Chapter 21. Electromagnetic Induction

G2

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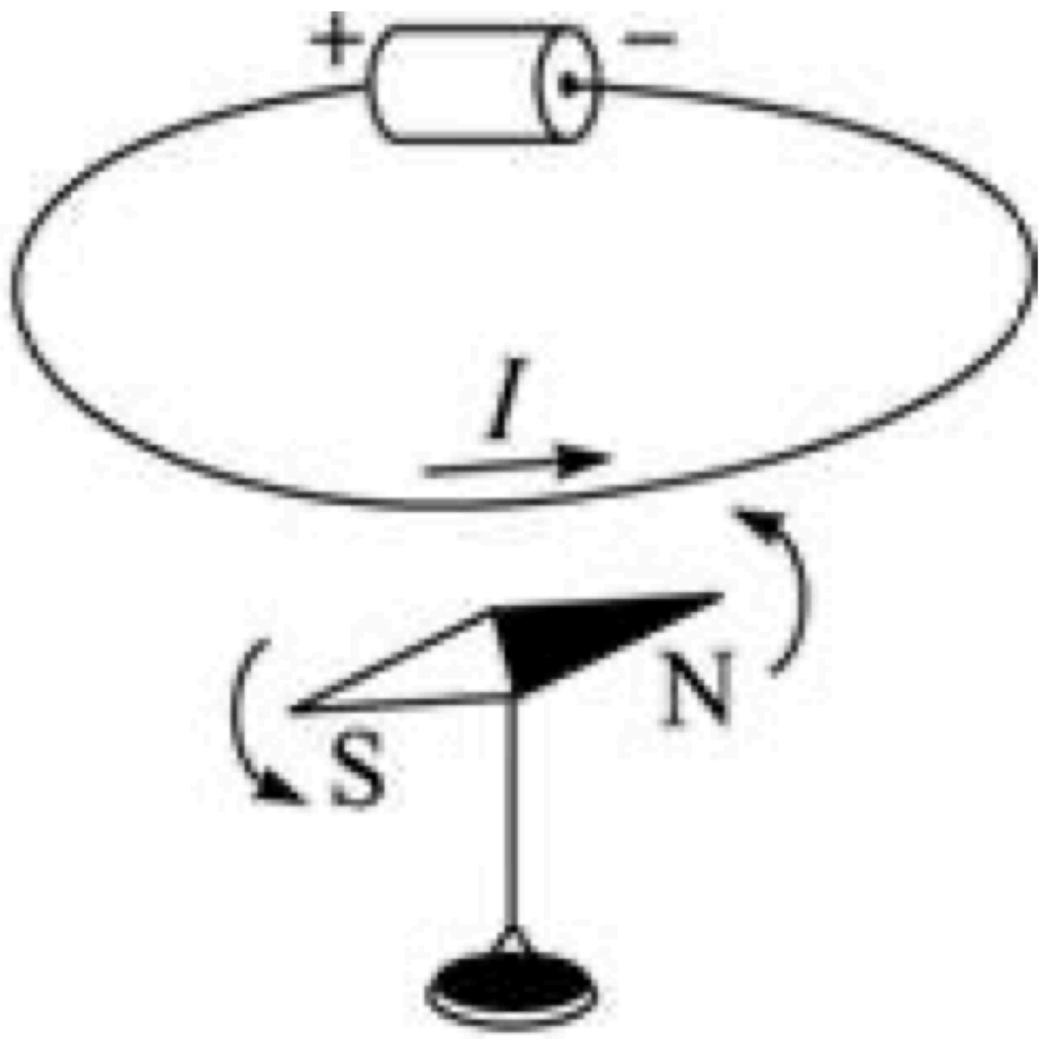
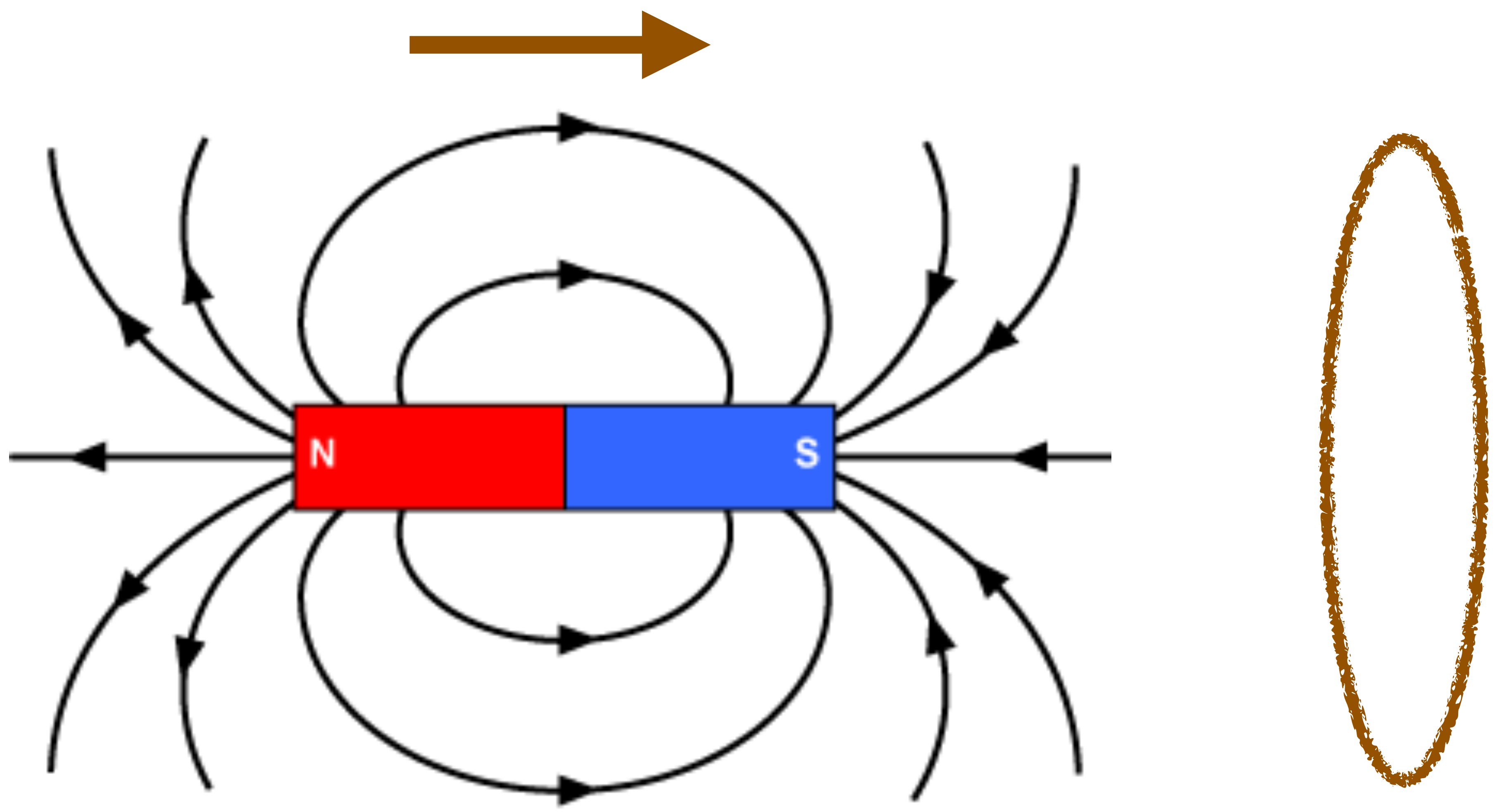
10/2023

Generating Electricity

Current can create magnetic field, can magnetic field creates electricity?





Current → Magnetic field

Moving charge

Magnetic Field → Current

Moving B

Electromagnetic induction

Electromagnetic induction: the induction of an **e.m.f**. across an electrical conductor when the conductor **move across** a magnetic field or there is change in **magnetic flux** in the conductor

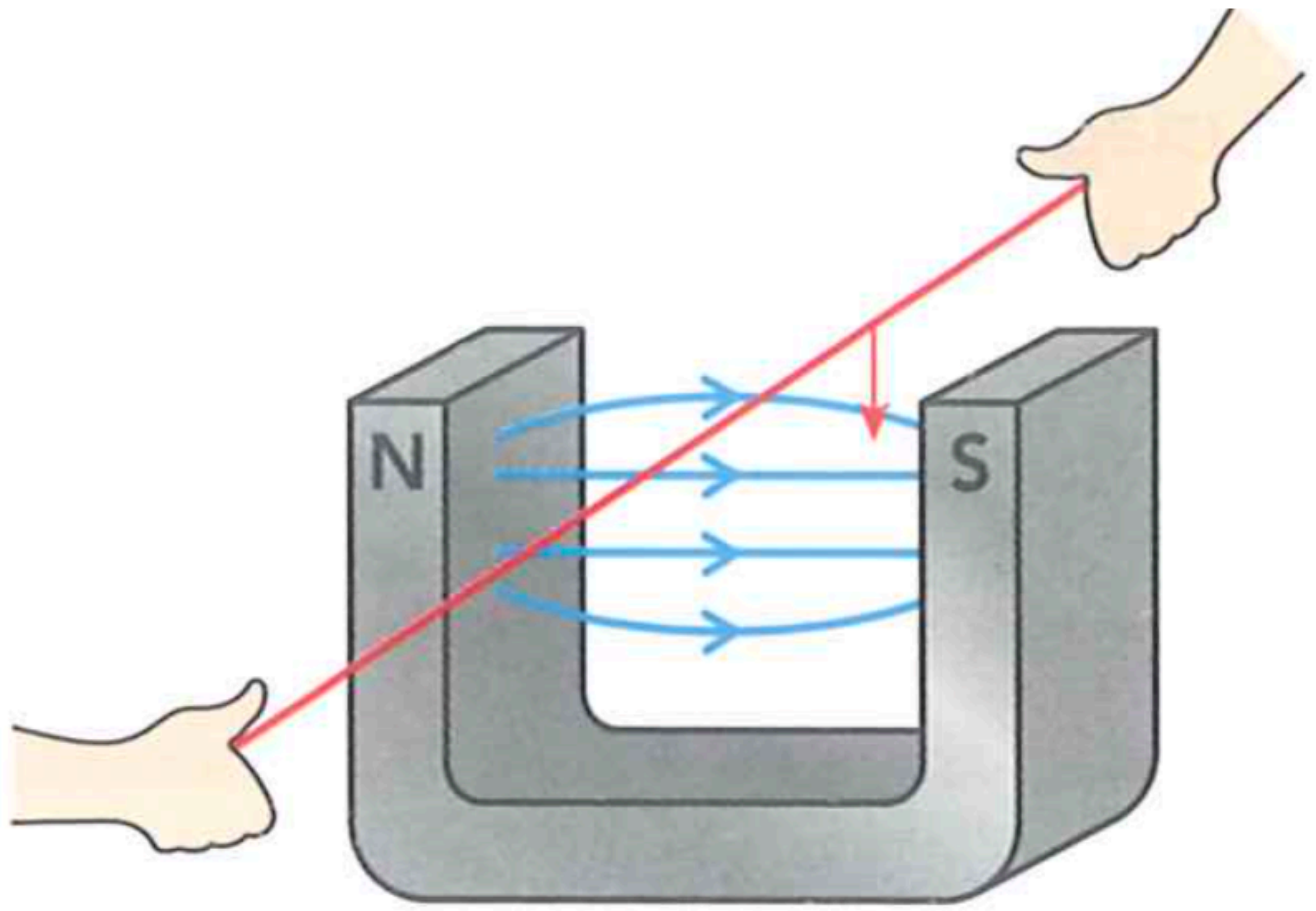
Two ways to induce e.m.f. :

1. Wire cutting field lines
2. Magnetic flux change in coil

Induction by cutting field lines

Induction by cutting field lines

Watch the demo below, think about <u>what kind of motion can induce the current</u> in the single wire?



What kind of motion can induce a current?

1. Keep magnet stationary, Move wire up btw poles => current flow in one direction
2. Keep magnet stationary, Move wire down btw poles => current flow in opposite direction
3. Keep wire stationary, move magnets up around wire => current flow as in situation 2
4. Keep wire stationary, move magnets down around wire => current flow as in situation 1

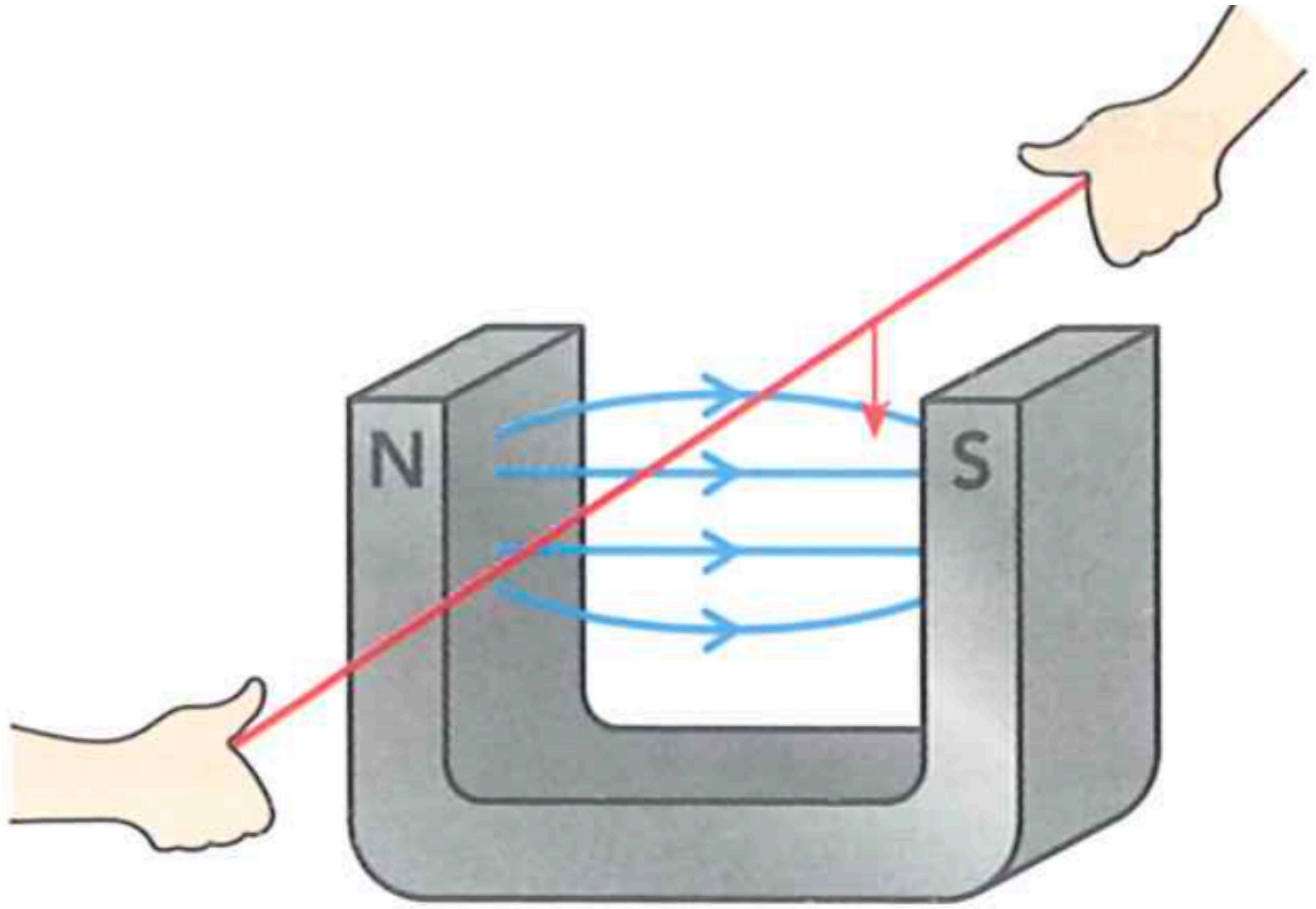
Cutting field lines → **Current/e.m.f.**

Induction by cutting field lines

How to increase the induced current?

- Use stronger magnet
- Move wire/magnetic quickly relative to each other
- Add more turns of wire

→ cutting more field lines per unit time



Induction by cutting field lines

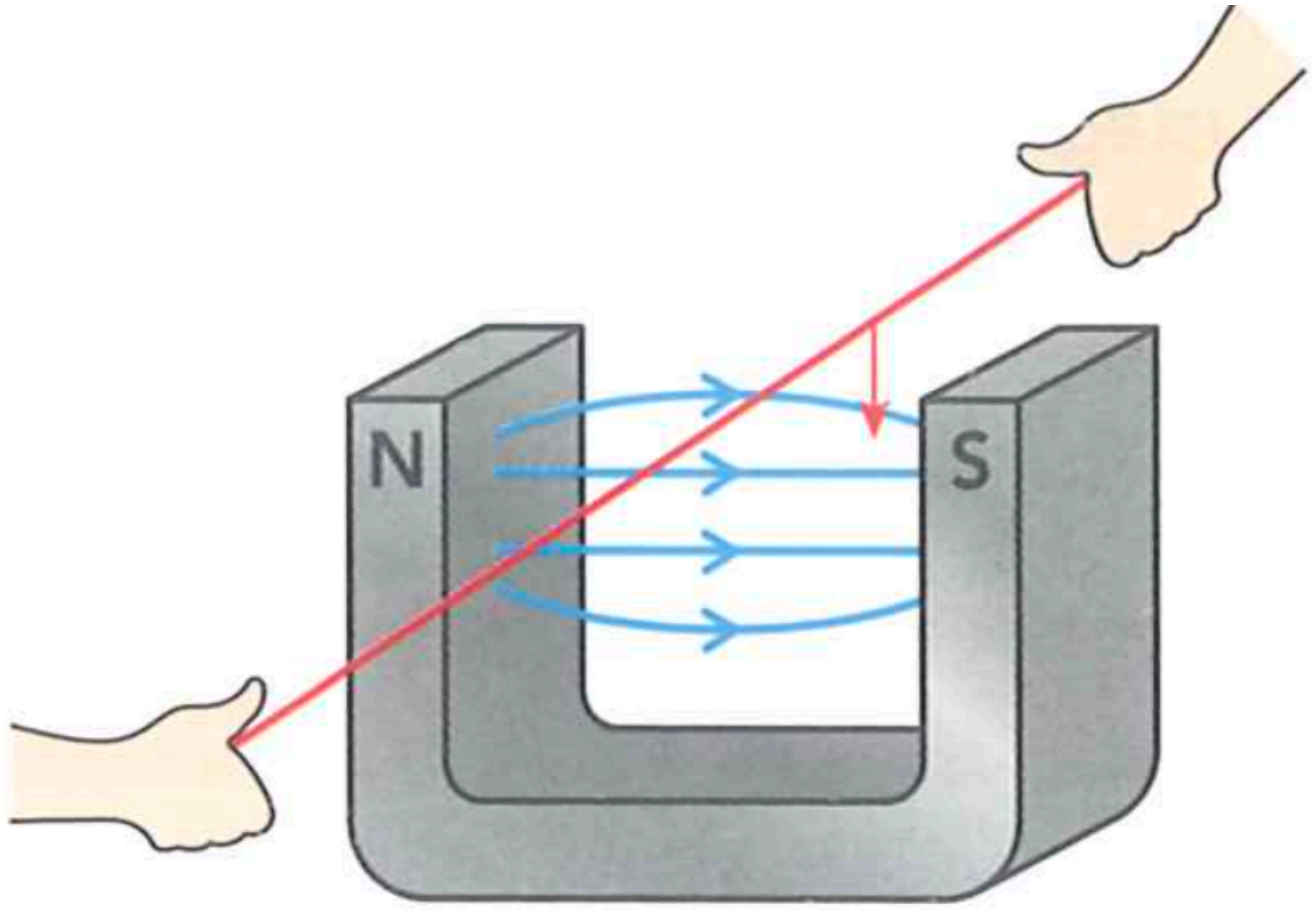
Why cutting filed lines can induce a current/e.m.f.?

