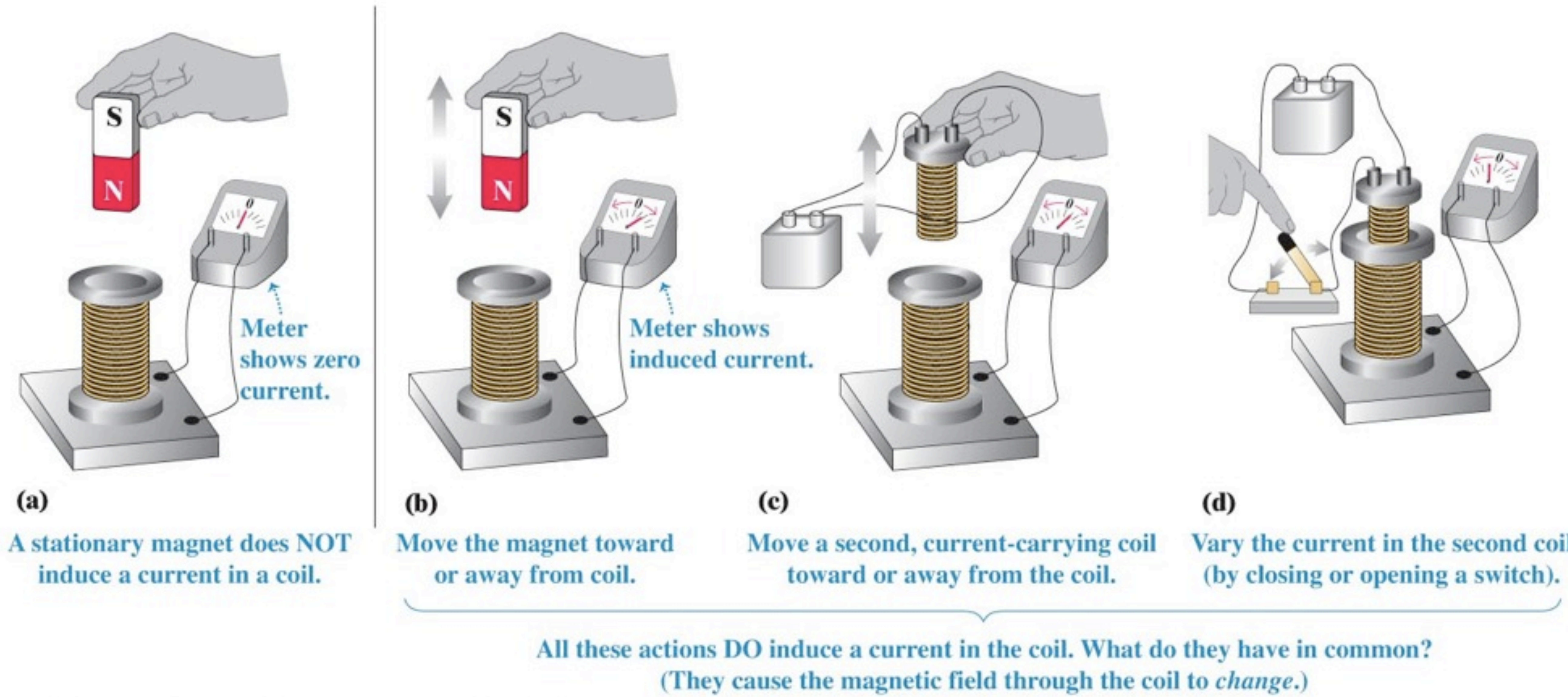
electromagnetic induction

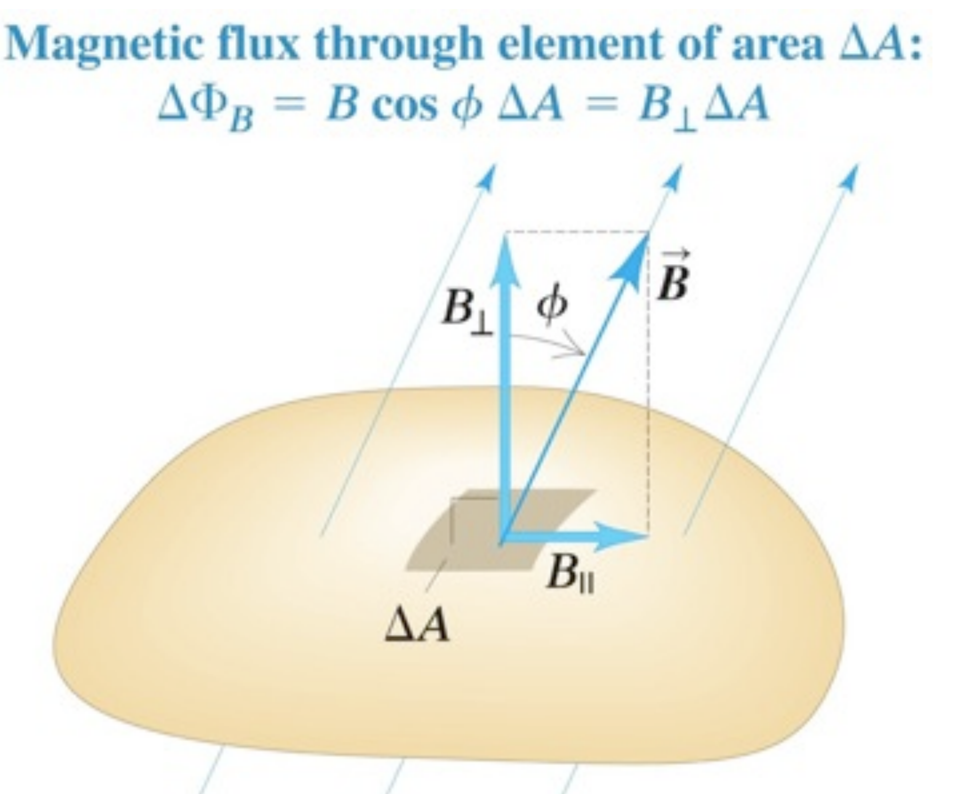
experimental basis of induction

➜ seems we can induce a current in a loop with a changing magnetic field



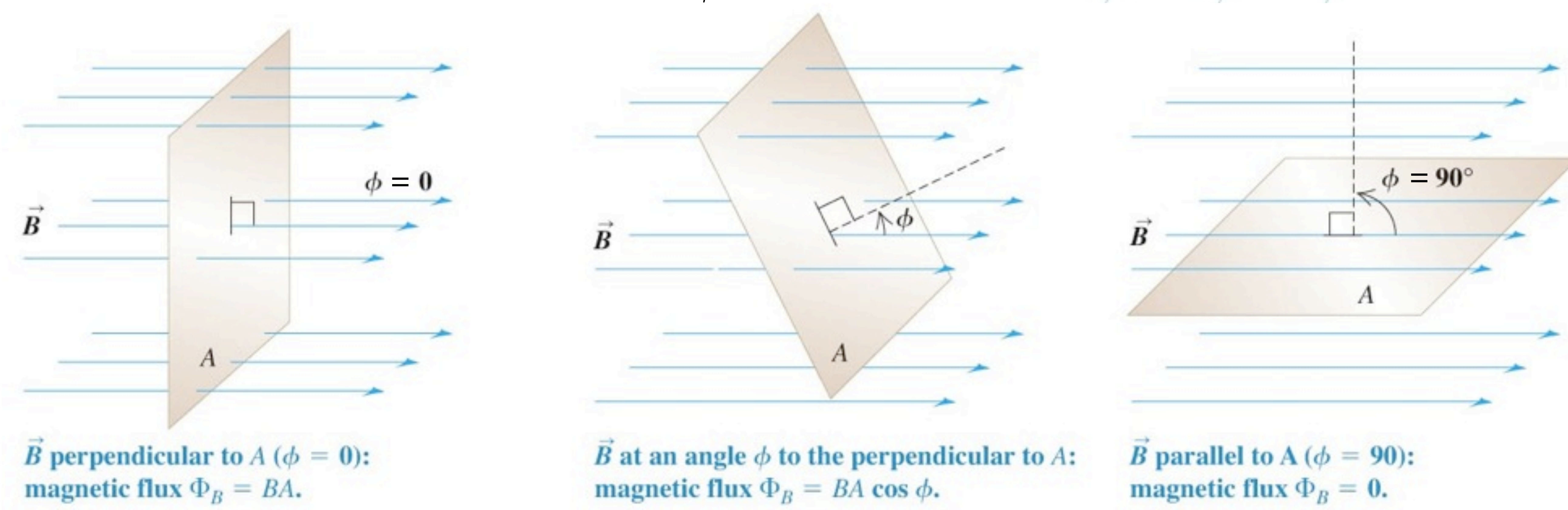
magnetic flux

➜ useful to define a quantity called **magnetic flux**



➜ for a plane surface of area **A**

$$\Phi_B = B_\perp A = BA\cos\phi$$



$\vec{B}$ perpendicular to A ($\phi = 0$): magnetic flux $\Phi_B = BA$.

