LECTURE 21 Questions

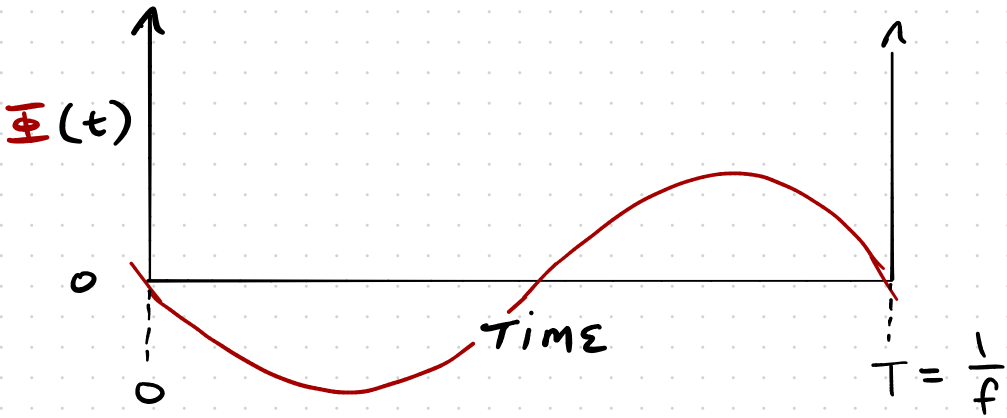
Q1) GENERATORS

a) CONVINCE YOURSELF THAT THE EMF GENERATED BY A LOOP/COIL ROTATING IN A MAGNETIC FIELD IS PROPORTIONAL TO THE FREQUENCY OF ROTATION.

DO THIS IN TWO WAYS:

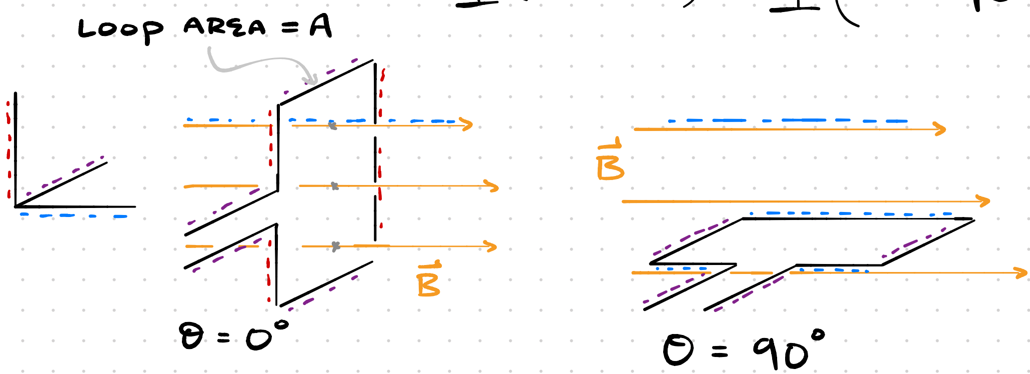
(i)

- ON THE NEXT PAGE I'VE MADE A PLOT THE FLUX Φ THRU THE LOOP FOR ONE FULL ROTATION WHEN THE ROTATION FREQUENCY IS f (E.G. $f = 1\,\text{Hz}$):



- NOW, SUPERIMPOSE ON THE PLOT THE FLUXES $\Phi_2(t)$ & $\Phi_{1/2}(t)$ WHERE THE ROTATION FREQUENCIES ARE $2f$ & $\frac{1}{2}f$, RESPECTIVELY.
- WHICH OF THE THREE CASES HAS THE LARGEST SLOPE $\left|\frac{\Delta\Phi}{\Delta t}\right|$?
- NOTE: WHY IS THE AMPLITUDE OF ALL THREE SINE WAVES THE SAME?

ii) • CALCULATE THE DIFFERENCE IN FLUX $\Delta\Phi = \Phi(\theta = 0^\circ) - \Phi(\theta = 90^\circ)$:



[IN GENERAL, $\Phi = \underline{B}A\cos\theta$]