Movement of wire can be seen as movement of electrons in the wire, which causes a current, current in a magnetic field produces a force (Ampere's force/Lorenz's force) on the current/ electrons, causing electron to move which is current

According to the explanation above can you draw the direction of current of following situation?

Electrons moving into the paper

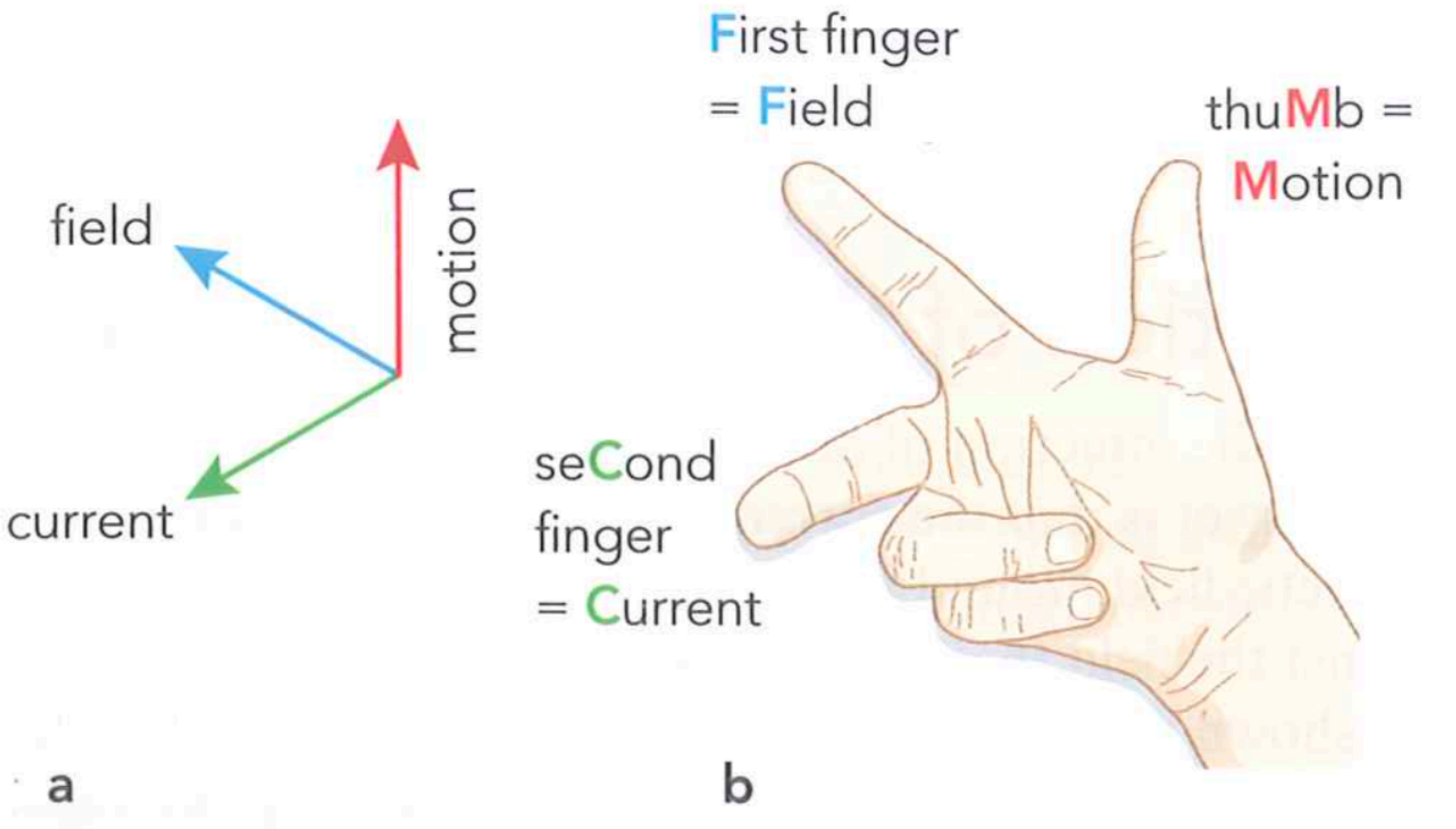
Current out of the paper

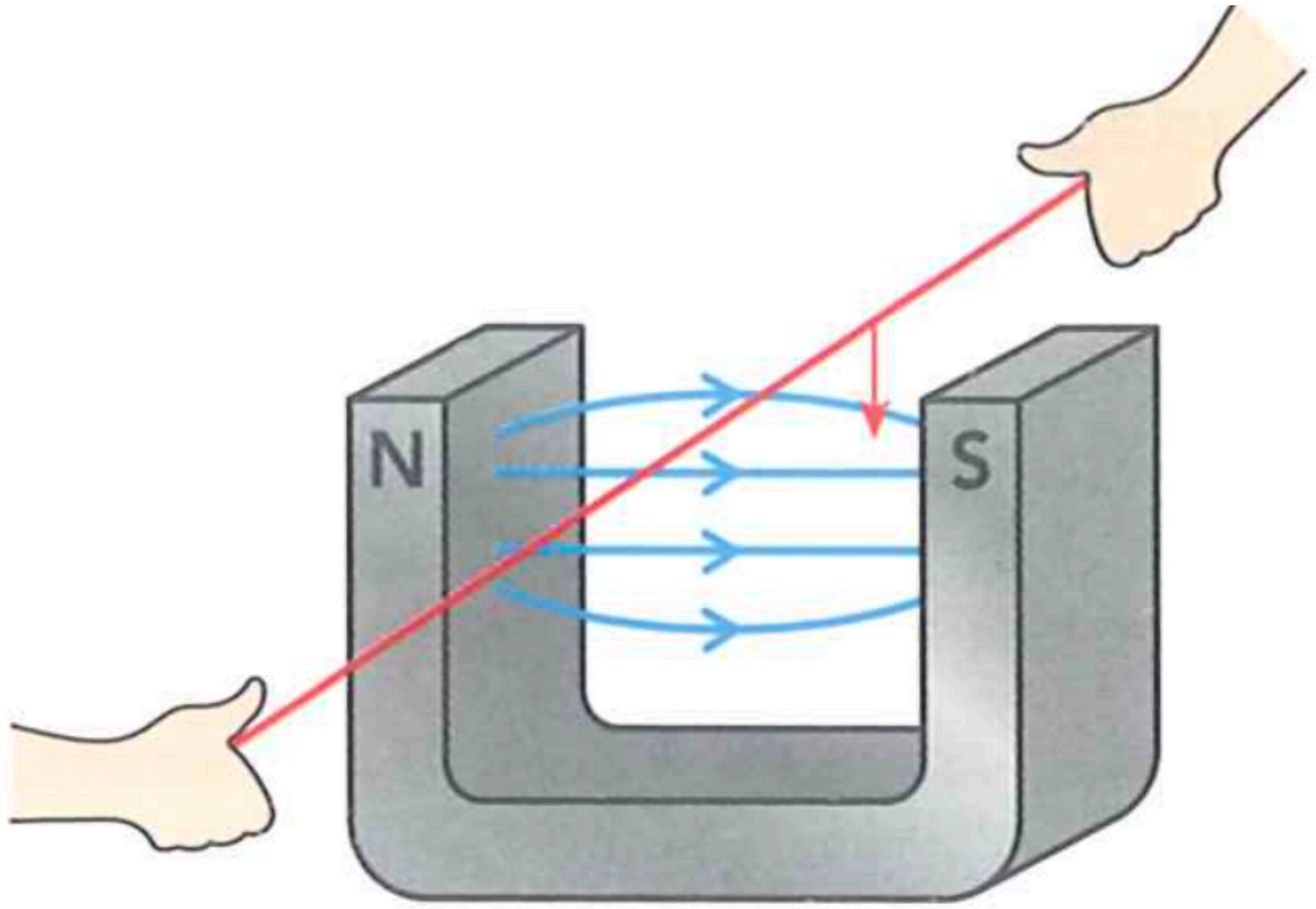


Induction by cutting field lines

An **easier** way to determine direction of induced current in a wire

➜ **Fleming's right hand rule**





Electromagnetic induction

Exercise 21.0:

Fig. 9.1 shows a thin, straight rod XY placed in the magnetic field between the poles of a magnet. The wires from the ends of XY are connected to a centre-zero voltmeter.

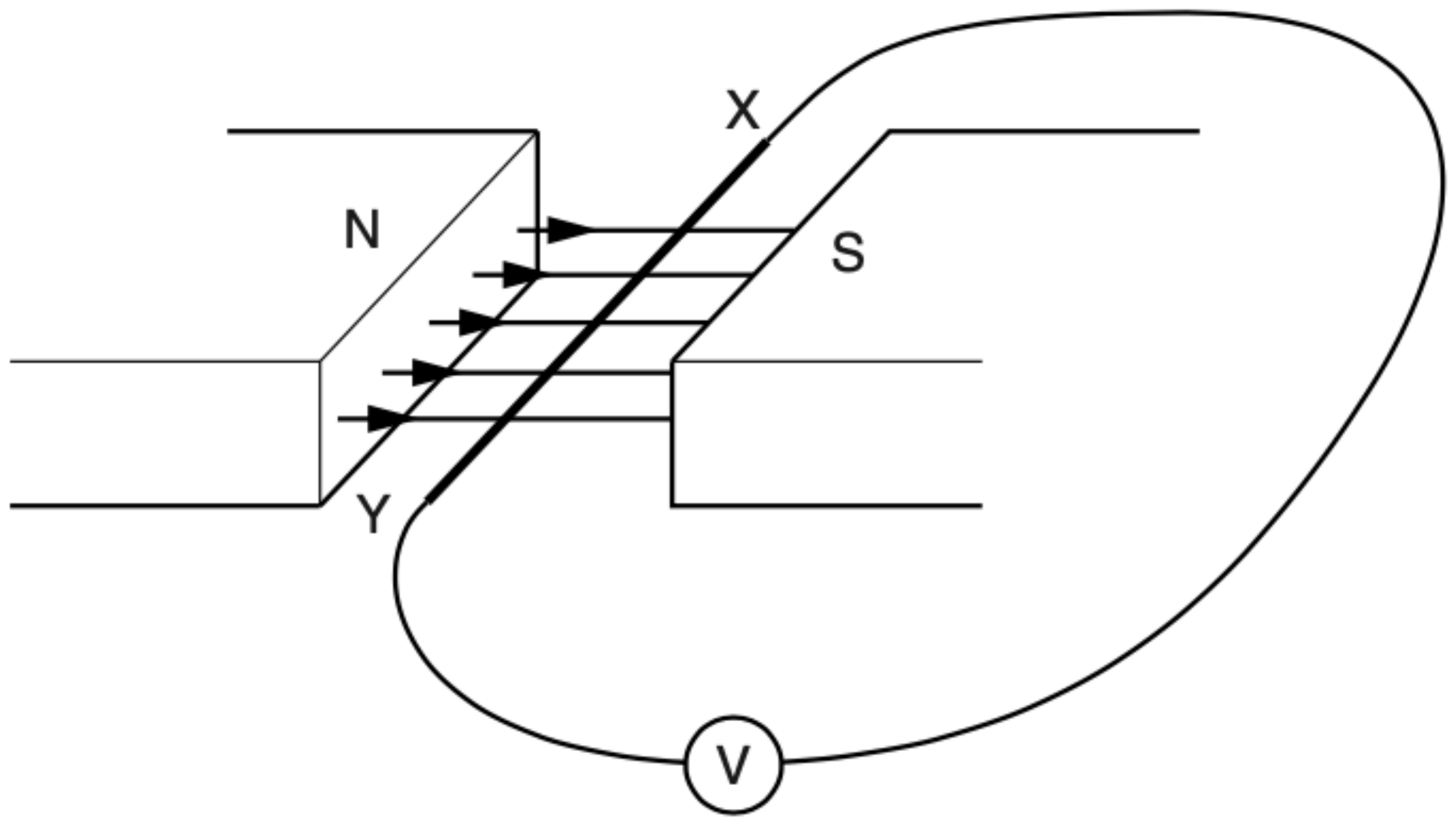


Fig. 9.1

(a) When XY is moved slowly upwards the needle of the voltmeter shows a small deflection.

(i) State how XY must be moved to produce a larger deflection in the opposite direction.

....

.... [2]

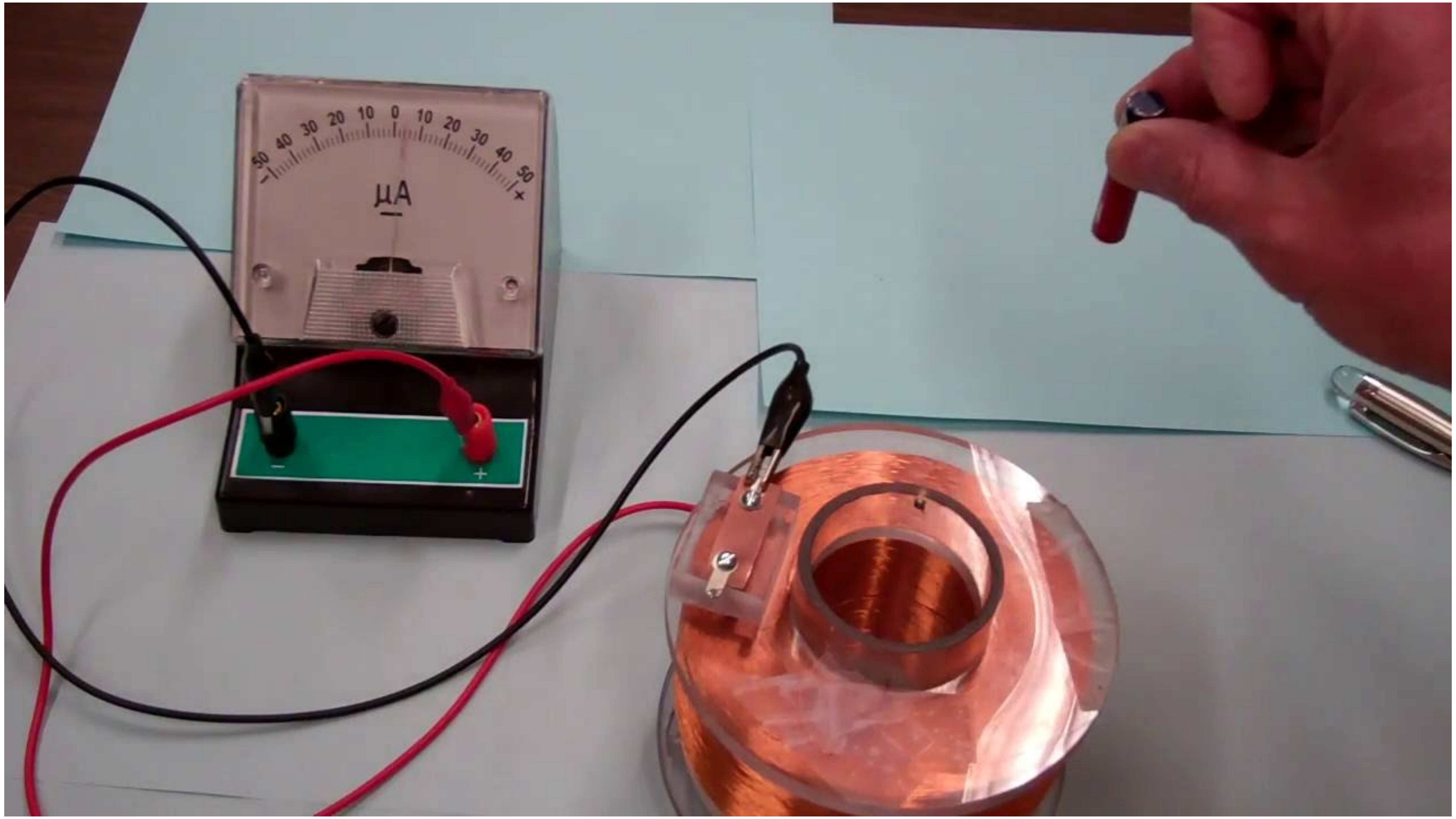
(ii) XY is now rotated about its central point by raising X and lowering Y. Explain why no deflection is observed.

....

....

