Cambridge IGCSE · Physics 0625 · Notes

Energy, work and power

Read online at **pastopic.com/cambridge/physics-0625/notes/energy-work-and-power**

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Read first: **Mass and weight**, **Forces**

What you need to know

This topic has four parts: energy, work, energy resources and power. Most of it is Core; the parts marked **Extended only** are tested on Papers 2 and 4 only. By the end of it you should be able to:

1. **State the energy stores:** kinetic, gravitational potential, chemical, elastic (strain), nuclear, electrostatic and internal (thermal).
2. **Describe how energy moves between stores** during events and processes. It is transferred by forces (**mechanical work**), by electric currents (**electrical work**), by **heating**, and by **waves** (light and other electromagnetic waves, sound).
3. **Know the principle of conservation of energy** and use it in simple examples, including reading simple energy flow diagrams.
4. **Extended only:** recall and use $E_k = \frac{1}{2}mv^2$ for kinetic energy.
5. **Extended only:** recall and use $\Delta E_p = mg\Delta h$ for the change in gravitational potential energy.
6. **Extended only:** use conservation of energy in harder examples with several stages, including reading **Sankey diagrams**.
7. **Understand that work done equals energy transferred**, for mechanical and electrical work, and recall and use $W = Fd = \Delta E$.
8. **Describe how useful energy or electricity is obtained** from fossil fuels, biofuels, water (waves, tides, hydroelectric dams), geothermal resources, nuclear fuel, light from the Sun (solar cells) and infrared from the Sun (solar panels that heat water), and the Sun as the source of wind, including where a **boiler, turbine and generator** are used.
9. **Give advantages and disadvantages** of each method: renewability, availability, reliability, scale and environmental impact.
10. **Understand efficiency** in words: how much of the energy put in comes out as useful energy.
11. **Extended only:** know that radiation from the Sun is the main source of energy for all our energy resources **except geothermal, nuclear and tidal**.
12. **Extended only:** know that the Sun releases energy by **nuclear fusion**, and that research is under way into using fusion to generate electricity on a large scale.
13. **Extended only:** define efficiency as useful energy output ÷ total energy input (× 100%) and as useful power output ÷ total power input (× 100%), and use both.

14. **Define power** as work done per unit time and as energy transferred per unit time, and recall and use $P = \frac{W}{t}$ and $P = \frac{\Delta E}{t}$.

Understand it

Energy stores

Energy is never "used up"; it just moves from one **store** to another. Learn the seven stores and an example of each:

Store	Where it is
Kinetic	anything moving: a car, the wind, flowing water
Gravitational potential	anything raised up: water behind a dam, a book on a shelf
Chemical	fuels, food, batteries, biofuels
Elastic (strain)	anything stretched, squashed or bent: a spring, a drawn bow, a mattress
Nuclear	the nuclei of atoms: uranium fuel, the Sun
Electrostatic	charges pushing or pulling each other: a charged balloon
Internal (thermal)	anything hot: the hotter it is, the more is stored

Light, sound and electricity are **not** stores. They are ways that energy **moves** between stores. Name stores in full: "gravitational potential energy", not just "potential energy".

Energy transfers

Energy moves between stores in four ways:

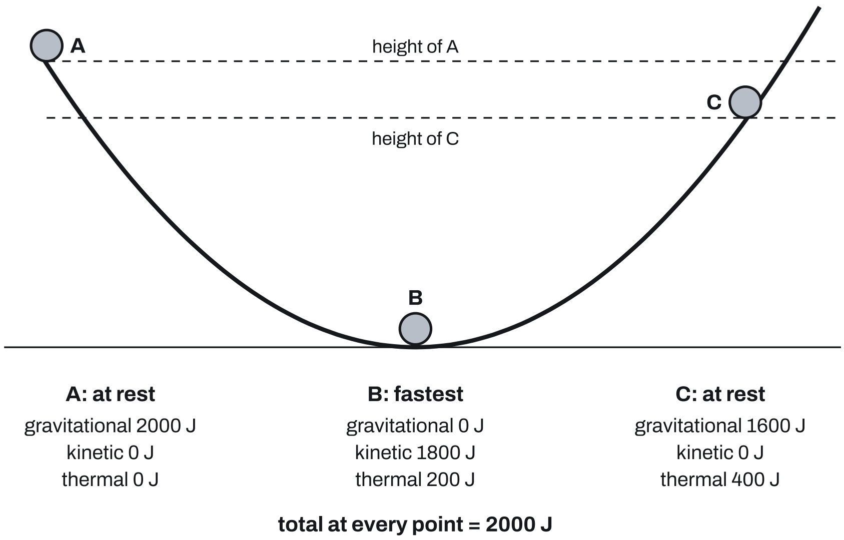
- **Mechanical work**: a force moves something. A hand pushing a trolley, brakes slowing a wheel, a spring pushing a toy.
- **Electrical work**: an electric current carries energy. A battery driving a motor, a generator sending energy along cables.
- **Heating**: energy moves from a hotter object to a colder one. A hot kettle warming the air around it.
- **Waves**: light and other electromagnetic waves, and sound. Sunlight reaching a solar cell, a loudspeaker making sound.