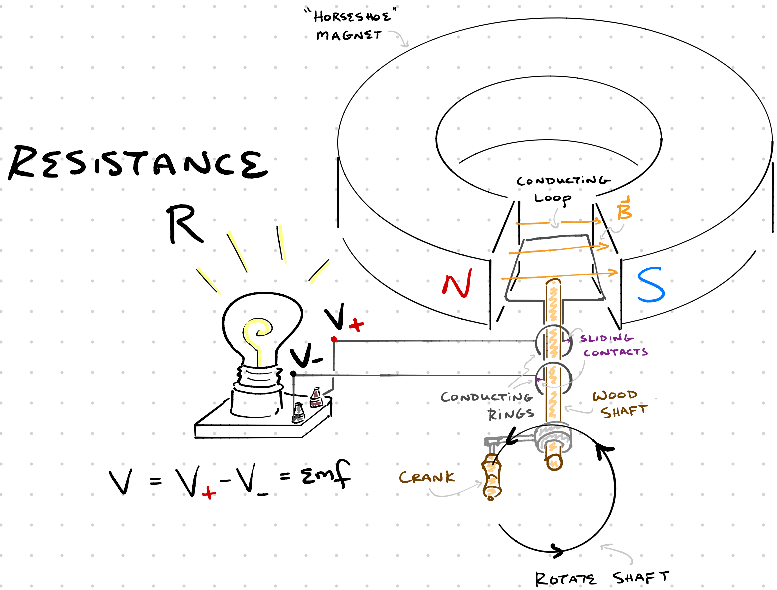
• WHAT IS THE <u>TIME</u> Δt THAT IT TAKES FOR THE LOOP TO ROTATE 90°?

  • HINT: IT DEPENDS ON THE FREQUENCY!

• COMBINE TO DETERMINE $\dfrac{\Delta\Phi}{\Delta t} = \text{emf}$ (1 LOOP)

• HOW DOES emf DEPEND ON FREQUENCY?

b) Suppose we want to <u>use</u> our generated emf to do something useful, like lighting a lightbulb:



- If we want the bulb to glow brightly, we need a large voltage across the bulb:

$$\left(P = V^2/R\right)$$

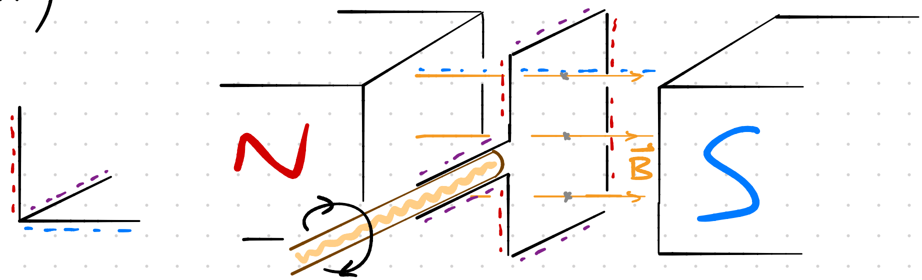
so we want a large emf induced in our loop, and therefore want to turn the crank as fast as possible (from part [a] you found that emf is proportional to frequency).

Even in the absence of friction, the operator of this hand-crank generator will find it harder to keep the loop rotating as he/she increases the frequency of rotation. To help you figure out why this happens, I've broken the chain of reasoning into multiple steps:

(i)

- FROM OHM'S LAW AND KIRCHOFF'S CURRENT LAW, ARGUE THAT THE CURRENT IN THE COIL IS PROPORTIONAL TO THE INDUCED EMF, AND SO PROPORTIONAL TO THE ROTATION FREQUENCY.

ii)

