Unit 8

Electricity and Magnetism

Electric Current…

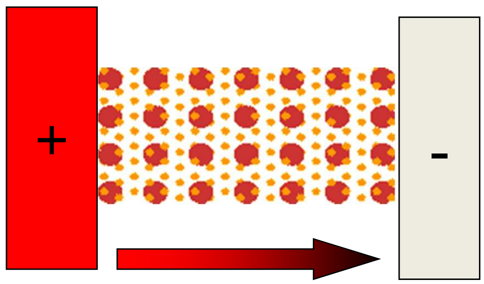
- …..Is the movement of electric charges.

REQUIREMENTS FOR A CURRENT TO FLOW

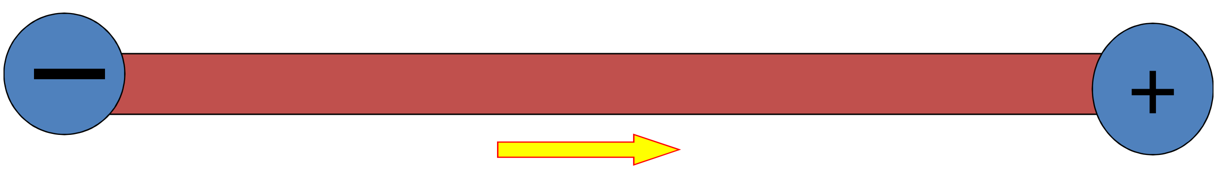
1. A Conducting Path
2. A Source of Potential Difference

i.e. a source of VOLTS - V

e.g. **C**ell [battery] or **G**enerator



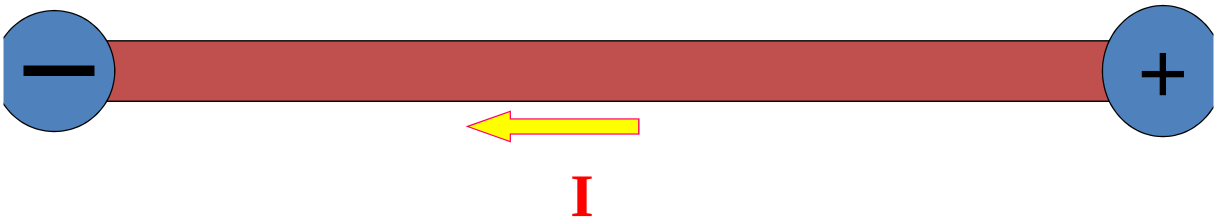
Current vs. Electron Flow



I_e

In metals electrons move from the negative terminal (repulsion) to the positive terminal (attraction). We call it an electron flow I_e.

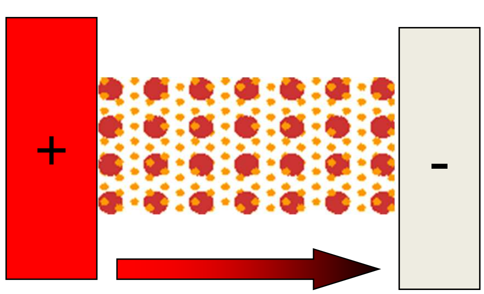
Current vs. Electron Flow



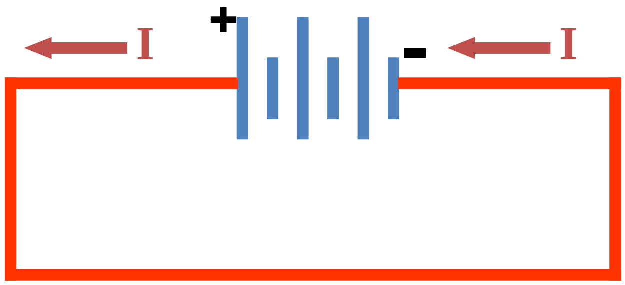
The direction of electric current is *<u>opposite</u>* to the electron flow. It is equivalent to the movement of positive charges.

