



ELECTROMAGNETIC INDUCTION

CHAPTER 25

ELECTROMAGNETIC INDUCTION

- Electric current can be produced in a wire simply by moving a magnet in or out of loops of wire without an additional voltage source.
- This phenomenon of inducing voltage by changing the magnetic field in loops of wire is called **electromagnetic induction**.

ELECTROMAGNETIC INDUCTION

- Voltage is caused (induced) by the relative motion between a wire and a magnetic field.
- This is regardless of which moves, the magnet or the wire.
- The amount of voltage induced depends on how fast the magnetic field lines are entering or leaving the coil.
- The faster the motion, the more voltage, the slower the motion, the lower the voltage.

ELECTROMAGNETIC INDUCTION

- The greater the number of loops of wire, the greater the induced voltage.
- The greater the number of loops, however, the more difficult it is to push the magnet into the coil!
- This is because the induced voltage makes a current, which repels the magnet.
- More loops mean more voltage, which means more work needed to induce it.

ELECTROMAGNETIC INDUCTION

- Electromagnetic induction is all around us.
- It is in the “sensors” that trigger traffic lights at some intersections.
- Hybrid cars use it to convert braking energy into electric energy in their batteries.

ELECTROMAGNETIC INDUCTION

- Security systems (metal detectors) at airports use electromagnetic induction to trigger the alarm.
- ATM cards use EM induction when the magnetic strip is swiped through the scanner.

FARADAY'S LAW

- The induced voltage in a coil is proportional to the product of its number of loops, the cross-sectional area of each loop, and the rate at which the magnetic field changes within these loops.

FARADAY'S LAW

- The amount of current produced depends not only on the induced voltage but also on the resistance of the coil and the circuit to which it is connected.

FARADAY'S LAW

- There are three ways to induce voltage in a loop of wire:
 - By moving the loop near a magnet
 - By moving a magnet near the loop
 - By changing the current in a nearby loop

GENERATORS AND ALTERNATING CURRENT

- When one end of a magnet is repeatedly plunged into and back out of a coil of wire, the direction of the induced voltage alternates.
- As the magnet enters the coil, the induced voltage in the coil is directed one way.
- As the magnet leaves the coil, the voltage is induced in the opposite direction.

GENERATORS AND ALTERNATING CURRENT

- The frequency of the alternating voltage that is induced equals the frequency of the changing magnetic field within the loop.

GENERATORS AND ALTERNATING CURRENT

- It is more practical to move the coil than to move the magnet.
- Rotating the coil in a stationary magnetic field has the same effect.
- This arrangement is called a generator.

GENERATORS AND ALTERNATING CURRENT

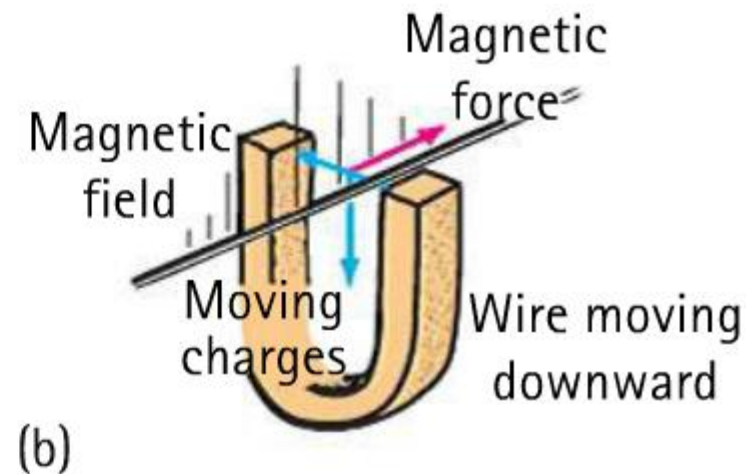
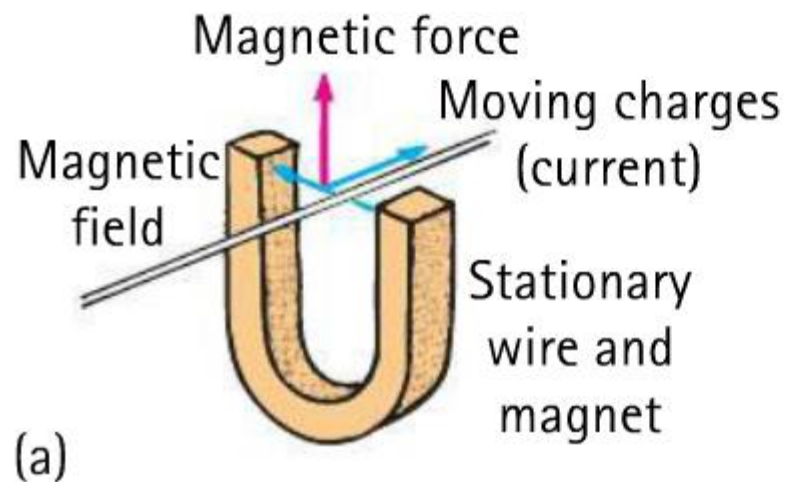
- Generators and Motors are built the same, but the roles of input and output are reversed.
- In a motor, electricity is put into the coil to induce motion.
- In a generator, the coil is moved to induce electrical voltage.
- Both simply transform one form into another!

GENERATORS AND ALTERNATING CURRENT

- Both motors and generators use the principle that moving electrons experience a force that is perpendicular to both their velocity and the magnetic field through which they move.

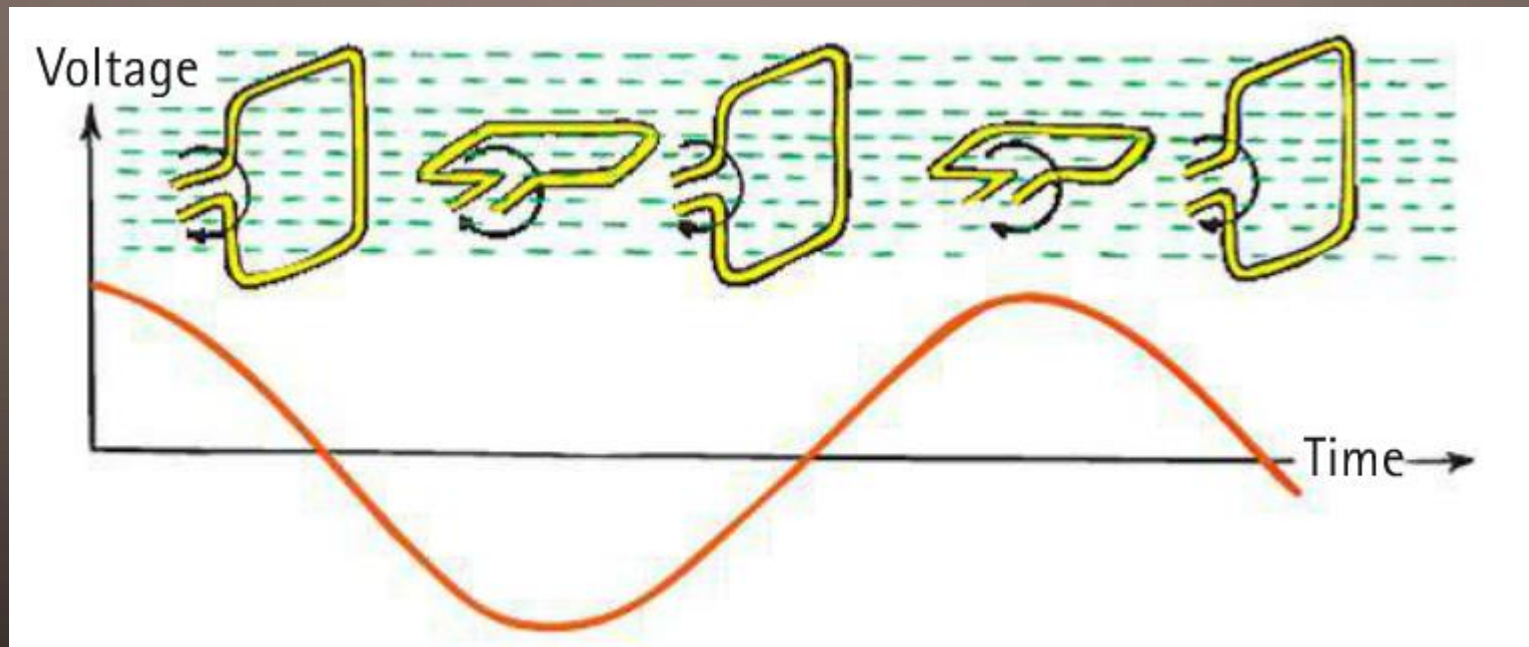
GENERATORS AND ALTERNATING CURRENT

- The movement of the wire in a magnetic field due to electric current, we will call the **motor effect**.
- The induction of current as a result of the wire, we will call the **generator effect**.