Describing a process means naming the store it starts in, how it moves, and the store it ends in. A torch: **chemical** store of the battery → **electrical work** → the lamp gives out **light**, and it warms up (**thermal** store of the lamp and the surroundings). A car braking: **kinetic** store of the car → mechanical work by friction in the brakes → **thermal** store of the brakes.

Conservation of energy

The principle of conservation of energy: energy cannot be created or destroyed. It can only be transferred from one store to another. So the total energy after any process equals the total energy before it.

Some energy almost always ends up in the thermal store of the surroundings (through friction, air resistance or electrical resistance). This energy is **wasted**: it is still there, but spread out and no longer useful.



On the way down from A to B, the gravitational potential store empties and the kinetic store fills. On the way up from B to C, the kinetic store empties and the gravitational store fills again. But C is **lower** than A, because friction and air resistance keep moving energy into the thermal store. The total never changes: $1800 + 200 = 2000$ J and $1600 + 400 = 2000$ J. The same idea explains why a bouncing ball rises less each time: at every bounce some energy goes to the thermal store of the ball and the ground, and some leaves as sound.

Other examples you should be able to describe:

- **Falling freely** (no air resistance): gravitational potential → kinetic, by mechanical work done by the weight.
- **Falling with air resistance**: gravitational potential → kinetic **and** thermal (of the object and the air).
- **A mass bouncing on a spring**: energy keeps moving between the kinetic, gravitational potential and elastic stores. The elastic store is fullest at the lowest point, where the spring is most stretched; the gravitational store is smallest there.
- **A person climbing stairs**: chemical store of the body → gravitational potential (and thermal, as the body warms up).

Work done

When a force moves something in the direction of the force, it **does work**, and the work done equals the energy transferred:

$$W = Fd = \Delta E \qquad (W \text{ in J},\ F \text{ in N},\ d \text{ in m}).$$

1 joule is the work done when a force of 1 N moves something 1 m. A 50 N push moving a box 3.0 m does $50 \times 3.0 = 150$ J of work, so 150 J is transferred to the box (to its kinetic store, and to the thermal store of the floor through friction).

- **No movement, no work.** Holding a heavy bag still, or pushing a wall that doesn't move, does no work on it.
- **Lifting:** the force is the **weight** and the distance is the **vertical height**. Lifting a 600 N student 2.5 m does $600 \times 2.5 = 1500$ J of work, which goes into their gravitational potential store.
- **Along a slope:** use the force **along the slope** times the distance **along the slope**: pulling with 30 N along an 8.0 m slope does $30 \times 8.0 = 240$ J.

Work done is **energy**, so its unit is the joule (J), not the watt.

Kinetic and gravitational potential energy

Extended only. The energy in the kinetic store of a mass m moving at speed v is

$$E_k = \tfrac{1}{2}mv^2.$$

An 800 kg car at 15 m/s has $\frac{1}{2} \times 800 \times 15^2 = 90\,000$ J. Because the speed is **squared**, doubling the speed makes the kinetic energy **four** times bigger.

Extended only. Lifting a mass m through a height Δh increases its gravitational potential energy by

$$\Delta E_p = mg\Delta h, \qquad g = 9.8 \text{ N/kg}.$$

Lifting a 2.0 kg bag 5.0 m gives $2.0 \times 9.8 \times 5.0 = 98$ J. The height is the **vertical** height, whatever path it takes. mg is the weight, so this is the same as work done = weight × height.

Extended only. If a falling object loses all its gravitational potential energy to kinetic energy (no air resistance), then $\frac{1}{2}mv^2 = mg\Delta h$. The mass cancels, so

$$v = \sqrt{2g\Delta h}.$$

A stone falling 5.0 m reaches $\sqrt{2 \times 9.8 \times 5.0} = 9.9$ m/s, whatever its mass. Run it backwards to find how high a ball thrown upwards goes: $\Delta h = \dfrac{v^2}{2g}$.

Power

Power is the rate of doing work, or of transferring energy: the work done (or energy transferred) **per unit time**.

$$P = \frac{W}{t} = \frac{\Delta E}{t} \qquad (P \text{ in W},\ t \text{ in s}).$$

1 watt $=$ 1 joule per second. A motor that does 1500 J of work in 5.0 s has a power of $1500 \div 5.0 = 300$ W. A more powerful machine does the **same** work in **less** time, or more work in the same time. 1 kW $= 1000$ W and 1 MW $= 1\,000\,000$ W.

