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IGCSE PHYSICS 0625 · TOPICAL PAST PAPERS

Energy, Work & Power — Paper 2

Worked Solutions (Theory / Structured)

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Energy, Work & Power — Paper 2 · Worked Solutions

These are **Megalecture worked solutions** for the topical Paper 2 (theory / structured) compilation on **Energy, Work & Power**. Every part below was solved from first principles by the Megalecture team — none of the wording is copied from any official Cambridge mark scheme. Calculations use the standard relationships $E_k = ½mv^2$, GPE = mgh, $W = Fd$, $P = E/t$, efficiency = useful output ÷ total input, and conservation of energy, with g taken as 10 N/kg unless a question states otherwise. Questions are numbered as in the compilation; final answers are shown in **bold colour with units**.

Energy sources, efficiency & power of a person

Question 1 Hydroelectric power station

Water from a lake is used to produce electricity in a turbine house (Fig. 4.1).

(a) State where the water in Fig. 4.1 has the least potential energy.
Gravitational PE is least where the water is **lowest**. The water that has flowed out at the bottom — i.e. the water in **the river (the outflow, at the lowest level)** — has the least gravitational potential energy.

(b)(i) In 30 minutes the water loses 5.0×10^3 J of energy and 4.5×10^3 J of electrical energy is produced. Calculate the efficiency.

efficiency = useful output ÷ total input = $4.5 \times 10^3 \div 5.0 \times 10^3$
= 0.90 → **0.90 (90%)**

(b)(ii) Calculate, in watts, the electrical power output.

P = energy ÷ time = 4.5×10^3 J ÷ (30 × 60) s = 4500 ÷ 1800
= **2.5 W**

(c) One advantage of the hydroelectric station over coal-burning stations:
it uses a **renewable** energy source (the water is continually replenished by rainfall) and it does **not burn fuel, so it produces no carbon dioxide or other polluting gases**.

(d) One harmful effect on the environment:
building the dam **floods a large area of land** upstream, destroying habitats and forcing people/wildlife to move (it also disrupts the natural flow of the river).

Question 2 Measuring a person's power (running up stairs)

A student measures the power he produces by running up a flight of stairs.

(a)(i) List all the readings he must take:

- his **weight** (or his mass, to find weight = mg);
- the **vertical height** gained — the total height of the flight of stairs;
- the **time** taken to run up the stairs.

(a)(ii) One precaution for an accurate reading:
start and stop the stopwatch at the exact instants he begins and finishes (or repeat the timing several times and average) so the time is measured accurately; measure the vertical height (not the slope distance).

(b) Equations he must use to calculate his power:

weight: **W = m × g**

work done lifting himself: **work = W × h** (= gain in gravitational PE = mgh)

power: **P = work ÷ time** = mgh ÷ t

Question 3 Block diagram of a power station

(a) Labelling the boxes after the boiler (boiler → … → … → … → electrical energy output):
boiler → **turbine** → **generator** → **transformer** → electrical energy output.
The boiler makes steam, the steam spins the turbine, the turbine drives the generator which produces electricity, and the transformer steps up the voltage for transmission. (Motor and solar panel are not used.)

(b) One environmental problem caused by burning oil:
burning oil releases **carbon dioxide, which adds to the greenhouse effect / global warming** (also acidic sulfur-dioxide gases that cause acid rain).

(c)(i) Why oil is described as non-renewable:
it is **used up far faster than it is formed** — once the existing reserves are burned they cannot be replaced within a useful timescale.

(c)(ii) One renewable energy source: **solar (Sun), wind, hydroelectric, tidal, wave or geothermal** — any one.

Question 4 Falling sheet of paper (h–t graph)

A piece of paper falls from 4.0 m; Fig. 1.1 shows height *h* against time *t*.

(a) What happens to the speed as it falls:
the gradient of the graph (the rate at which height decreases) gets steeper, so the paper **speeds up at first; the graph then becomes a straight line, so the paper reaches a constant (terminal) speed** for the rest of the fall.

(b) Speed at *t* = 1.5 s — read the gradient of the graph at that time. The line is straight near *t* = 1.5 s, falling from about *h* = 1.7 m at 1.0 s to about 0.3 m at 2.0 s.

speed = gradient = Δh ÷ Δt = (1.7 − 0.3) ÷ (2.0 − 1.0) ≈ 1.4 ÷ 1.0

≈ **1.4 m/s** (accept ≈ 1.3–1.5 m/s from the graph)

(c) Main energy change between *t* = 1.0 s and 2.0 s (constant speed):
the paper falls but does not speed up, so **gravitational potential energy is transferred to thermal (heat) energy of the air and paper** through air resistance (kinetic energy stays constant).