$\vec{B}$ at an angle ϕ to the perpendicular to A: magnetic flux $\Phi_B = BA\cos\phi$.

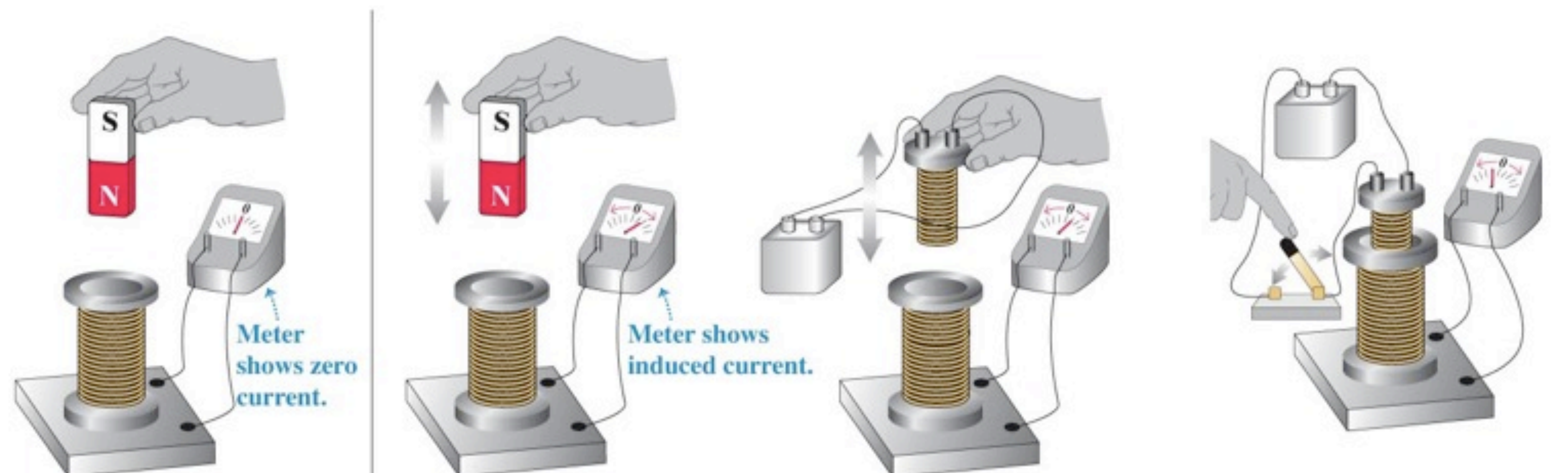
$\vec{B}$ parallel to A ($\phi = 90$): magnetic flux $\Phi_B = 0$.

Faraday's law of induction

➜ Faraday discovered the relation between the change in the flux through a loop and the emf induced in that loop

$$\mathcal{E} = \left| \frac{\Delta \Phi_B}{\Delta t} \right|$$

➜ it's the **change** in flux that induces an emf



(a) A stationary magnet does NOT induce a current in a coil.

(b) Move the magnet toward or away from coil.