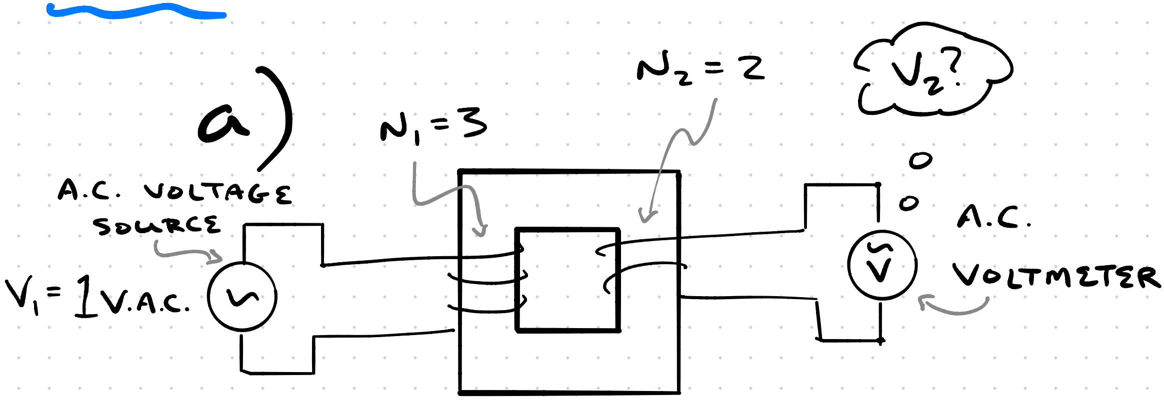


In the diagram above, draw the direction of the induced current and induced magnetic field as the loop as rotated clockwise. Replace the current-carrying loop with its bar-magnet equivalent, and show that this bar-magnet opposes the clockwise-rotation.

Qualitatively, how does the strength of this effective bar-magnet relate to the frequency of rotation?

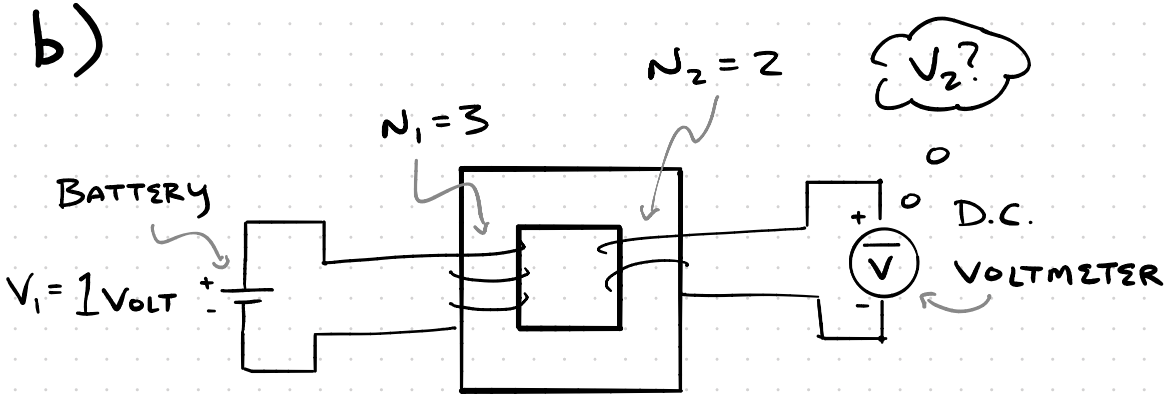
Q2) TRANSFORMERS

a)



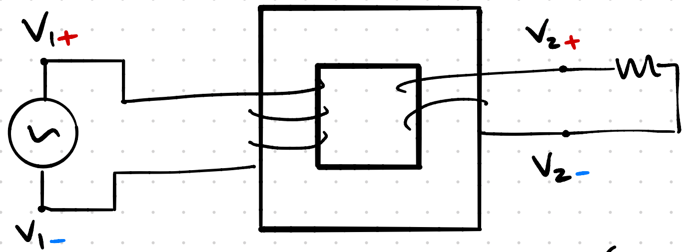
$V_2 =$ ___ V.A.C.?

b)

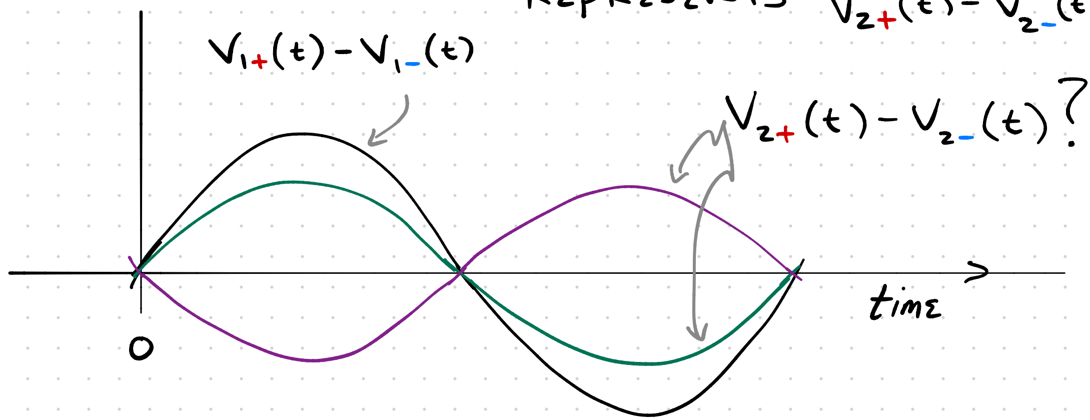


$V_2 =$ ___ VOLTS?