.... [2]

Induction by moving a magnet relative to a coil



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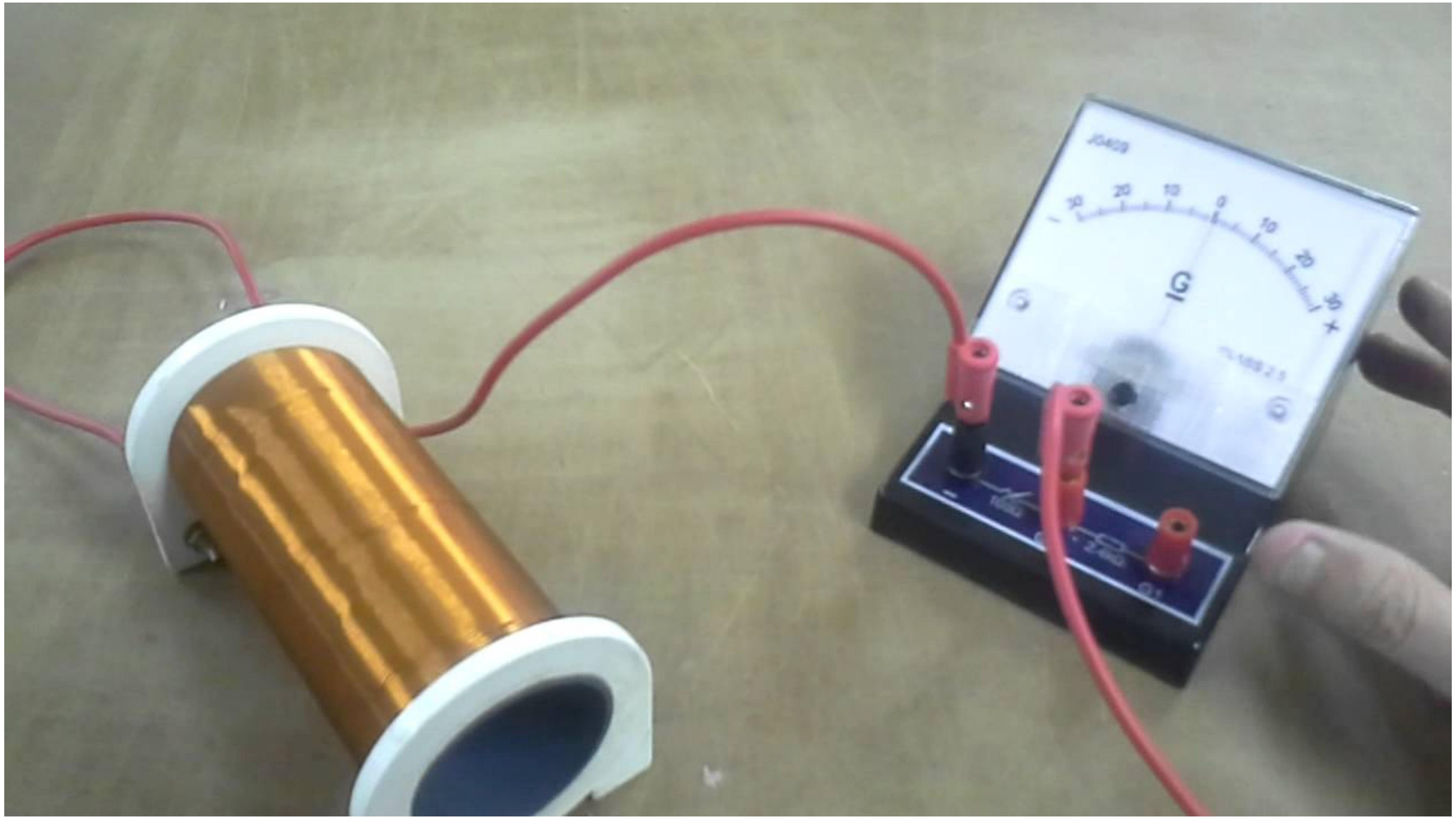
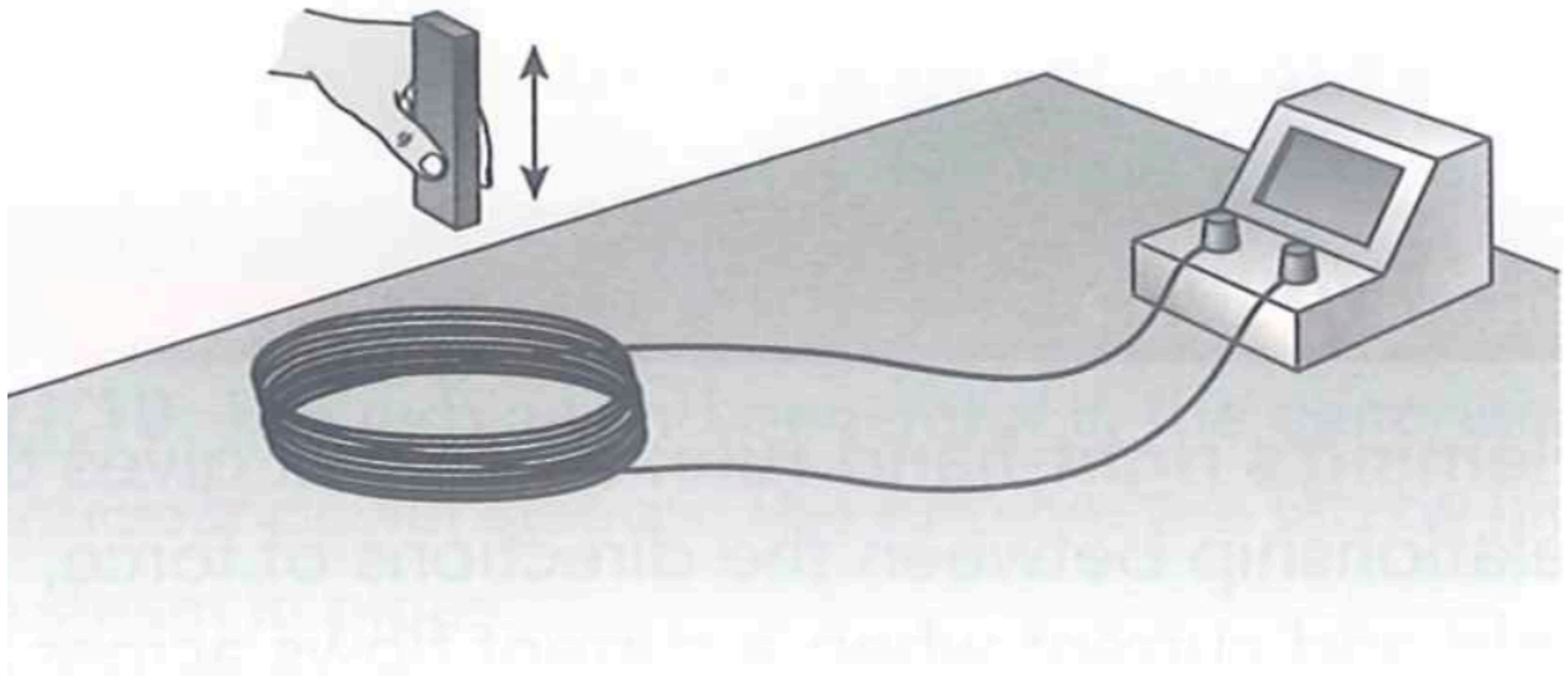


Induction by moving a magnet relative to a coil



What kind of motion can induce a current?

Relative movement btw coil and magnet

Cutting field lines/ change flux/linkage inside coil → **Current/ e.m.f.**

Increase the induced current e.m.f.?

- Use stronger magnet
- Move coil/magnetic quickly relative to each other
- Add more turns of wire

Electromagnetic induction

Why does the movement btw magnet and coil induce a e.m.f or current?

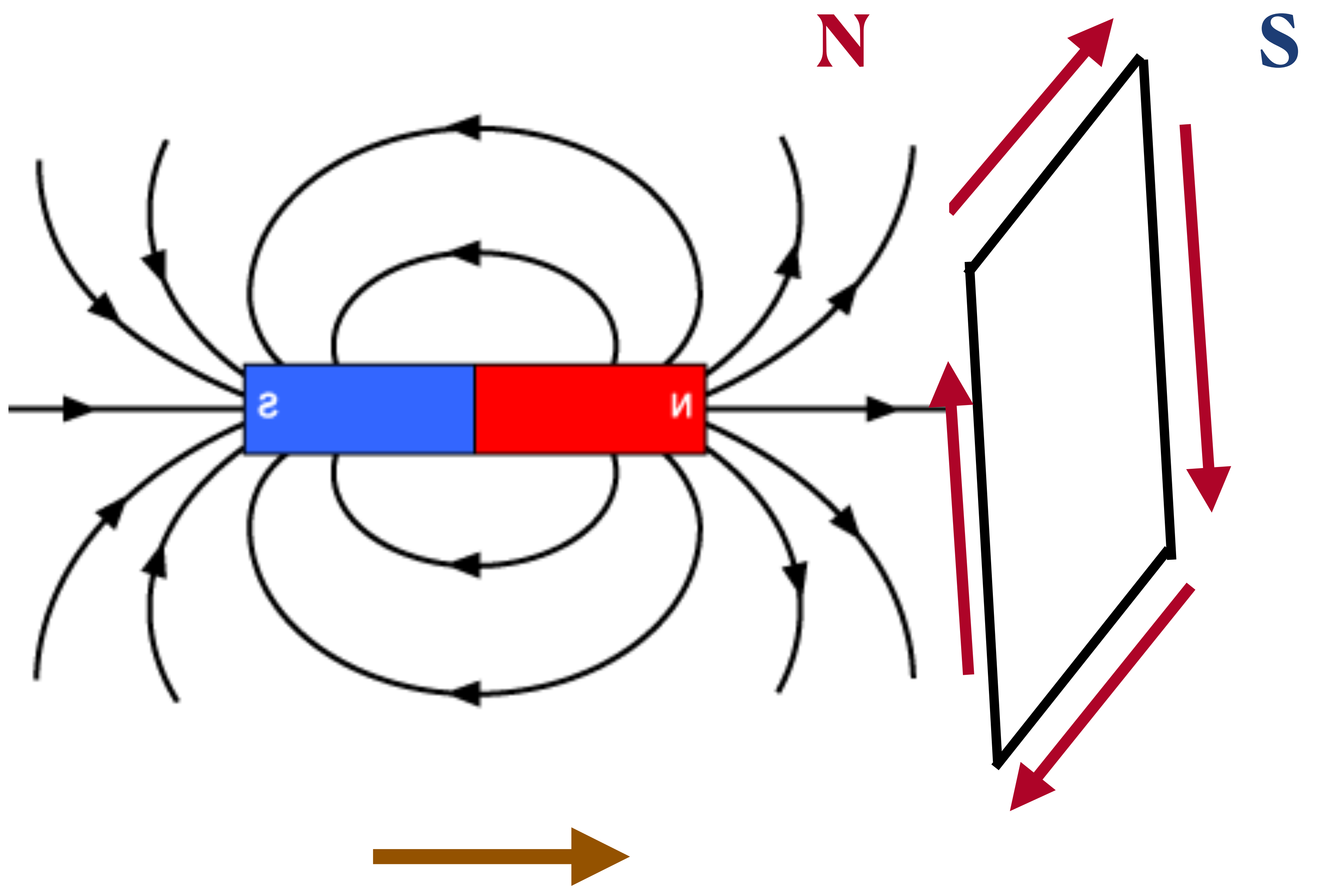
When moving a coil closer to the magnet,

*the wire of the coil **cuts the magnetic field** lines of the magnet*

Or

*The change of magnet field **flux is changing***

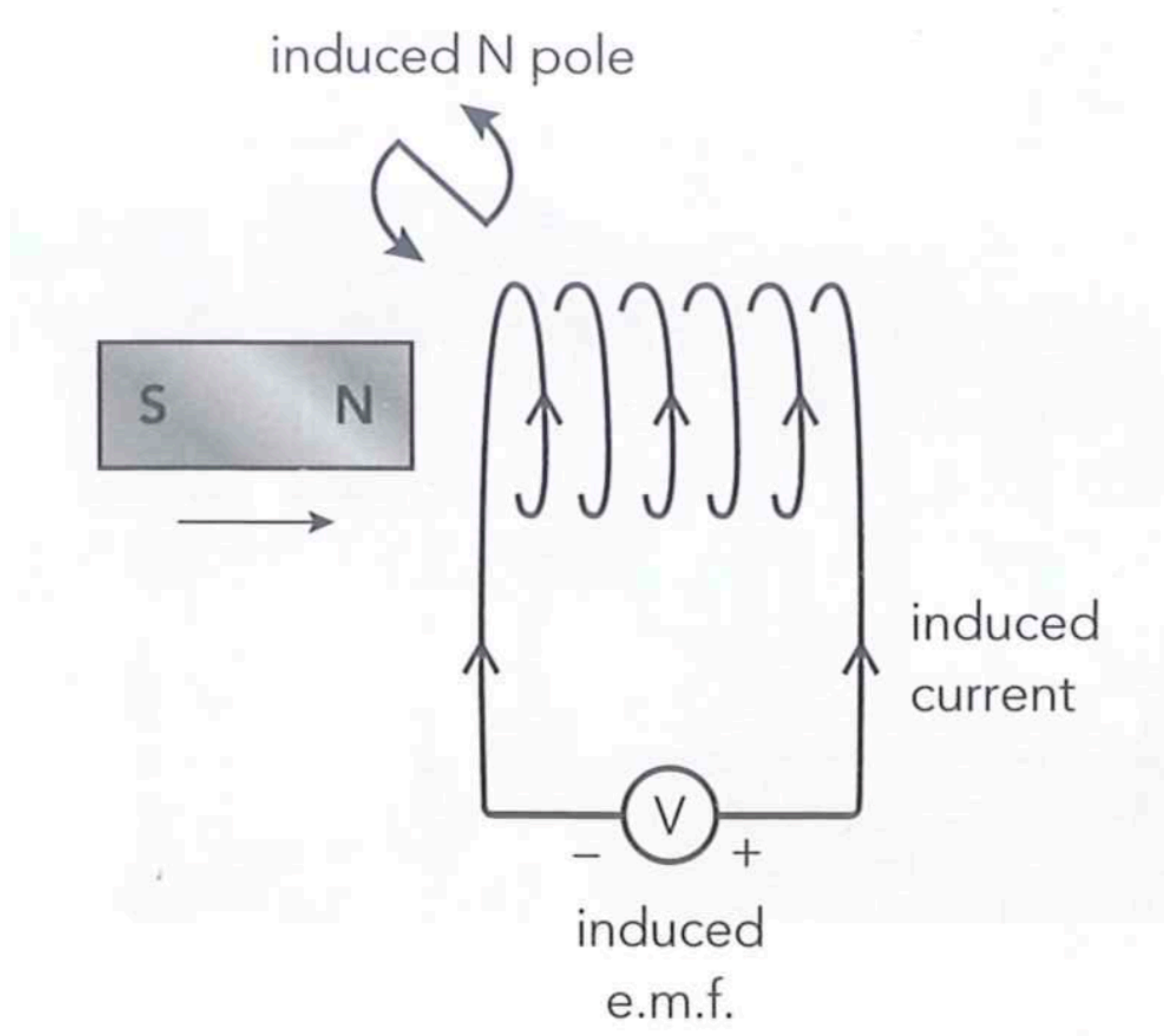
https://phet.colorado.edu/sims/html/faradays-law/latest/faradays-law_all.html



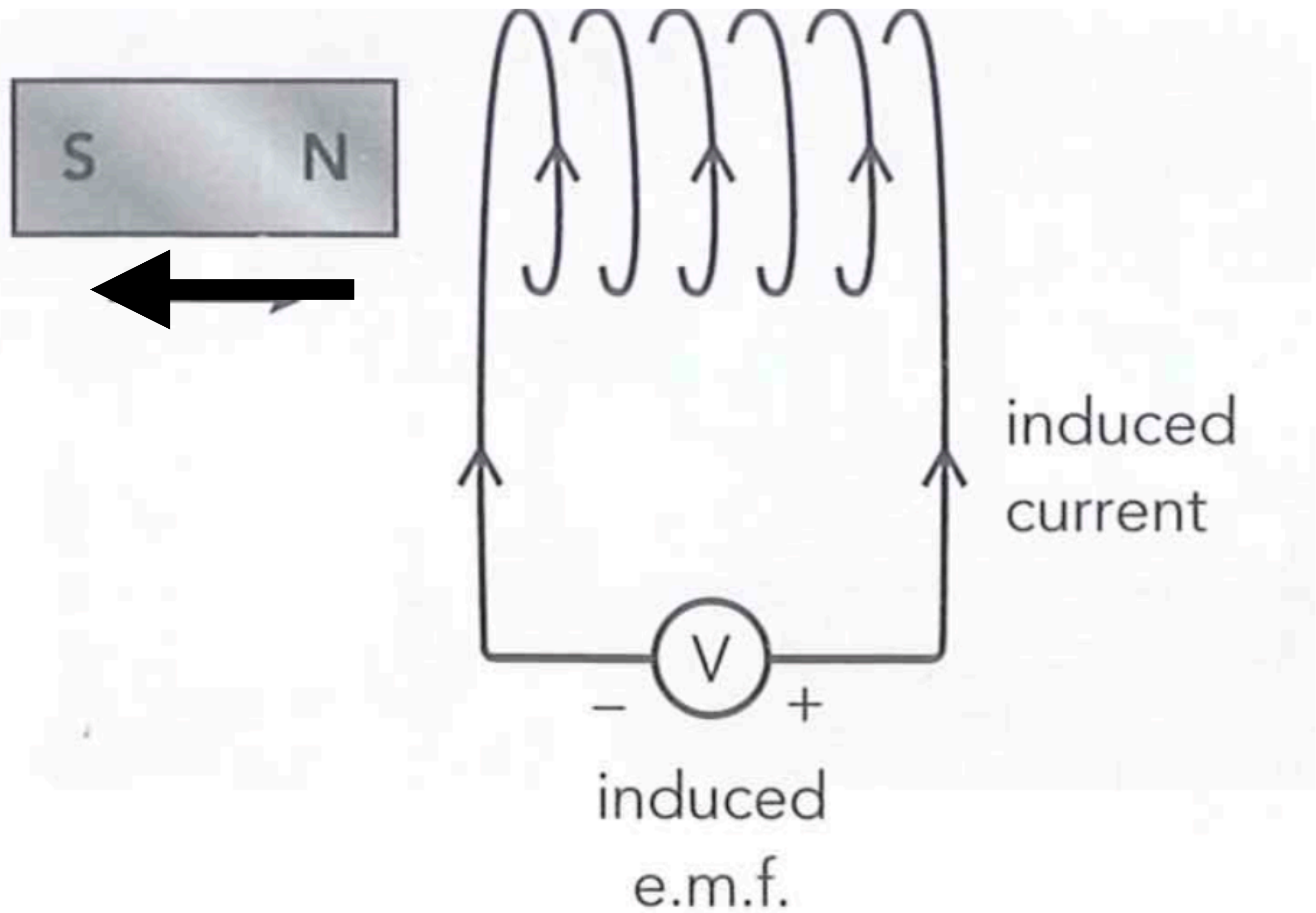
Electromagnetic induction

An **Easier** way to Determine direction of current in the coil:

➡ **Lenz's law** : The direction of an induced current always opposes the change in the circuit or the magnetic field that produce it.