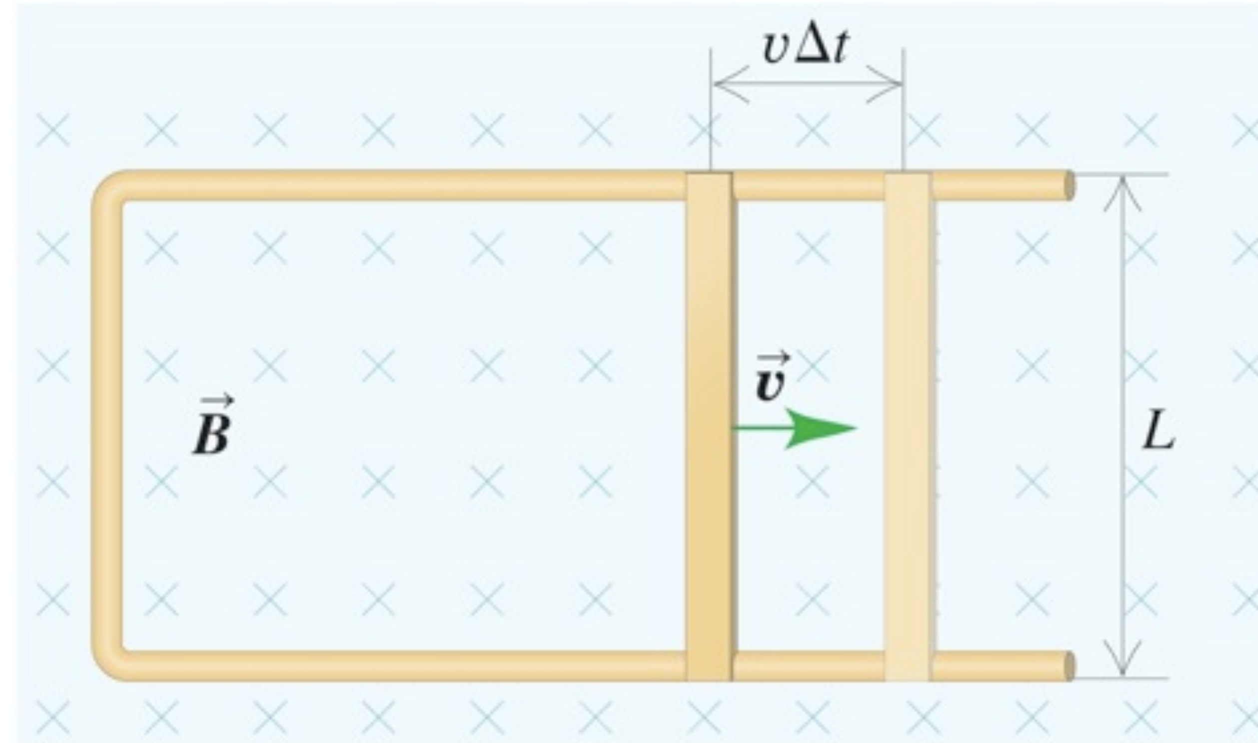
(c) Move a second, current-carrying coil toward or away from the coil.

(d) Vary the current in the second coil (by closing or opening a switch).

All these actions DO induce a current in the coil. What do they have in common? (They cause the magnetic field through the coil to *change*.)

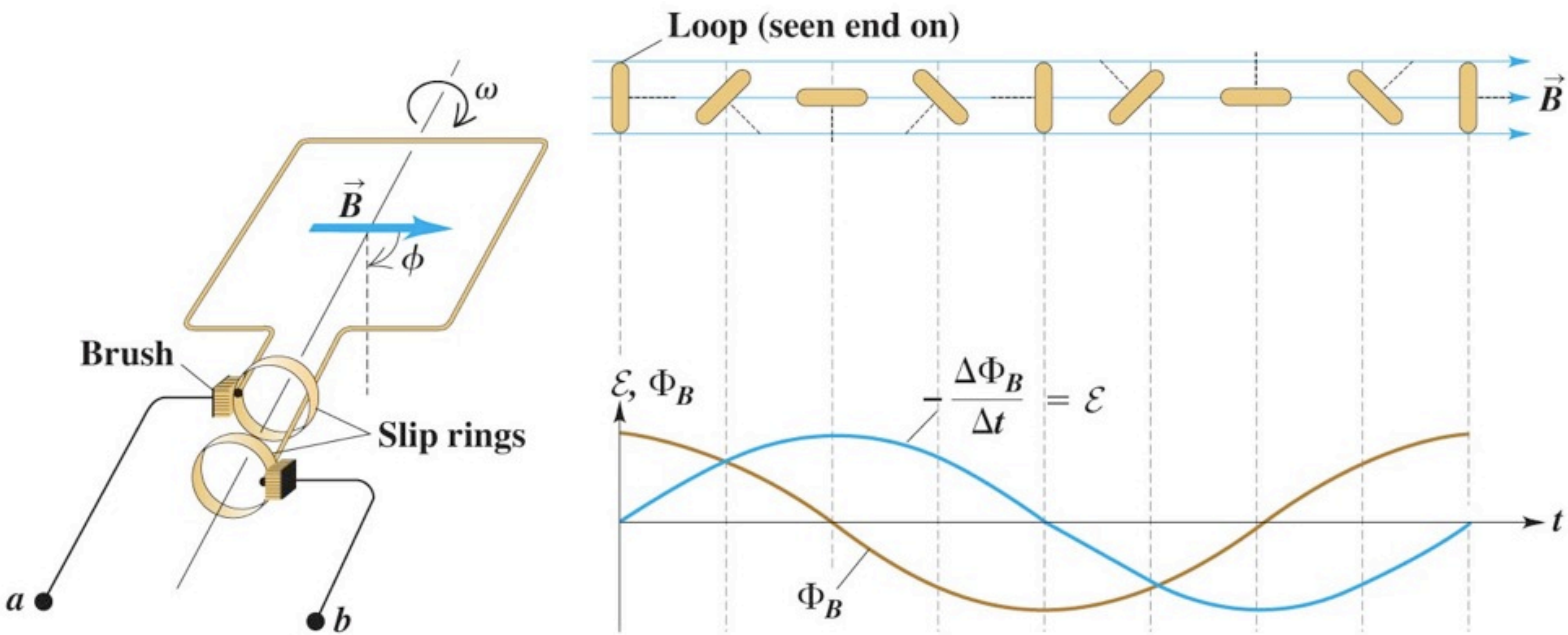
Faraday’s law of induction

➜ what emf do we generate if we move the slider to the right at a speed of v = 2.5 m/s in a field of magnitude 0.60 T? The slider is 10 cm long.