c)

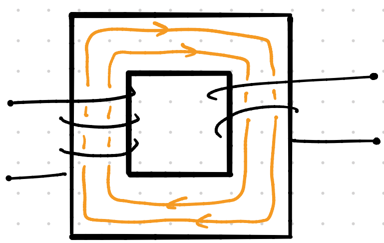


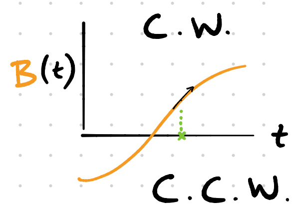
• WHICH CURVE (— OR —) REPRESENTS $V_{2+}(t) - V_{2-}(t)$?



• DETERMINE USING THE FOLLOWING STEPS:

(i) • CONSIDER A MOMENT WHEN THE FLUX IS INCREASING IN THE CLOCKWISE DIRECTION:

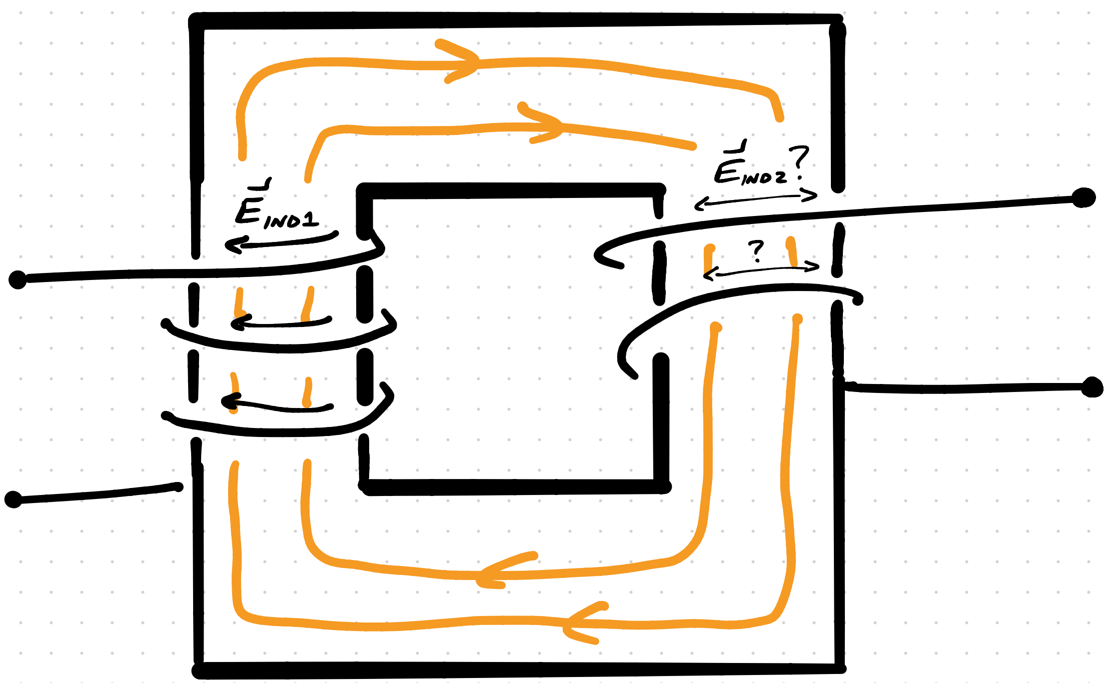




- The changing magnetic flux induces an electric field $\vec{E}_{IND1}$ and $\vec{E}_{IND2}$ in the two coils in the direction parallel to the current that would oppose the change in flux.

(LENS' LAW)

To illustrate I have drawn $\vec{E}_{IND1}$. Following the example, draw $\vec{E}_{IND2}$.