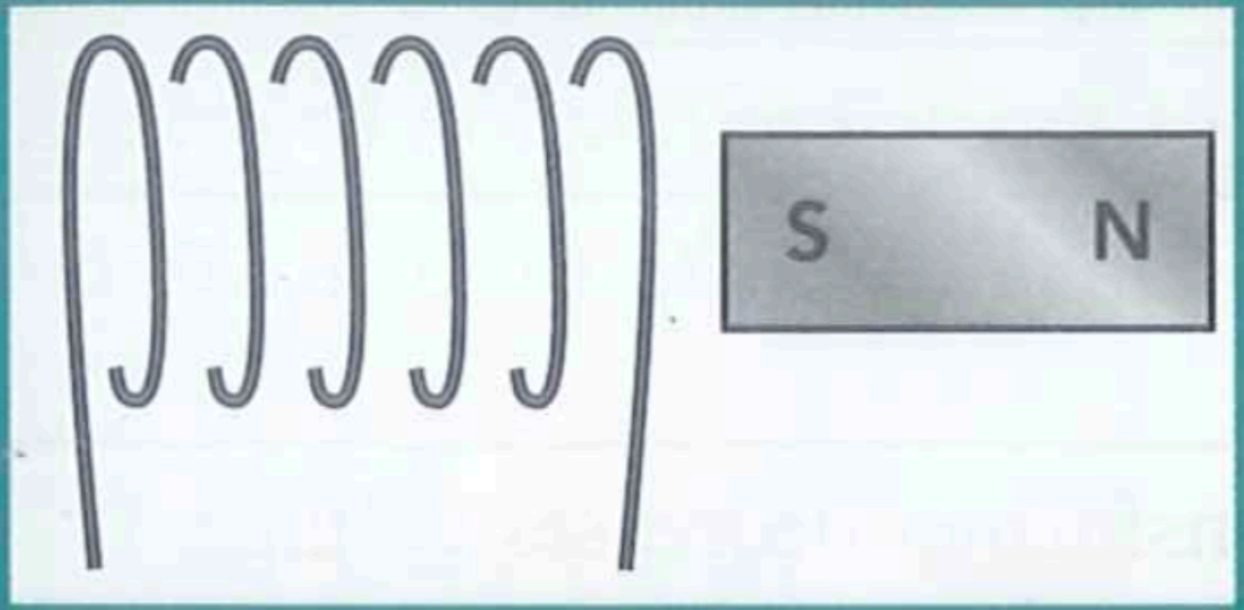
What if the magnet now moving away?



Understanding Lenz's law in the point of view of **Energy:** the generated current always opposes the change of magnetic field, a external force needed to make the B continue to make the change/extra work need to be done =>**mechanical energy** transfers to **electrical energy** in the generated current

Exercise

4 The diagram shows a coil and a magnet. When the magnet is moved away from the coil, current flows.



Which one of the following describes what happens? [1]

A Current flows clockwise in the coil, creating a north pole which attracts the south pole of the bar magnet.

B Current flows anticlockwise, creating a north pole which repels the south pole of the bar magnet.

C Current flows anticlockwise, creating a south pole which repels the south pole of the bar magnet.

D Current flows anticlockwise, creating a north pole which attracts the south pole of the bar magnet.

Exercise

5 a Which statement describes electromagnetic induction? [1]

A the production of an e.m.f across an electrical conductor when there is relative movement between the conductor and a magnetic field

B the production of an e.m.f across an electrical conductor when there is no movement between the conductor and a magnetic field

C the production of an e.m.f across an electrical conductor when there is relative movement between the conductor and an induced current

D the production of an e.m.f across an electrical conductor when there is no movement between the conductor and an induced current

b Describe an experiment to demonstrate electromagnetic induction using a horseshoe magnet, a piece of copper wire and a sensitive ammeter. You may include a diagram in your answer. [3]

c State **two** factors which affect the size of the current induced in this experiment. [2]

[Total: 6]

Recap

Electromagnetic induction: the production of an **e.m.f**. across an electrical conductor when the conductor **move across** a magnetic field or there is change in **magnetic flux** in the conductor

Two ways to induce e.m.f. :

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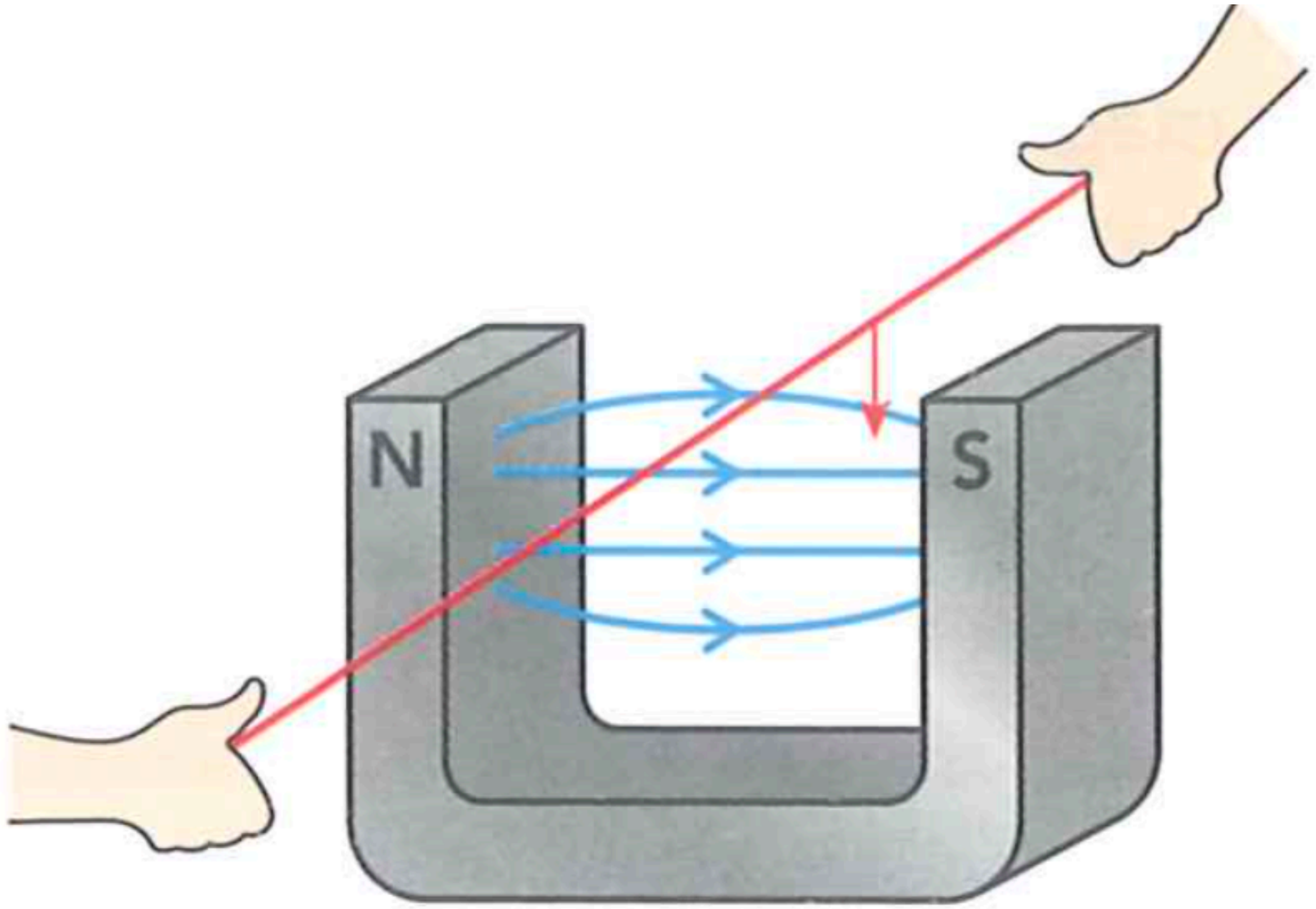
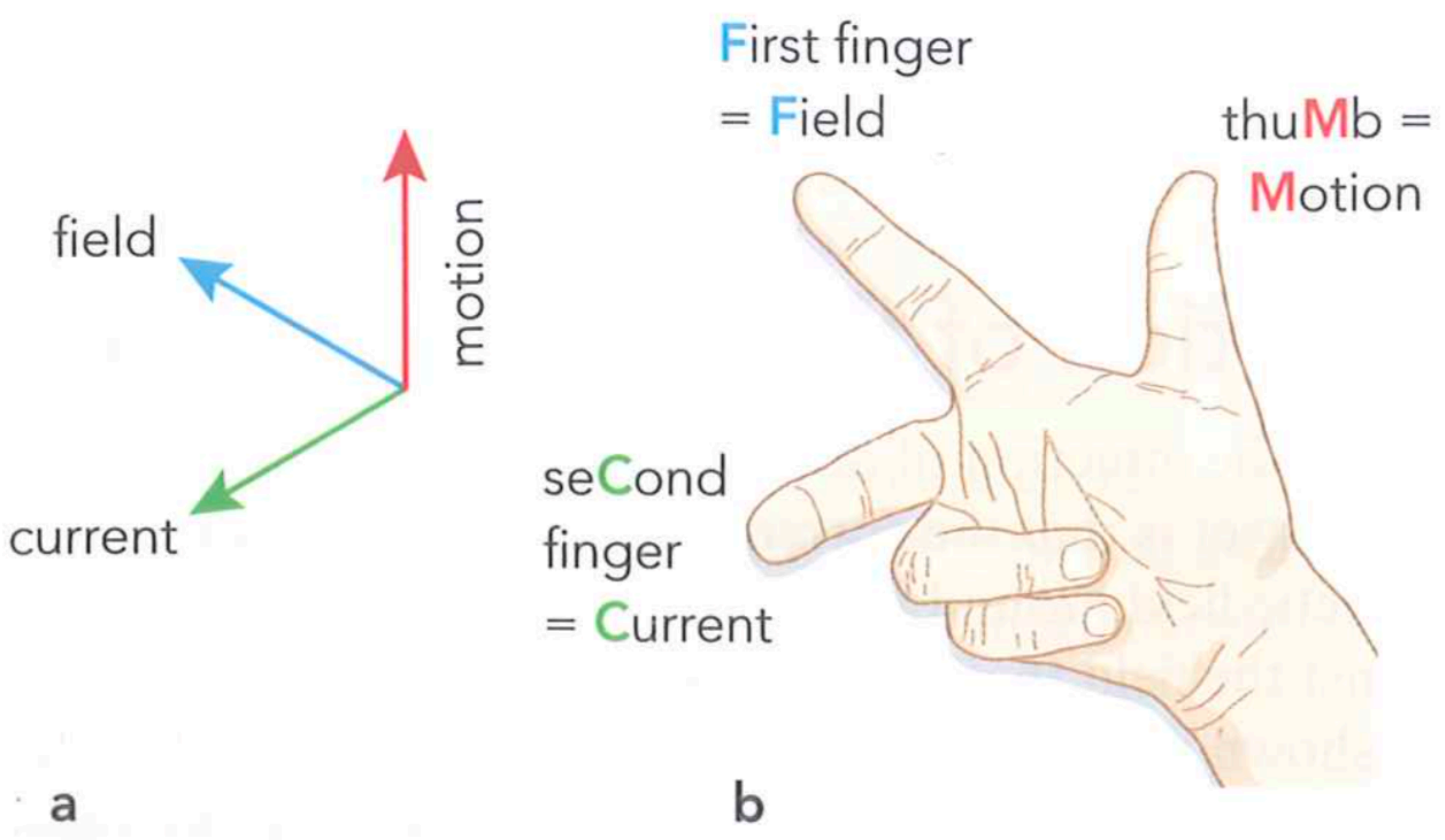
Induction by cutting field lines

Cutting field lines → Current/e.m.f.



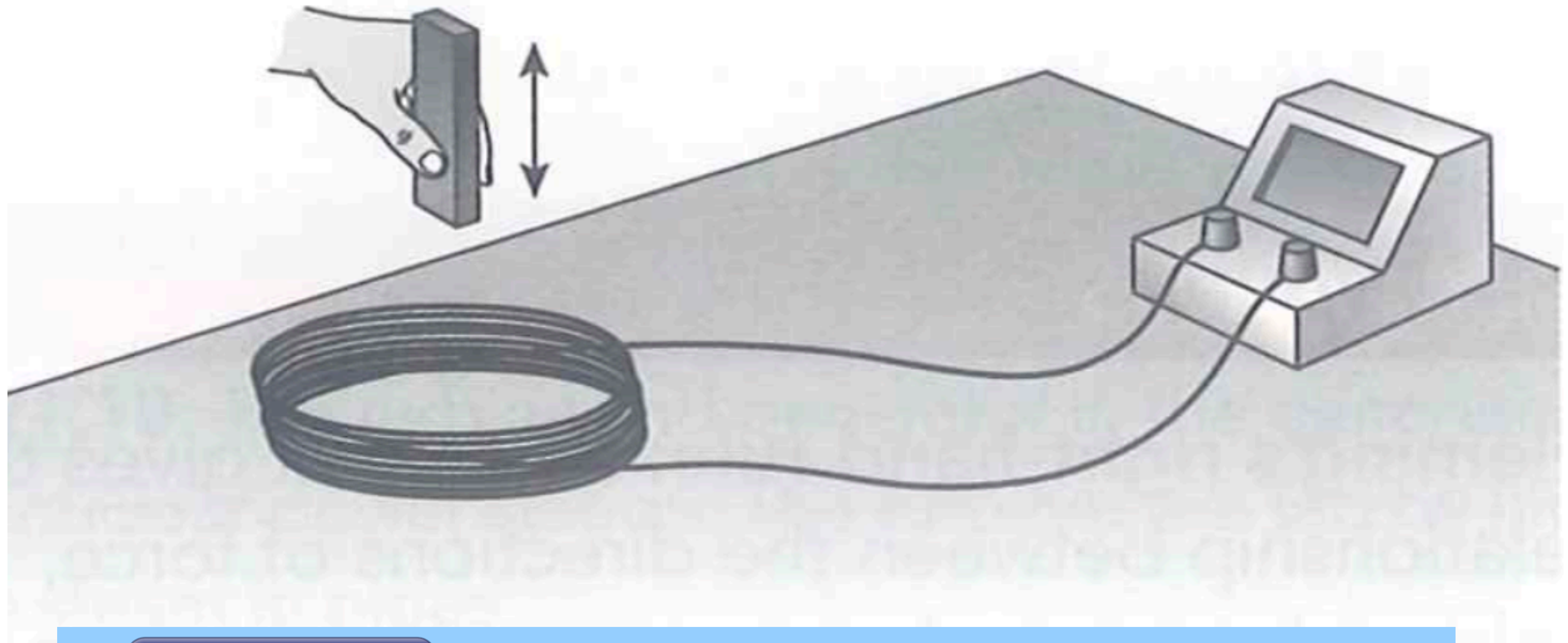
→ Direction of induced current:

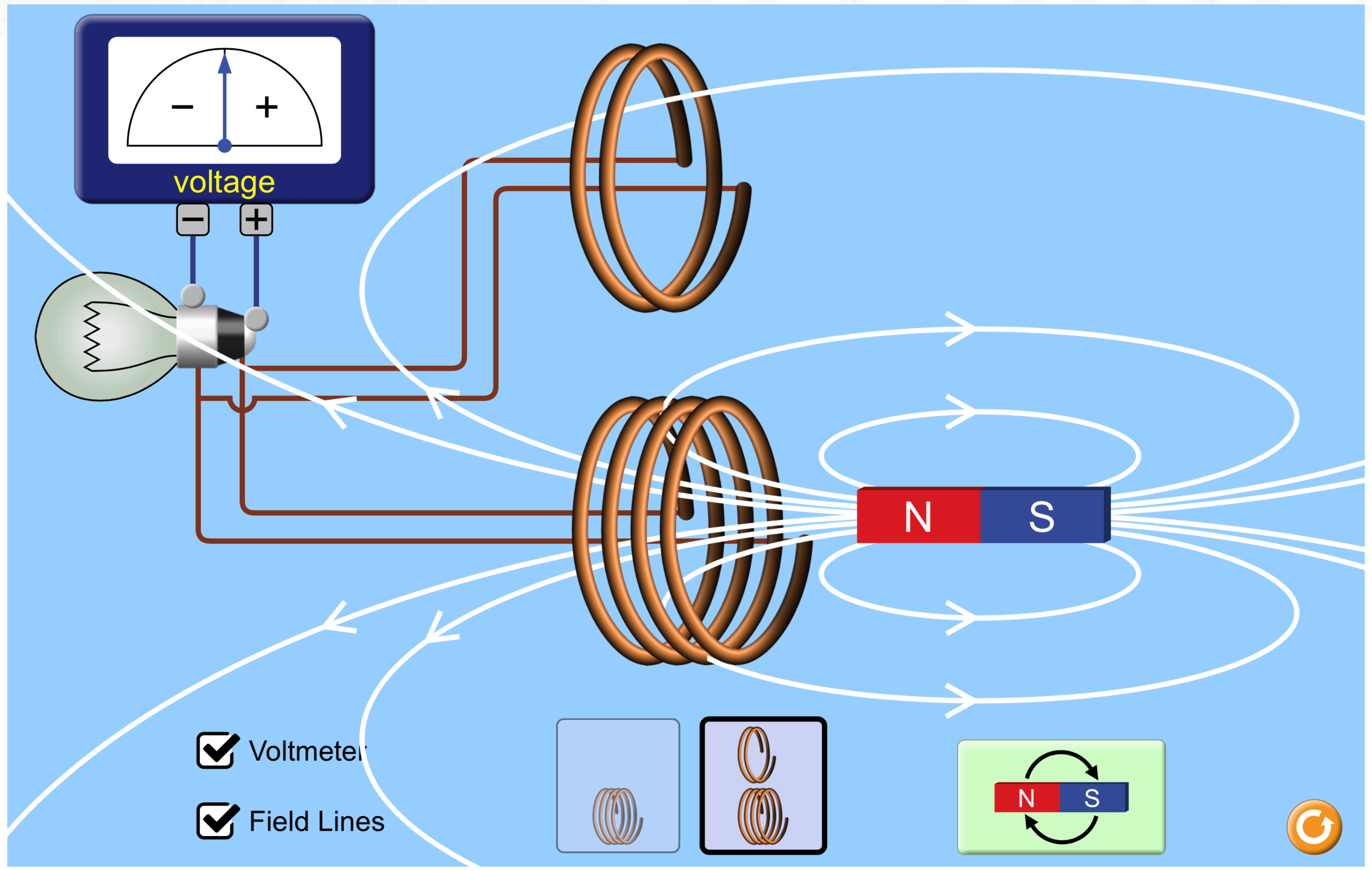
Fleming's right hand rule



Reason: wire cuts field lines induces current/e.m.f..

Induction by moving a magnet relative to a coil





What kind of motion can induce a current?

Relative movement btw wire and magnet

Cutting field lines/ change flux/linkage inside coil → **Current/ e.m.f.**

Increase the induced current e.m.f.?

