

Electromagnetic induction

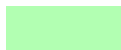
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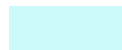
Revision notes for one topic, free to download.

These are the summary notes only. The full edition of this booklet also carries the worked examples, the required practicals and the formula sheets, with every topic in one place.

Colour Codes



Definitions



Diagrams



Notes and warnings



Sub-topic headings

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Define Electromagnetic induction

- inducing a potential difference across a conductor when there is relative movement between the conductor and a magnetic field.

Define Induced potential difference

- the p.d. produced across the ends of a conductor by electromagnetic induction; a current flows if the circuit is complete.

Define Transformer

- a device with two coils on a soft iron core that changes the size of an alternating potential difference.

Define Primary coil

- the input coil of a transformer, connected to the a.c. supply.

Define Secondary coil

- the output coil, in which a p.d. is induced.

Define Soft iron core

- the easily magnetised and demagnetised core that carries the changing magnetic field from the primary coil to the secondary coil.

Define Step-down transformer

- fewer turns on the secondary than the primary; decreases p.d. and increases current.

Define Efficiency of transmission

- the fraction of the generated energy that reaches the consumer rather than being dissipated heating the cables.

HIGHER TIER

NOTE

READ THIS FIRST — COMBINED SCIENCE KEEPS ONLY SIX STATEMENTS

This is the shortest physics topic in Combined Science. Edexcel states plainly that **specification points 13.1, 13.3, 13.4, 13.7 and 13.11 are in the GCSE in Physics only.**

Combined Science does include:

- 13.2**
- HT ONLY** the factors affecting the size and direction of an induced potential difference, and how the induced magnetic field opposes the original change
- 13.5 HT ONLY** how an alternating current in one circuit induces a current in another in a transformer
- 13.6**
- HT ONLY** that a transformer can change the size of an alternating voltage
- 13.8** why the national grid transmits at high voltages and then at lower voltages locally
- 13.9** where and why **step-up** and **step-down** transformers are used in the grid
- 13.10** the transformer **power** equation, $V_p \times I_p = V_s \times I_s$

Combined Science does not include: the general statement of the generator effect and large-scale generation (13.1); **alternators and dynamos**, slip rings and the split-ring commutator (13.3); **microphones, loudspeakers and headphones** (13.4); the **turns-ratio equation** $V_p \div V_s = N_p \div N_s$ (13.7); and the quantitative $P = I^2R$ explanation of high-voltage transmission (13.11).

Transformer equations in Combined Science: only **one** — the power equation of 13.10. *Appendix 4: Equations in Combined Science* does **not** contain the turns-ratio equation at all, so you will never be asked to use numbers of turns in a calculation.

Tiering: 13.2, 13.5 and 13.6 are printed in **bold**, so they are **Higher Tier only**. 13.8, 13.9 and 13.10 are examined at **both tiers** — so a Foundation-tier student still needs the national grid and the transformer power equation.

Core practicals: there are **none** in Topic 13. "Investigate factors affecting the generation of electric current by induction" is a *suggested* practical only, so it cannot be examined as a named core practical.

Define Step-up transformer

- more turns on the secondary than the primary; increases p.d. and decreases current.

Define National grid

- the network of transformers, pylons and cables that transfers electrical energy from power stations to consumers.

13.1 Factors affecting the induced potential difference (13.2)

HIGHER TIER

Moving a magnet and a conductor relative to each other **induces a potential difference** across the conductor; if the conductor is part of a complete circuit, a **current** flows. Hold them still and nothing is induced. (Combined Science does not assess this statement on its own — it is the background you need for 13.2.)

HT ONLY The size of the induced potential difference increases if you:

- move the magnet or conductor **faster** (a faster rate of change of the field);
- use a **stronger magnet** (greater magnetic flux density);
- use **more turns** on the coil;
- use a coil of **larger area**, or add an iron core.

HT ONLY The direction of the induced potential difference is reversed if you:

- reverse the **direction of movement** (push the magnet in rather than pull it out);
- reverse the **poles of the magnet** (north pole first rather than south pole first).

HT ONLY The induced field opposes the original change. The induced current itself creates a magnetic field, and that field always acts to **oppose the change that produced it**.

- Push a north pole into a coil and the near end of the coil becomes a **north** pole, pushing back against the magnet.
- Pull the magnet out and the near end becomes a **south** pole, trying to pull it back.
- Either way you must do **work** against this opposing force — that is where the electrical energy comes from, so energy is conserved. If the induced field helped the motion instead, you would get energy from nothing.

ANALOGY

Field lines are like blades of grass and the conductor is a lawnmower — you only get an output while you are *cutting* through them, and you get more the faster you cut and the thicker the grass. Standing still in the middle of the lawn produces nothing. That is 13.2 in one picture: faster movement and a stronger field both mean a larger induced p.d.

WATCH OUT

"A magnet sitting inside a coil induces a p.d." It does not. There must be a **change** — relative movement, or a changing current in a nearby coil. A stationary magnet, or a steady direct current, produces a steady field and induces nothing.

13.2 How a transformer works (13.5, 13.6)

HIGHER TIER

HT ONLY A **transformer** is two coils of insulated wire wound on a **soft iron core**. There is no electrical connection between them.

HT ONLY How an **alternating current** in one circuit induces a **current** in another (13.5):

1. An **alternating** current in the **primary coil** produces a magnetic field that is constantly **changing** in size and direction.
2. The **soft iron core** is easily magnetised and demagnetised, so it carries this changing field round to the secondary coil with very little loss.
3. The changing magnetic field through the **secondary coil** induces an **alternating potential difference** across it (electromagnetic induction).
4. If the secondary circuit is complete, an alternating current flows in it.