a rotational generator

➜ uniformly rotating loop in a constant magnetic field

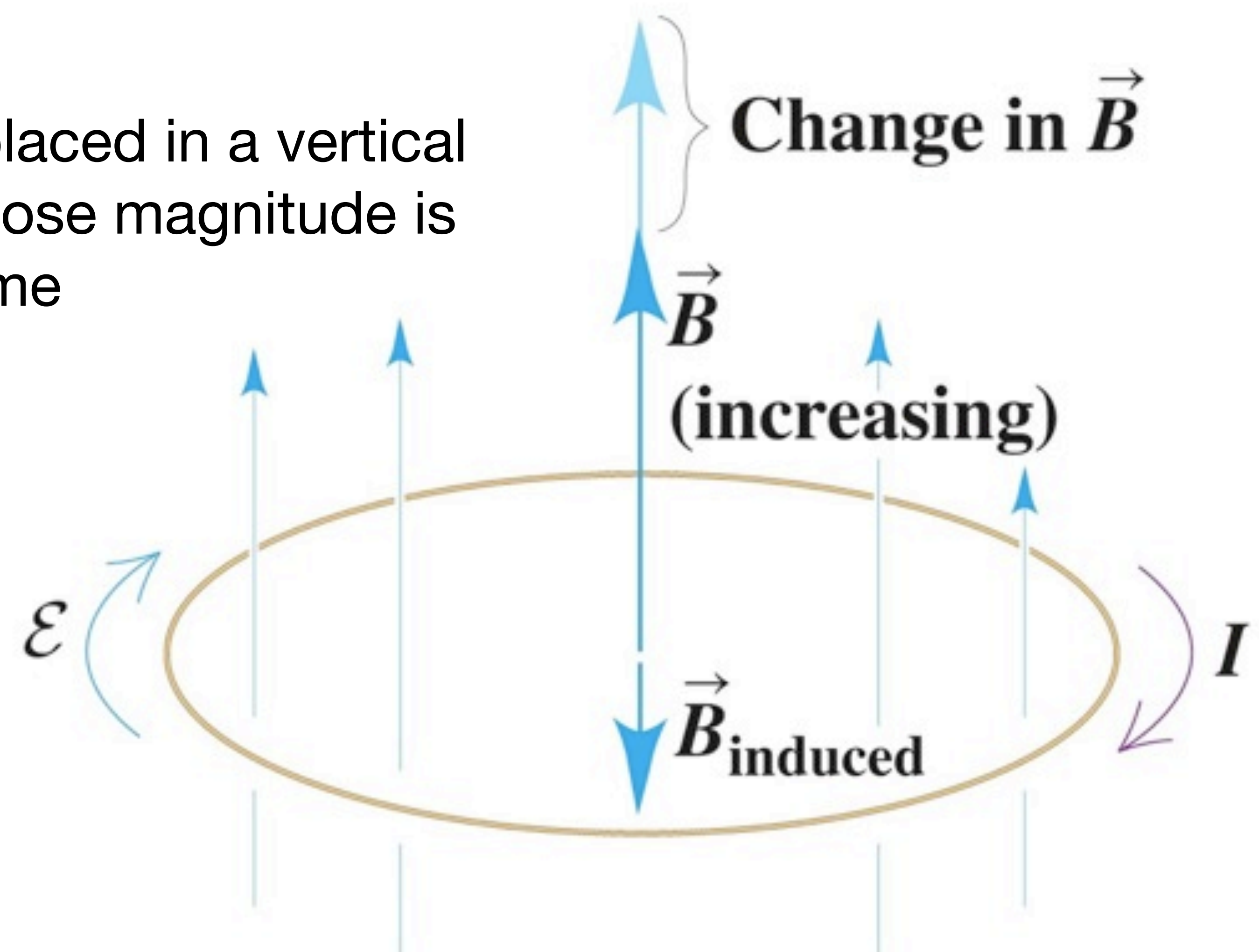


Lenz's law

➜ to find the direction of the induced emf or current we look to 'Lenz's law', which is simply a way to keep track of signs in Faraday's law:

> **"the direction of any magnetically induced current is such as to oppose the direction of the phenomenon causing it"**

a loop of wire is placed in a vertical magnetic field whose magnitude is increasing with time



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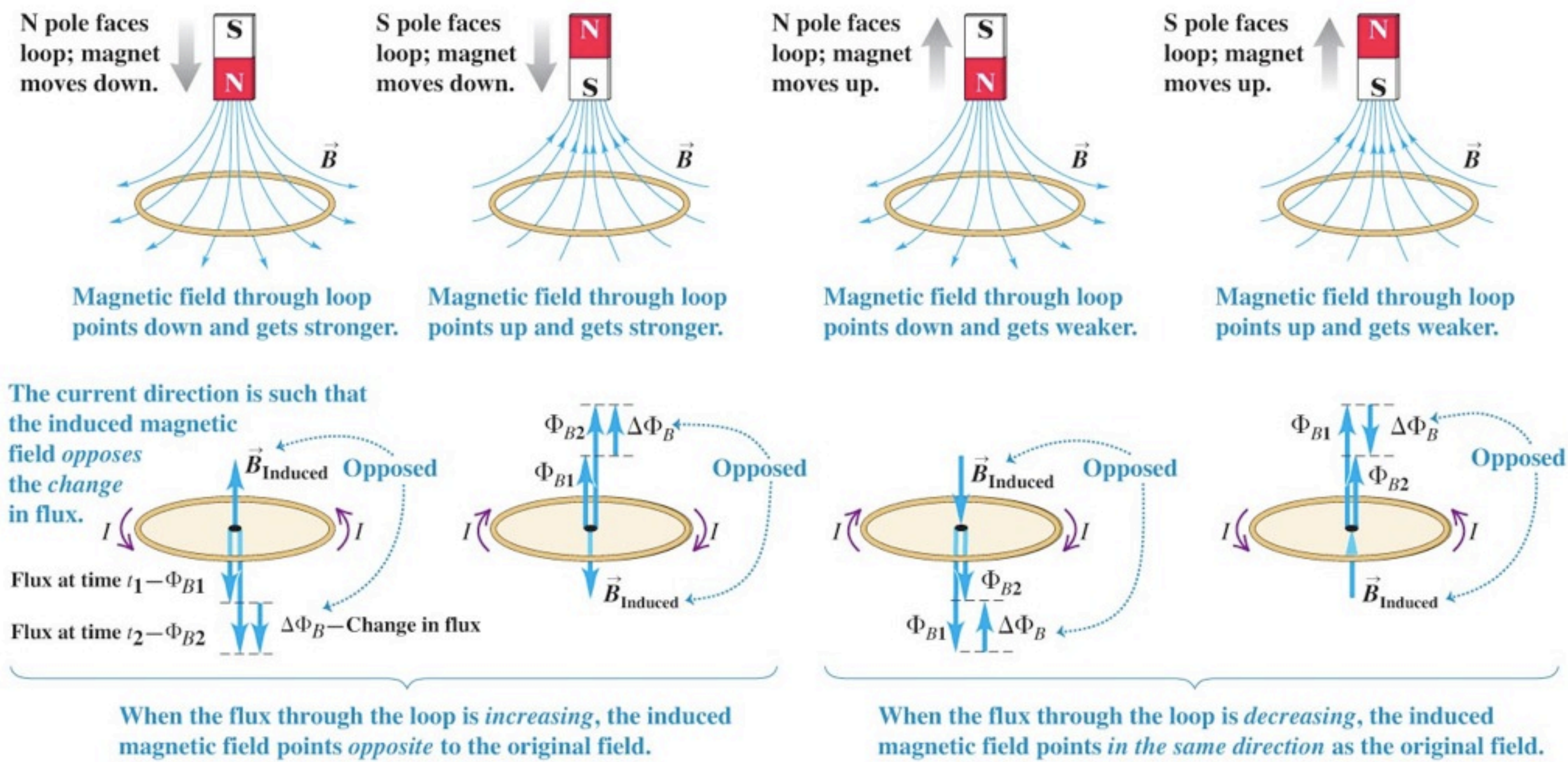