Rearranged: energy $= P \times t$. A 2.0 kW heater on for 3 hours transfers $2000 \times 3 \times 3600 = 21\,600\,000$ J. Electricity companies measure energy in **kilowatt-hours** (kWh): 1 kWh is the energy transferred by a 1 kW appliance in 1 hour, which is $3\,600\,000$ J. The same heater transfers $2.0 \times 3 = 6.0$ kWh. The kilowatt-hour is a unit of **energy**, not power.

Efficiency

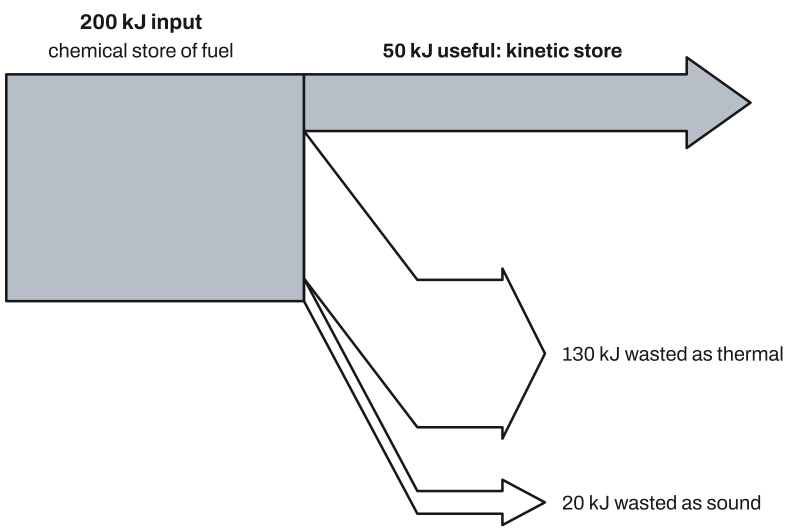
No machine turns all its input energy into useful energy: some is always wasted, usually as thermal energy (and sound). **Efficiency** tells you what fraction is useful. A very efficient machine **wastes very little** energy. It says nothing about how powerful or how fast it is.

Extended only.

$$\text{efficiency} = \frac{\text{useful energy output}}{\text{total energy input}} (\times 100\%) = \frac{\text{useful power output}}{\text{total power input}} (\times 100\%).$$

A lamp that gives out 12 J of light for every 60 J of electrical energy put in is $\frac{12}{60} \times 100\% = 20\%$ efficient; the other 48 J heats the lamp and the room. Efficiency can **never** be more than 100% (or 1): that would mean creating energy.

Extended only. A **Sankey diagram** shows the energy flow as arrows whose **widths** are to scale. The input arrow splits: useful energy carries straight on, wasted energy bends away.



efficiency = 50 ÷ 200 × 100% = 25% (width of each arrow = energy)

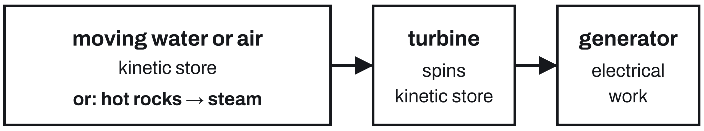
The output widths always add up to the input width (conservation of energy). Here the efficiency is $\frac{50}{200} \times 100\% = 25\%$. In an exam Sankey diagram you may be given a scale (for example, one grid square $= 10$ J) and have to count squares.

Energy resources

Most electricity comes from spinning a **generator**. In a **thermal power station** a fuel heats water in a **boiler** to make high-pressure steam, which spins a **turbine**, which turns the generator.

thermal power station (fossil fuels, biofuels, nuclear fuel)

hydroelectric, tides, waves, wind, geothermal: no fuel, no boiler



Resource	How it gives useful energy	Renewable?
Fossil fuels (coal, oil, gas)	burned: chemical store → thermal store of water in the boiler → steam → turbine → generator	no
Biofuels (wood, crop waste, ethanol)	burned the same way as fossil fuels	yes: new plants can be grown
Nuclear fuel (uranium)	**nuclear fission** in a reactor heats water → steam → turbine → generator	no
Geothermal	water pumped down to hot rocks underground comes back as steam (or hot water) → turbine → generator, or heats buildings directly	yes
Hydroelectric dam	water in the gravitational store behind the dam flows down, gains kinetic energy and turns turbines at the bottom → generator	yes
Tides	water trapped behind a barrage at high tide flows out through turbines (or tidal currents turn underwater turbines) → generator	yes
Waves	the up-and-down motion of waves drives a turbine → generator	yes
Wind	moving air (kinetic store) turns the blades of a turbine → generator	yes
Solar cells	light from the Sun is transferred **directly** to electrical work, with **no** turbine or generator	yes
Solar panels	infrared from the Sun heats water flowing through black pipes	yes

Renewable means it will not run out, because it is replaced naturally (the wind keeps blowing, crops regrow). It does **not** mean "can be reused". Hydroelectric, tidal, wave, wind, solar and geothermal need **no fuel** and do not release carbon dioxide or other polluting gases while they generate.