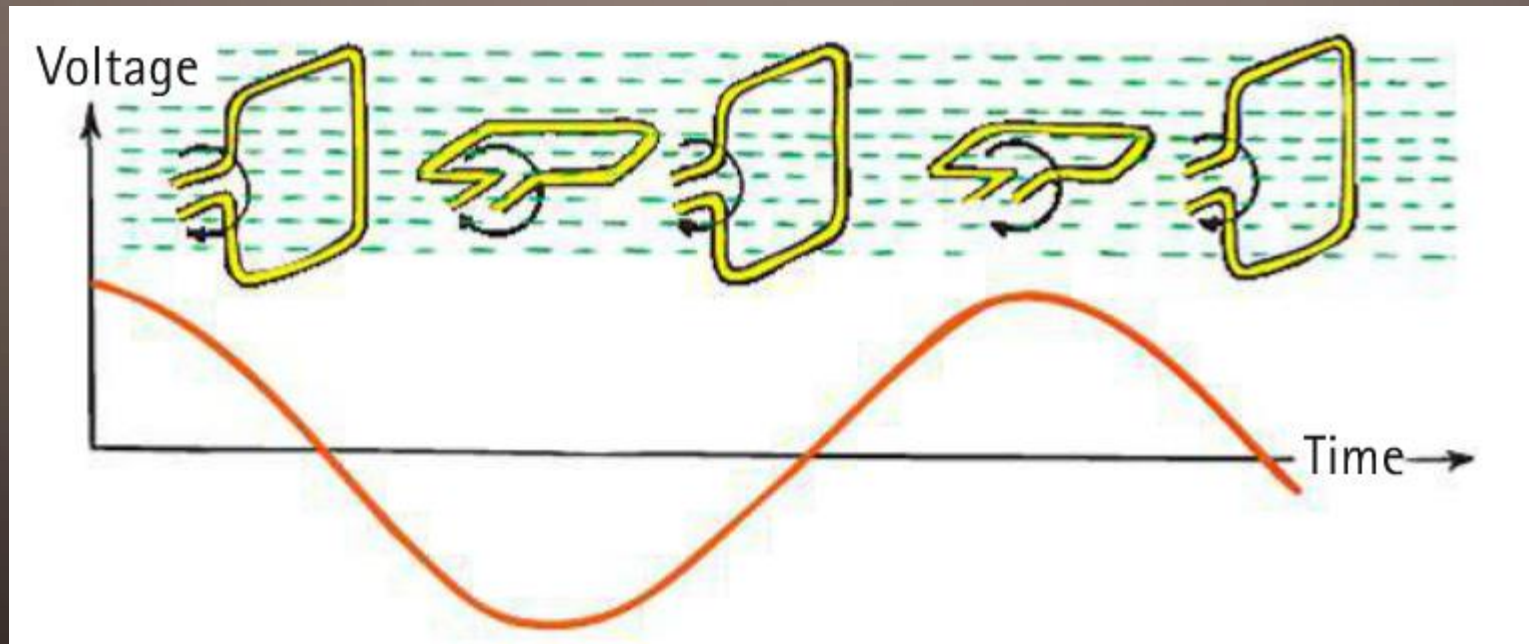
GENERATORS AND ALTERNATING CURRENT

- When the loop is rotated in the magnetic field, there is a change in the number of field lines within the loop.



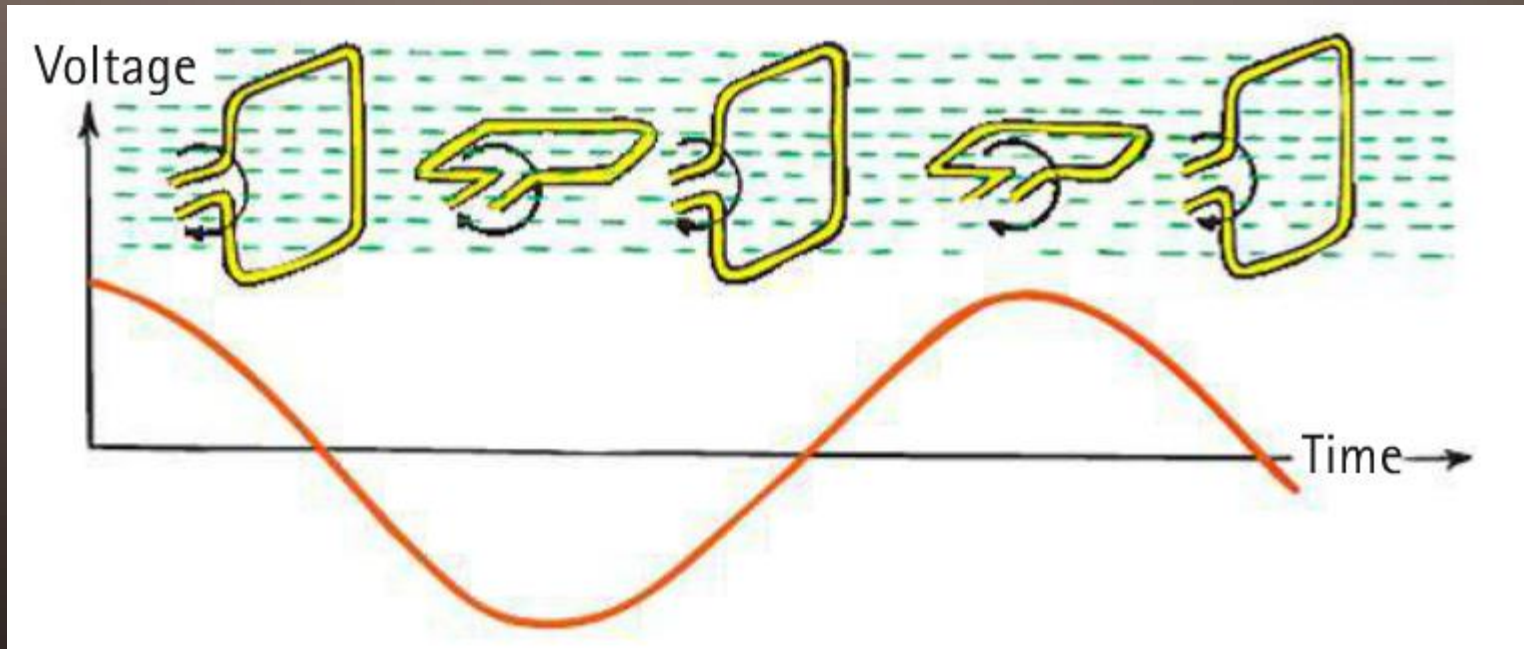
GENERATORS AND ALTERNATING CURRENT

- When the plane of the loop is perpendicular to the field lines, the maximum number of lines is enclosed in the loop.

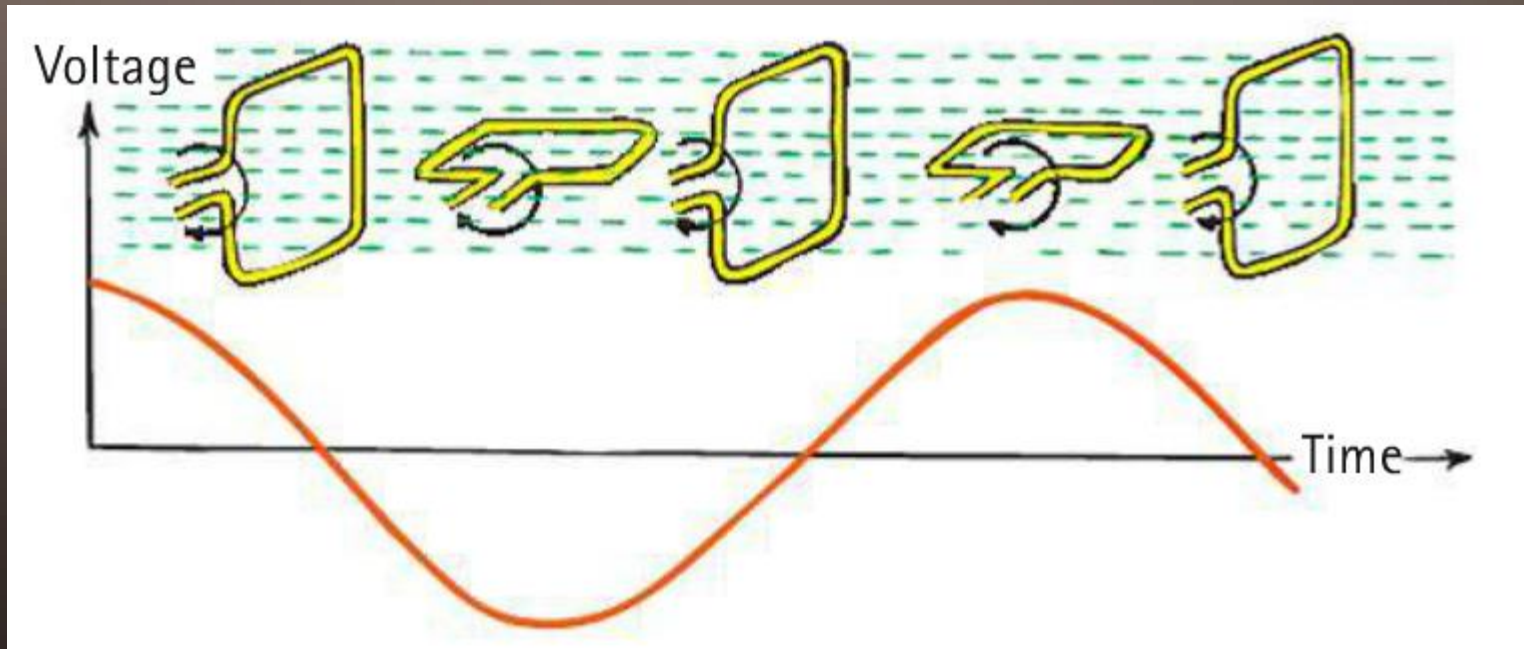


GENERATORS AND ALTERNATING CURRENT

- As the loop rotates, it “chops” the field lines, so that fewer lines are enclosed.