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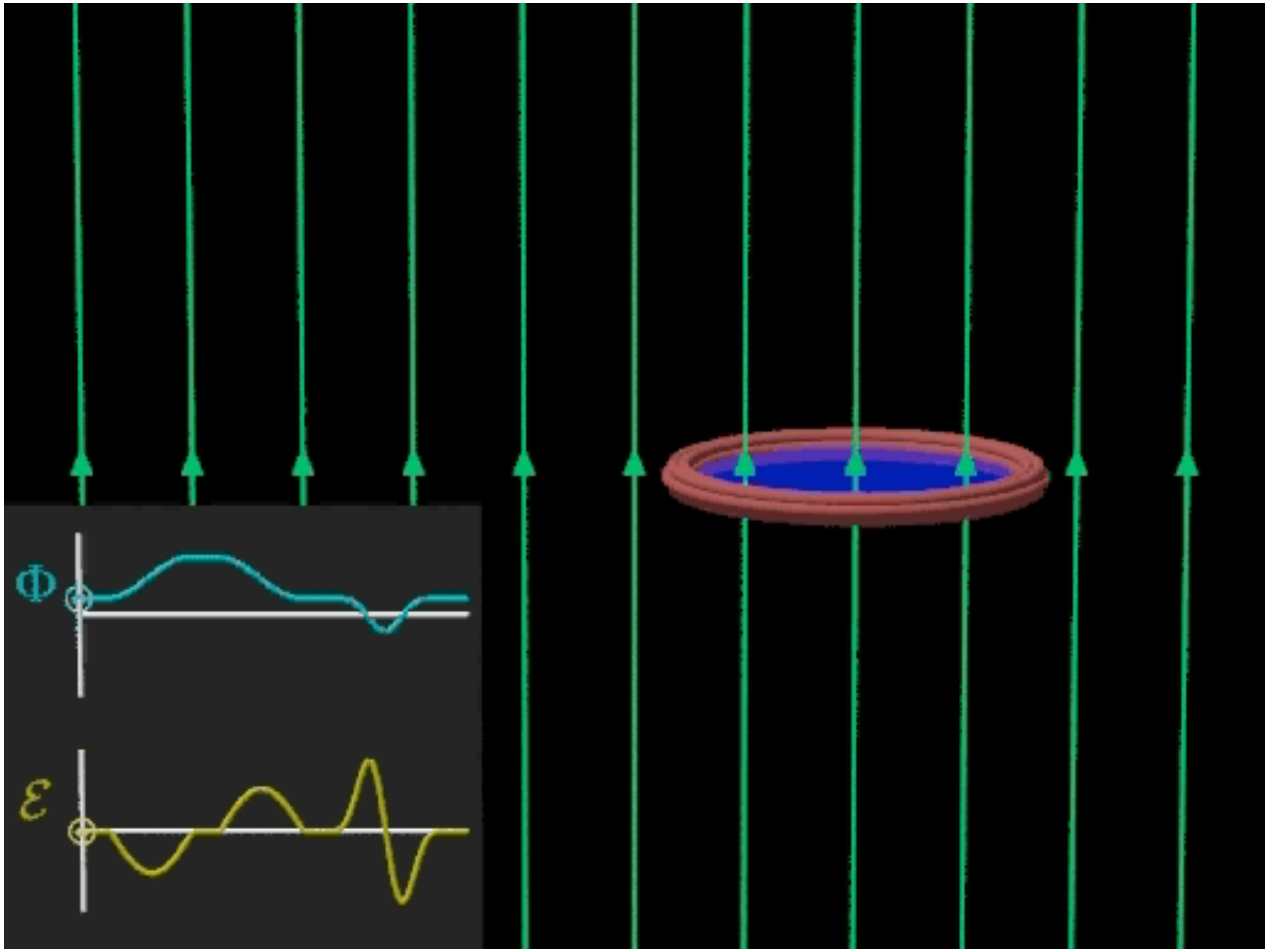
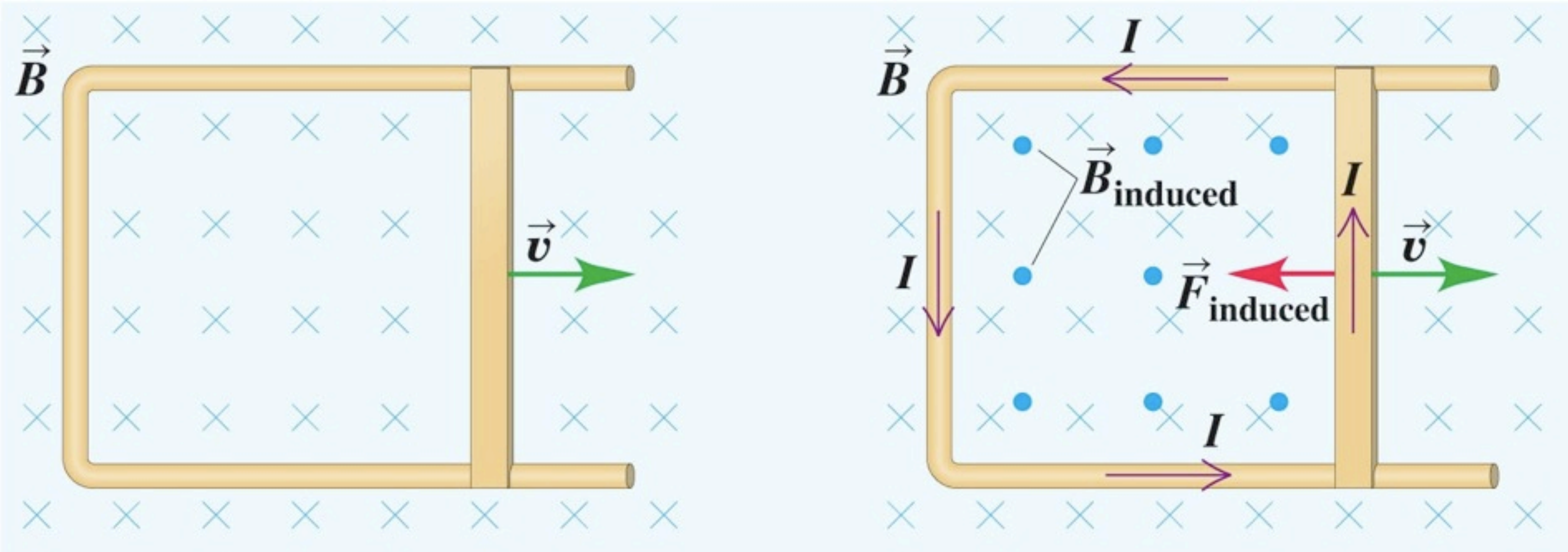


