. Do not confuse a percentage-point difference with a relative percentage change.

Higher Tier reasoning. Lubrication reduces frictional dissipation in a lifting motor; insulation reduces unwanted thermal transfer from hot-water storage. At fixed input, reduced unwanted transfers can leave more useful output and a greater efficiency. At fixed useful output, $E_{\text{input}} = E_{\text{useful}}/\eta$, so greater efficiency means less required input. “Useful” depends on the intended task: heating is useful for warming a room and may be unwanted in a lifting motor.

National and global energy resources

The main energy resources are **fossil fuels** (coal, oil, gas), **nuclear fuel**, bio-fuel, wind, hydroelectricity, geothermal, tides, the Sun and water waves.

A **renewable** resource is replenished as it is used. Fossil and nuclear fuels are **non-renewable** on a human timescale. Replenishment, availability when needed, and environmental impact are different questions. Renewable does not mean continuous or harmless. Compare uses in transport, electricity generation and heating. Descriptions of generating machinery are not required here.

■ Fuel resources: uses and trade-offs

- **Coal, oil and gas:** electricity or heating; oil-derived fuels are widely used in transport. Generation depends on fuel supply and maintenance. Combustion releases carbon dioxide; sulfur in fuel can produce sulfur dioxide, contributing to acid rain.
- **Nuclear fuel:** electricity, using a finite fuel. Maintenance and outages affect availability. There is no fuel-combustion CO_2 during generation, but radioactive waste needs safe management.
- **Bio-fuel:** transport, heating or electricity. Its biological source can be replaced, but production takes land and time. Burning releases CO_2 . Regrowth can absorb CO_2 , but the overall balance also depends on cultivation, processing and land-use change; carbon neutrality is not automatic.

■ Six other renewable resources

Resource	Availability / example use
wind	electricity; variable wind
Sun	electricity or heating; daylight and clouds matter
hydroelectricity	electricity; stored water helps, but supply is limited
geothermal	heating or electricity; suitable sites matter
tides	electricity; predictable timing, variable output
water waves	electricity; variable sea conditions

Wind turbines can affect wildlife and cause noise; solar installations need space and materials. Reservoirs can flood land and alter river habitats. Geothermal development involves local drilling. Tidal and wave installations can affect marine habitats and are costly to build and maintain. Distinguish environmental impacts from technical constraints and economic costs. Claims about no fuel-combustion emissions during operation do not mean zero impact over manufacture, construction and disposal.

■ Worked example: actual operating time

AQA GCSE Physics June 2024 Paper 1H Q02.5 gives one nuclear station generating for 92% of a 365-day year. With f the generating fraction:

$$t_{\text{operating}} = f t_{\text{year}}$$

$$t_{\text{operating}} = 0.92 \times 365 \text{ days} = 335.8 \text{ days}$$

About 336 days (this question's scheme accepts 335 or 336). The station did not generate all year; do not generalise its percentage to every station. This time fraction alone gives neither electrical energy output nor efficiency.

■ Interpret a trend: attempt, then check

Teacher-written fictional data, with only two categories contributing to each total:

Period	Fossil / TWh	Renewable / TWh
A	80	20
B	90	60

TWh is an energy unit. Find each total and fossil-fuel share. Did the amount of fossil energy fall?

Check:

$$E_A = E_{\text{fossil},A} + E_{\text{renewable},A} = 80 \text{ TWh} + 20 \text{ TWh} = 100 \text{ TWh}$$

$$E_B = E_{\text{fossil},B} + E_{\text{renewable},B} = 90 \text{ TWh} + 60 \text{ TWh} = 150 \text{ TWh}$$

$$s_A = E_{\text{fossil,A}}/E_A = 80 \text{ TWh}/(100 \text{ TWh}) = 0.80 = 80\%$$

$$s_B = E_{\text{fossil,B}}/E_B = 90 \text{ TWh}/(150 \text{ TWh}) = 0.60 = 60\%$$

The share fell by 20 percentage points, but fossil energy rose by 10 TWh. A decreasing share alone cannot establish decreasing emissions.

■ Make a decision with evidence

Teacher-written task: a clinic needs electricity all night. Solar panels produce no output at night; a maintained gas generator can run when fuel is supplied. Solar generation has no fuel-combustion CO₂; gas combustion releases CO₂. Explain the trade-off, propose a possible supply and identify missing evidence.

Check: solar alone does not meet the night-time requirement. Solar with charged storage or another backup could work if power and stored energy meet demand. Gas can supply power at night, with fuel and maintenance, but releases CO₂. Check demand, storage capacity, charging conditions, fuel supply, costs and the site before choosing. Funding is an economic constraint; access to reliable care is a social concern. Planning rules are political constraints, and sharing costs and benefits fairly raises ethical questions. Science identifies and measures problems; decisions also depend on these constraints. A conclusion should follow the evidence and stated priorities; no stock final sentence guarantees credit.

Checklist before you call this topic done

■ Retrieval 1: connect the equations

Teacher-written: a motor takes 5.0 J in 2.0 s. It starts a 0.50 kg cart from rest on a level track. The cart gains 4.0 J of kinetic energy; the remainder heats the system and surroundings. Find final speed, efficiency for accelerating the cart, mean input power, and the remaining energy transfer. Attempt before checking.

Check: because the initial speed is zero, final kinetic energy is 4.0 J.

$$E_k = \frac{1}{2}mv^2 \Rightarrow v = \sqrt{2E_k/m}$$

$$v = \sqrt{2E_k/m} = \sqrt{2 \times 4.0 \text{ J}/(0.50 \text{ kg})} = 4.0 \text{ m/s}$$

$$\eta = E_{\text{useful}}/E_{\text{input}} = 4.0 \text{ J}/(5.0 \text{ J}) = 0.80 = 80\%$$

$$P_{\text{input}} = E_{\text{input}}/t = 5.0 \text{ J}/(2.0 \text{ s}) = 2.5 \text{ W}$$

$$E_{\text{other}} = E_{\text{input}} - E_{\text{useful}} = 5.0 \text{ J} - 4.0 \text{ J} = 1.0 \text{ J}$$

That 1.0 J is transferred by heating. Energy is conserved.

■ Retrieval 2: diagnose three claims

1. RP1: all heater input is used as the block's energy gain, though some heats the room. With mass and measured temperature rise fixed, what happens to calculated specific heat capacity?
2. RP2: both insulation layers and water volume change. Why is the conclusion about layers insecure? State controls.
3. Solar panels are called a guaranteed night-time supply because solar is renewable. What is wrong and what extra provision is needed?

Check:

1. $c = E_{\text{gained}}/(m\Delta\theta)$. Using the larger input overestimates c in the stated case.
2. Two changed variables confound the result. Keep volume, container, starting temperature, timing and surroundings fixed; repeat measurements and compare temperature falls over the same time.
3. Replenishment does not ensure power when needed. Adequate charged storage or another supply is required at night.

Use the terms requested, show equations and units, and follow the question's precision instruction. A cause and its physical consequence are more useful than a memorised checklist.