The Current rule

The direction of electric current (I) is from high potential **(+)** to the low potential (-)



Current in a Circuit

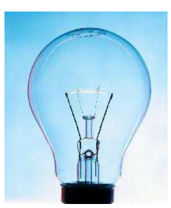


The unit of electric current is the ***ampere***.

The symbol for the ampere is ***A***.

The “shortcut” for ampere is the ***amp***.

Typical current values



Light Bulb - 1 A

TV - 4 A

Toaster - 10 A

Typical current values

Calculator - 0.002 A

Watch – 0.000 13 A

Other Units of Electric Current

1 μA = 0.000 001 A = 10^{-6} A

1mA = 0.001 A = 10^{-3} A

1 A = basic unit

1kA = 1000 A

CURRENT

A measure of the number of electric charges ***(Q)*** passing a point of a circuit in one second.

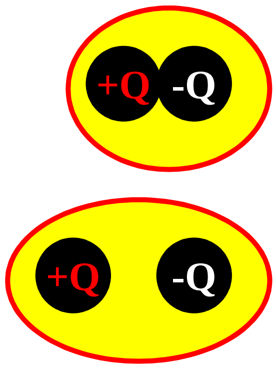
$$\boxed{I = Q/\Delta t = charge/time}$$

Electric Current

$$I = \frac{Q}{\Delta t}$$

Quantity	Symbol	SI unit
current	I	A (ampere)
amount of charge	Q	C (coulomb)
time interval	Δt	s (second)

Electric potential
- Charge Separation



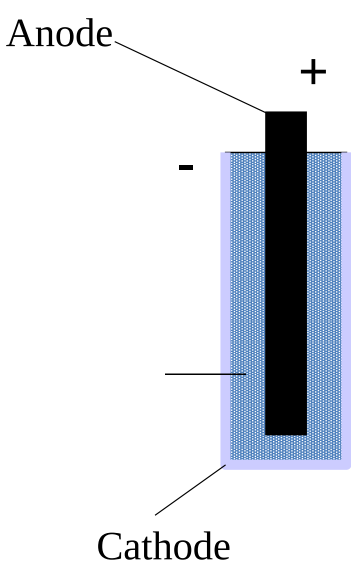
-The object is neutral

Moving one of the charge away from the other requires energy!

Separated charges have (electric) **potential energy**

and the capacity to do work

A Chemical Cell (battery)



•A chemical cell separates charges.

•The energy used for separation is a chemical energy.

•This energy is converted to electrical energy.

Voltage –the ability to "push" electrons through a circuit

Electric Potential Difference

- Electric Potential Difference
  - The electric potential difference between two points in a circuit is the change in the electric potential energy of charges between those points divided by of the amount of the charge.

$$V = \frac{\Delta E_Q}{Q}$$

Electric Energy and Power

$$V = \frac{\Delta E_Q}{Q}$$

$$\Delta E_Q = V \times Q$$
$$Q = I \times \Delta t$$
$$\Delta E_Q = V \times I \times \Delta t$$

$P = \frac{\Delta E_Q}{\Delta t}$ (power)

$$P = \frac{V \times I \times \Delta t}{\Delta t}$$

- $\boldsymbol{P = V \times I}$

Electric potential (voltage) is measured in

V O L T S

Symbol - V

Other units:

1 mV = 0.001 V

1 kV = 1000 V

1 μV = $1x10^{-6}$ V

What does an electric current flowing through a conductor depend on?

1. **Potential difference - voltage**
2. **Properties of the conductor - RESISTANCE**

Electrical resistance

The ability of a conductor to impede the flow of charges.