Question 5 Rubbing hands — work and power

(a) Main energy conversion that warms the hands:
kinetic energy (of the moving hand) is converted to thermal (heat) energy by friction between the hands.

(b) Why pressing harder makes them warmer:
pressing harder increases the **friction force**, so more work is done against friction for the same movement, producing more heat.

(c)(i) F = 1.2 N, one hand moves 0.080 m per movement; number of movements for 2.0 J.

work per movement = F × d = 1.2 × 0.080 = 0.096 J

number = 2.0 ÷ 0.096 = 20.8 → **21 movements** (nearest whole number)

(c)(ii) Each movement takes 0.20 s; average power.

P = work per movement ÷ time = 0.096 J ÷ 0.20 s

= **0.48 W**

Question 6 Motor and lift (elevator)

Input power to the motor = 6200 W; lift + man have mass 580 kg and rise 12 m in 15 s.

(a) Define the watt:
one watt is **one joule of energy transferred per second** (1 W = 1 J/s).

(b)(i) Tension in the cable at constant speed.

At constant speed the cable tension equals the weight: T = mg = 580 × 10

= **5800 N**

(b)(ii) Increase in potential energy.

GPE = mgh = 580 × 10 × 12 = **69 600 J** (6.96×10^4 J)

(b)(iii) Efficiency of the motor.

useful output power = GPE ÷ t = 69 600 ÷ 15 = 4640 W

efficiency = useful output ÷ input = 4640 ÷ 6200 = 0.748

= **0.75 (75%)**

Question 7 Small hydroelectric system

Each minute, water carries 14 000 J of kinetic energy; half of it is given to the generator.

(a)(i) Power input to the generator.

energy to generator each minute = ½ × 14 000 = 7000 J

P = energy ÷ time = 7000 J ÷ 60 s = 116.7 W

≈ **120 W** (1.2×10^2 W)

(a)(ii) Why only some of the water's kinetic energy reaches the generator:
some energy is lost as **heat and sound through friction** (in the turbine bearings and against the water), and the water still moves after passing the turbine, so it keeps some kinetic energy.

(b)(i) Meaning of renewable energy:
a source that is **naturally replaced as fast as it is used, so it will not run out**.

(b)(ii) One non-renewable source: **coal, oil, natural gas or nuclear (uranium)** — any one.

Question 8 Cyclist over a hill (conservation of energy)

A cyclist starts from rest at A, rides up and over a hill, and brakes to rest at B (A and B at the same height).

(a) Energy changes as she pedals up at constant speed:
she does work, so **chemical energy in her muscles is transferred to gravitational potential energy** as

she rises; because the speed is constant her kinetic energy stays the same, and some energy is also lost as **heat** (friction/air resistance).

(b) How conservation of energy applies to the whole trip A → B:
energy is never created or destroyed. Since A and B are at the same height and she is at rest at both, the chemical energy she supplies plus the small kinetic energy she had is all eventually transferred to **heat (thermal energy)** in the brakes, tyres and surrounding air — the total energy is unchanged.

(c) GPE increased by 5400 J, mass 60 kg, g = 10 N/kg; find the height above A.

GPE = mgh → h = GPE ÷ (mg) = 5400 ÷ (60 × 10) = 5400 ÷ 600

= **9.0 m**

Question 9 Windsurfer — kinetic energy at constant speed

Total mass of windsurfer, sail and board = 90 kg; constant speed 5.0 m/s.

(a) Total kinetic energy.

$E_k = \frac{1}{2}mv^2 = \frac{1}{2} \times 90 \times (5.0)^2 = \frac{1}{2} \times 90 \times 25$

= **1125 J** (≈ 1.1×10^3 J)

(b)(i) Why the board moves at constant speed:
the speed is steady, so the resultant force is zero — the **forward force from the wind is balanced by the resistive (drag) force from the water and air** (forces are equal and opposite).

(b)(ii) The wind does work, yet the kinetic energy does not increase — explain using conservation of energy:
the work done by the wind is not stored as extra kinetic energy; at constant speed it is **transferred at the same rate to heat (thermal energy) as the surfer pushes through the water and air (drag)**, so the total kinetic energy stays the same — energy is conserved.

Question 10 Press-up — work, moments and force

Weight 600 N acts down from the centre of mass; hands are 0.40 m from the centre of mass and the toes a further 0.80 m (so hands to toes = 1.2 m).