Judge each method on:

	Advantages	Disadvantages
Fossil fuels	reliable, available at any time, large scale	non-renewable; release carbon dioxide (global warming) and sulfur dioxide (acid rain)
Biofuels	renewable; can use waste	release carbon dioxide when burned; need large areas of land
Nuclear	reliable, very large scale, no carbon dioxide	non-renewable; radioactive waste that stays dangerous for a long time; risk of an accident
Geothermal	reliable (always on), no fuel	only in a few places (hot rocks near the surface); small scale
Hydroelectric	reliable, can start quickly when demand rises, large scale	floods valleys, destroying habitats and homes; only where there are rivers and hills
Tides	reliable and predictable (two tides a day)	only in some bays and estuaries; barrages harm habitats and shipping
Waves	renewable	unreliable (depends on the weather); small scale
Wind	no fuel, no pollution while running	unreliable (no wind, no power); noisy; spoils the view; many turbines needed
Solar	no fuel, no pollution while running; good in remote places	unreliable (none at night, less on cloudy days); large areas needed

Solar cells and solar panels are often coated or painted **black**, because black surfaces are good absorbers (and poor reflectors) of radiation, so they take in more of the energy.

Energy can be **stored** for when a resource isn't available, for example in rechargeable batteries (a chemical store) or by pumping water up into a reservoir (a gravitational store).

Where the energy comes from

Extended only. The Sun releases energy by **nuclear fusion**: small nuclei (hydrogen) join to make bigger ones (helium). Its energy reaches the Earth by **radiation**. Radiation from the Sun is the main source of energy for **all** our energy resources **except three**:

- **geothermal**: heat from inside the Earth;
- **nuclear**: energy in uranium nuclei, released by fission;
- **tidal**: tides are caused mainly by the Moon's gravity.

Everything else comes from the Sun: fossil fuels and biofuels (plants grew using sunlight), wind (the Sun heats the atmosphere unevenly, so air moves), waves (made by the wind), hydroelectric (the Sun evaporates water, which falls as rain on high ground), and solar power itself.

Extended only. Scientists are researching how to use nuclear **fusion** to generate electricity on a large scale. It is **not yet** used in power stations.

Key facts and formulas

The 0625 papers have no formula sheet, so learn every equation. The value of g is printed on the front of the paper.

Formula	Status
Work done $W = Fd = \Delta E$ (force × distance moved in the direction of the force)	Learn it
Power $P = \dfrac{W}{t}$ and $P = \dfrac{\Delta E}{t}$; so $\Delta E = Pt$	Learn it
Extended only: kinetic energy $E_k = \frac{1}{2}mv^2$	Learn it
Extended only: change in gravitational potential energy $\Delta E_p = mg\Delta h$	Learn it
Extended only: efficiency $= \dfrac{\text{useful energy output}}{\text{total energy input}}(\times 100\%)$	Learn it
Extended only: efficiency $= \dfrac{\text{useful power output}}{\text{total power input}}(\times 100\%)$	Learn it
Extended only: falling from rest with no air resistance: $v = \sqrt{2g\Delta h}$ (from $\frac{1}{2}mv^2 = mg\Delta h$)	Learn it
Wasted energy $=$ total input $-$ useful output	Learn it
$g = 9.8$ N/kg $= 9.8$ m/s²	Given
Units: energy and work in J (kJ, MJ); power in W (kW, MW); 1 W $= 1$ J/s; 1 kWh $= 3.6 \times 10^6$ J	Learn it

How to do it

We have tagged 247 questions for this topic across Papers 1–4, 2021–2025; 42 are repeats on other papers, leaving 205 different questions. 43 of the 205 mix two or more types, so the counts add up to more than 205.

Question type	Questions
Energy resources and generating electricity	62
Energy stores, transfers and conservation	53
Work done, $W = Fd$	45
Power	41
Extended only: kinetic and gravitational potential energy	37
Efficiency, energy flow and Sankey diagrams	30

1. Energy resources and generating electricity (62 questions)

1. **"Describe how … generates electricity"**: give the chain of stores and parts in order. Name the **store** at the start, and each of boiler (if there is one), turbine and generator. For a coal station: "coal is burned; the thermal energy boils water to make steam; the steam turns a turbine; the turbine turns a generator, which

produces electricity."

2. **"Advantages and disadvantages"**: pick points that fit the words renewability, availability, reliability, scale, environmental impact. Be specific: "does not release carbon dioxide" or "no fuel needed", not "eco-friendly".
3. **"Is it renewable? Explain"**: yes or no, then **why**: "the wind will not run out", "coal takes millions of years to form and will run out".