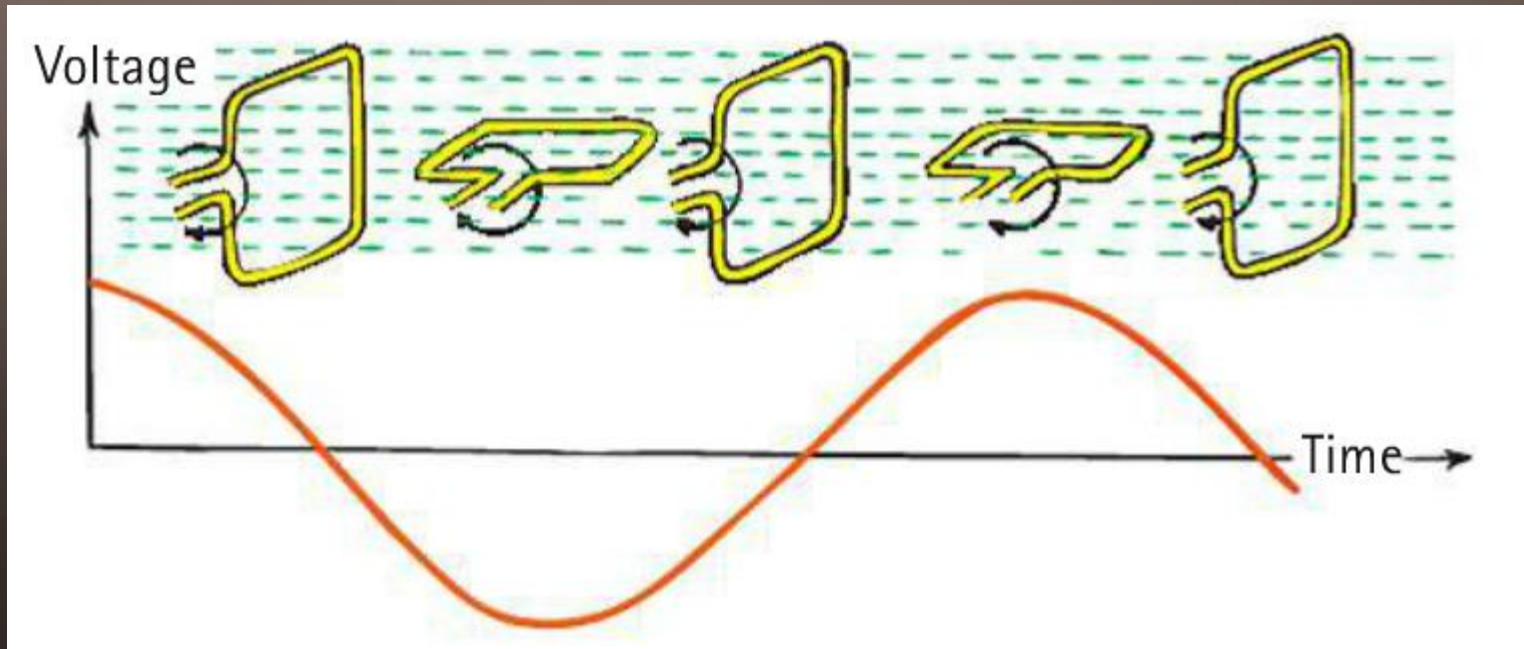


GENERATORS AND ALTERNATING CURRENT



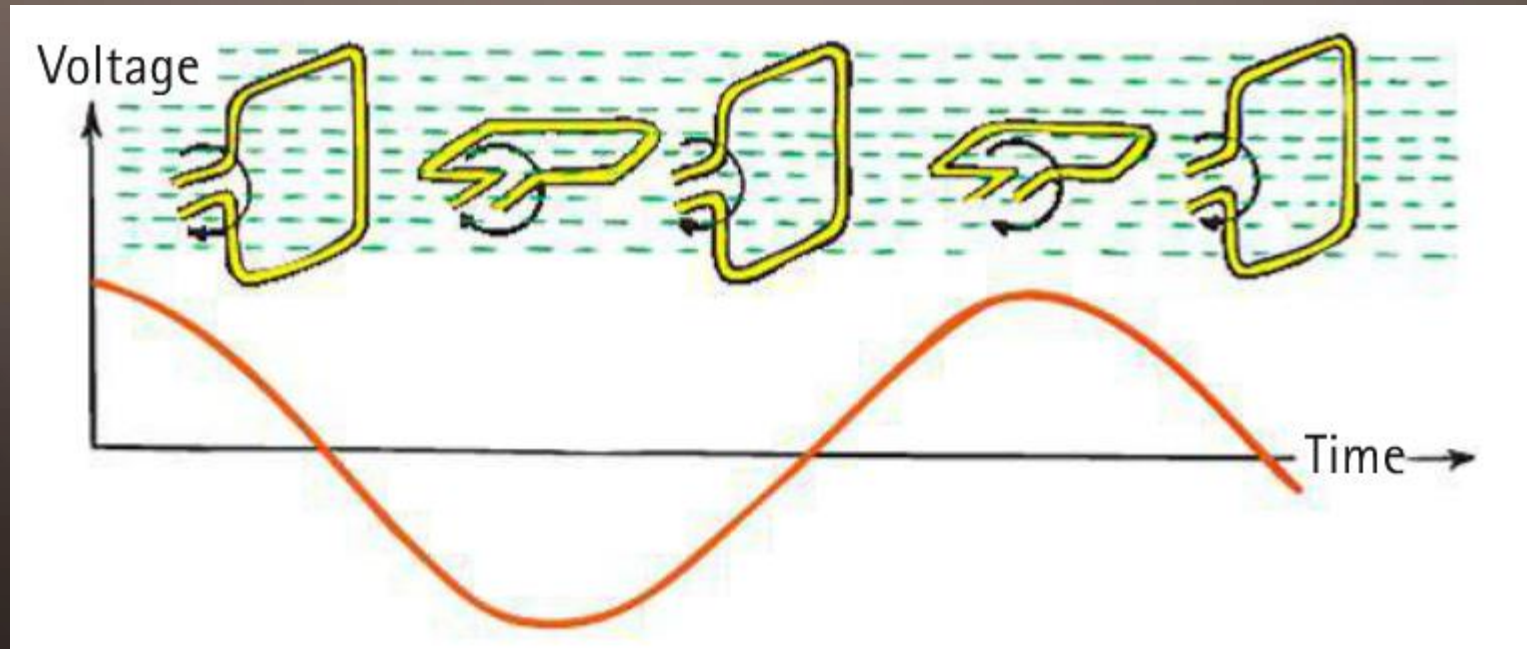
GENERATORS AND ALTERNATING CURRENT

- When the plane of the loop is parallel to the field lines, none are enclosed.