(a)(i) Why he does work as his body rises:
he exerts an upward force and his body (its centre of mass) **moves up in the direction of that force**, so work = force × distance is done against gravity.

(a)(ii) Form of energy used to do this work: **chemical energy (stored in his muscles)**.

(b)(i) Moment of the weight about his toes.

distance of weight (centre of mass) from toes = 0.80 m

moment = F × d = 600 × 0.80 = **480 N m**

(b)(ii) Value of the force F at the hands (balance moments about the toes).

F acts at the hands, 1.2 m from the toes. For equilibrium: F × 1.2 = 480

F = 480 ÷ 1.2 = **400 N**

Efficiency, energy transfer & heating

Question 11 Two kettles — efficiency and useful power

In one minute: electric kettle takes 120 000 J and gives 95 000 J to the water; gas kettle takes 130 000 J and gives 90 000 J to the water.

(a)(i) Efficiency of the electric kettle.

efficiency = useful (heat to water) ÷ total supplied = 95 000 ÷ 120 000
= 0.79 → **0.79 (79%)**

(a)(ii) Useful power of the gas kettle.

useful power = useful energy ÷ time = 90 000 J ÷ 60 s
= **1500 W**

(b) Which kettle boils the water first (same mass, same start temperature):
the **electric kettle** boils first — it delivers more useful heat to the water each minute (95 000 J vs 90 000 J), so it raises the water's temperature faster.

(c) One difference between molecules in steam and in boiling water:
molecules in the steam are **much further apart and move faster / more freely** than those in the liquid water (steam molecules have more energy and far weaker forces between them).

Question 12 Electric motor lifting a load

Load weight 5.0 N raised 3.5 m at constant speed; motor efficiency 0.65 (65%).

(a) Increase in gravitational potential energy of the load.

GPE = weight × height = 5.0 × 3.5 = **17.5 J**

(b)(i) Formula linking efficiency, energy input and useful output:
efficiency = useful energy output ÷ total energy input (× 100% for a percentage).

(b)(ii) Energy input to the motor.

energy input = useful output ÷ efficiency = 17.5 ÷ 0.65
= **27 J** (26.9 J)

(c) Why the efficiency is less than 100%:
some of the input energy is **transferred to heat (and sound) by friction in the motor and pulley** instead of lifting the load, so the useful output is always less than the input.

Question 13 Child on a swing (energy transfer)

From A to B the child falls 0.60 m and loses 240 J of GPE; g = 10 N/kg.

(a) How another child can accurately time one complete swing:
time **several complete swings (e.g. 10 or 20)** with a stopwatch and **divide the total time by the number of swings** — this reduces the effect of reaction-time error and gives an accurate time for one swing.

(b)(i) Mass of the child.

GPE lost = mgh → m = GPE ÷ (g × h) = 240 ÷ (10 × 0.60) = 240 ÷ 6.0
= **40 kg**

(b)(ii) Two reasons why her kinetic energy at B is not 240 J:

1. some energy is lost as **heat through air resistance** as she swings down;
2. some energy is lost as **heat (and sound) due to friction** where the rope rubs the branch.

Question 14 Raising a flag — work and GPE

Flag mass 0.35 kg raised 6.0 m; g = 10 N/kg.

(a) Define work done:
work done = **force × distance moved in the direction of the force** (it is the energy transferred when a force moves its point of application).

(b) Increase in gravitational potential energy of the flag.

GPE = mgh = 0.35 × 10 × 6.0 = **21 J**

(c) Why the work done on the rope is larger than the value in (b):
the woman also does work against **friction in the pulley and against air resistance**, and against the weight of the rope being raised — this extra work appears as heat, so more work is done on the rope than is stored as GPE of the flag.

Question 15 Stretching a spring (extension & Hooke's law)

Lengths for loads 0–5.0 N: 200, 235, 270, 305, 350, 420 mm; unstretched length 200 mm.

(a) Completing the extension column (extension = length − 200 mm):

for 4.0 N: 350 − 200 = **150 mm**

for 5.0 N: 420 − 200 = **220 mm**

(0 N → 0, 1.0 N → 35, 2.0 N → 70, 3.0 N → 105 mm, as given)

(b) Load that produces an extension of 49 mm — use the straight-line (proportional) region, where 35 mm of extension is produced by each 1.0 N.

in the Hooke's-law region, extension ÷ load = 35 mm per N (35, 70, 105 for 1, 2, 3 N)

load = 49 ÷ 35 = **1.4 N**

(c)(i) Comparing the two forms of energy at A and at B (the load is pulled down from A to B and held still; no KE at either point):

energy stored in spring: **larger at B**

gravitational PE of load: **larger at A**

At B the spring is stretched more, so it stores more elastic energy; the load is lower at B, so its gravitational PE is greater at the higher point A.