- Use stronger magnet
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Electromagnetic induction

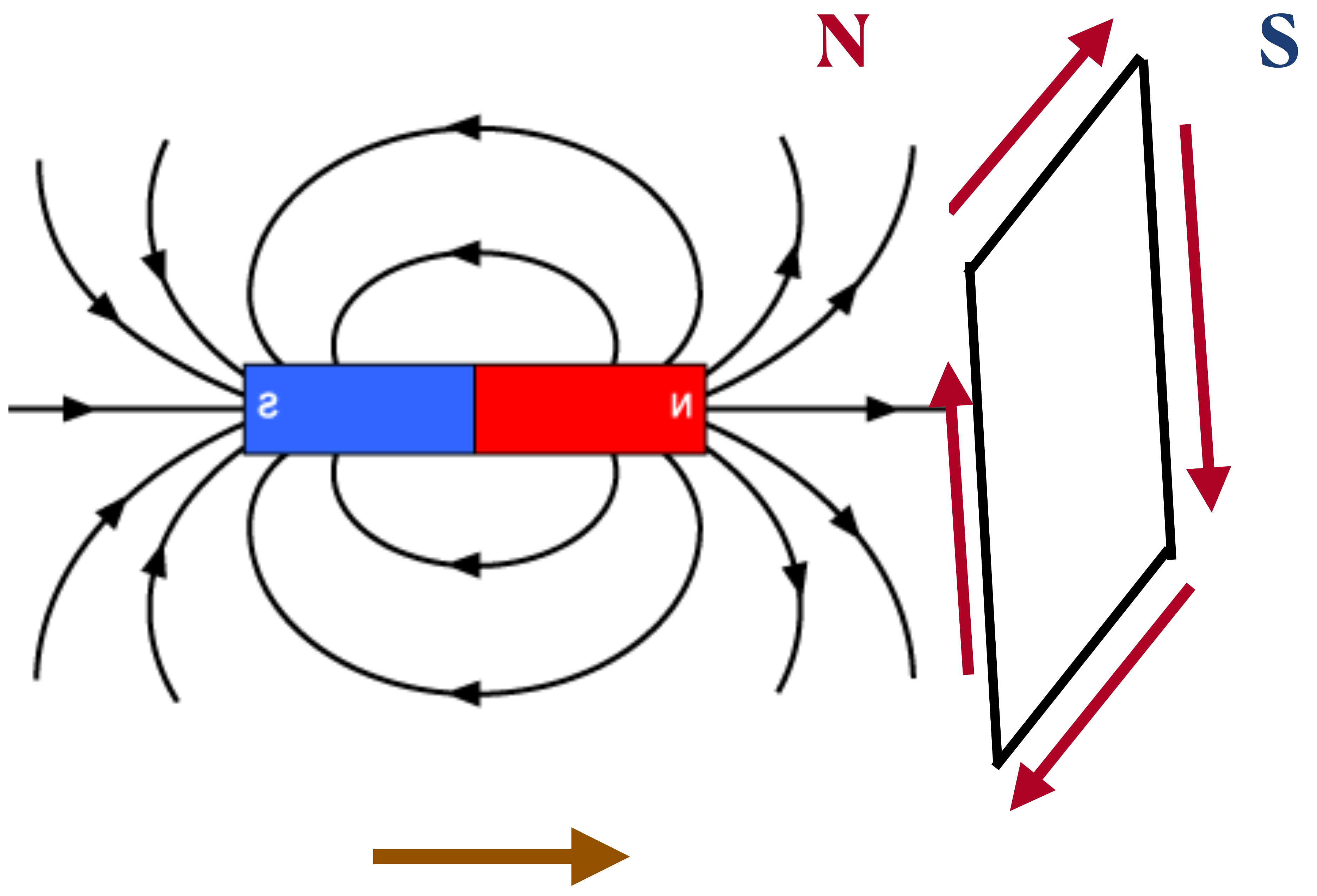
Why does the movement btw magnet and coil induce a e.m.f or current?

When moving a coil closer to the magnet,

*the wire of the coil **cuts the magnetic field** lines of the magnet*

Or

*The change of magnet field **flux is changing***



Electromagnetic induction

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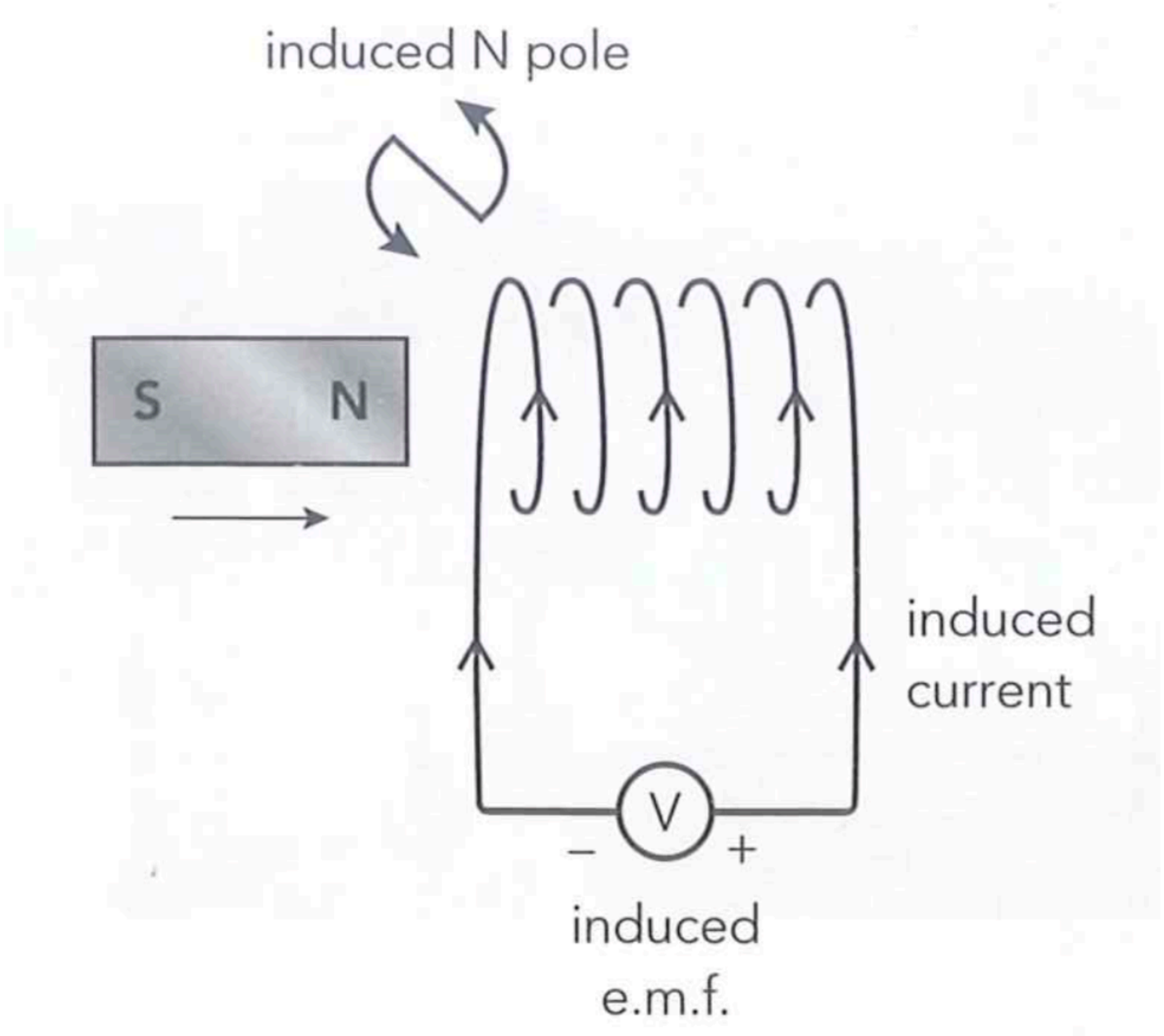
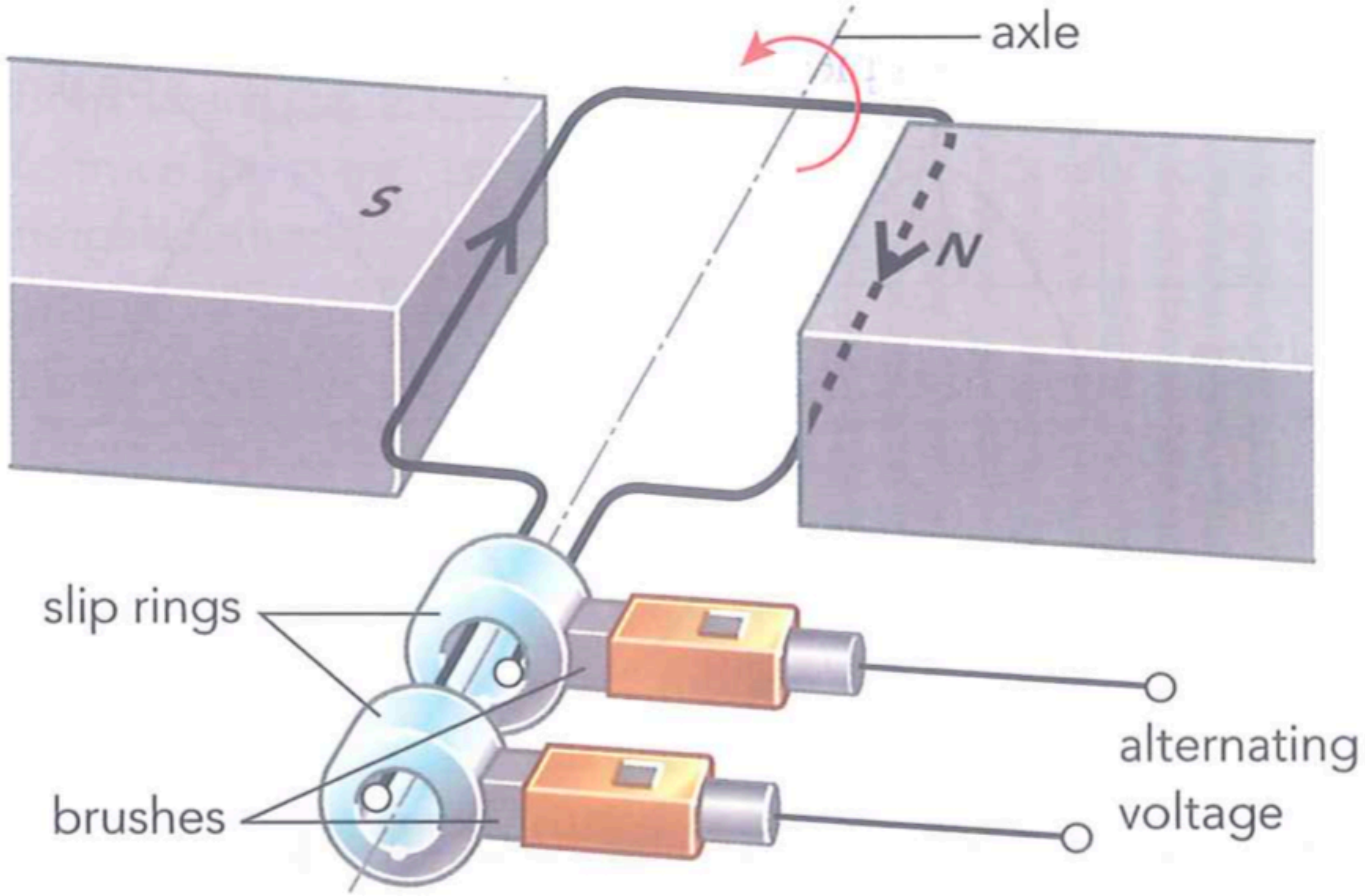
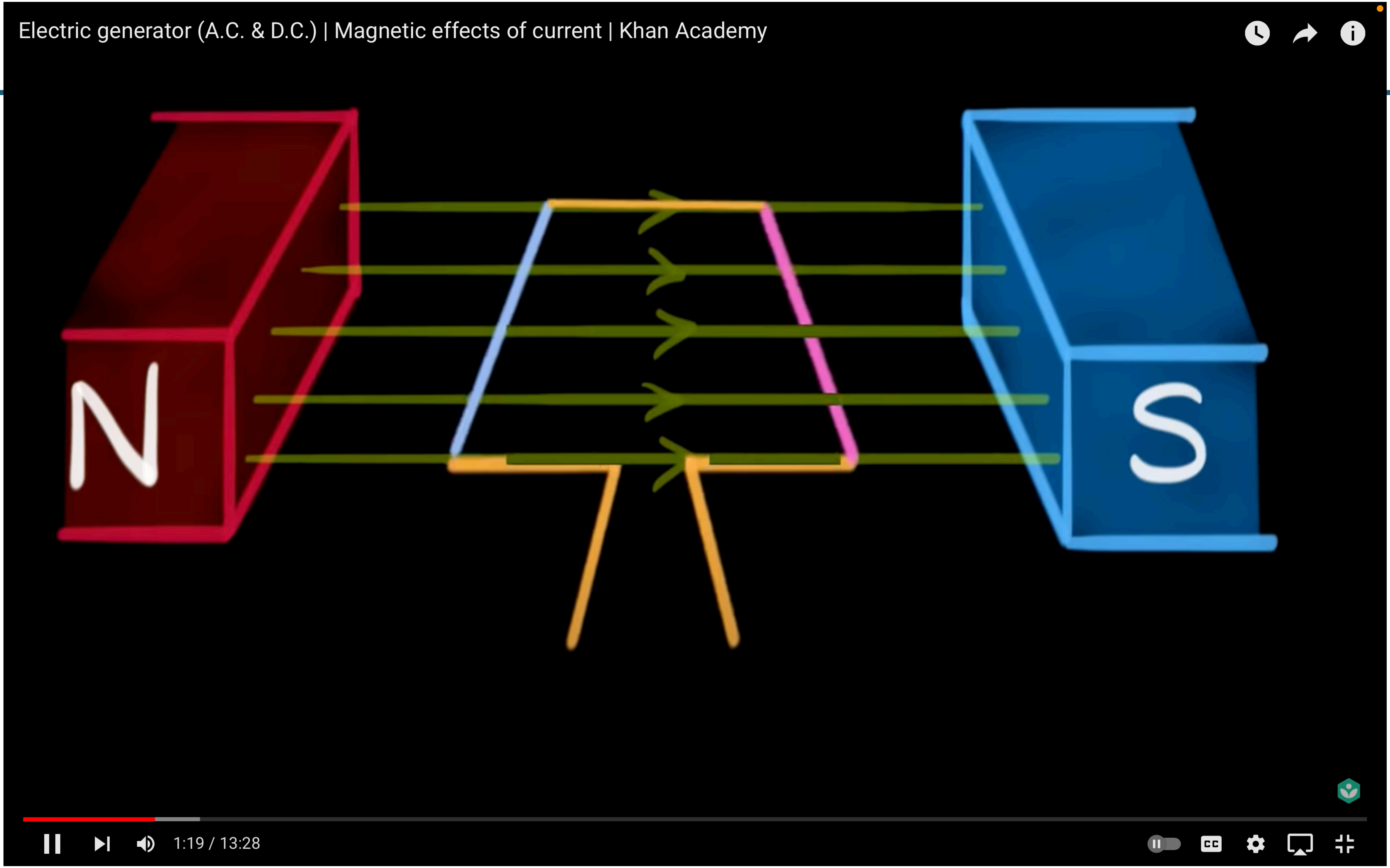


A.C. Generator

Why can generator generate current/e.m.f.?




Electric generator (A.C. & D.C.) | Magnetic effects of current | Khan Academy
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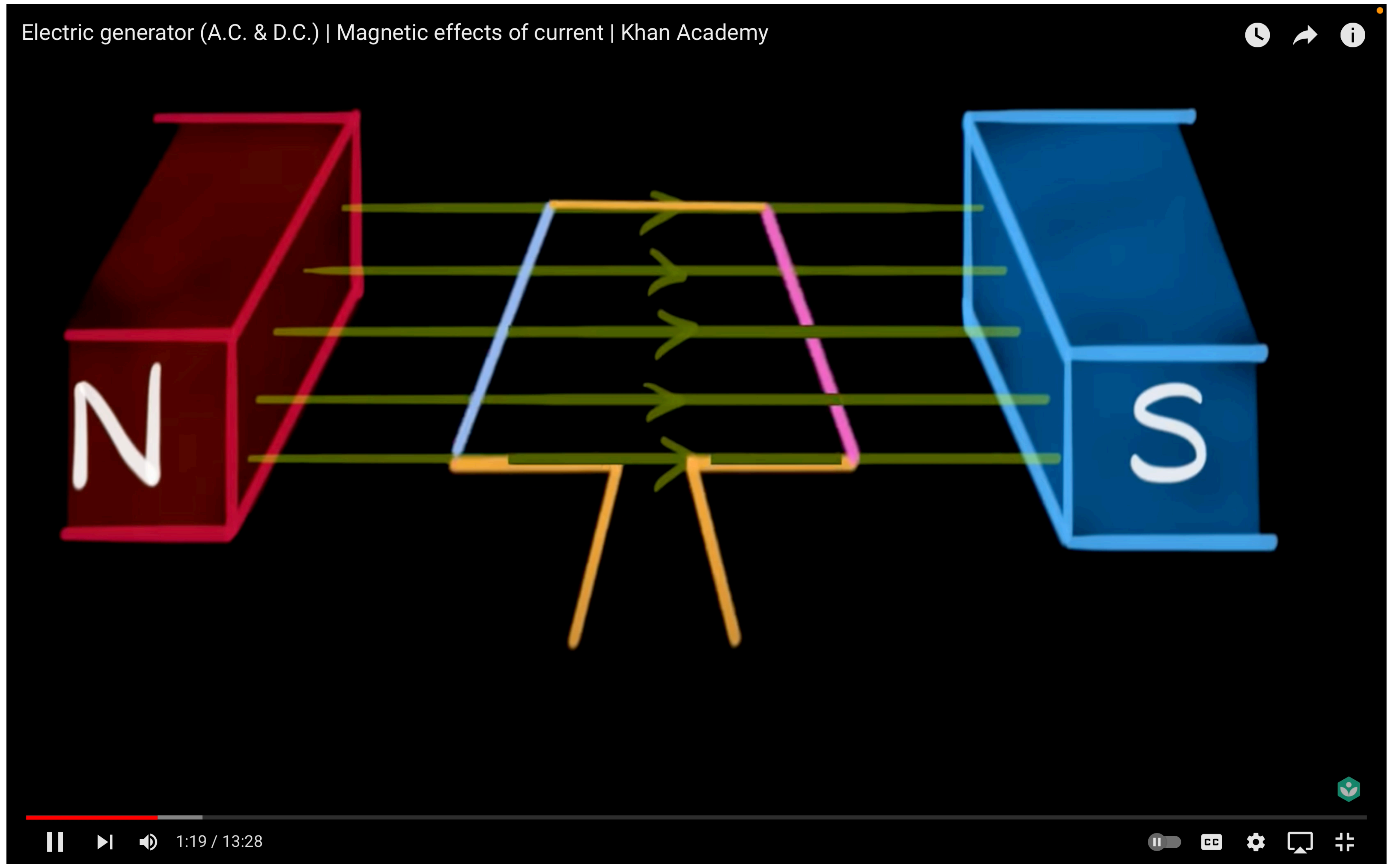
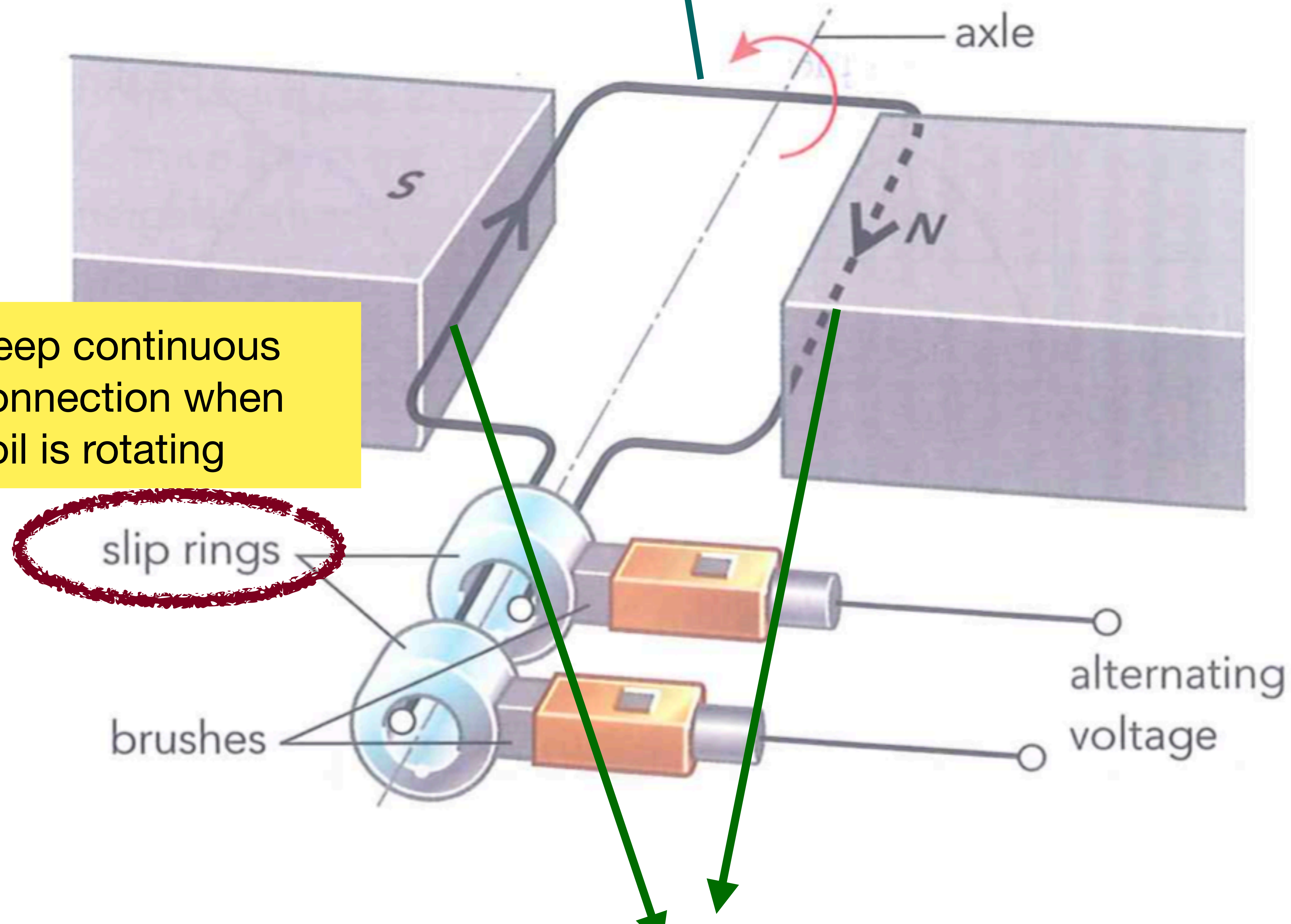
A.C. Generator