Variations you will meet:

- **Which resources use a boiler?** Fossil fuels, biofuels and nuclear fuel. Hydroelectric, tides, waves and wind do **not**: they turn the turbine directly. Geothermal has no fuel and no boiler either: hot rocks underground turn the water into steam.
- **Which resource needs no generator?** Solar cells: light gives electricity directly.
- **Name the store** in a resource: fossil fuels and biofuels, **chemical**; water behind a dam, **gravitational potential**; wind, flowing water and waves, **kinetic**; uranium, **nuclear**.
- **Extended only: "Which resources don't get their energy from the Sun?"** Geothermal, nuclear and tidal. Tidal energy comes mainly from the Moon.
- **Extended only: the Sun's process.** Energy is released by **fusion** in the Sun, travels by **radiation**, and can be stored on Earth in, for example, biofuels. Fusion power stations are still being researched.
- **Complete a table** of renewable or not, and polluting or not. Nuclear is non-renewable but does not cause air pollution; fossil fuels are both non-renewable and polluting.
- **Order the stages** of wind power from the Sun: the Sun heats the atmosphere unevenly → pressure differences → air moves → wind turns the blades → blades turn the generator → electricity.
- **Storing energy** from wind or solar for later: rechargeable batteries, or pumping water up to a high reservoir.
- **Reading a chart** of the share of each resource: work out what went up and down, and whether the renewable share changed.

2. Energy stores, transfers and conservation (53 questions)

1. **Name the store at the start** (for example chemical in a battery).
2. **Name how it moves**: mechanical work, electrical work, heating, or waves (light, sound).
3. **Name the stores at the end**, including the wasted thermal store of the surroundings.
4. **State the principle** if asked: energy cannot be created or destroyed; it can only be transferred between stores.

Variations you will meet:

- **Complete a flow diagram**: for example a laptop: chemical store (battery) → **electrical** work → useful **light** and **sound** from the screen and speakers, with wasted energy heating the laptop and then the surroundings.
- **"Which list contains only stores?"** Reject any list with light, sound or electrical in it.

- **Increases and decreases.** A falling object: gravitational potential **decreases**, kinetic **increases**. Brakes: kinetic of the bike **decreases**, thermal of the brakes **increases**. Air through a wind turbine loses kinetic energy (it slows down).
- **Springs and bungee cords.** Stretching or squashing stores **elastic** energy. Moving down while the cord stretches: gravitational decreases, elastic increases, kinetic may go either way.
- **Why a ball bounces lower each time** or a ball on a track stops lower than it started: some energy is transferred to the thermal store (of the ball, ground and air) and as sound, so less is left for the gravitational store.
- **Energy stores in the body**: climbing or lifting uses the chemical store; the gravitational, kinetic and thermal stores increase.
- **Ways to transfer energy to an object**: heating it, shining light on it, passing a current through it, or pushing it (work) all transfer energy.

3. Work done, W = Fd (45 questions)

1. **Write the equation**: work done $=$ force × distance, $W = Fd$.
2. **Pick the right force and distance.** The distance must be in the **direction of the force**: vertical height for lifting (force $=$ weight), distance along the floor for pushing.
3. **Substitute and give the unit, J.** If the answer line has a unit space, write J.

For example, a force of 80 N drags a sledge 12 m: $W = 80 \times 12 = 960$ J.

Variations you will meet:

- **Weight or mass?** If a mass is given, find the weight first ($W = mg$). 20 bricks of 4.0 kg lifted 2.0 m: weight $= 20 \times 4.0 \times 9.8$ N, then × 2.0.
- **Distances in cm**: 5 cm $= 0.05$ m.
- **Slope with a force along it**: force along the slope × distance along the slope. The vertical height is only used with the **weight**.
- **Work equals energy transferred.** Work done lifting something $=$ its gain in gravitational potential energy. Work done by friction bringing something to rest $=$ its kinetic energy lost. If a force does work on a box that gains 30 J of kinetic energy while 10 J is transferred to thermal by friction, the work done is 40 J.
- **Final kinetic energy** after a force acts: add the work done by a push along the motion; subtract the work done against a resistive force.
- **Braking force or distance** from kinetic energy: $F = \frac{E_k}{d}$ or $d = \frac{E_k}{F}$.
- **When is work done?** Only when something moves in the direction of the force. A load hanging still, a book resting on a shelf, a man pushing a box that won't move: no work done on it.
- **"Which quantities are needed?"** Force and distance only; time is not needed for work (it is for power).
- **The unit**: the joule, J. A newton metre (N m) is the same size, but write J.

4. Power (41 questions)

1. **Find the work done or energy transferred** first, if not given ($W = Fd$, $mg\Delta h$, and so on).
2. **Convert the time to seconds**: minutes × 60, hours × 3600.
3. $P = \dfrac{W}{t}$, and give the unit, **W** (watts).

For example, the sledge above pulled in 6.0 s: $P = 960 \div 6.0 = 160$ W. 2.4 kJ transferred in 1.0 minute: $P = 2400 \div 60 = 40$ W.