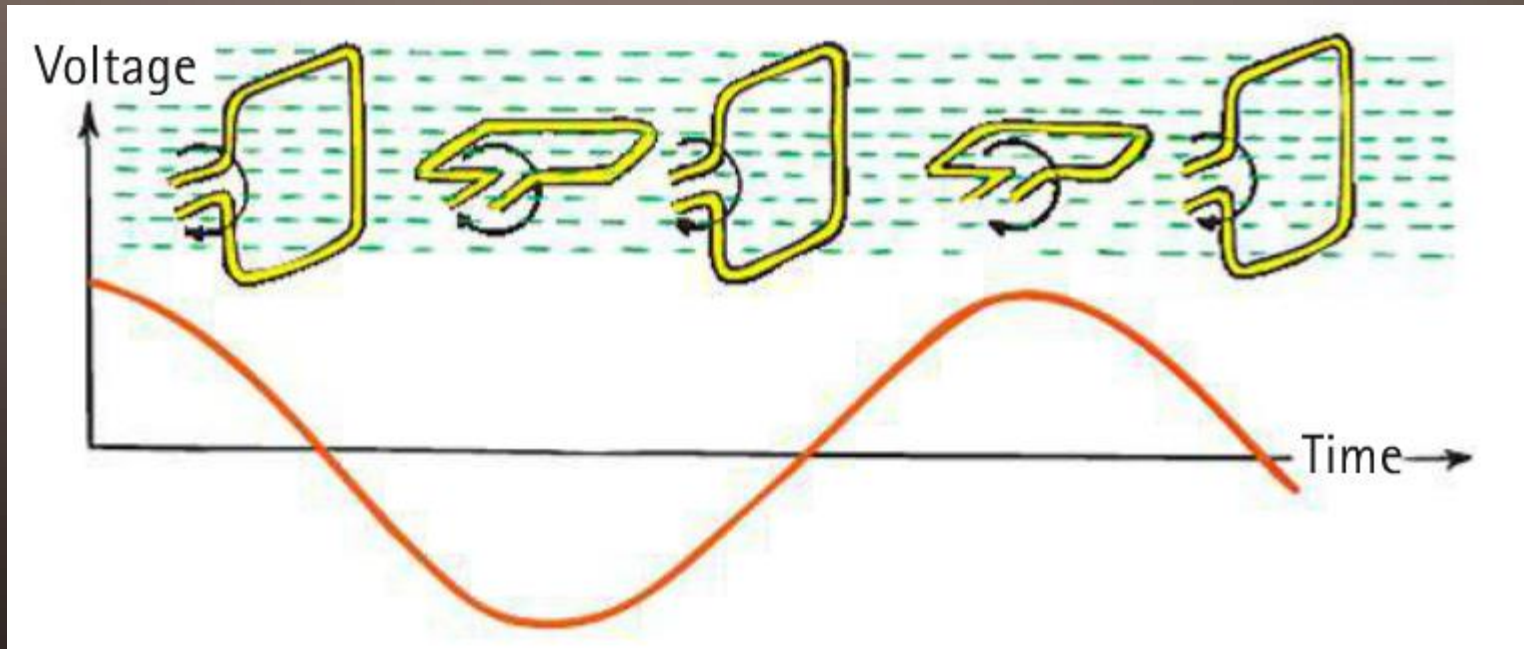
GENERATORS AND ALTERNATING CURRENT

- The greatest change in rate of change of field lines occurs when the number of enclosed field lines goes through zero.
- The greatest induced voltage is also when the loop goes through its parallel to the lines orientation.



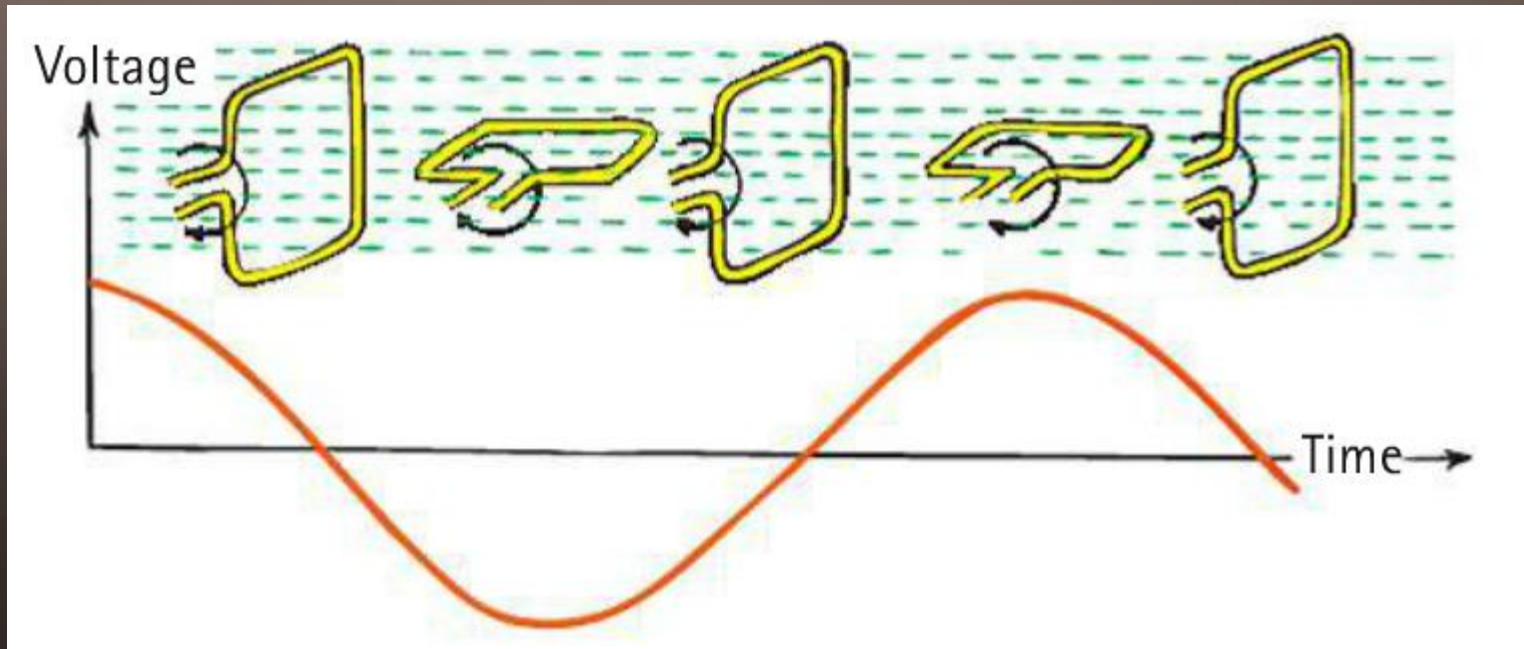
GENERATORS AND ALTERNATING CURRENT

- Continued rotation increases and decreases the number of enclosed lines in cyclic fashion.
- The greatest rate of change of field lines occurs when the number of enclosed field lines goes through zero.



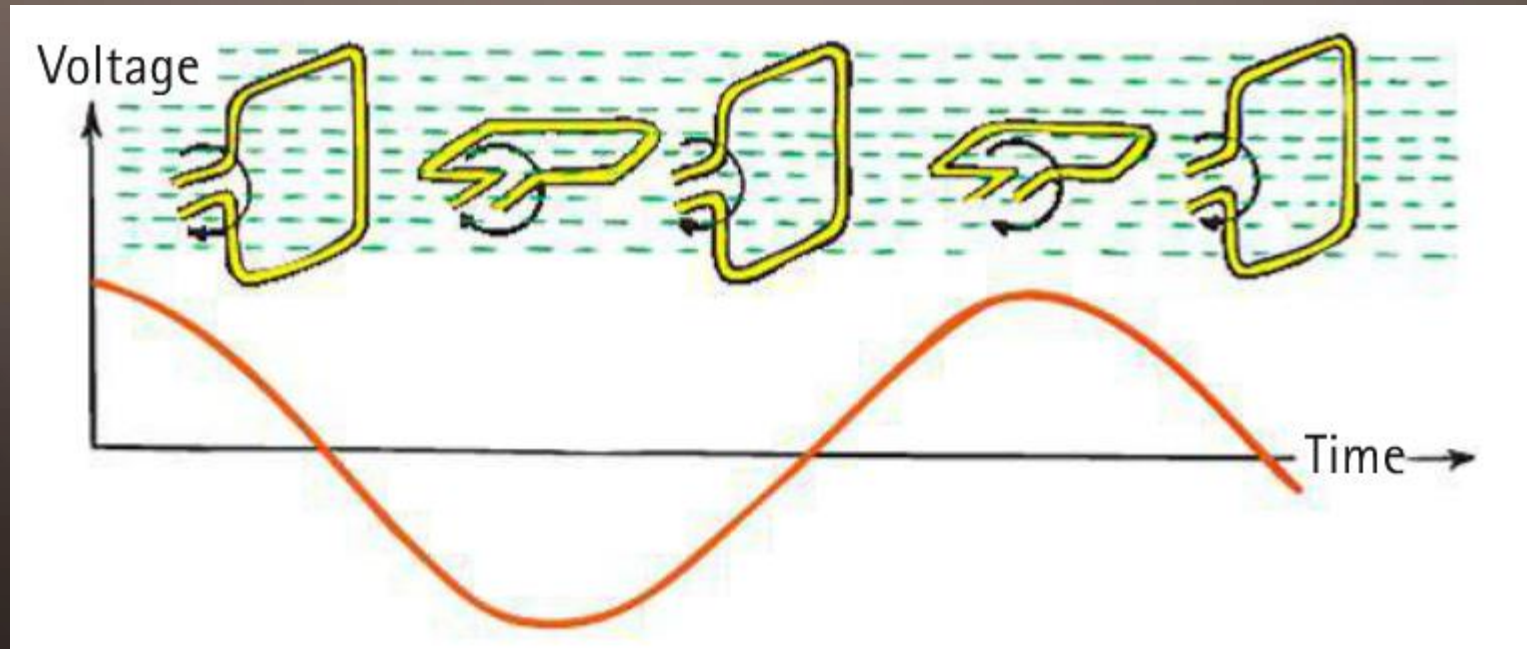
GENERATORS AND ALTERNATING CURRENT

- The induced voltage is greatest as the loop rotates through the parallel to the lines orientation.
- Because the voltage induced by the generator alternates, the current produced is an alternating current.