No cutting field lines

Keep continuous connection when coil is rotating

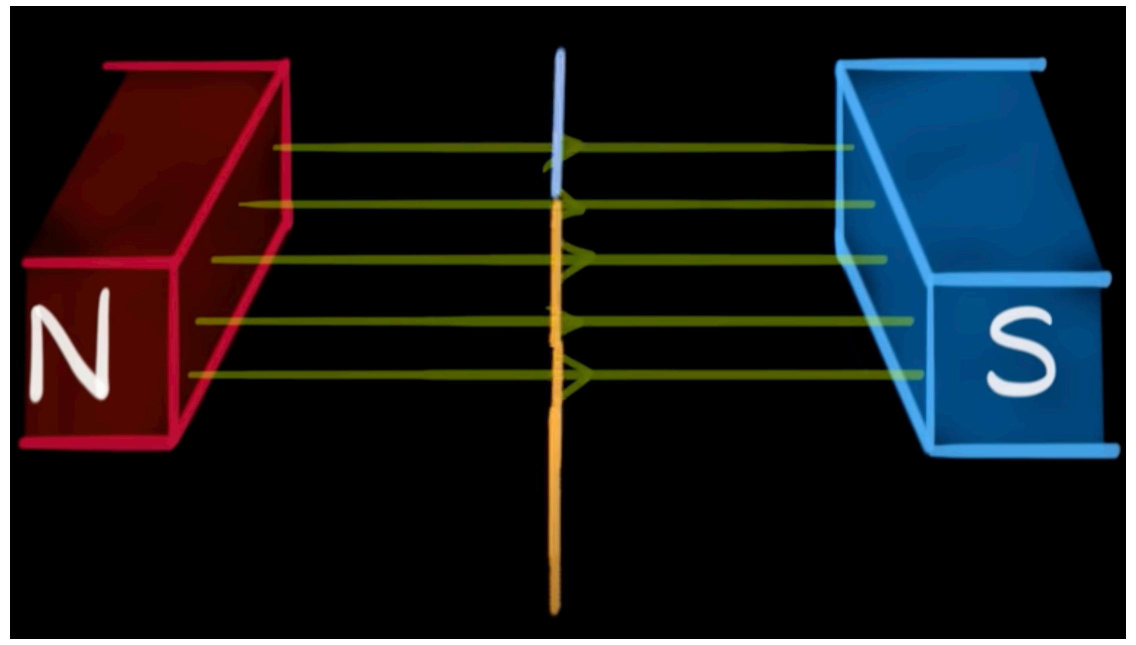


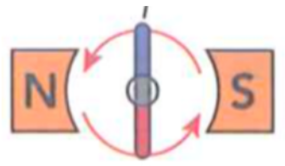
Cutting field lines!!

How the generated current changes over time?