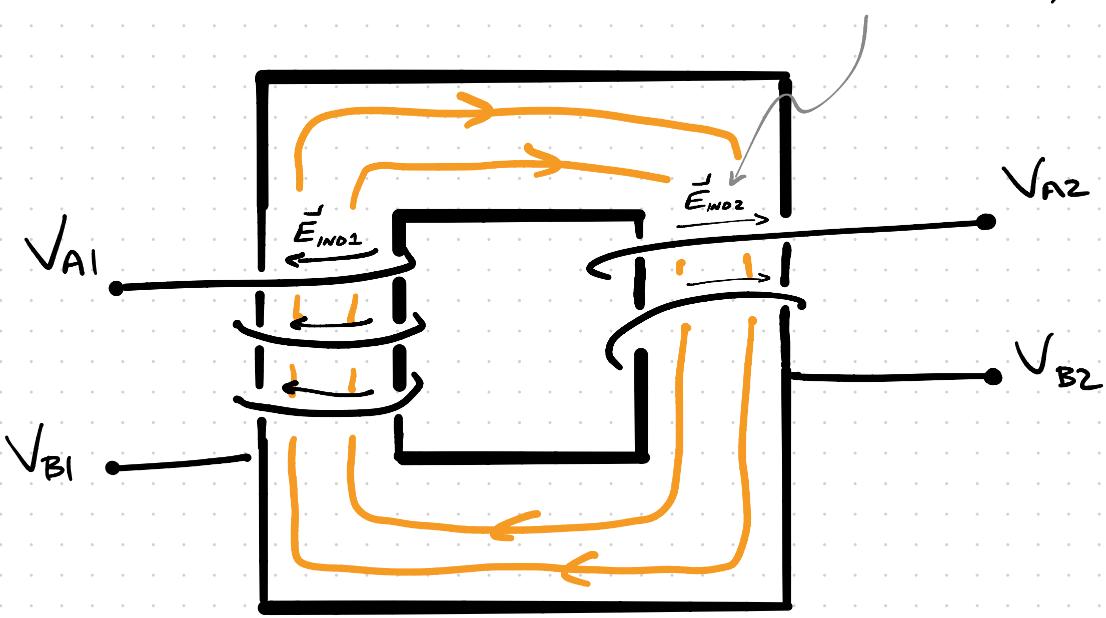
ii)

Since the coils are made of conducting material, the net electric field in either coil must be very small. The induced fields $\vec{E}_{IND1}$ and $\vec{E}_{IND2}$ are almost perfectly cancelled by additional electric fields $\vec{E}_{V1}$ and $\vec{E}_{V2}$ created by the electric potential differences (voltages) between the ends of the loops.

Draw $\vec{E}_{1V}$ and $\vec{E}_{2V}$. Knowing that electric field lines of $\vec{E}_{1V}$ and $\vec{E}_{2V}$ point from higher electric potential to lower electric potential, show:

- $V_{A1} > V_{B1}$,
- $V_{A2} > V_{B2}$

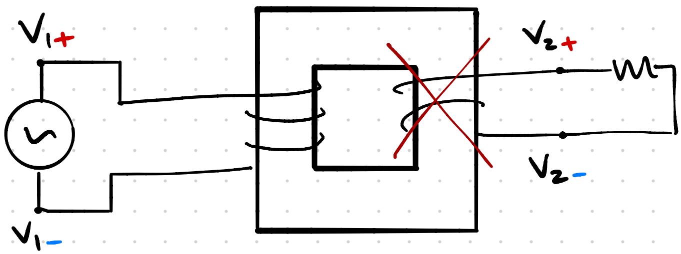
(FROM PART i)



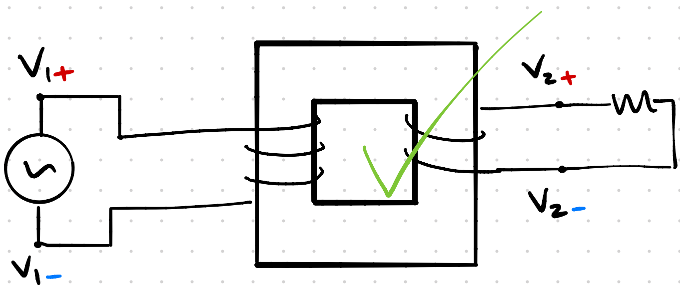
iii) USE ANSWER FROM PART ii) TO DETERMINE WHETHER $V_{2+}(t) - V_{2-}(t)$ FOLLOWS THE — OR — CURVE i.e. is iT "IN-PHASE" OR "180° OUT OF PHASE" w/ $V_{1+}(t) - V_{1-}(t)$?

d)

- HOW DOES THIS CHANGE iF WE WRAP COiL #2 "THE OTHER WAY"?