(c)(ii) How conservation of energy applies when the student pulls the load down:
the **work done by the student (chemical energy from his muscles) is transferred into the extra elastic energy stored in the spring**, while the gravitational PE of the load decreases as it goes down. No energy is created or destroyed — it is simply transferred from one store to another (with a little lost as heat).

Kinetic energy, GPE and energy conservation in motion

Question 16 Pole-vaulter (max speed, KE and height)

Forward force 320 N; resistive force rises with speed (Fig. 3.2); top speed 8.4 m/s; mass 60 kg; g = 10 N/kg.

(a) Why the maximum speed is 8.4 m/s:
from the graph the resistive force equals the 320 N forward force at a speed of 8.4 m/s. There the **resultant force is zero, so there is no acceleration and the speed stays constant** at its maximum value.

(b)(i) Maximum kinetic energy as he runs (state the formula).

$E_k = \frac{1}{2}mv^2 = \frac{1}{2} \times 60 \times (8.4)^2 = \frac{1}{2} \times 60 \times 70.56$

= **2116.8 J** (≈ 2100 J)

(b)(ii) Height he rises if all this KE becomes GPE (give an appropriate number of sig figs).

$mgh = E_k \rightarrow h = E_k \div (mg) = 2116.8 \div (60 \times 10) = 2116.8 \div 600 = 3.528$ m

to 2 significant figures (the speed has 2 s.f.): **3.5 m**

Question 17 Mobile phone — sound traces and energy

(a)(i) Drawing the second note (louder and higher pitch) on the oscilloscope:
draw a wave with **larger amplitude** (taller peaks, because it is louder) and **more waves in the same width / shorter wavelength** (higher frequency, because it is higher pitch).

(a)(ii) Explain the differences between the two traces:
the louder note has a **greater amplitude** (the trace is taller); the higher-pitch note has a **higher frequency, so its waves are closer together** (more complete waves across the screen / shorter period).

(b) Useful energy change inside the battery as it charges from the mains:
electrical energy is converted to chemical energy stored in the battery.

Question 18 Water wheel and generator

Each second the water loses 2000 J of potential energy; electrical output 1200 J each second.

(a) Two main energy changes as the water flows:

1. **gravitational potential energy** → **kinetic energy** as the water falls and turns the wheel;
2. **kinetic energy** → **electrical energy** in the generator.

(b) Efficiency of the process.

efficiency = useful output ÷ input = 1200 ÷ 2000 = 0.60

= **0.60 (60%)**

(c) Two ways the device wastes energy:

1. **friction** in the wheel and generator bearings produces heat;
2. the water still moves after leaving the wheel (it **carries away kinetic energy**), and energy is also lost as **sound**.

Question 19 Geothermal energy — heating water and making steam

Cold water at 20 °C is pumped to hot rocks; 1000 kg of water returns as steam at 100 °C. c = 4200 J/(kg °C); specific latent heat of vaporisation = 2.3×10^6 J/kg.

(a)(i) Name of the renewable source shown: **geothermal energy** (heat from inside the Earth / hot rocks).

(a)(ii) Meaning of renewable energy source:
one that is **continually replaced by nature, so it does not run out** with use.

(b)(i) Energy needed to heat 1000 kg of water from 20 °C to 100 °C.

$E = mc\Delta T = 1000 \times 4200 \times (100 - 20) = 1000 \times 4200 \times 80$

$= \mathbf{3.36 \times 10^8}$ **J** (336 MJ)

(b)(ii) Energy needed to turn 100 kg of water at 100 °C into steam.

$E = mL = 100 \times 2.3 \times 10^6$

$= \mathbf{2.3 \times 10^8}$ **J** (230 MJ)

Question 20 Waterfall — GPE to thermal energy

Water at 7.2 °C falls 700 m; g = 10 N/kg; c = 4200 J/(kg °C).

(a) Change in GPE of each kilogram of water.

GPE = mgh = 1 × 10 × 700 = **7000 J** (per kg)

(b) Temperature of the water in the pool, assuming all this energy heats the water.

energy = $mc\Delta T \rightarrow \Delta T$ = energy ÷ (mc) = 7000 ÷ (1 × 4200) = 1.67 °C

new temperature = 7.2 + 1.67 = **8.9 °C** (8.87 °C)

Question 21 Pushing a boat through a tunnel — work

Two men exert a total forward force of 1680 N and push the boat 50.0 m.