Lenz's law & the slide wire generator

➜ find the direction of the current induced and the force on the rod



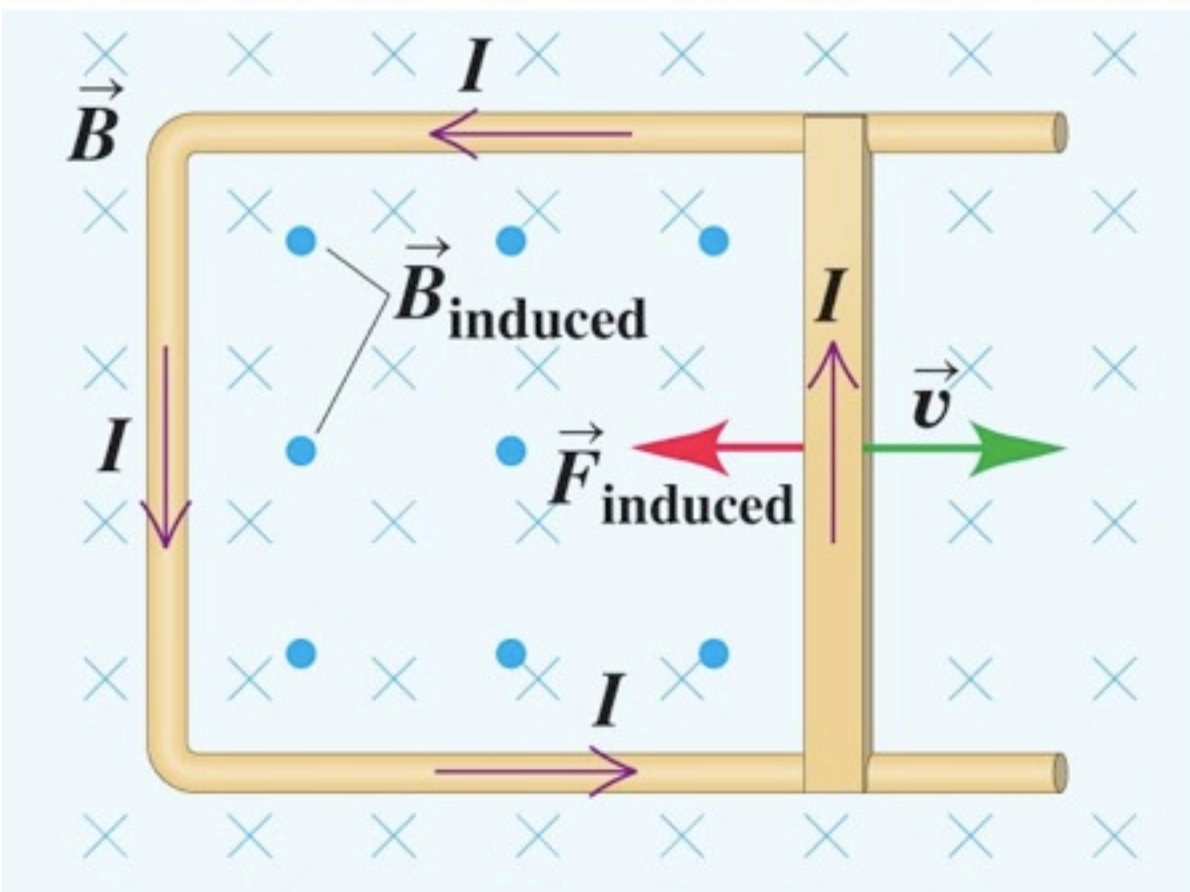
(a) Slide wire moving in magnetic field

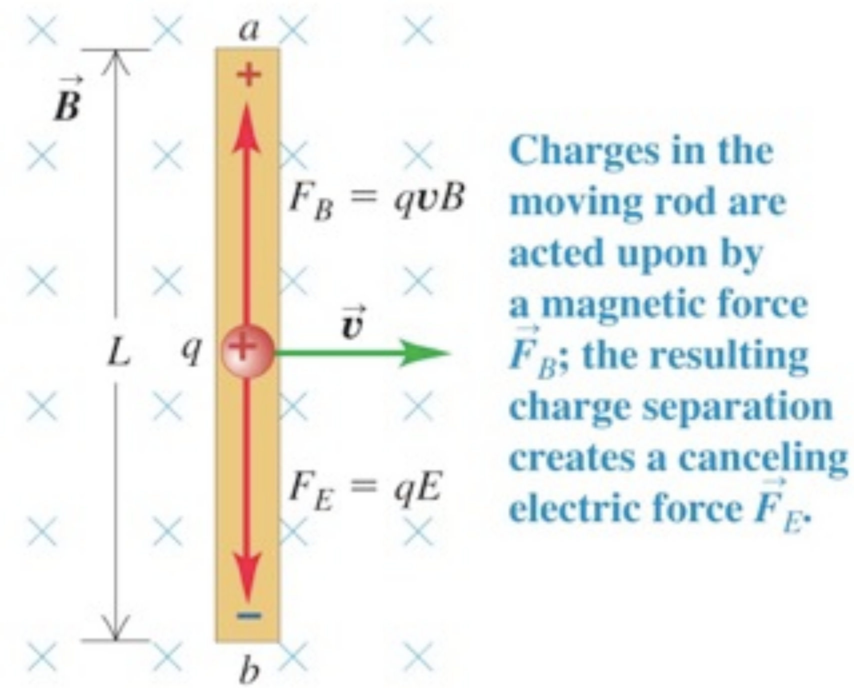
(b) Induced current, magnetic field, and magnetic force on slide wire

➜ note that the force is opposing the motion generating the current in line with Lenz's law
➜ note that the original field will be stronger than the induced field, so the right-hand rule application has the field into the page
➜ note also that this is energy conservation at work - imagine what would happen if the force were in the opposite direction

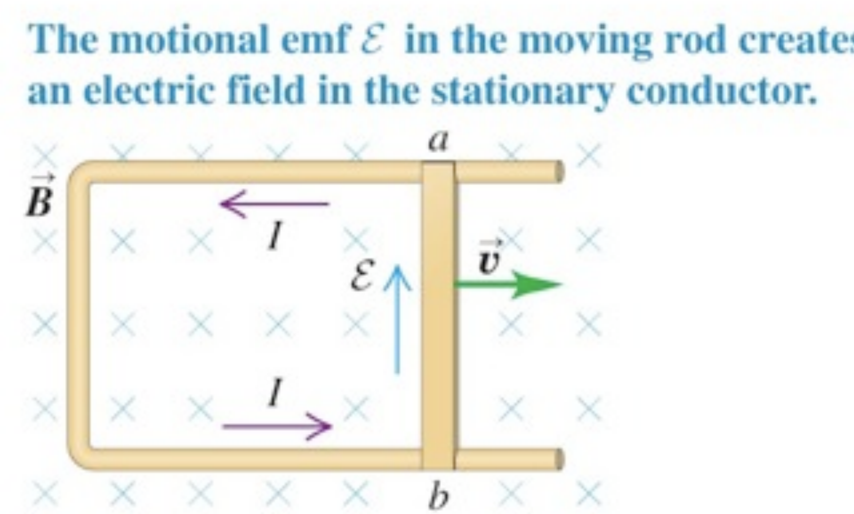
Lenz's law & the slide wire generator

➜ find the direction of the current induced and the force on the rod





(a) Isolated moving rod



(b) Rod connected to stationary conductor

➜ the moving bar is clearly acting as an emf source, with the magnetic forces on the moving charges allowing the current to flow against the electric field

mutual inductance

➜ Faraday's law allows us to induce an emf using a loop in changing magnetic field