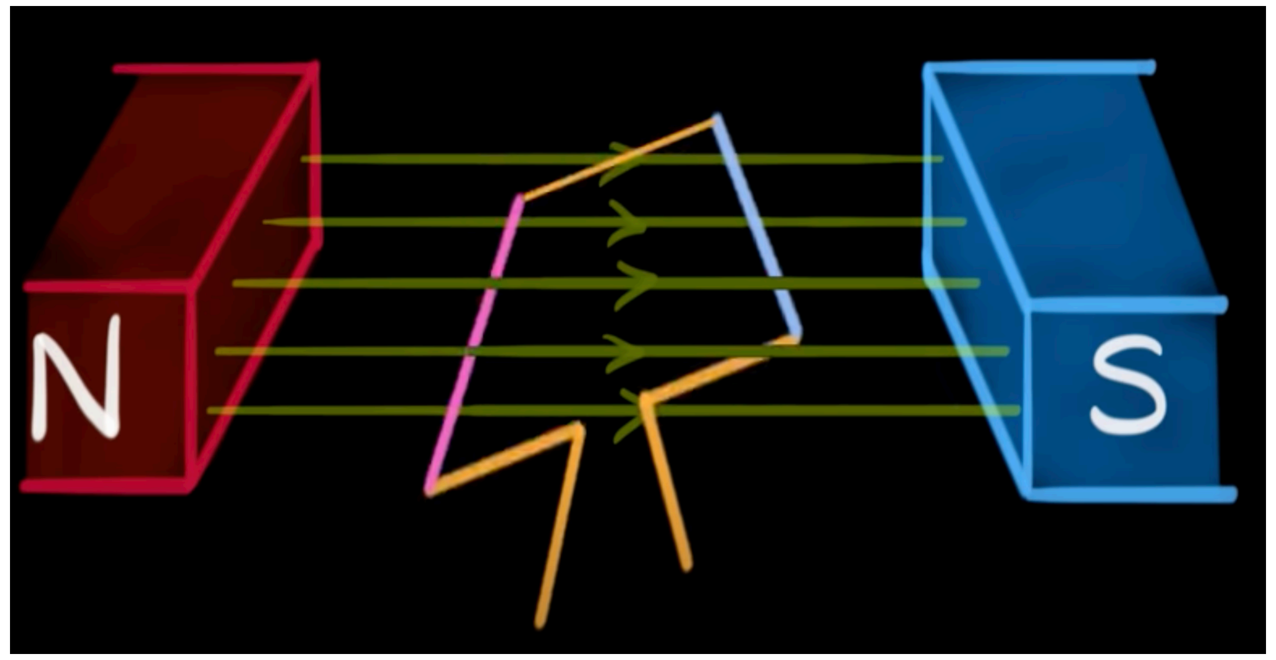
https://javalab.org/en/ac_generator_en/

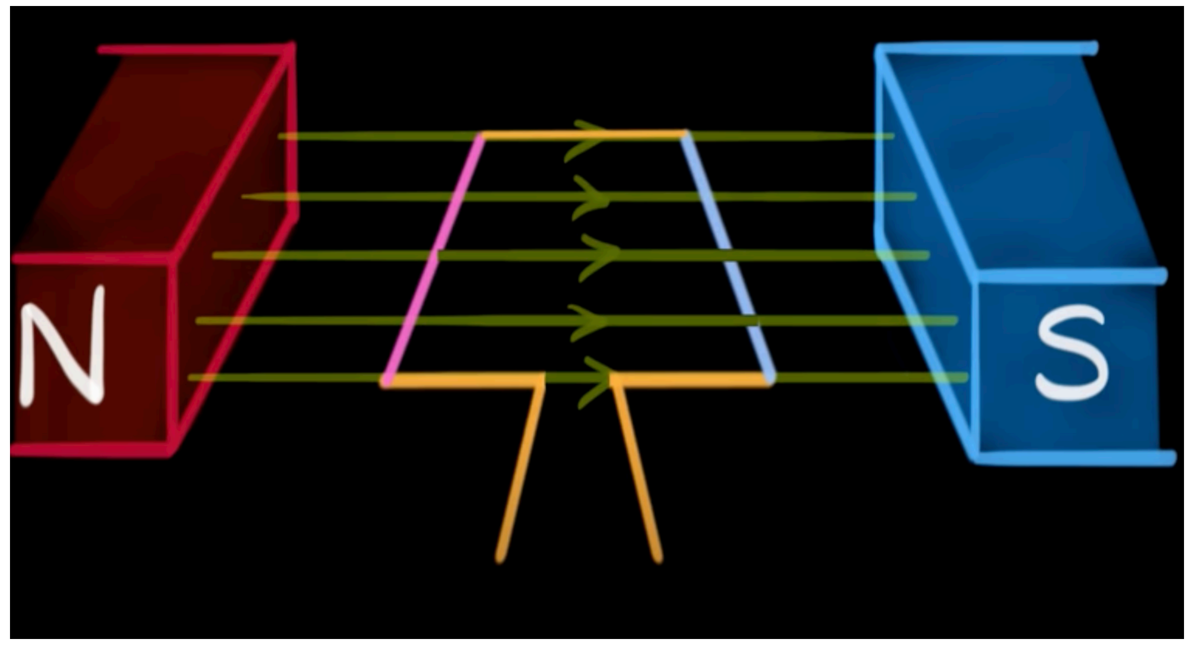
A.C. Generator

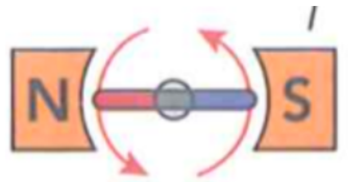




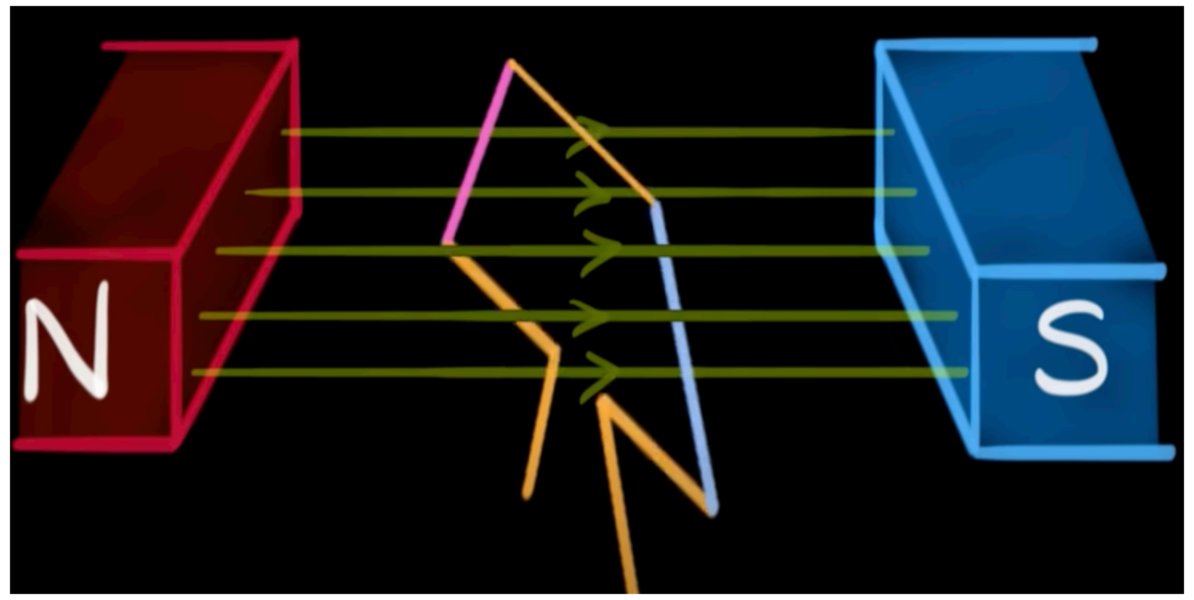
zero voltage

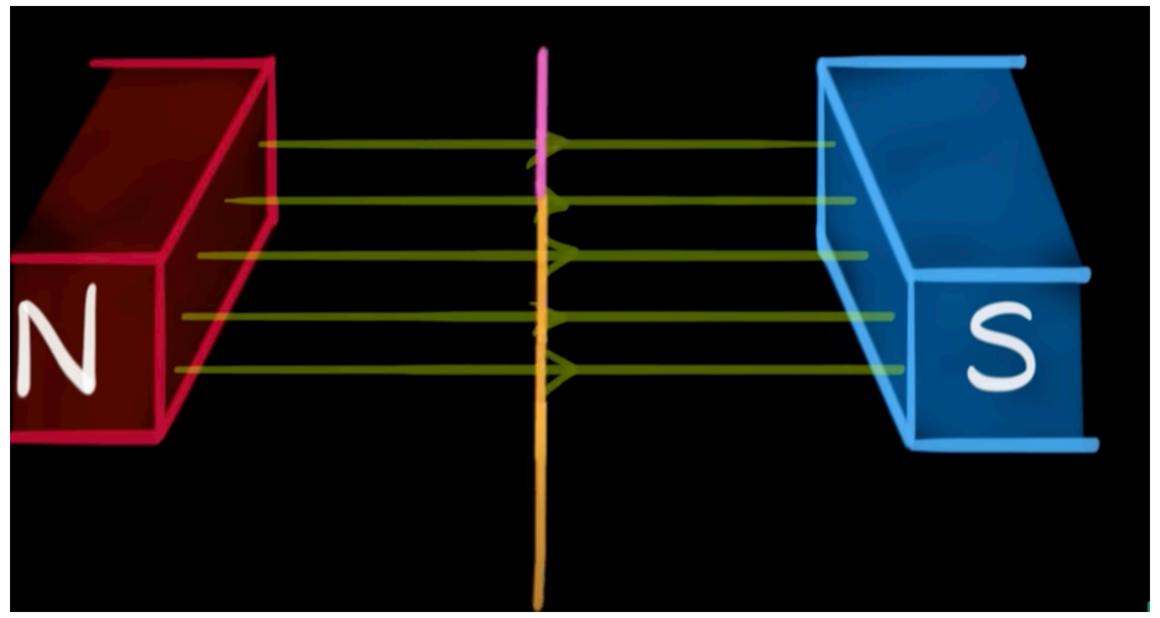


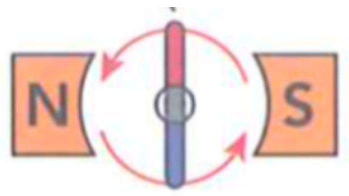




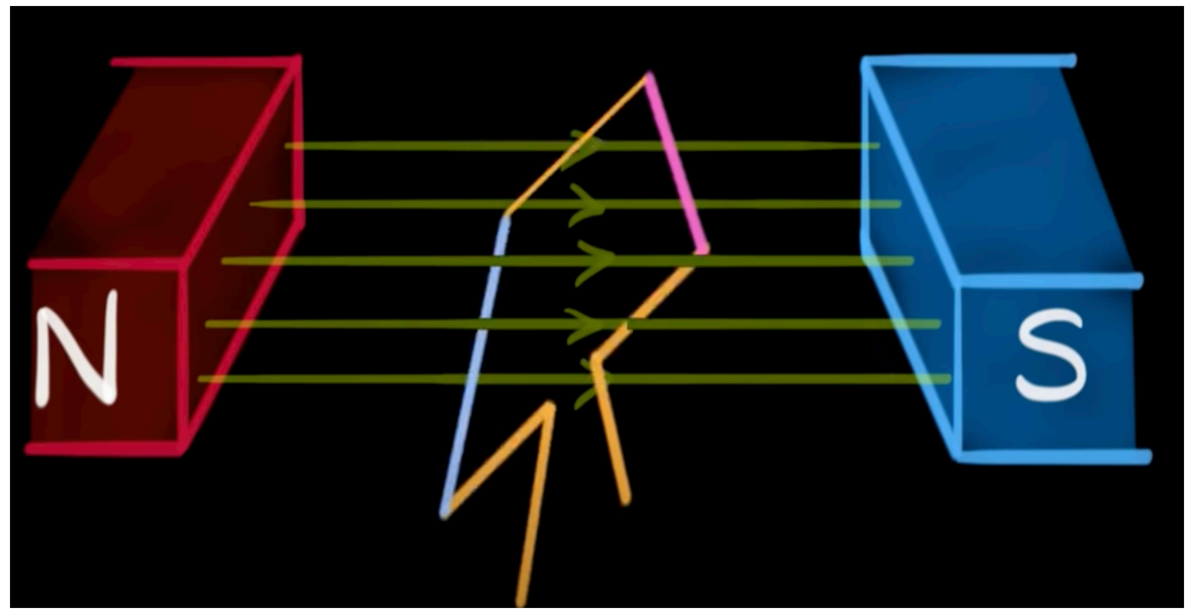
peak voltage

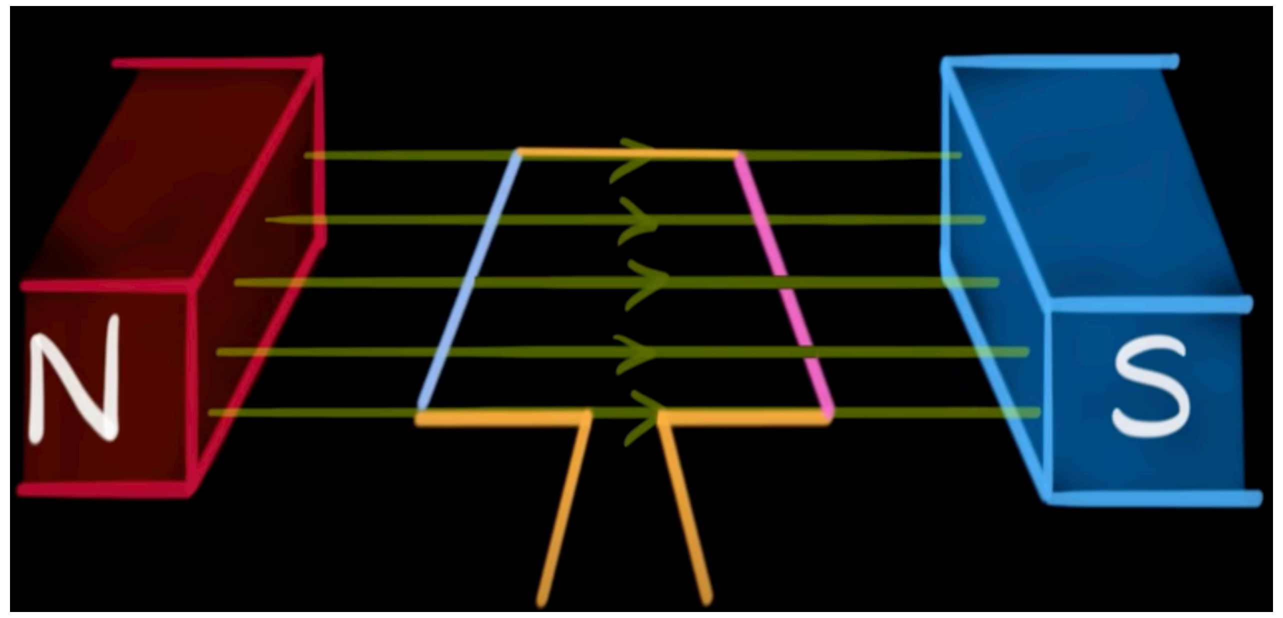


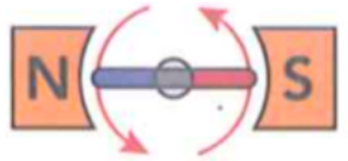




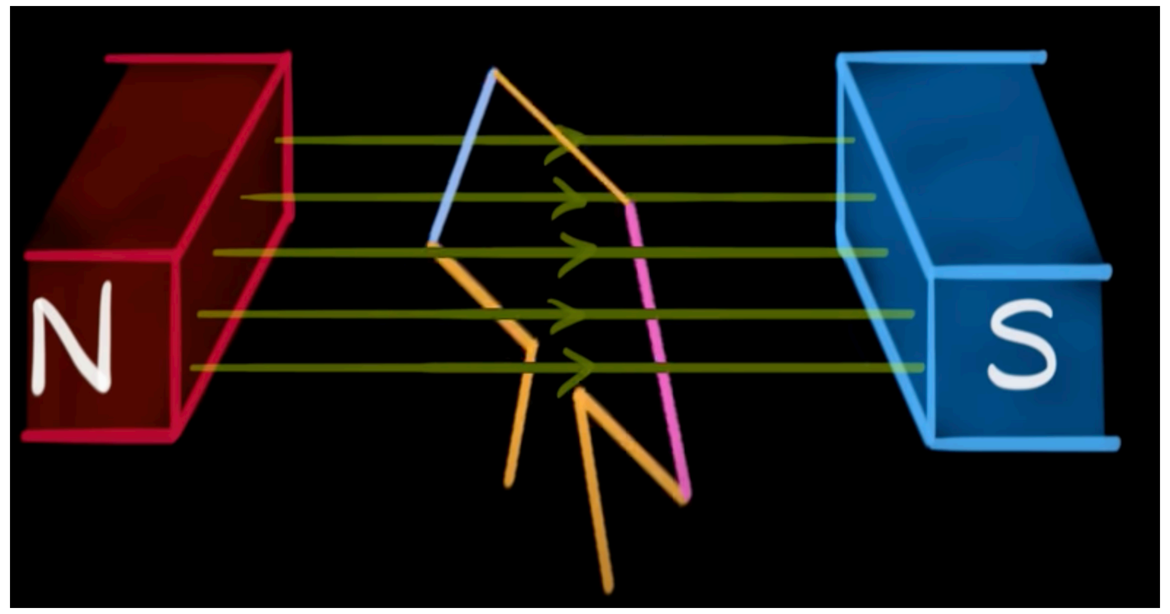
zero voltage



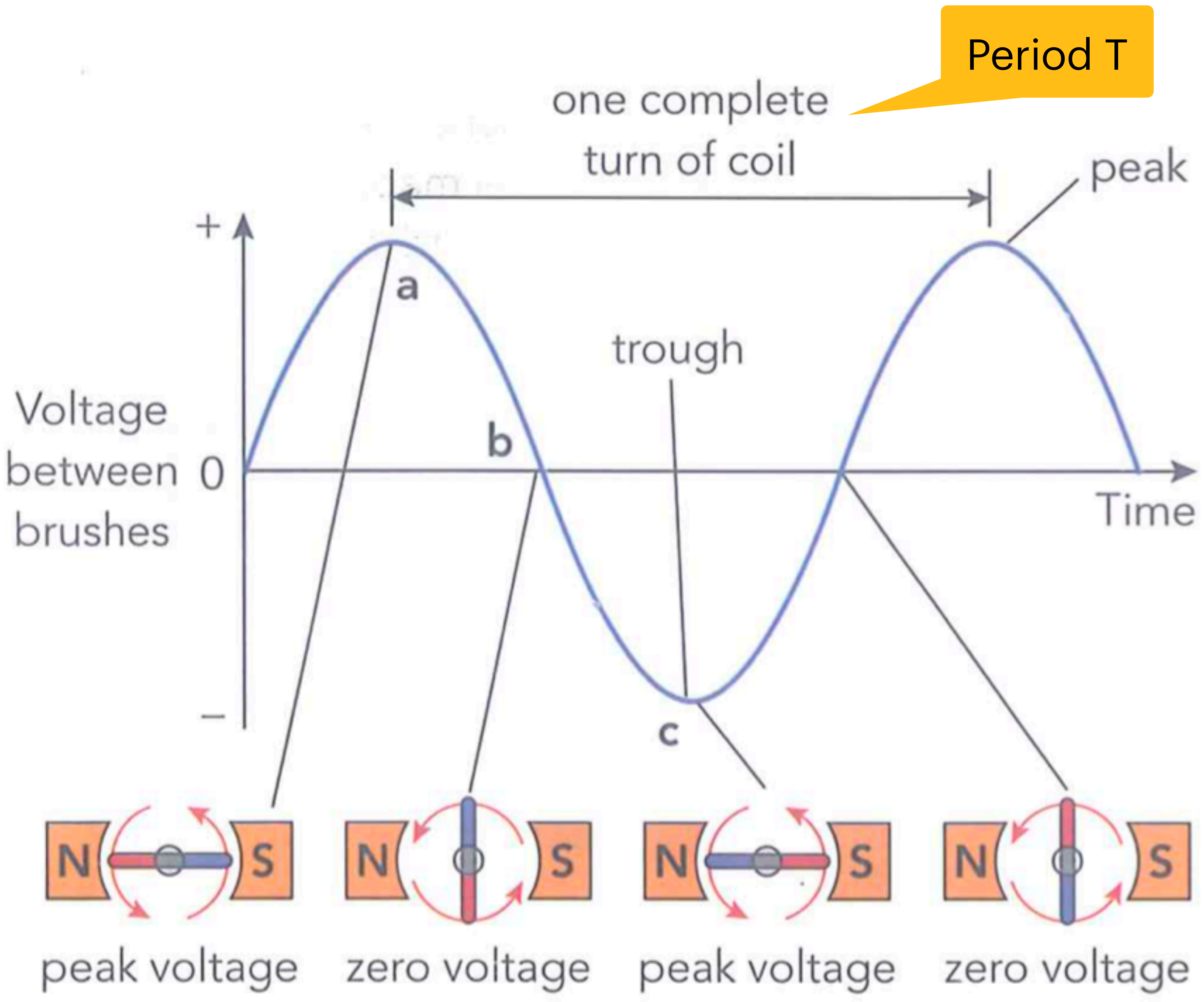




peak voltage



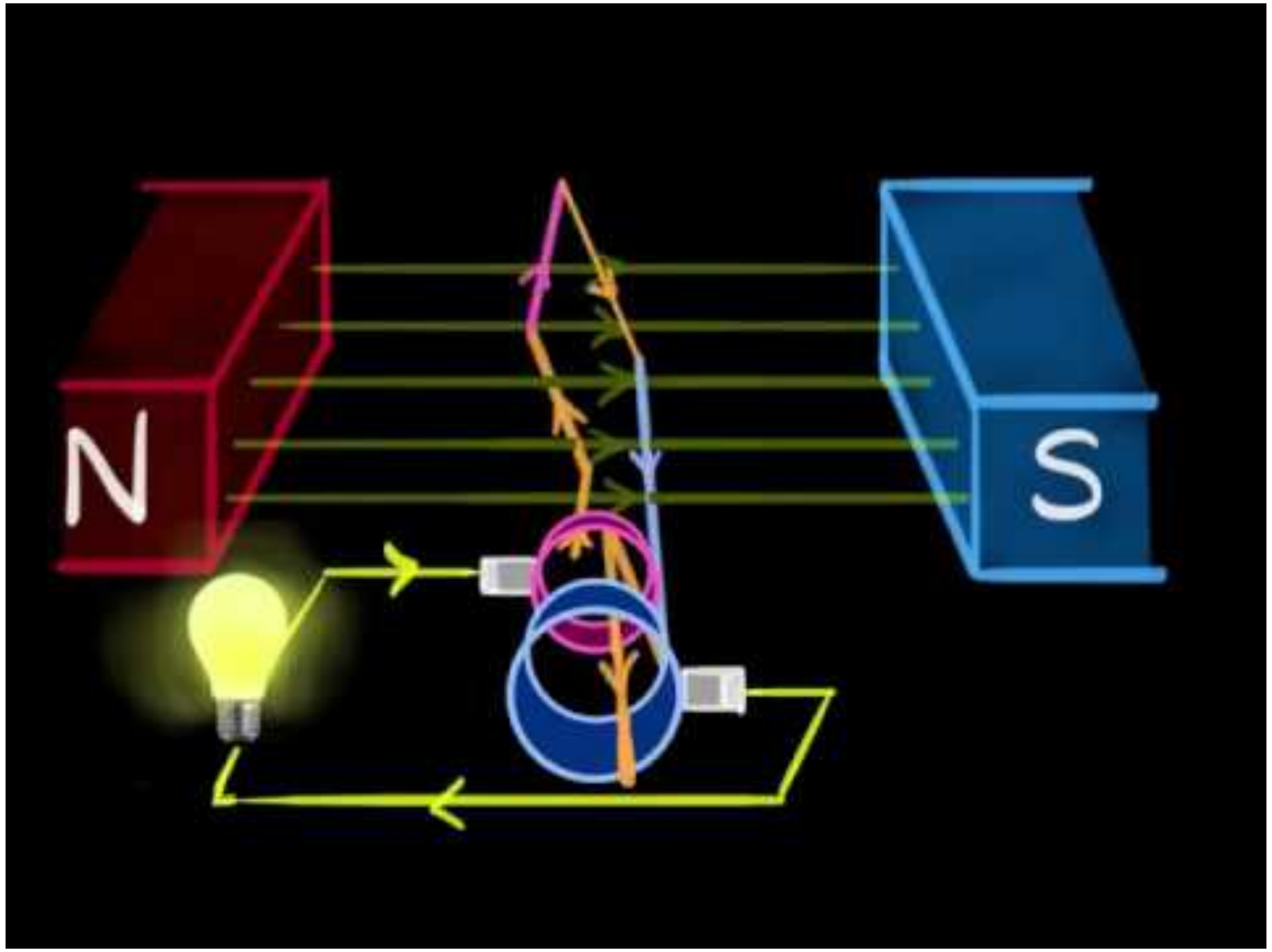
A.C. Generator

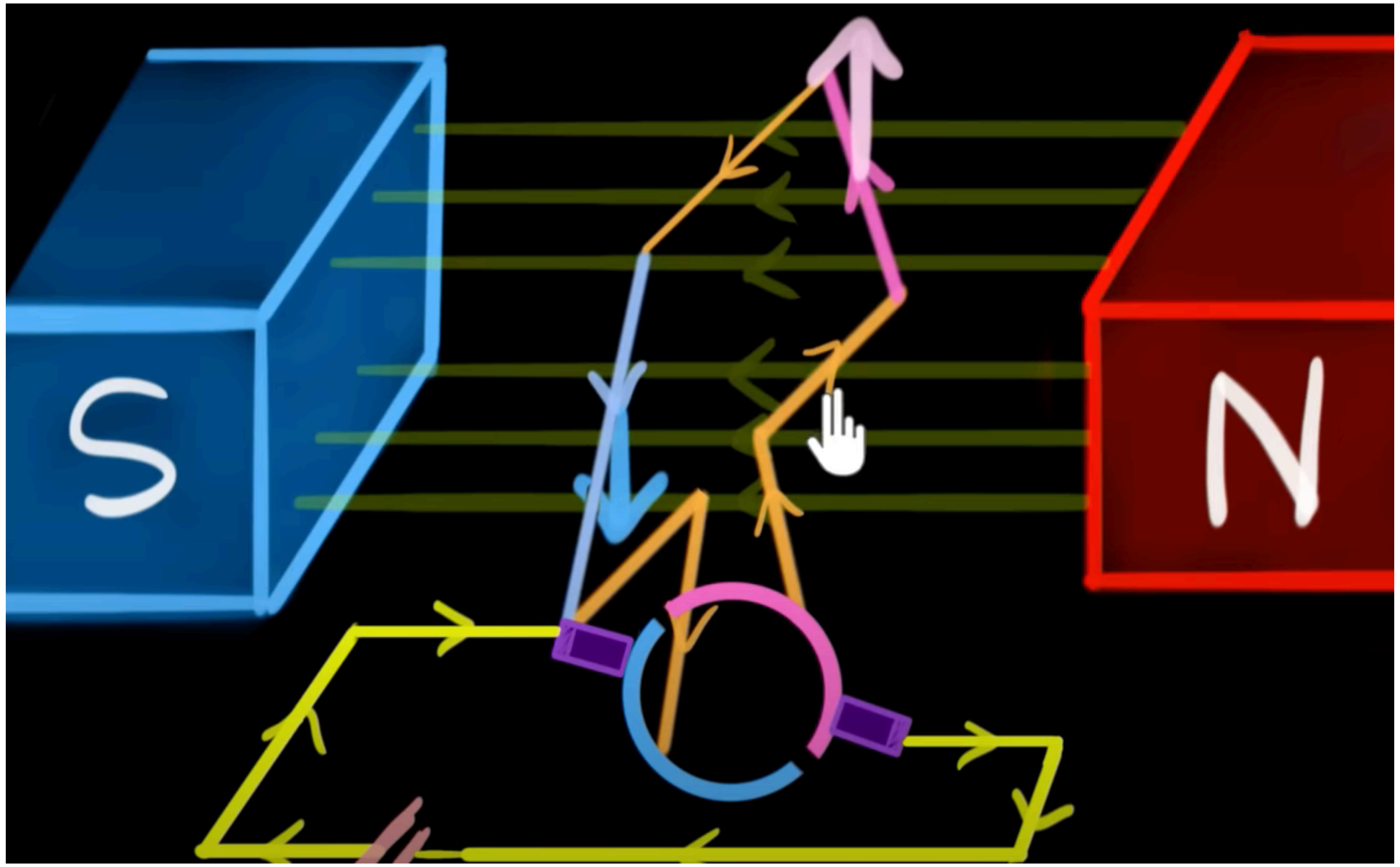


Increase generated voltage?

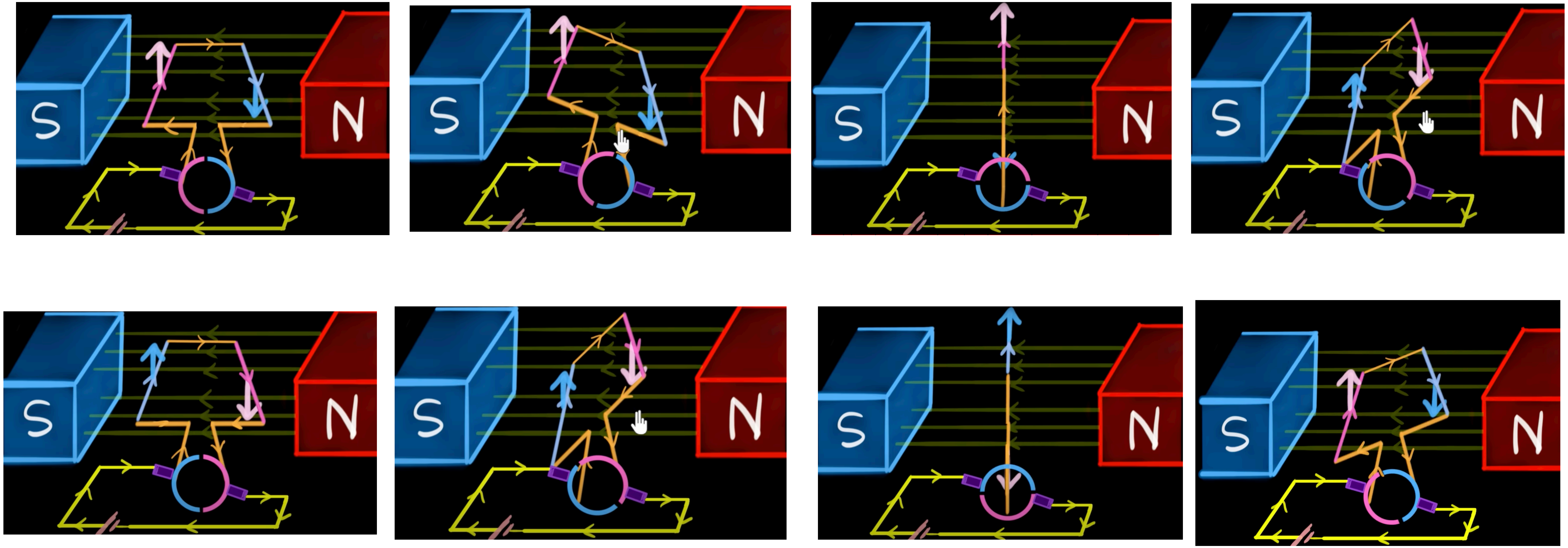
- turn the coil more rapidly
- use a coil with more turns of wire
- use a coil with a bigger area
- use stronger magnets.