Variations you will meet:

- **Rearranging**: $t = \dfrac{W}{P}$ for the time a machine takes; $E = Pt$ for the energy transferred.
- **Most powerful** (multiple choice): same work, **shortest time**; or same time, most work. Compare $\dfrac{W}{t}$ for each option.
- **Meaning of a power rating**: "900 W" means 900 J of energy is transferred **every second**.
- **Combined changes**: if a crane lifts 3 times the weight through $\frac{1}{4}$ of the height in $\frac{1}{2}$ the time, the power is $3 \times \frac{1}{4} \div \frac{1}{2} = \frac{3}{2}$ times as much.
- **Power from force and distance**: $P = \dfrac{Fd}{t}$, so $t = \dfrac{Fd}{P}$.
- **Kilowatt-hours**: energy in kWh $=$ power in kW × time in hours. A 250 W appliance for 4 h uses $0.250 \times 4 = 1.0$ kWh. Define 1 kWh as the energy transferred by a 1 kW appliance in 1 hour.
- **Electrical power**: questions sometimes combine this with $P = IV$ from the electricity topic.
- **What must be measured** to find the power of someone climbing stairs or a motor lifting a load: their weight (or the force), the vertical height (or distance), and the **time**.

5. Kinetic and gravitational potential energy (37 questions)

Extended only.

1. **Choose the equation**: $E_k = \frac{1}{2}mv^2$ for moving, $\Delta E_p = mg\Delta h$ for a change of height.
2. **Convert** grams to kilograms and km/h or other units to m/s first.
3. **Substitute**, remembering to **square the speed** (and only the speed).
4. **For a speed from an energy**, rearrange: $v = \sqrt{\dfrac{2E_k}{m}}$. A 5.0 kg object with 250 J has $v = \sqrt{\dfrac{2 \times 250}{5.0}} = 10$ m/s.

For example, a 70 kg runner at 4.0 m/s has $\frac{1}{2} \times 70 \times 4.0^2 = 560$ J.

Variations you will meet:

- **Falling and throwing (no air resistance)**: kinetic energy gained $=$ gravitational potential energy lost, so $v = \sqrt{2g\Delta h}$ or $\Delta h = \dfrac{v^2}{2g}$.

- **With air resistance or friction**: kinetic energy gained $=$ gravitational potential energy lost $-$ work done against the resistance. If a sledge loses 450 J of gravitational energy and does 120 J of work against friction, it gains $450 - 120 = 330$ J of kinetic energy.
- **Heights between two levels**: use the **difference**, $mg(h_1 - h_2)$, and the vertical height, not the length of a slope.
- **Scaling**: doubling the speed multiplies E_k by 4; doubling the mass or the height doubles the energy.
- **Rate of energy transfer** (hydroelectric, a "gravity lamp"): find the energy for **one second** of flow: power $= \dfrac{mg\Delta h}{t}$, or (mass per second) × g × height. For moving water or wind, power $= \frac{1}{2}$ × (mass per second) × v^2.
- **Link to other topics**: a speed found from energy may then be used for momentum ($p = mv$) or heating ($mc\Delta\theta$); a speed from a speed–time graph may be used for E_k.

6. Efficiency, energy flow and Sankey diagrams (30 questions)

1. **Find the useful output and the total input** (energies or powers). Read the question: which output is useful?
2. **Extended only:** efficiency $= \dfrac{\text{useful output}}{\text{total input}} \times 100\%$.
3. **Wasted energy** $=$ total input $-$ useful output; in a Sankey diagram, add up all the wasted arrows.
4. **Give the answer** as a percentage or a decimal, as the question shows, never above 100%.

For example, a motor that gives 1500 J of useful work for 2000 J of electrical energy is $\frac{1500}{2000} \times 100\% = 75\%$ efficient.

Variations you will meet:

- **Output from efficiency**: useful output $=$ efficiency × input. A 35% efficient engine with 400 W input gives $0.35 \times 400 = 140$ W.
- **Input from efficiency**: total input $=$ useful output ÷ efficiency. A 30% efficient turbine giving 90 W needs $90 \div 0.30 = 300$ W input.
- **Mixed quantities**: if the input is a power and the output an energy, change one using $E = Pt$ first.
- **"State what 22% efficiency means"** (or "not very efficient"): only 22% of the energy input is transferred to useful output; the rest is wasted, mostly as thermal energy.
- **Why the useful output is less than the input**: energy is wasted heating the motor (and surroundings) through friction and resistance, and as sound.
- **Counting a Sankey diagram**: use the scale to turn widths into energies. Useful energy $+$ all the wasted energies $=$ input.
- **Number of devices needed**: find what one device gives in the same time, then divide the total needed by it. Round **up** to a whole number, because too few would not be enough.
- **Impossible values**: any efficiency above 100% must be a mistake.

Worked examples

The bold codes show where marks are earned, as in Cambridge mark schemes. The number is how many marks.

- **A1** accuracy mark: for a correct answer; it needs the M mark before it.
- **B1** mark for a correct result on its own, with no method needed.

Example 1

A crane lifts a crate of weight 450 N through a vertical height of 12 m in 15 s.