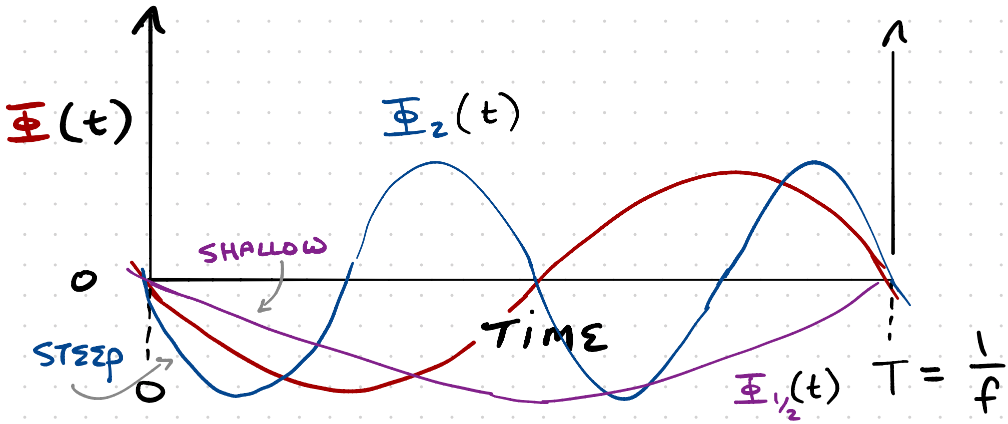
NOT THIS WAY,



BUT THIS WAY!

ANSWERS: Q1 a)

i)



ii)

- $\theta = 0^\circ$: INTERCEPTS MOST $\vec{B}$ FIELD LINES.

$$\longrightarrow \Phi(0^\circ) = BA\cancelto{1}{\cos(0^\circ)} = BA$$

- $\theta = 90^\circ$: INTERCEPT NO $\vec{B}$ FIELD LINES.

$$\longrightarrow \Phi(90^\circ) = BA\cancelto{0}{\cos(90^\circ)} = 0$$

$\longrightarrow \Delta\Phi = BA$

Δt = TIME TO GO FROM

$\theta = 0^\circ \longrightarrow \theta = 90^\circ$

$= \frac{1}{4} \times$ TIME TO GO FROM

$\theta = 0^\circ \longrightarrow \theta = 360^\circ$

$= \frac{1}{4} \times T$ ← PERIOD

$= \frac{1}{4} \times \frac{1}{f}$ ← FREQUENCY

$$\longrightarrow \text{emf} = \frac{\Delta\Phi}{\Delta t} = \frac{BA}{1/4f} = 4fBA$$

$$\underline{\propto f}$$

b) i)

- CURRENT THRU RESISTOR (LIGHT-BULB):

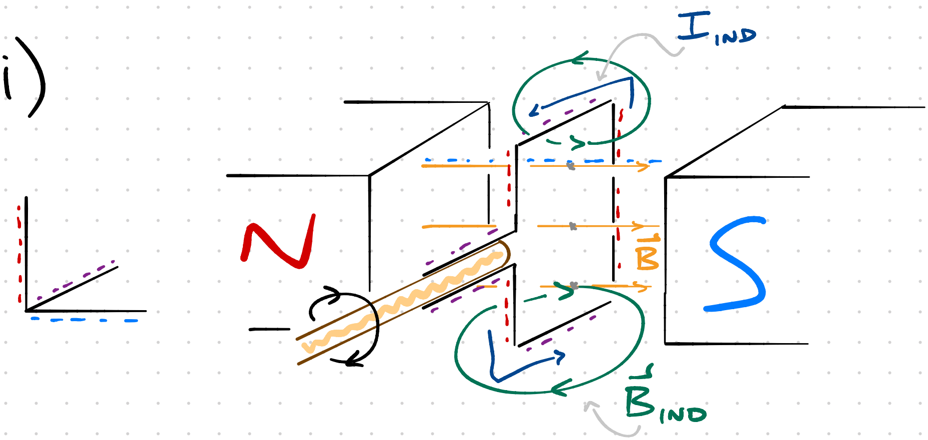
$$I_R = \frac{V}{R} \quad (\text{OHM'S LAW})$$

- (K.C.L.): CURRENT THRU COIL = " " RESISTOR.