A.C. Generator vs D.C. Motor

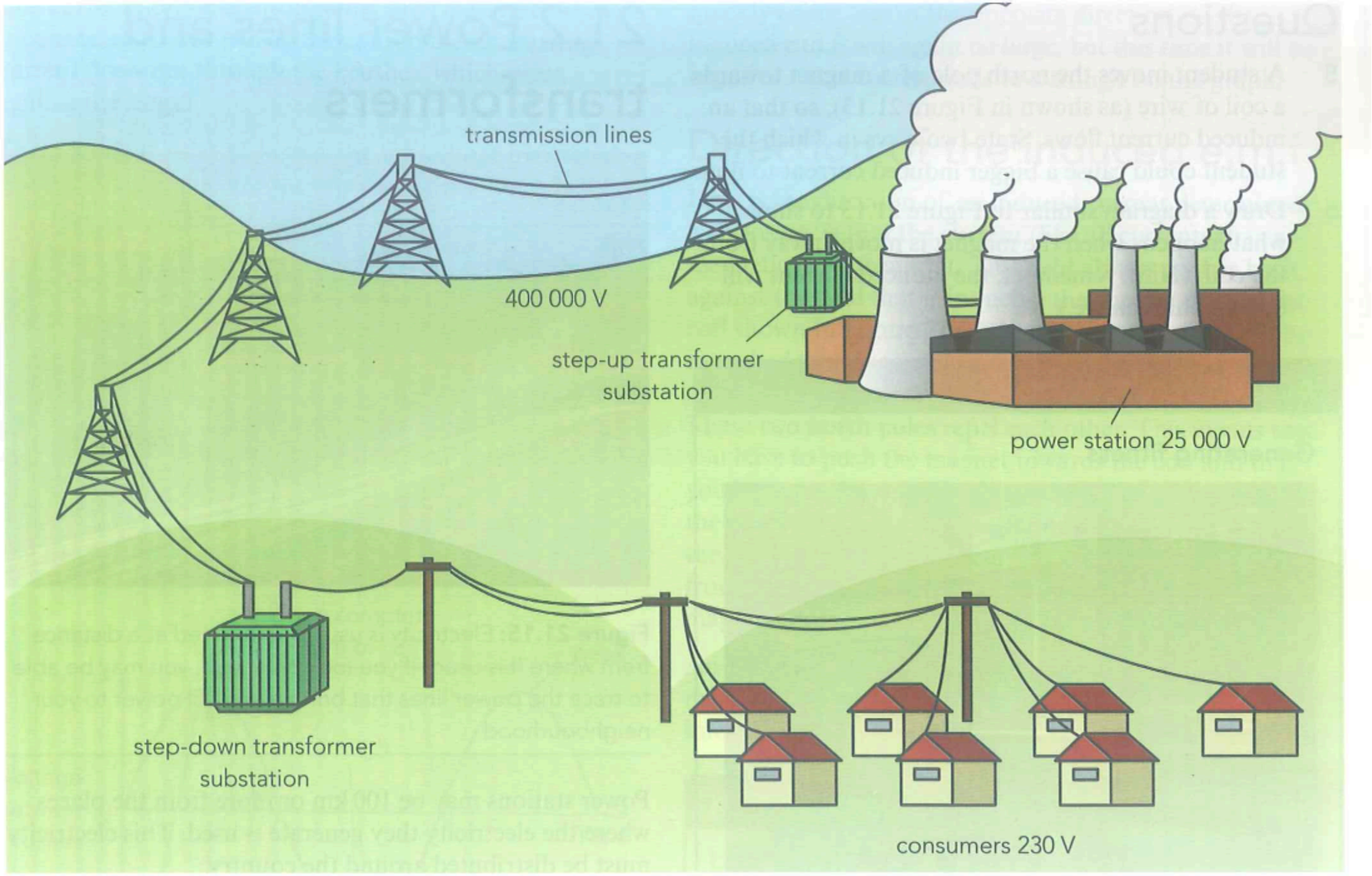




D.C. Motor



Power lines and National Grid



Power lines and National Grid

Why use high voltage transmitting electricity?

Power loss:

$$P_{loss} = I2R$$

Power lines and National Grid

Exercise 21.2:

A 20kW generator gives an output of 500V. This is transmitted to a workshop by cables with a resistance of 20 ohms. Calculate:

A. the power loss in the cables.

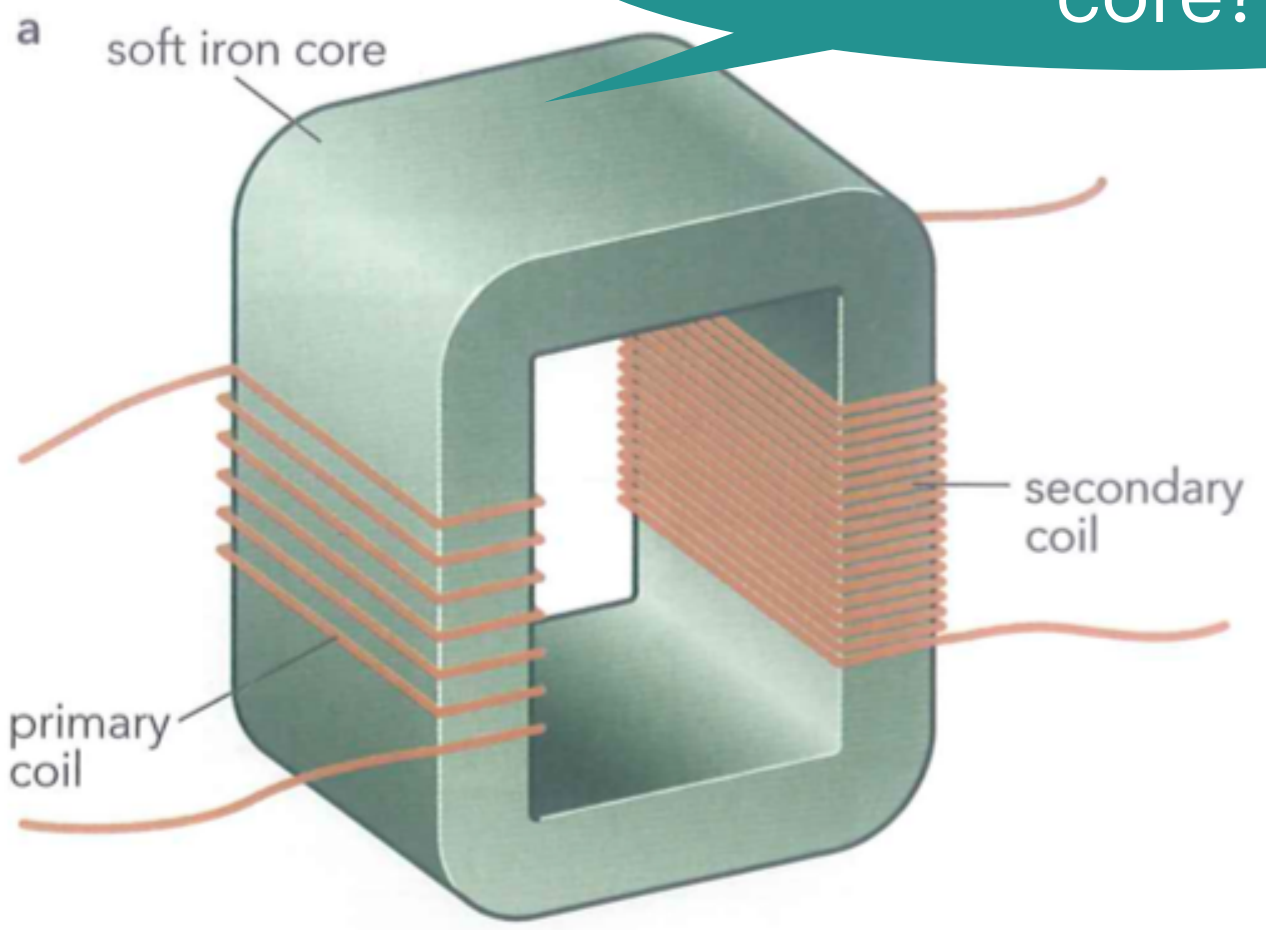
B. If the output is increased somehow to 20kV, calculate the power loss in this case.

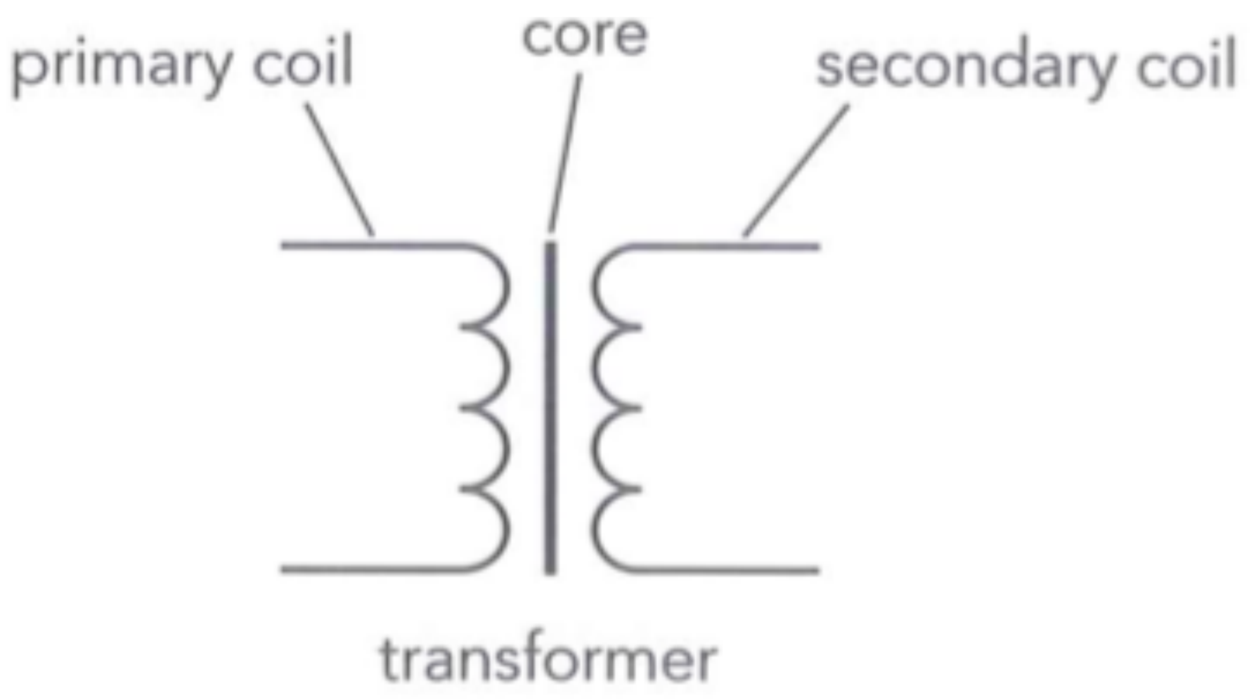
Transformer

How to get high/low voltage?

➜ **transformers**

Why soft iron core?





$$\boxed{\frac{N_P}{N_S} = \frac{V_P}{V_S}}$$

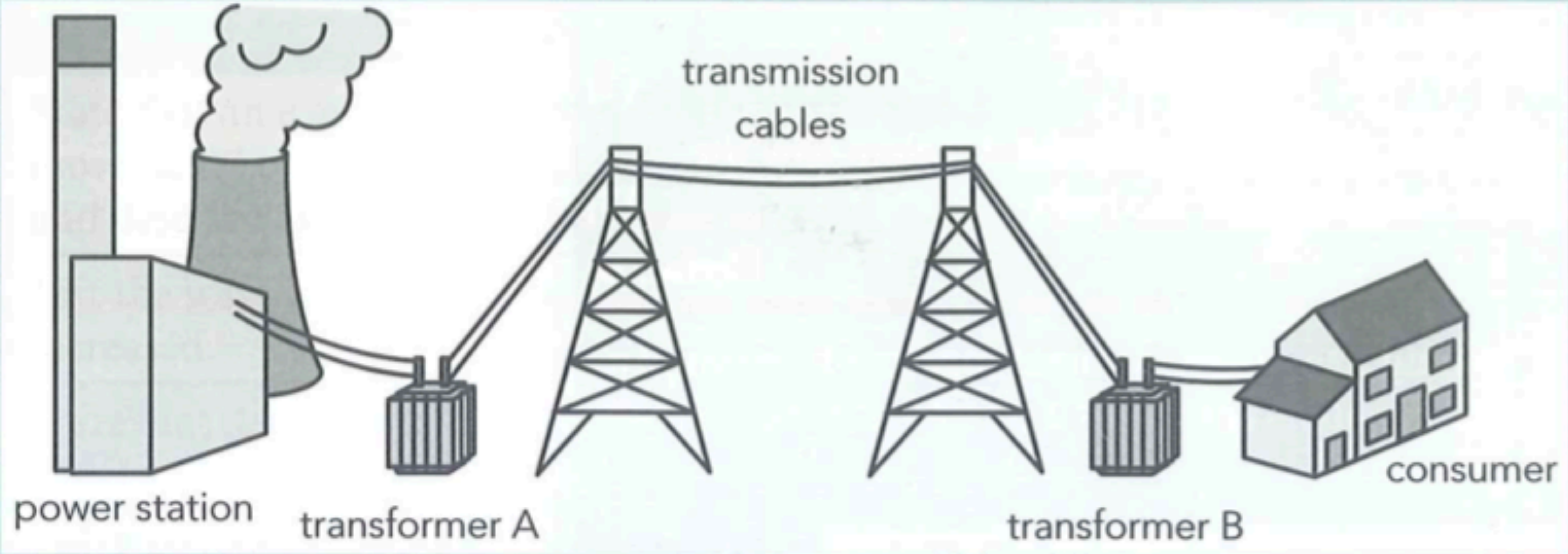
Step-up transformer: A transformer which increases the voltage of an a.c. supply; $N_P < N_S$

Step-down transformer: A transformer which decreases the voltage of an a.c. supply; $N_P > N_S$

Transformer

Exercise 21.3:

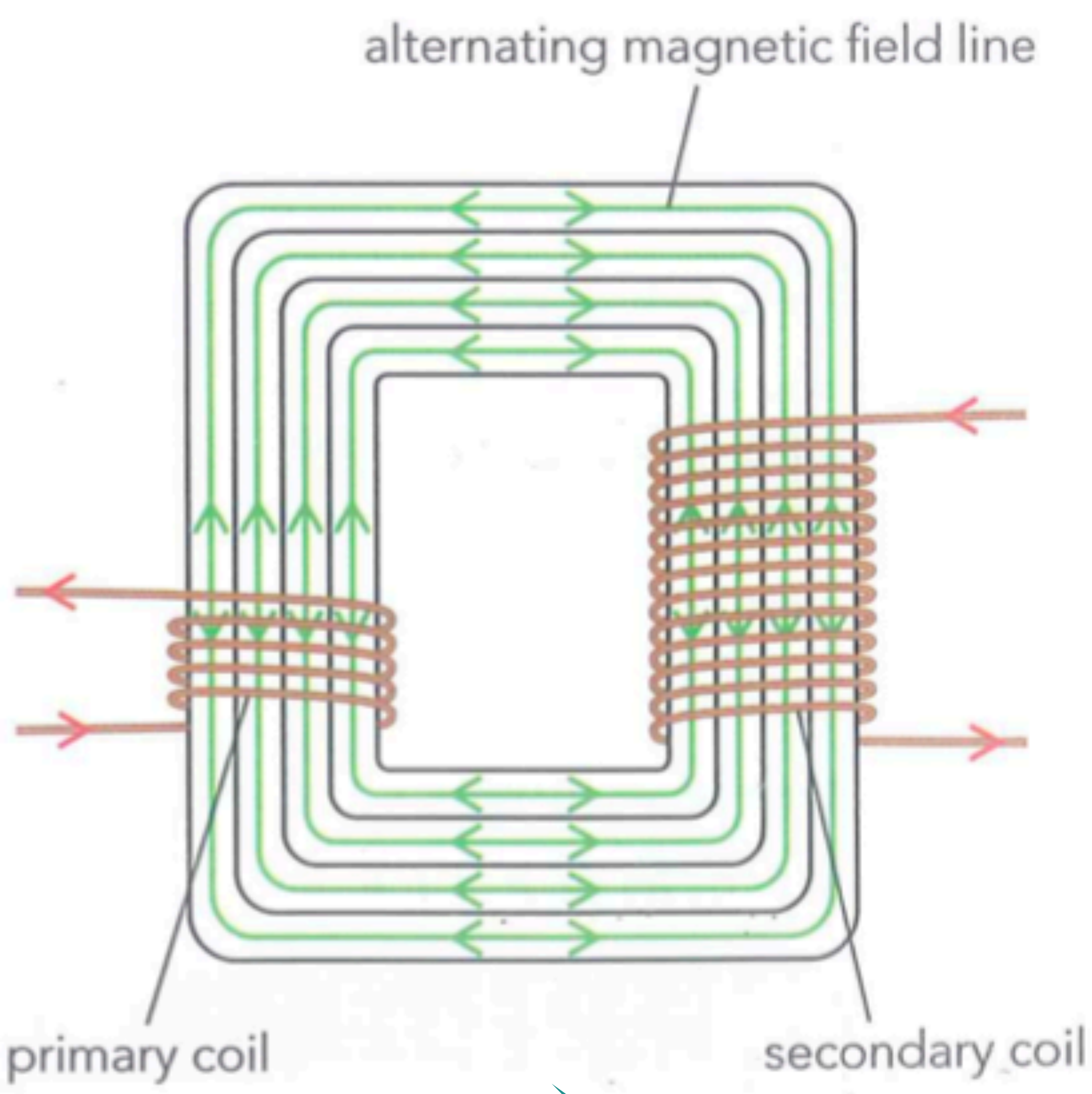
7 a Transformers are used in the national grid to change the voltage of the supply. For transformers A and B, state whether the transformer is step-up or step-down, and explain why the voltage change is necessary. **[4]**



b A transformer in the national grid has 800 turns on the primary coil and 16 000 on the secondary. The primary voltage is 25 kV. Calculate the secondary voltage. **[2]**

[Total: 6]

How transformers work?



Only a.c. current can use transformer

1. **Alternating/changing current** in **primary coil** produces a **changing magnetic field**
2. This changing magnetic field transfers to **second coil** through **iron core**
3. Causes **changing magnetic flux** in second coil/ **cut** by secondary coil
4. Which **induces alternating current** in second coil

Why soft iron core?

iron core is a soft magnetic material, so it can be easily magnetized; using it will make it easy to transfer magnetic field induced in primary to secondary coil.