HT ONLY A **transformer** can change the size of an **alternating voltage (potential difference)** (13.6) — the size of the output depends on the numbers of turns on the two coils. **More** turns on the secondary than on the primary gives a **larger** output p.d. (step-up); **fewer** turns gives a **smaller** output p.d. (step-down). You need this in words only: Combined Science has **no turns-ratio equation**.

WATCH OUT

Transformers only work with a.c. A steady direct current would produce a steady, unchanging magnetic field, and an unchanging field induces nothing in the secondary coil. If a question shows a transformer connected to a battery, the answer is "no output".

13.3 The transformer power equation (13.10)

13.4 The national grid (13.8, 13.9)

The **national grid** transfers electrical energy from power stations to homes, shops and factories.

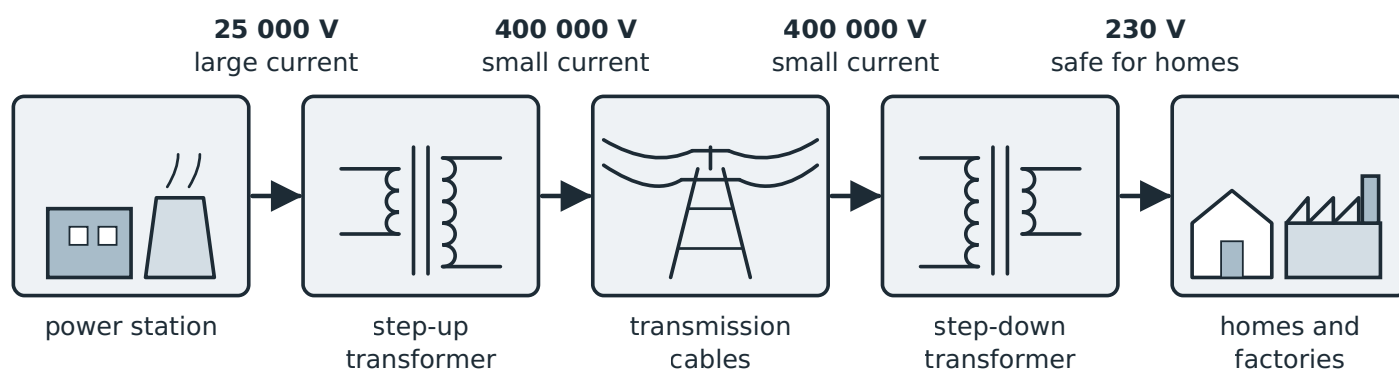
- **Step-up transformers** are used **at the power station**, raising the p.d. from about 25 000 V to 132 000 V or more for the transmission cables (13.9).
- **Step-down transformers** are used at substations **in each locality**, lowering the p.d. in stages to 230 V for domestic use (13.9).
- **Why transmit at high voltage (13.8):** for a given power transmitted, a **high p.d. means a small current** in the cables. A small current means **much less energy is wasted heating the transmission lines**, so the **efficiency of transmission is improved** and less fuel is needed for the same energy delivered.
- The p.d. must be reduced again locally because hundreds of thousands of volts would be extremely dangerous in homes, and domestic appliances are designed for 230 V.

	Step-up transformer	Step-down transformer
Turns	More turns on the secondary than the primary	Fewer turns on the secondary than the primary
Effect on p.d.	Increases it	Decreases it
Effect on current	Decreases it	Increases it
Where in the grid	At the power station, before transmission	At local substations, before consumers
Why	Low current in the cables reduces heat loss	Makes the supply safe and usable at 230 V

The argument in words, as 13.8 wants it.

1. A power station generates a fixed **power**.
2. A **step-up transformer** raises the p.d. Because the power is fixed and $V_p \times I_p = V_s \times I_s$, raising the p.d. must **reduce the current** by the same factor.
3. When there is a current in a resistance there is an energy transfer that **heats** the cables (10.22–10.23). A smaller current means far less of this heating, so far less energy is dissipated in the transmission lines.
4. More of the generated energy therefore reaches the consumer: transmission is more **efficient**.
5. A **step-down transformer** then lowers the p.d. again for safe local use.

The national grid and its step-up and step-down transformers



Reducing the energy dissipated in the cables

- The transmission cables have resistance, so some energy is dissipated by heating as current flows.
- A transformer does not change the power that is transferred: $P = VI$ stays the same. So if the p.d. is stepped up, the current is stepped down.
- The power wasted in the cables is $P = I^2R$, so it depends on the square of the current: halving the current cuts the wasted power to a quarter.
- A high potential difference and a low current therefore make the National Grid an efficient way of transferring energy.

$$P = I^2 R$$

P = power wasted in the cables, watts (W)

I = current in the cables, amperes (A)

R = resistance of the cables, ohms (Ω)

Stepping the potential difference up 16 times steps the current down 16 times, so the power wasted in the cables falls by $16^2 = 256$ times.

NOTE

The **quantitative** version of this argument — using $P = I^2 \times R$ to show that cutting the current by a factor of 100 cuts the wasted power by 10 000 — is statement **13.11, which is in the GCSE in Physics only**. Combined Science asks for the reasoning in words (13.8) and the power equation for the transformer itself (13.10). You have met $P = I^2 \times R$ in Topic 10, where it is on **list a: recall and apply**, so you can still use it — but no Combined Science question will require the grid calculation.

Use of mathematics — make calculations using ratios and proportional reasoning to convert units and to compute rates (maths skills 1c, 3c); make calculations of the energy changes associated with changes in a system, recalling or selecting the relevant equations for mechanical, electrical and thermal processes (1a, 1c, 3c). Suggested practical: investigate factors affecting the generation of electric current by induction.