(a) Calculate the work done on the crate. **[3]**

(b) Calculate the useful power output of the crane. Include the unit. **[4]**

(c) State the energy store of the crate that increases. **[1]**

(d) **Extended only.** The power input to the crane's motor is 900 W. Calculate the efficiency of the crane. **[2]**

(a) Work done $=$ force × distance **C1** $= 450 \times 12$ **C1** $= 5400$ J **A1**.

(b) Power $=$ work done ÷ time **C1** $= 5400 \div 15$ **C1** $= 360$ **A1** W **B1**.

(c) Gravitational potential energy (store). **B1**

(d) Efficiency $= \dfrac{\text{useful power output}}{\text{total power input}} \times 100\%$ **C1** $= \dfrac{360}{900} \times 100\% = 40\%$ **A1**.

Example 2

Extended only. A ball of mass 0.40 kg is thrown vertically upwards at 12 m/s.

(a) Calculate the kinetic energy of the ball as it leaves the hand. **[2]**

(b) Air resistance is ignored. Calculate the maximum height the ball reaches. **[3]**

(c) In fact, the ball only reaches a height of 6.5 m. Calculate the work done against air resistance on the way up. **[2]**

(a) $E_k = \frac{1}{2}mv^2$ **C1** $= \frac{1}{2} \times 0.40 \times 12^2 = 28.8 \approx 29$ J **A1**.

(b) All the kinetic energy goes to the gravitational potential store: $mg\Delta h = 28.8$ **C1**.

$\Delta h = \dfrac{28.8}{0.40 \times 9.8}$ **C1** $= 7.3$ m **A1**.

(c) Gravitational potential energy gained $= 0.40 \times 9.8 \times 6.5 = 25.48$ J **C1**.

Work done against air resistance $= 28.8 - 25.48 = 3.3$ J **A1** (transferred to the thermal store of the air and ball).

Example 3

Extended only. In a hydroelectric power station, 1500 kg of water flows through the turbines each second after falling a vertical height of 120 m.

(a) Calculate the gravitational potential energy lost by the water each second. **[3]**

(b) The electrical power output is 1.40 MW. Calculate the efficiency of the power station. **[2]**

(c) Calculate the power wasted. **[1]**

(d) Apart from cost, state one advantage and one disadvantage of hydroelectric power compared with a coal-fired power station. **[2]**

(a) $\Delta E_p = mg\Delta h$ **C1** $= 1500 \times 9.8 \times 120$ **C1** $= 1\,764\,000$ J, so 1.76×10^6 J each second (1.76 MW) **A1**.

(b) Efficiency $= \dfrac{1.40 \times 10^6}{1.764 \times 10^6} \times 100\%$ **C1** $= 79\%$ **A1**.

(c) $1.764 - 1.40 = 0.36$ MW **B1**.

(d) Advantage: renewable, or releases no carbon dioxide (no fuel is burned). **B1** Disadvantage: flooding the valley destroys habitats (or homes), or it can only be built where there are suitable rivers and hills. **B1**

Example 4

Extended only. The moving air reaching a wind turbine transfers energy to it at a rate of 500 kW. The turbine's electrical power output is 200 kW.

(a) Explain why the Sun is the main source of wind energy. **[2]**

(b) Calculate the efficiency of the turbine. **[2]**

(c) On a windy day the turbine runs at this output for 18 hours. Calculate the electrical energy it produces, in kWh. **[2]**

(d) A village needs 4500 kWh of electrical energy each day. Calculate how many hours a day the turbine would have to run at full output to supply it, and suggest why the village still needs another energy resource or a way of storing energy. **[3]**

(a) The Sun heats the atmosphere (and the ground) unevenly, which makes regions of different air pressure **B1**; air moves from high to low pressure, and this moving air is the wind **B1**.

(b) Efficiency $= \dfrac{\text{useful power output}}{\text{total power input}} \times 100\%$ **C1** $= \dfrac{200}{500} \times 100\% = 40\%$ **A1**.

(c) Energy $= Pt = 200\ \text{kW} \times 18\ \text{h}$ **C1** $= 3600$ kWh **A1**. (Keeping kW and hours gives kWh directly.)

(d) Time $= \dfrac{E}{P} = \dfrac{4500}{200}$ **C1** $= 22.5$ hours a day **A1**. The wind does not blow steadily all day and every day, so the supply is unreliable: even the windy day above gives only 3600 kWh, 80% of what is needed. The village needs a reliable back-up (or batteries or pumped water to store energy from windy times) **B1**.