(a) Work done on the boat.

work = force × distance = 1680 × 50.0 = **84 000 J** (8.4×10^4 J)

(b) Why the boat's KE at the end is less than the work done on it:
not all the work becomes kinetic energy — some is transferred to **heat through the water resistance (drag) and friction**, so the gain in kinetic energy is less than the total work done.

Question 22 Head torch — conservation of energy and LEDs

(a) State the principle of conservation of energy:
energy **cannot be created or destroyed; it can only be transferred from one store/form to another, and the total amount of energy stays the same**.

(b)(i) Main energy change in the cells (battery) of the torch:
chemical energy → electrical energy.

(b)(ii) Two forms of energy produced in the filament lamp:
light energy and **thermal (heat) energy**.

(c) Comparing the LED torch with the filament torch (both give equally bright light, but the LED is far more efficient):
both produce the same useful **light energy**, but the LED torch wastes **far less heat (thermal) energy** than the filament lamp — most of its electrical energy becomes light, so very little is lost as heat.

Question 23 Counter-balanced elevator — minimum power

A concrete block of equal mass to the empty lift balances it; people of total weight 4900 N rise 24 m in 28 s.

(a) Why very little work is done lifting the empty elevator:
the counterweight (concrete block) has the **same mass as the empty lift, so as the lift goes up the block goes down** — the loss of GPE of the block almost exactly supplies the gain in GPE of the lift, so the motor only has to overcome friction.

(b) Minimum power output of the motor (it only has to lift the people, since the lift is balanced).

work to lift people = weight × height = 4900 × 24 = 117 600 J

power = work ÷ time = 117 600 ÷ 28

= **4200 W** (4.2 kW)

Question 24 Skier — weight, height and braking force

Skier mass 85 kg starts from rest at T; KE at bottom B = 5.5×10^4 J; g = 10 N/kg; he stops at P, 33 m beyond B.

(a)(i) Weight of the skier.

W = mg = 85 × 10 = **850 N**

(a)(ii) Minimum possible height difference between T and B (assume no energy lost, so GPE lost = KE gained).

$mgh = E_k \rightarrow h = E_k \div (mg) = 5.5 \times 10^4 \div 850$

= **65 m** (64.7 m)

It is a minimum because in reality friction and air resistance remove some energy, so the real drop must be larger to give the same KE.

(b) Average horizontal force on the skier between B and P (all his KE is removed by this force over 33 m).

work done by force = KE removed: $F \times d = 5.5 \times 10^4$

$F = 5.5 \times 10^4 \div 33$ = **1700 N** (1670 N)

Question 25 Motor lifting bricks on a building site

g = 10 N/kg; mass of bricks 54 kg lifted 2.8 m in 3.0 s.

(a)(i) Work done in lifting the bricks.

work = mgh = 54 × 10 × 2.8 = **1512 J** (≈ 1500 J)

(a)(ii) Useful output power of the motor.

P = work ÷ time = 1512 ÷ 3.0 = **504 W** (≈ 500 W)

(b) Two reasons the electrical power supplied exceeds the useful output:

1. energy is wasted as **heat from friction** in the motor and pulley;
2. energy is wasted as **heat in the motor's coil (resistance)** and as sound.

(c)(i) Completing the circuit diagram to measure the power supplied to the motor:
connect an **ammeter in series** with the motor and a **voltmeter in parallel** across the motor (battery, ammeter and motor in one loop; voltmeter across the motor terminals).

(c)(ii) How the power supplied is calculated:
power = voltage × current ($P = V \times I$), using the voltmeter and ammeter readings.

Question 26 Bungee jumper — GPE, speed and energy changes

Man mass 75 kg; g = 10 N/kg. He falls 20 m before the rope tightens; the platform is high above him; he is first stopped 25 m below the platform.

(a)(i) Change in gravitational potential energy as he falls 20 m.

GPE = mgh = 75 × 10 × 20 = **15 000 J** (1.5×10^4 J)

(a)(ii) His speed at 20 m (all the GPE has become KE, since the rope is not yet stretched).