➜ but we know that we can produce a magnetic field using a current carrying loop

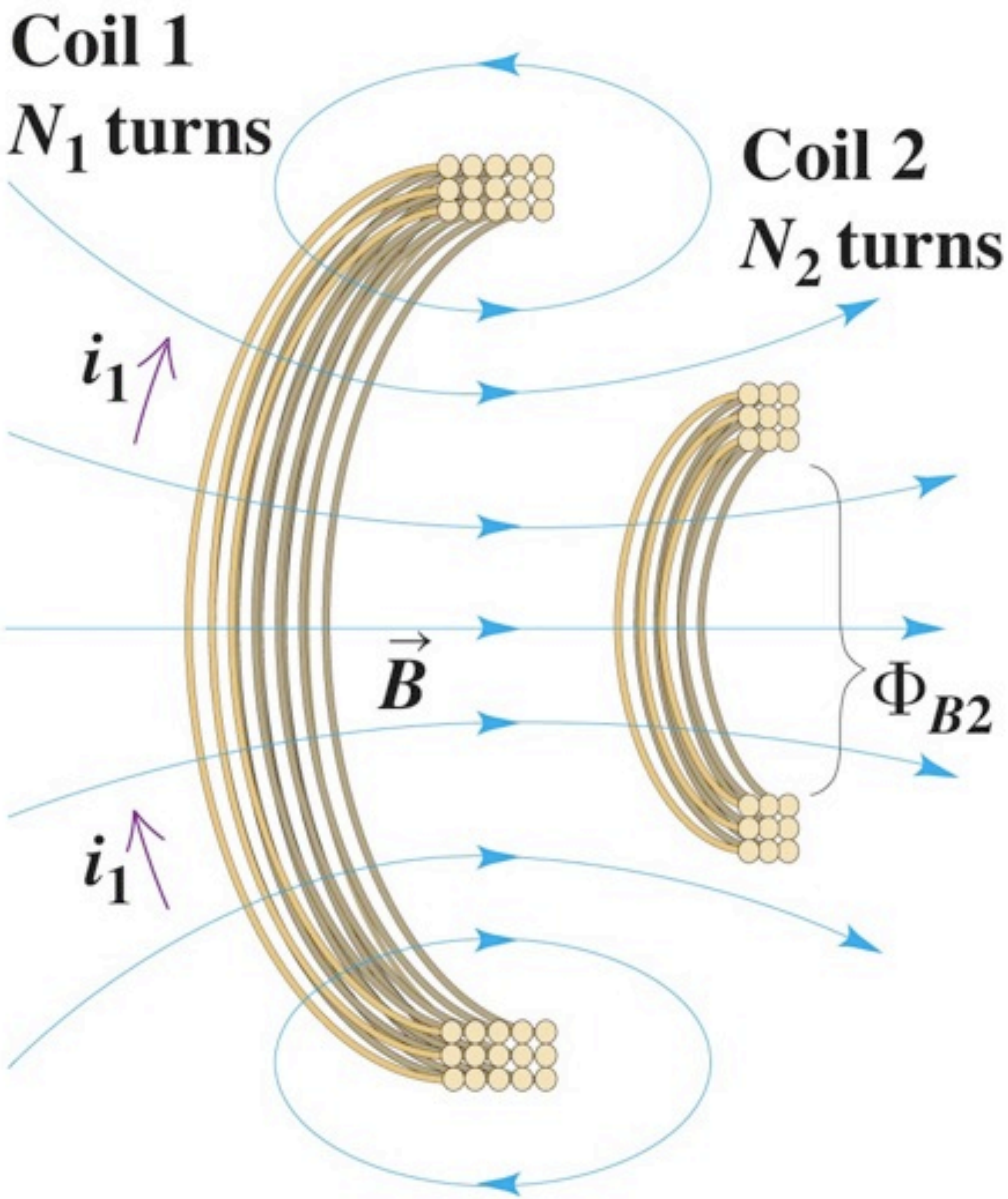
➜ so if we put two loops near each other and put a changing current through one of them, we can induce an emf (and current) in the other

➜ this is the basis of the transformer, a device based upon induction that can transform potential differences,

> e.g. convert the few volts produced by your car battery into the tens of thousands of volts required to cause sparks in the plugs
>
> or reduce the 500,000V signal in overhead power-lines down to the 120V required inside your house