GENERATORS AND ALTERNATING CURRENT

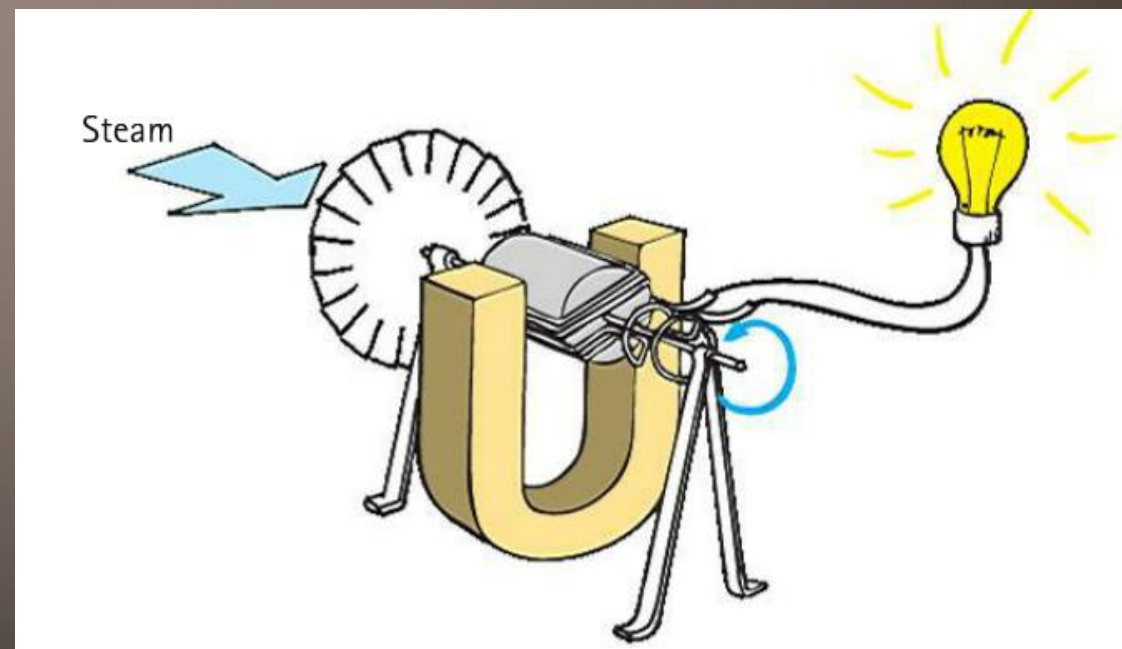
- Continued rotation increases and decreases the number of enclosed lines in cyclic fashion.
- The greatest change in rate of change of field lines occurs when the number of enclosed field lines goes through zero.





POWER PRODUCTION

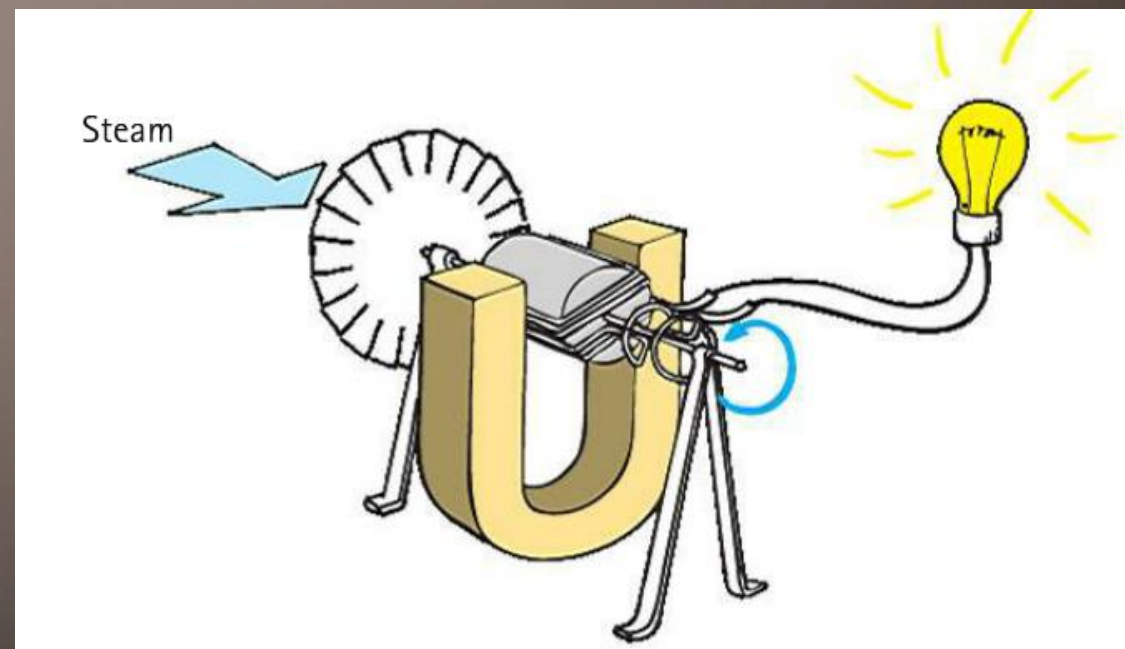
- Modern generators are a bit more complicated.
- They generally have armatures (remember, the wire coils are wrapped around an iron core...) that spin within a magnetic field.



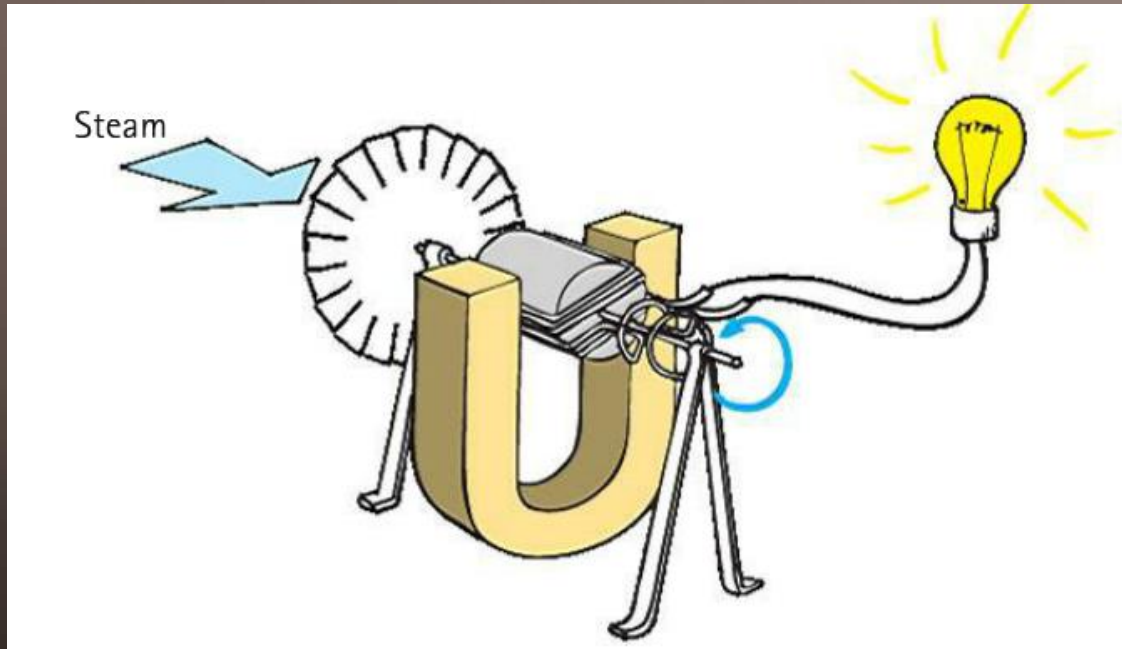


POWER PRODUCTION

- They are made to spin by means of a turbine.
- The turbine is in turn spun by water (hydroelectric), wind or steam (coal, oil, hydroelectric, or nuclear).