E_k = GPE lost → ½mv² = 15 000

$v^2 = (2 \times 15\,000) \div 75 = 30\,000 \div 75 = 400$

$v = \sqrt{400}$ = **20 m/s**

(b) Energy changes as he falls from 20 m down to 25 m below the platform (ignoring air resistance):
over this last 5 m the rope is stretching and bringing him to rest, so his **gravitational potential energy and kinetic energy are both transferred to elastic (strain) energy stored in the stretched rope**. At the lowest point he is momentarily at rest, so all of it is stored as elastic energy in the rope.

Question 27 Black car driving up a hill in sunshine

(a)(i) One way the car gains thermal energy:
it **absorbs heat/infrared radiation from the Sun** (a black surface is a good absorber), and friction/the hot engine also warm it.

(a)(ii) One way the car loses thermal energy:
it **radiates heat to (and is cooled by air passing over) the cooler surroundings** (a black surface is also a good emitter).

(b) Other energy changes as the car accelerates up the hill:
chemical energy in the fuel is converted to kinetic energy (it speeds up) and to **gravitational potential energy** (it rises up the hill); some is also wasted as **heat and sound**.

Question 28 Lorry braking — KE and braking force

Lorry mass 4.4×10^4 kg at 20 m/s; stops in 40 m.

(a) Kinetic energy of the lorry.

$E_k = \frac{1}{2}mv^2 = \frac{1}{2} \times 4.4 \times 10^4 \times (20)^2 = \frac{1}{2} \times 4.4 \times 10^4 \times 400$

= **8.8×10^6 J** (8 800 000 J)

(b)(i) Formula relating work done to braking force:
work done = braking force × distance ($W = F \times d$).

(b)(ii) Braking force (the work done by the brakes removes all the KE over 40 m).

$F \times d = E_k \rightarrow F = E_k \div d = 8.8 \times 10^6 \div 40$

= **2.2×10^5 N** (220 000 N)

Question 29 Water tank on a tractor

Tractor + tank = 4100 kg empty and 6500 kg full; density of water = 1000 kg/m³.

(a) Volume of water when the tank is full.

mass of water = 6500 − 4100 = 2400 kg

volume = mass ÷ density = 2400 ÷ 1000 = **2.4 m³**

(b)(i) Form of energy that is decreasing as the tractor accelerates along a level road:
chemical energy (in the fuel) is decreasing.

(b)(ii) What happens to this energy:
it is converted mainly into **kinetic energy** as the tractor speeds up, with some lost as **heat and sound** (friction, engine, drag).

(c) GPE gained by the water carried up a height of 850 m (g = 10 N/kg).

GPE = mgh = 2400 × 10 × 850

= **2.04×10^7 J** (20.4 MJ)

Question 30 Oil-burning power station — efficiency, input power, waste

(a) Form of energy stored in the oil before it is burnt: **chemical energy**.

(b)(i) Is oil renewable or non-renewable?
non-renewable — it took millions of years to form and is being used up far faster than it can be replaced, so the supply will eventually run out.

(b)(ii) One environmental issue from burning oil:
it releases **carbon dioxide, which increases the greenhouse effect / global warming** (also sulfur oxides that cause acid rain).

(c)(i) Meaning of efficiency:
the **fraction (or percentage) of the energy input that is transferred to useful (wanted) energy output**.

(c)(ii) 1. Input power, given efficiency 0.38 and electrical output 1.9×10^9 W.

input power = useful output ÷ efficiency = $1.9 \times 10^9 \div 0.38$

= **5.0×10^9 W** (5.0 GW)

(c)(ii) 2. Energy wasted in 2.0 hours.

power wasted = input − useful = $5.0 \times 10^9 - 1.9 \times 10^9 = 3.1 \times 10^9$ W

energy wasted = power × time = $3.1 \times 10^9 \times (2.0 \times 3600)$

= **2.2×10^{13} J** (≈ 22.3 TJ)

Question 31 Skateboarder on a curved ramp

(headed "Question 30" in the source; it is a separate question and is shown here in sequence.)

Skateboarder mass 45 kg descends a vertical height of 1.8 m; g = 10 N/kg.

(a)(i) Change in gravitational potential energy.

GPE = mgh = 45 × 10 × 1.8 = **810 J**

(a)(ii) Two forms of energy that increase as she descends:
1. **kinetic energy** (she speeds up); 2. **thermal (heat) energy** of the board, ramp and air (friction and air resistance).

(b)(i) Direction of the resultant force on her at the lowest point (she travels in part of a vertical circle):
vertically upwards — towards the centre of the circular path (the upward push of the ramp is greater than her weight there).

(b)(ii) How the upward force from the ramp compares with her weight at the lowest point:
because she is accelerating towards the centre of the circle (upwards), the **ramp's upward force is greater than her weight** (it must supply both her weight and the centripetal force).