Common mistakes

- **Vague stores.** "Potential energy" is not enough: write **gravitational** potential or **elastic** potential. The battery's store is **chemical**, not "electrical". Examiners see these every year.
- **Calling light, sound or electricity a store.** They are ways energy is transferred; the stores are the seven in the list.
- **Getting work done wrong**: dividing force by distance, or multiplying by time. Work $=$ force × distance, and nothing else.
- **Using the wrong distance.** For lifting, use the vertical height, not the length of the slope or stairs; for a force along a slope, use the distance along the slope.
- **Units and prefixes.** Convert minutes and hours to seconds for power, kJ to J and MW to W (or keep both in the same unit). Work and energy are in J, power in W: writing J for a power or W for an energy loses the unit mark.
- **Inverting the power or efficiency equation**, for example time ÷ work, or input ÷ output. If an efficiency comes out above 100%, you have it upside down.
- **Forgetting the square or the square root** in $E_k = \frac{1}{2}mv^2$. $v = \dfrac{E_k}{m}$ is wrong; $v = \sqrt{\dfrac{2E_k}{m}}$.
- **Using the wrong input for efficiency.** The input is the total energy going **in** (for a power station, the energy of the fuel or falling water), not the electrical output.
- **Hydroelectric power does not heat water.** There is no boiler or steam: falling water turns the turbines directly.
- **"Renewable" does not mean "reusable".** Biofuels are renewable because the plants regrow, even though each batch can only be burned once.
- **Vague advantages.** "Eco-friendly", "clean" or "no pollution" are too vague. Say what is not released (carbon dioxide, sulfur dioxide) or that no fuel is needed.
- **Defining the kilowatt-hour as "kilowatts per hour"**. It is an amount of energy: what a 1 kW appliance transfers in 1 hour.

How to get the marks

- **Write the equation first**, in words or symbols ($W = Fd$, $P = \frac{W}{t}$, $E_k = \frac{1}{2}mv^2$). In calculations the first mark is often for the equation, the second for the numbers substituted, then the answer.
- **"Include the unit"** means there is a separate mark for it: J for work and energy, W for power.
- **"Show that"**: write the equation, the numbers, and an answer to **one more significant figure** than printed (for example $12\,900$ J when told "about $13\,000$ J").

- **"Describe the energy transfers"**: name each store in full and the way the energy moves between them, in order. "Your answer should refer to stores" means name them, not just "energy is transferred".
- **"Describe how a power station generates electricity"**: the sequence of store → boiler → steam → turbine → generator. Leave out the fuel and boiler for hydroelectric, wind, tides, waves and geothermal (hot rocks make the steam).
- **"State the principle of conservation of energy"**: two points: energy cannot be created or destroyed; it can only be transferred between stores.
- **Advantages and disadvantages**: one clear point each, in terms of renewability, availability, reliability, scale or environmental impact. Cost is usually excluded by the question.
- **Efficiency**: answer as a percentage or a decimal, as the answer line shows, and no more than 100%.
- **Accuracy**: give 2 or 3 significant figures, keeping full values until the end. "Give your answer as a whole number" of devices means round up if needed.
- **Multiple choice**: work it out first; wrong options are usually the slips above (no square, time not converted, wrong height, wasted and useful swapped).

Quick check

1. (a) Name the energy store that increases when an archer pulls back a bow string. (b) **Extended only.** Which of these resources do **not** get their energy mainly from the Sun: coal, geothermal, wind, tidal, nuclear?
2. A student pushes a box 3.5 m across the floor with a force of 60 N. It takes 7.0 s. Calculate the work done and the power.
3. **Extended only.** A car of mass 1200 kg travels at 20 m/s. Calculate its kinetic energy. The brakes then give a constant force of 6000 N. Calculate the distance the car travels while stopping.
4. **Extended only.** A stone is dropped from a height of 20 m. Air resistance is ignored. Calculate the speed of the stone as it hits the ground.
5. **Extended only.** A lamp is 15% efficient. Each second, 60 J of electrical energy is supplied to it. Calculate the useful light energy and the wasted energy each second.

Answers

1. (a) The elastic (strain) store of the bow. (b) Geothermal, tidal and nuclear.
2. $W = Fd = 60 \times 3.5 = 210$ J. $P = \dfrac{W}{t} = \dfrac{210}{7.0} = 30$ W.
3. $E_k = \frac{1}{2} \times 1200 \times 20^2 = 240\,000$ J. All of it is removed by the work done by the brakes, so $Fd = 240\,000$ and $d = \dfrac{240\,000}{6000} = 40$ m.
4. $\frac{1}{2}mv^2 = mg\Delta h$, so $v = \sqrt{2 \times 9.8 \times 20} = 19.8$ m/s, about 20 m/s.
5. Useful light $= 0.15 \times 60 = 9.0$ J. Wasted $= 60 - 9.0 = 51$ J (to the thermal store of the lamp and surroundings).

Past questions to try

- **0625/43/O/N/25 Q3**: reading a Sankey diagram for a power station, its efficiency, and geothermal energy (Extended).
- **0625/33/O/N/25 Q2**: work done lifting a rock and the power of a truck, with units (Core).
- **0625/41/M/J/25 Q3**: energy transfers on a skateboard track and the work done climbing (Extended).
- **0625/31/M/J/24 Q4**: reasons to burn less fossil fuel, how hydroelectric power works, and storing wind energy (Core).