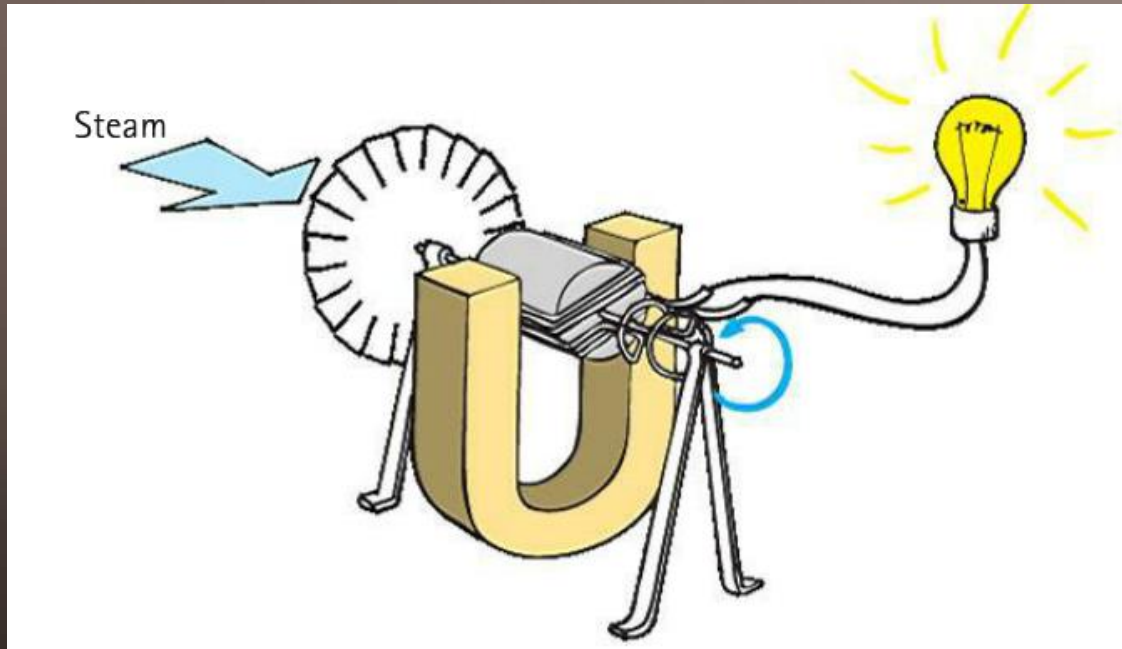
POWER PRODUCTION



- On an atomic level, here's what's happening:

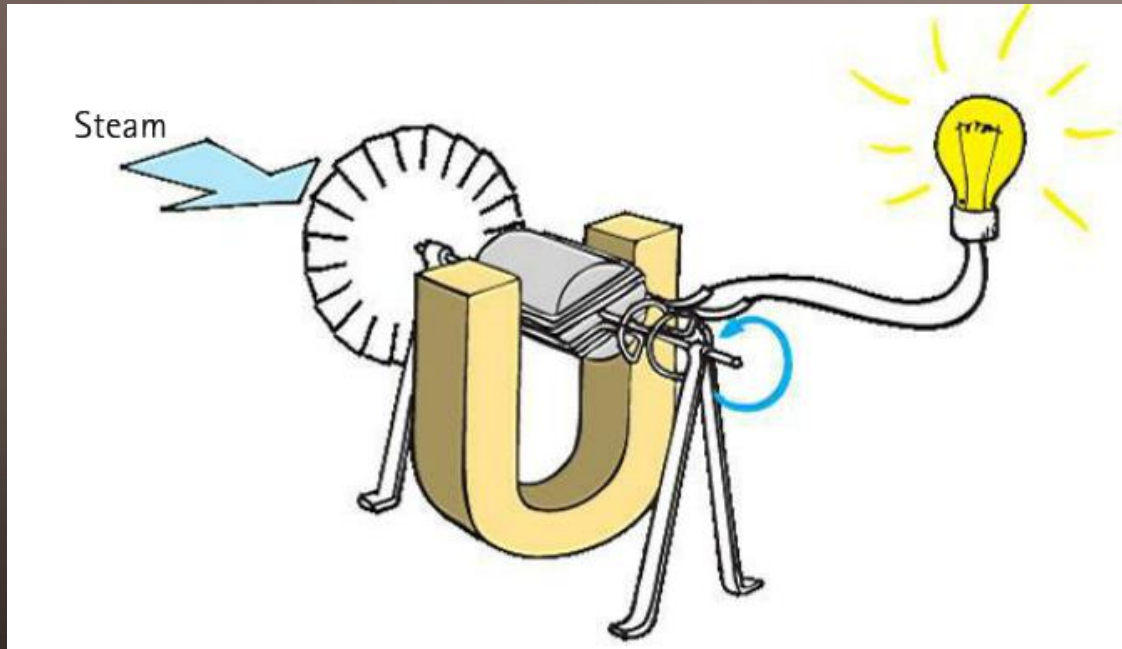
1. The wires in the armature cut through the magnetic field, and electromagnetic forces act on the negative and positive forces in the copper atoms.

POWER PRODUCTION



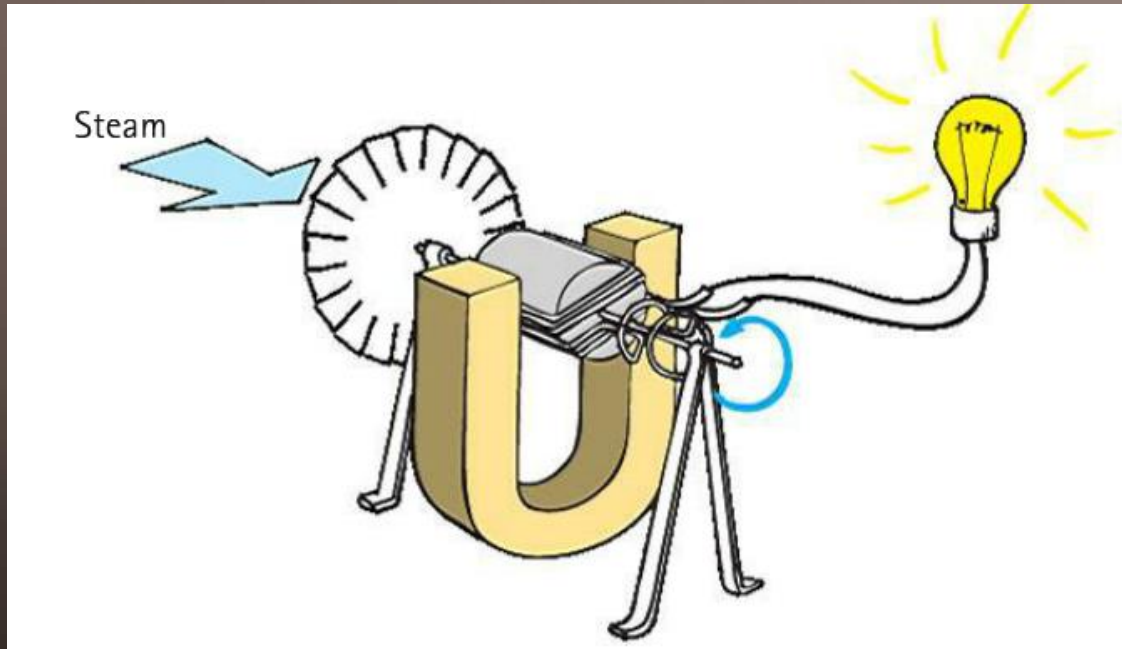
2. Electrons respond by swimming in one direction through the copper wire.

POWER PRODUCTION



3. The copper atoms (at this point positive copper ions) attempt to move in the opposite direction. (they are stuck in the crystal lattice, though, and can't move much.)

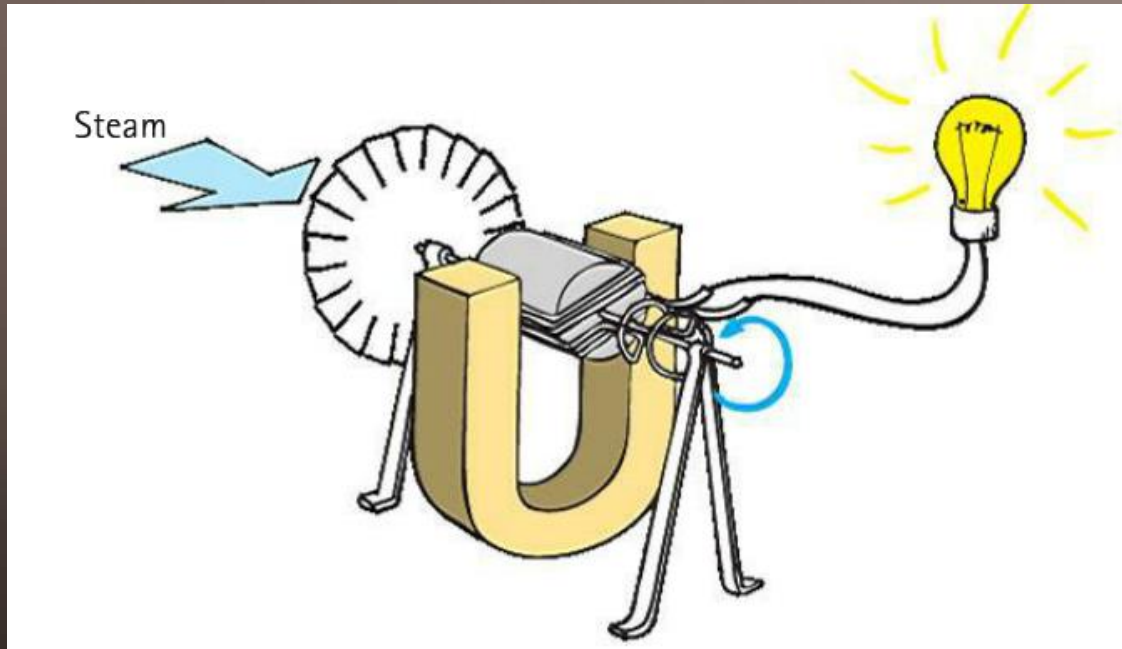
POWER PRODUCTION



4. Only the electrons are free to move, and slosh back and forth with each rotation of the armature.

5. The energy of this “sloshing” is collected at the electrode terminals of the generator.

POWER PRODUCTION



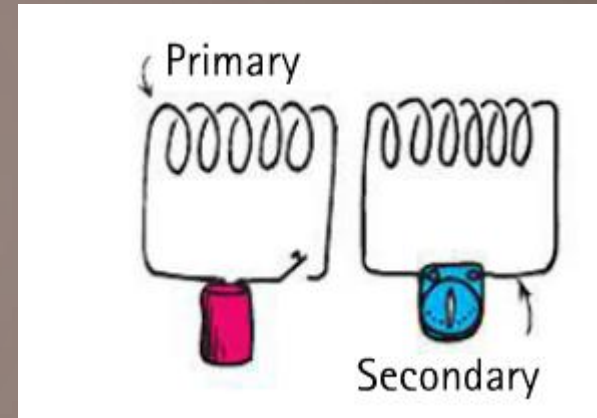
IMPORTANT NOTE:

Generators do NOT produce energy!!