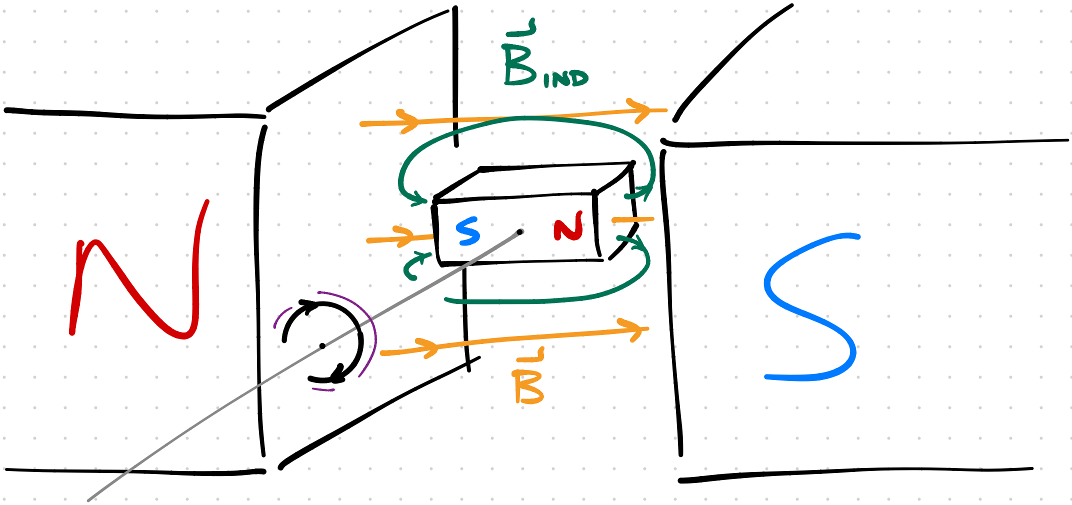
$$\longrightarrow \quad I_{COIL} = I_R = \frac{V}{R} = \frac{emf}{R} \propto f$$

$$(\text{since } emf \propto f)$$

ii)



- AS loop ROTATES AWAY FROM $\theta = 0$, LEFT → RIGHT FLUX FROM MAGNET DECREASES. $\vec{B}_{IND}$ points L→R inside loop To oppose THIS DECREASE.



Induced current in loop makes it effectively a bar magnet that is aligned with the field from the permanent magnet, and will resist attempts to rotate it out of alignment.

- $\vec{B}_{IND} \propto I_{IND} \propto \mathcal{E}mf \propto f$
  - Loop resists rotation more @ higher frequencies!

Q2) a)

$$\frac{V_2}{V_1} = \frac{N_2}{N_1}$$

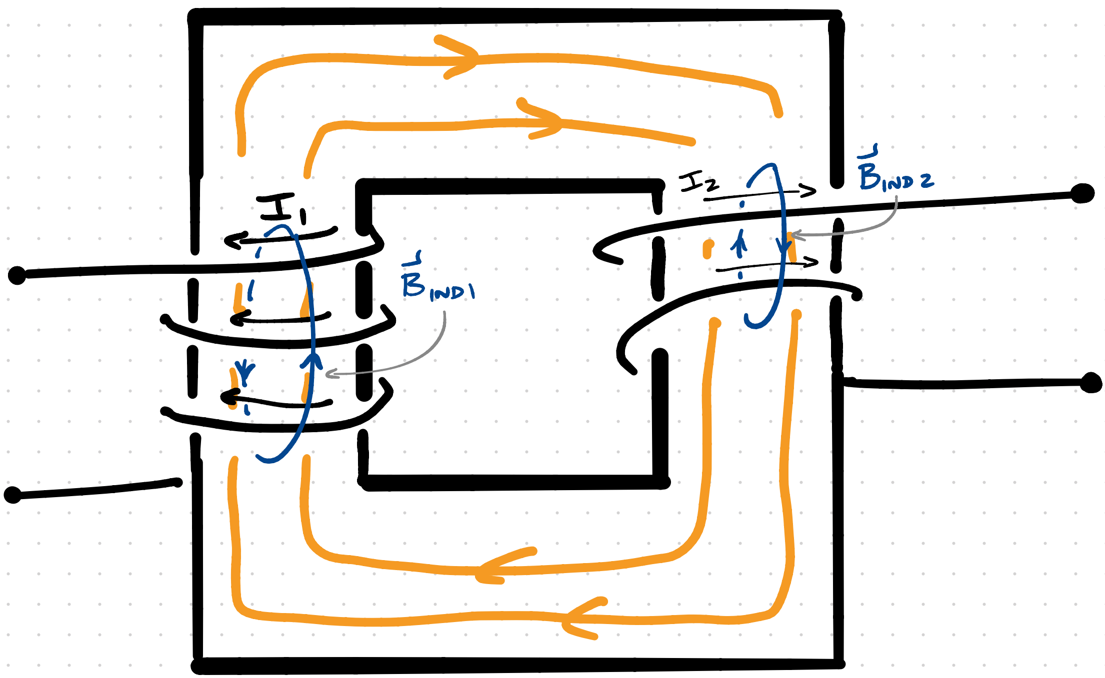
$$\longrightarrow V_2 = \frac{N_2}{N_1} V_1$$