Question 32 Nuclear fusion in the Sun; energy to Earth

(a) The process of nuclear fusion in the Sun:
in the Sun's extremely hot, dense core, **light nuclei (hydrogen nuclei) join together to form heavier nuclei (helium)**. The mass of the product is slightly less than the mass of the original nuclei, and this lost mass is released as a huge amount of **energy** ($E = mc^2$), which keeps the Sun shining.

(b) How the Sun's energy reaches the Earth:
it travels as **electromagnetic radiation (light and infrared)**, which can **pass through the vacuum of space** at the speed of light — radiation needs no material medium.

Question 33 Rock from space — KE, internal energy and speed

Rock mass 0.60 kg; on impact its temperature rises by 25 °C; c = 560 J/(kg °C).

(a) Equation for kinetic energy:
kinetic energy = $\frac{1}{2}mv^2$, where *m* is the mass of the object and *v* is its speed.

(b)(i) Increase in internal energy of the rock.

$E = mc\Delta T = 0.60 \times 560 \times 25 =$ **8400 J**

(b)(ii) Minimum speed of the rock on impact (assume all the KE became internal energy).

$\frac{1}{2}mv^2 = 8400 \rightarrow v^2 = (2 \times 8400) \div 0.60 = 16\,800 \div 0.60 = 28\,000$

$v = \sqrt{28\,000} =$ **170 m/s** (167 m/s)

(b)(iii) Why the real speed is higher than this:
not all the kinetic energy heats the rock — some is transferred to **heat in the surroundings (the ground/air) and to sound**, so the rock must have had more KE, i.e. a higher speed, than this calculation gives.

Question 34 Geothermal power station

Steam from underground spins a turbine and generator; water from the cooling tower at 30 °C is heated to 160 °C. c = 4200 J/(kg °C).

(a) Two energy sources likely to run out first (before geothermal): **coal** and **oil** (the non-renewable fuels — gas is also acceptable).

(b)(i) How the thermal energy in the water makes the turbine turn:
the heat **boils the water to make high-pressure steam; the moving steam pushes on the turbine**

blades, giving them kinetic energy so the turbine spins (steam's kinetic energy → kinetic energy of the turbine).

(b)(ii) Thermal energy to heat 90 kg of water from 30 °C to 160 °C.

$E = mc\Delta T = 90 \times 4200 \times (160 - 30) = 90 \times 4200 \times 130$

$= \mathbf{4.9 \times 10^7\ J}$ (49.14 MJ)

Question 35 Athlete stretching a strong spring

Average force 400 N; spring length increases from 70 cm to 93 cm; he repeats this over a period of 60 s.

(a) Forms of energy stored:
energy stored in the stretched spring = **elastic (strain) energy**; energy stored in the muscles = **chemical energy**.

(b) What happens if he stretches the spring beyond the limit of proportionality:
the spring no longer obeys Hooke's law (extension is no longer proportional to force) and, if stretched too far, it becomes **permanently deformed and will not return to its original length**.

(c)(i) Work done by the athlete in one extension (length change = 93 − 70 = 23 cm = 0.23 m).

work = average force × extension = 400 × 0.23 = **92 J**

(c)(ii) How the value in (i) can be used to find his average power over the 60 s:
count the number of extensions in the 60 s, multiply by the 92 J done each time to get the total work, then use **average power = total work ÷ time (60 s)**.

Question 36 Motor lifting a mass; induction (Lenz's law)

Battery 8.0 V drives a motor at current 1.5 A; it lifts a 150 g (0.150 kg) mass through 80 cm (0.80 m) in 4.0 s; g = 10 N/kg.

(a)(i) Circuit to measure the readings:
put an **ammeter in series** with the motor (to read the 1.5 A) and a **voltmeter in parallel** across the motor (to read 8.0 V).

(a)(ii) Electrical energy transferred to the motor in the 4.0 s.

energy = V × I × t = 8.0 × 1.5 × 4.0

= **48 J**

(a)(iii) Gravitational potential energy gained by the mass.

GPE = mgh = 0.150 × 10 × 0.80 = **1.2 J**

(a)(iv) Two reasons the GPE gained (1.2 J) is less than the electrical energy supplied (48 J):
1. energy is lost as **heat in the motor's coil (its resistance)**; 2. energy is lost as **heat and sound through friction** in the motor and bearings.