They convert mechanical energy into electrical energy!

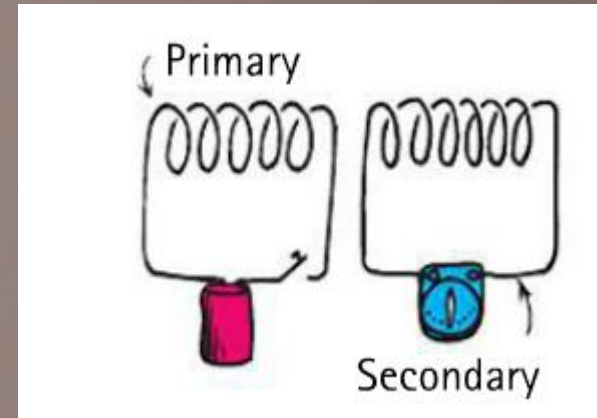
They do not defy the law of conservation of energy!!!

TRANSFORMERS



- Energy can be carried across empty space, transferred from one device to another with the arrangement of two coils.
- Here, one coil is connected to a battery, while the other is connected to a galvanometer.

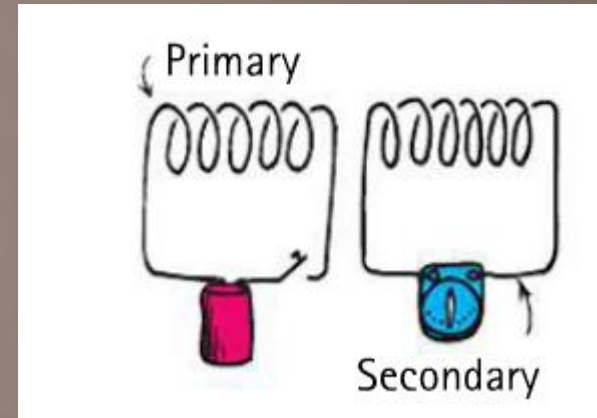
TRANSFORMERS



The input circuit (the one with the battery) is referred to as the **primary**.

The output circuit (the one with the galvanometer) is referred to as the **secondary**.

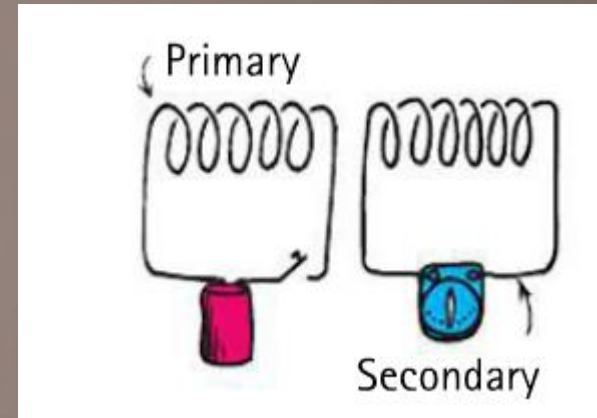
TRANSFORMERS



As soon as the switch is closed in the primary, current passes through its coil.

Current passes through the secondary also, even though there is no connection between the two.

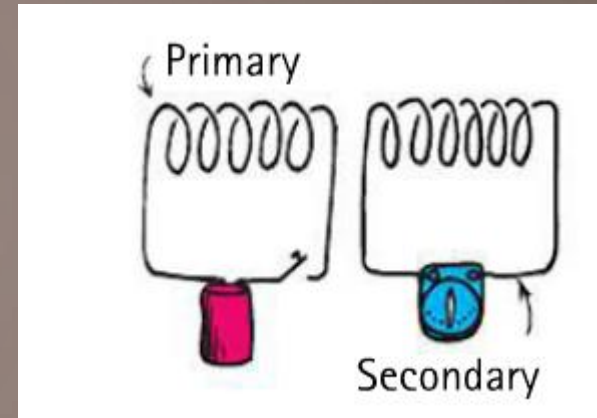
TRANSFORMERS



Although the current through the primary is now steady, there is only a brief surge of current through the secondary as the switch in the primary is closed.

When the switch in the primary is opened again, there is another surge of current through the secondary, but in the opposite direction.

TRANSFORMERS

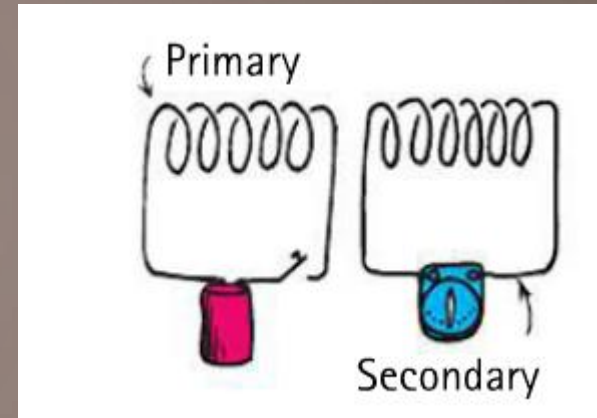


Here's what's happening:

A magnetic field builds up around the primary when the current begins to flow through the coil. (it is growing...changing)

Since the coils are near each other, this changing field extends to the secondary coil, inducing a voltage in the secondary.

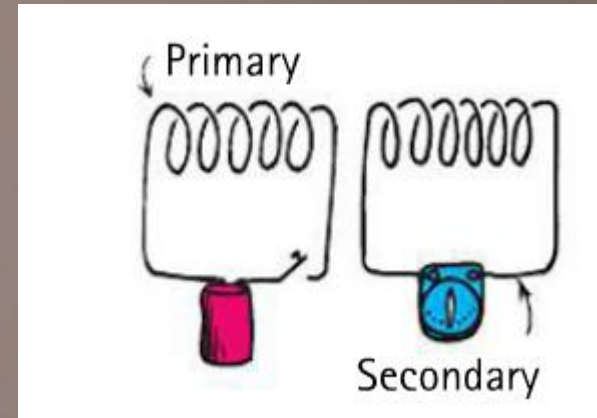
TRANSFORMERS



Remember, to induce a voltage, the magnetic field must be changing.

This induced voltage is only temporary, because the magnetic field created by the primary is only TEMPORARILY CHANGING!

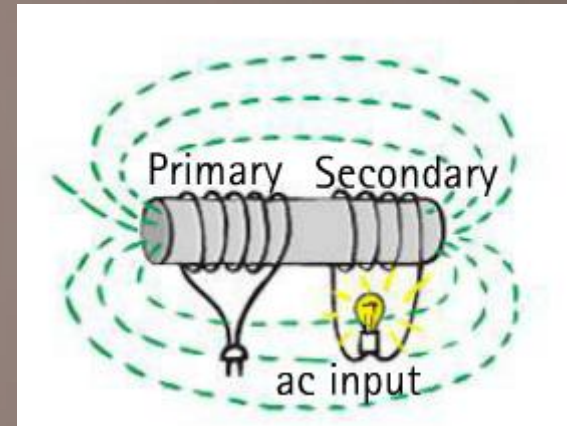
TRANSFORMERS



When the switch is turned off, the magnetic field around the primary changes again, and we get another voltage induced in the secondary.

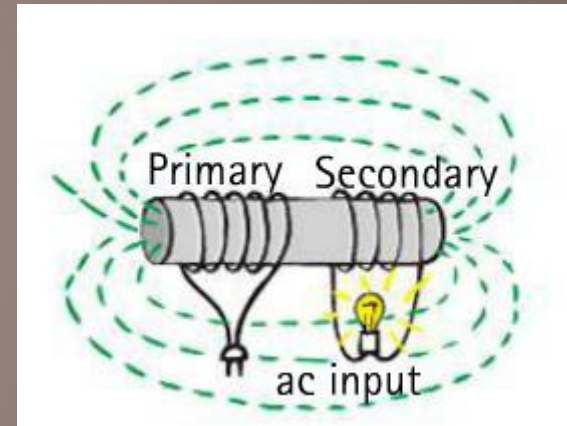
Voltage is induced whenever a magnetic field is changing through the coil, regardless of the reason it's changing.