mutual inductance

➜ two coils of wire



➜ induced emf in coil 2
due to the field from coil 1

$$\mathcal{E}_2 = N_2 \left| \frac{\Delta \Phi_{B2}}{\Delta t} \right|$$

➜ flux through coil 2 is
proportional to B_1, which
is proportional to i_1

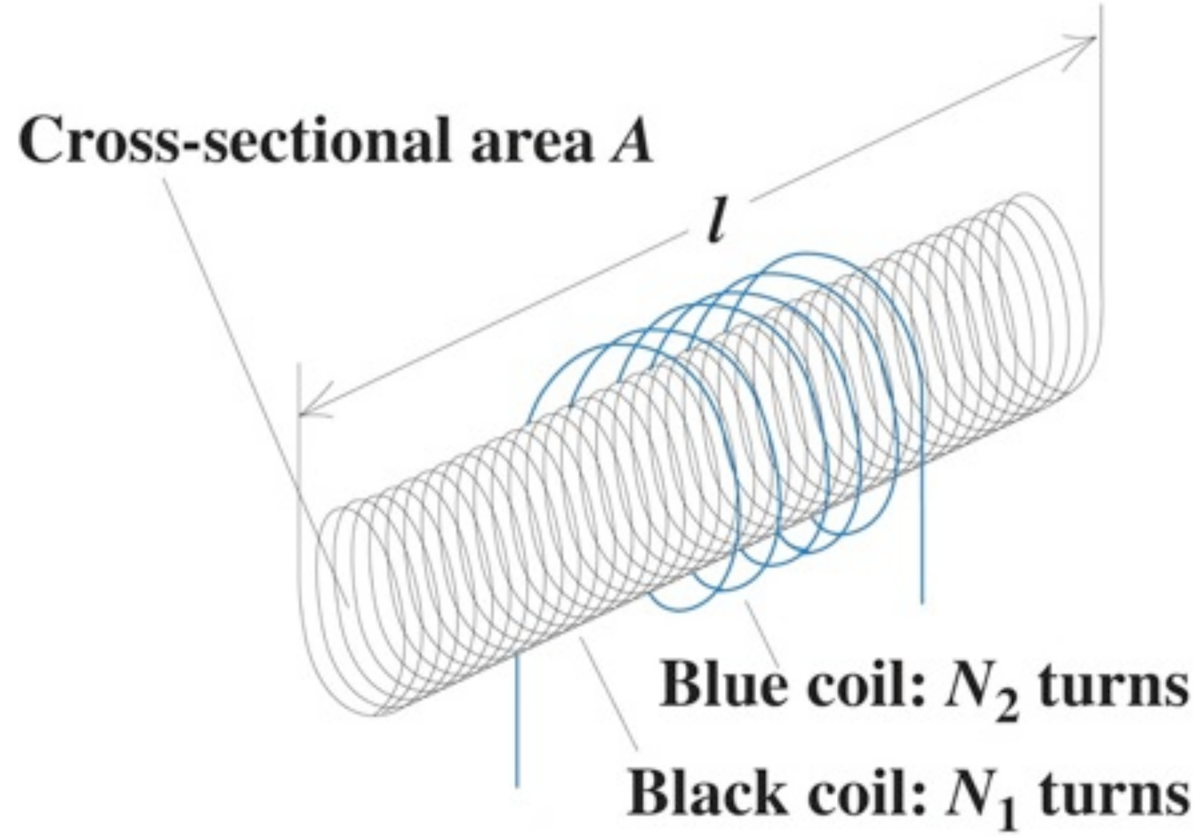
$$N_2 \left| \Phi_{B2} \right| = M_{21} \left| i_1 \right|$$

defines mutual induction

$$\mathcal{E}_2 = M_{21} \left| \frac{\Delta i_1}{\Delta t} \right|$$

mutual inductance of a Tesla coil

➜ a long solenoid of length l and cross-sectional area *A* is wound closely with N_1 turns of wire. An coil of N_2 turns surrounds it. Compute the mutual inductance.



➜ suppose coil 1 carries a current i_1

$$B_1 = \mu_0 \frac{N_1}{\ell} i_1$$

➜ then the flux through each turn of coil 2 is

$$\Phi_{B2} = B_1 A = \mu_0 \frac{N_1}{\ell} A\, i_1$$

➜ mutual inductance is defined by

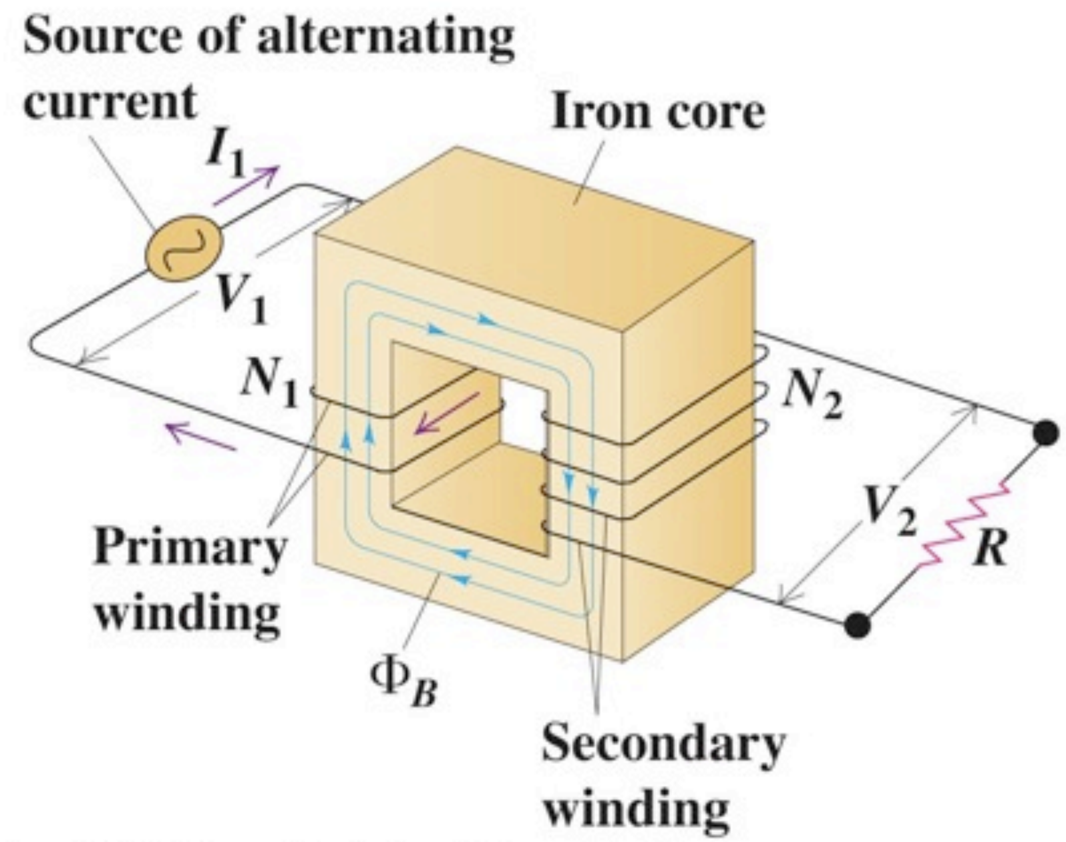
$$N_2 \left|\Phi_{B2}\right| = M_{21} \left|i_1\right|$$

➜ hence

$$M_{21} = \mu_0 \frac{N_1 N_2}{\ell} A$$

transformers

➜ an iron core traps the flux



$$\mathcal{E}_2 = N_2 \left| \frac{\Delta \Phi_B}{\Delta t} \right|$$

$$\mathcal{E}_1 = N_1 \left| \frac{\Delta \Phi_B}{\Delta t} \right|$$

➜ the ratio of voltages is the ratio of turns $\quad \dfrac{\mathcal{E}_2}{\mathcal{E}_1} = \dfrac{N_2}{N_1}$

➜ $N_2 > N_1$: $V_2 > V_1$ - a "step-up" transformer

➜ $N_2 < N_1$: $V_2 < V_1$ - a "step-down" transformer

➜ used to change the voltage of AC electricity, e.g. transmission lines at 500 kV need to be "stepped-down" to the 120/240 V required in your house