$$= \frac{2}{3} \times 1 \text{ V.A.C.}$$

b) $V_2 = 0$!

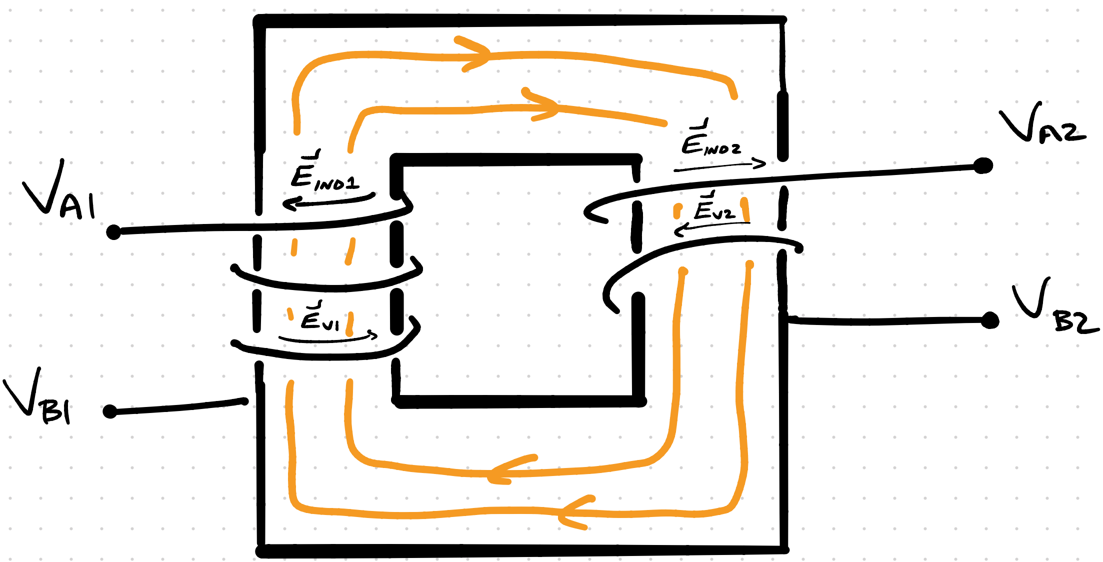
BATTERY OUTPUTS STEADY (D.C.) VOLTAGE, NEED CHANGING VOLTAGE FOR INDUCTION.

c) i) • DRAW CURRENTS THAT WOULD OPPOSE INCREASE IN CLOCKWISE FLUX:



• $\vec{E}_{IND1}$ & $\vec{E}_{IND2}$ RUN PARALLEL TO I_1 & I_2, RESPECTIVELY. (ϕ ANTI-PARALLEL)

ii) If $\vec{E}_V$ & $\vec{E}_{IND}$ cancel, they point opposite:



- Since $\vec{E}_V$ points from high potential to low potential:

$$V_{A1} > V_{B1}, \quad V_{A2} > V_{B2}.$$

iii)• THEREFORE, $V_1(t) - V_1(t)$ & $V_2(t) - V_2(t)$ OSCILLATE IN-PHASE (positive peak of one lines up w/ positive peak of other).

d) NOW THEY ARE 180° OUT OF PHASE

(REDO STEP (i) FROM (c) TO SEE THIS)