TRANSFORMERS



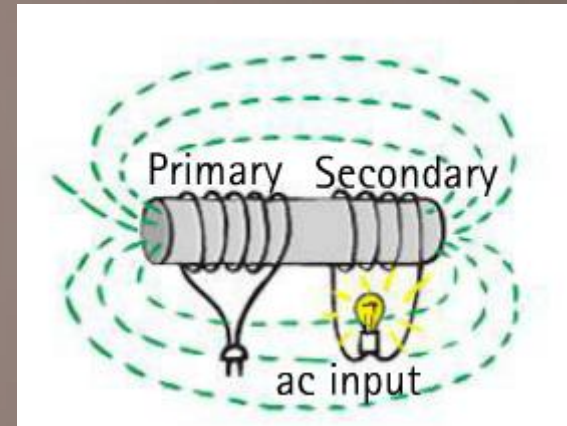
- If you place an iron core inside the coils, the magnetic field becomes stronger.
- The field is concentrated in the core, and extends into the secondary.
- The secondary then “feels” more of the field change.

TRANSFORMERS



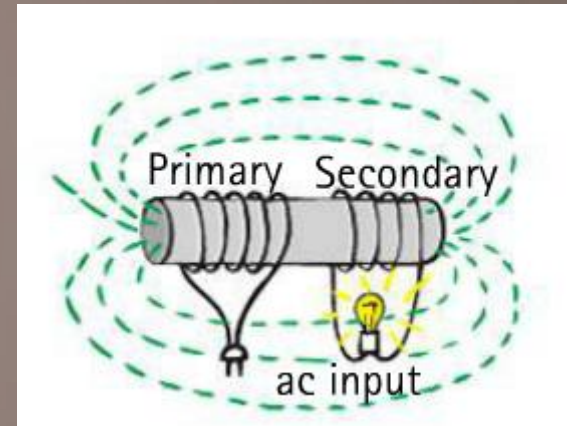
- If alternating current is used to power the primary, there is no need to continually open and close the switch!
- The frequency changes in the current through the primary now cause periodic changes in the magnetic field with the same frequency.

TRANSFORMERS



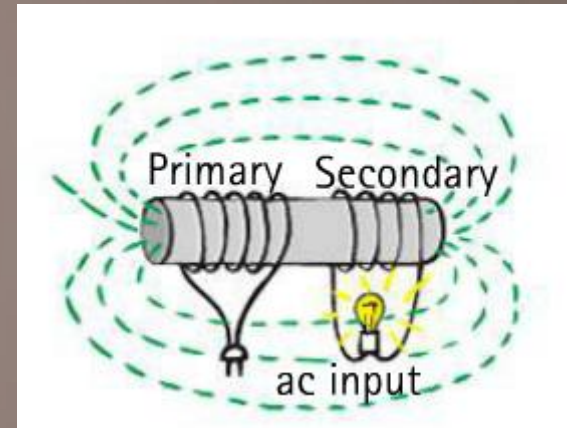
- If the primary and secondary have equal numbers of wire loops (called **turns**) then the input and output AC voltages will be equal.
- If the secondary coil has more turns than the primary, the alternating voltage produced in the secondary coil will be more than that produced in the primary.
- The voltage is said to be **stepped up**.

TRANSFORMERS



- If the secondary has fewer turns than the primary, the alternating voltage produced will be lower than that in the primary.
- The voltage is said to be **stepped down**.

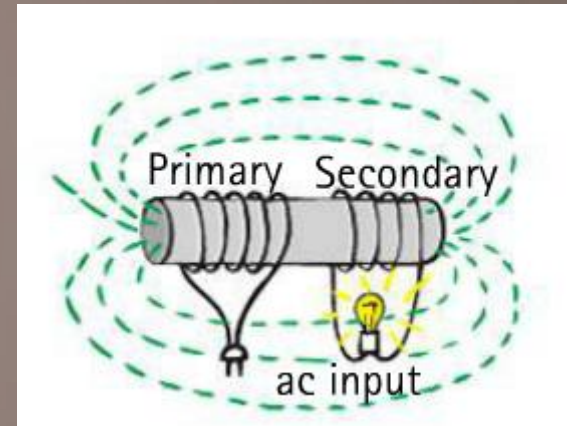
TRANSFORMERS



- The relationship between the primary and secondary voltages is given by:

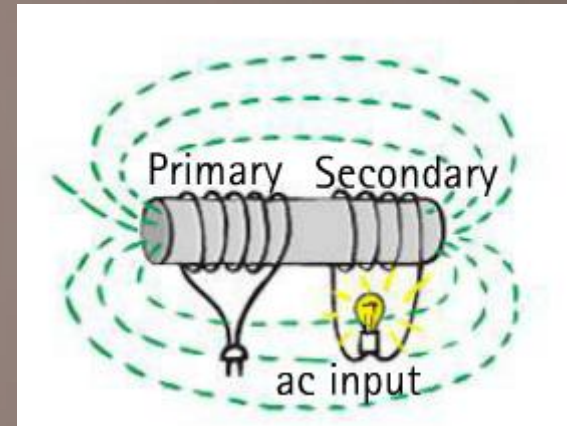
$$\frac{\text{primary voltage}}{\text{number of primary turns}} = \frac{\text{secondary voltage}}{\text{number of secondary turns}}$$

TRANSFORMERS



- The law of conservation of energy says we can't get something for nothing, so there is a trade-off with transformers.
- When the voltage is stepped up, there is a reduction in current. (in other words, the current in the secondary is less than the current in the primary).
- When the voltage is stepped down, the current in the primary is less than the current in the secondary.

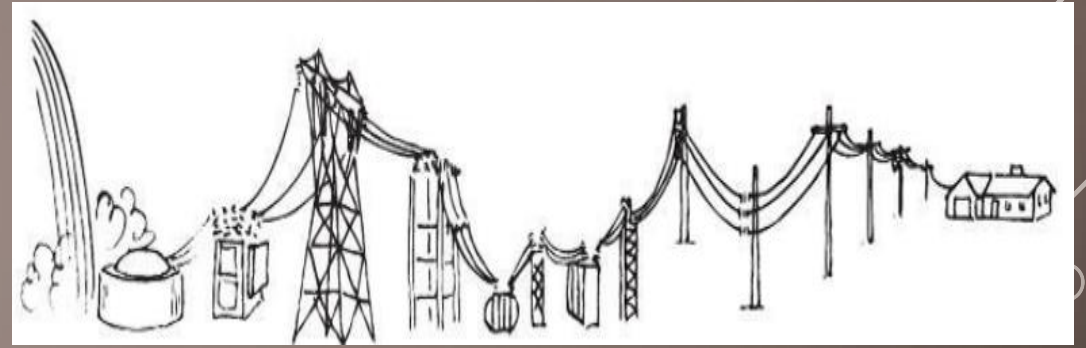
TRANSFORMERS



- Either way...
- *Power into primary = power out of secondary.*
- In other words...

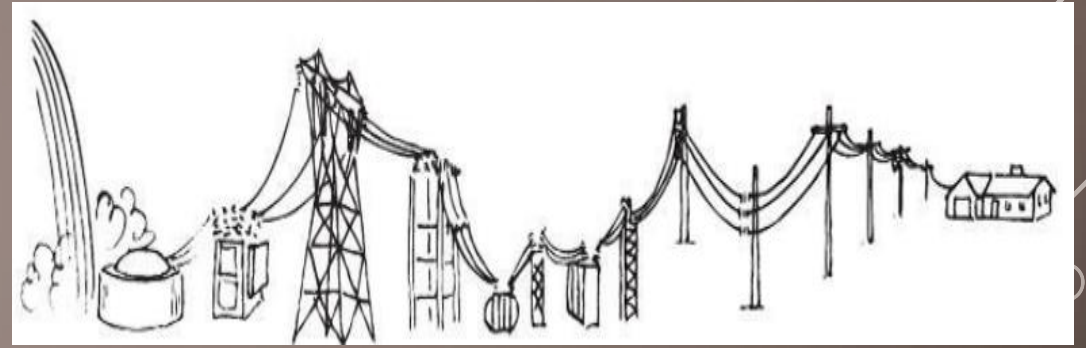
$$(\text{voltage} \times \text{current})_{\text{primary}} = (\text{voltage} \times \text{current})_{\text{secondary}}$$

POWER TRANSMISSION



- Most electric energy today is AC, because of how easy it is to transform from one voltage to another.
- Large currents in wires produce energy losses through heat, therefore, power is transported at high voltages and low currents.

POWER TRANSMISSION



- It is then stepped down (to lower voltages but higher currents) for distribution to homes and industry.
- Energy is transferred from one system of conducting wires to another by electromagnetic induction (transformers!).

FIELD INDUCTION

- We don't need wires to produce a field!!
- AN ELECTRIC FIELD IS INDUCED IN ANY REGION OF SPACE IN WHICH A MAGNETIC FIELD IS CHANGING WITH TIME!
- To go along with that...
- A MAGNETIC FIELD IS INDUCED IN ANY REGION OF SPACE IN WHICH AN ELECTRIC FIELD IS CHANGING WITH TIME!

FIELD INDUCTION