(b)(i) Why a voltage is produced as the coil turns:
as the coil spins it **cuts through (the magnetic flux of) the magnetic field**, so a voltage (e.m.f.) is **induced** in it (electromagnetic induction).

(b)(ii) Lenz's law and why the mass falls more slowly when A and B are joined:
Lenz's law: an induced current always flows in the direction that **opposes the change producing it**. When

the wire joins A and B, the induced voltage drives a current; by Lenz's law this current creates forces that **oppose the motion of the coil**, acting like a brake, so the coil (and the falling mass) is slowed down and takes longer to fall.

Question 37 Hydraulic press — work and efficiency

A 20 N force is applied to the handle, which moves down 0.60 m; piston Q rises 0.020 m and pushes the paper with a force of 400 N.

(a)(i) Define the moment of a force:
moment = **force × perpendicular distance from the pivot to the line of action of the force**.

(a)(ii) Why the force on piston P is greater than the force on the handle:
the handle is a lever: the force is applied **far from the pivot but acts on piston P close to the pivot**. Taking moments about the pivot, the smaller distance at P means a larger force is needed to give the same moment, so the force on P is greater.

(b) How the press gives a greater force on Q than on P:
the pistons share the same liquid pressure (pressure = force ÷ area is transmitted equally through the oil). Piston **Q has a larger area than P**, so the same pressure produces a **larger force on Q** (force = pressure × area).

(c)(i) Work done in moving the handle down.

work in = force × distance = 20 × 0.60 = **12 J**

(c)(ii) Efficiency of the press.

useful work out = force on Q × rise of Q = 400 × 0.020 = 8.0 J
efficiency = useful out ÷ work in = 8.0 ÷ 12 = 0.67
= **0.67 (67%)**

Question 38 Falling coin — GPE, KE and speed

A coin of mass *m* is dropped from rest from height *h*; g = 10 N/kg.

(a) Expressions:
gravitational potential energy at height *h* = **mgh**; kinetic energy at speed *v* = **$\frac{1}{2}mv^2$**.

(b) Speed of the coin dropped from 380 m (ignore air resistance, so KE gained = GPE lost).

$\frac{1}{2}mv^2 = mgh \rightarrow v^2 = 2gh = 2 \times 10 \times 380 = 7600$
$v = \sqrt{7600} =$ **87 m/s** (87.2 m/s)

(c)(i) Why a heavier and a lighter coin hit the ground at the same speed (no air resistance):
from $\frac{1}{2}mv^2 = mgh$, the mass **cancels**, giving $v = \sqrt{2gh}$. The final speed depends only on *g* and the height, not on the mass — so both coins reach the same speed.

(c)(ii) Why, when air resistance acts, coins of different mass do **not** hit at the same speed:
air resistance produces roughly the same drag force on similar coins, but this force causes a **larger deceleration on the lighter coin (smaller mass)**. So air resistance slows the lighter coin more, and the heavier coin reaches the ground at a greater speed.

Question 39 Wheelbarrow up a plank — GPE, work and efficiency

Wheelbarrow + load mass... a force of 290 N is used to push the load (weight 290 N shown) up a 2.0 m plank onto a platform 0.60 m high; g = 10 N/kg.

(a)(i) Gravitational potential energy gained by the wheelbarrow and its load (raised 0.60 m).

GPE = weight × height = 290 × 0.60 = **174 J**

(a)(ii) Work done by the worker pushing along the 2.0 m plank with a 290 N force.

work = force × distance = 290 × 2.0 = **580 J**

(a)(iii) Why the answer in (a)(ii) is more than (a)(i):
the worker must also do work against **friction** (between the wheel/barrow and the plank), so the work he does (580 J) is greater than the useful gain in GPE (174 J).

(b)(i) Meaning of efficiency:
the **fraction (or percentage) of the energy/work put in that becomes useful output** (here, useful GPE ÷ work done = 174 ÷ 580 ≈ 0.30, i.e. about 30%).

(b)(ii) One reason this method is so inefficient:
there is a **large friction force along the plank** (the wheelbarrow does not roll freely up the slope), so a big fraction of the work done is wasted as heat rather than lifting the load.

Note from Megalecture. These are original Megalecture worked solutions, prepared from first principles for revision use; none of the wording is taken from any official Cambridge mark scheme. Where a question asks for an explanation, the wording given is a model answer — equivalent correct physics in your own words is fine. Question 31 above is headed "Question 30" in the source compilation (a numbering repeat); it has been kept in sequence here. g = 10 N/kg throughout unless the question states otherwise, and final answers are rounded to a sensible number of significant figures.