Symbol - R

Units - Ω (ohms)

Ohm's Law

– The potential difference across a load equals the product of the current through the load and the resistance of the load.

$$V = IR$$

Quantity	Symbol	SI unit
potential difference	V	V (volt)
current	I	A (ampere)
resistance	R	Ω (ohm)

Ohm's Law

$$V = IR$$

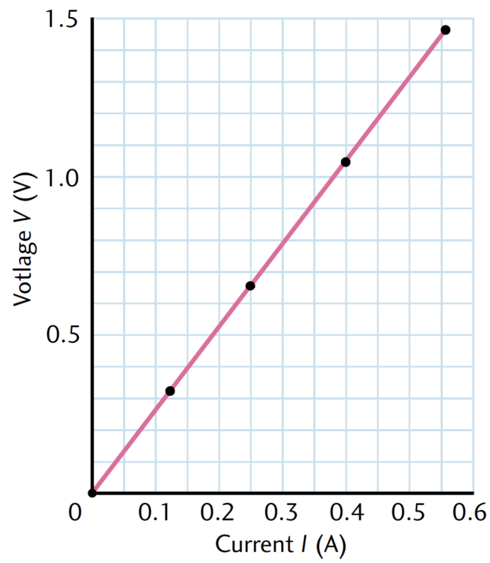


Table 16.4
Factors that Affect Resistance

Factor	Description	Proportionality
Length	The longer the conductor, the greater the resistance.	If the length is doubled, then the resistance is doubled $\frac{R_1}{R_2} = \frac{L_1}{L_2}$.
Cross-sectional area	The larger the cross-sectional area or thickness of the conductor, the less resistant it has to charge flow.	If the cross-sectional area is doubled, the resistance goes to half of its original value $\frac{R_1}{R_2} = \frac{A_2}{A_1}$.
Type of material	Some materials are better conductors than others. The general measure of the resistance of a substance is called the **resistivity**. Resistivity has units Ω·m.	If the resistivity (ρ) is doubled, then the resistance is also doubled. $\frac{R_1}{R_2} = \frac{\rho_1}{\rho_2}$
Temperature	Since moving charge is impeded by molecules, greater molecular motion at higher temperatures tends to increase the resistance.	An increase in temperature of the conductor usually contributes to an increase in the resistance, but not for all substances.

Resistance of a Conductor

- Resistance of a Conductor
  - The resistance of a conductor is the product of the resistivity and the length divided by the cross-sectional area.

$$R = \rho\frac{L}{A}$$

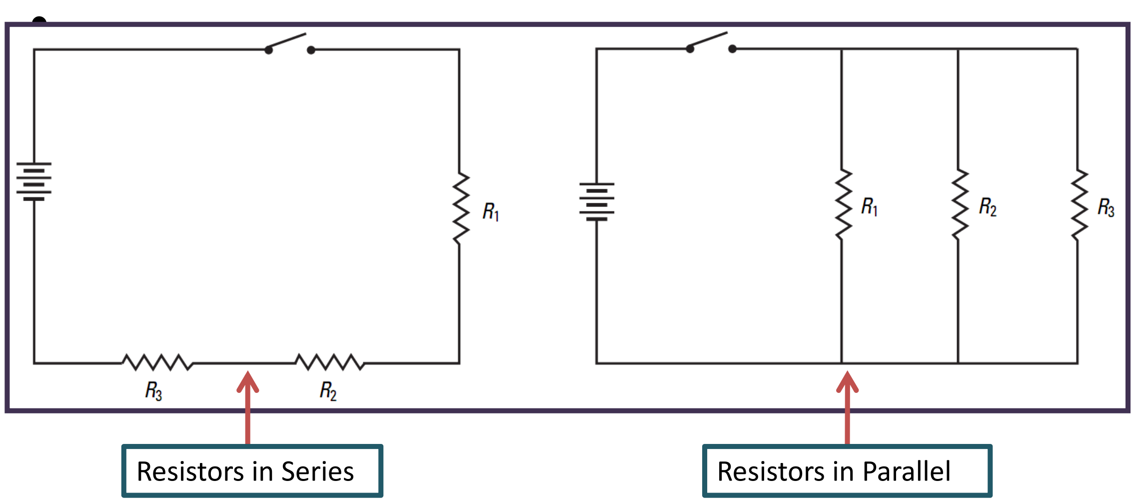
Resitivity of common materials

$$R = \rho\frac{L}{A}$$

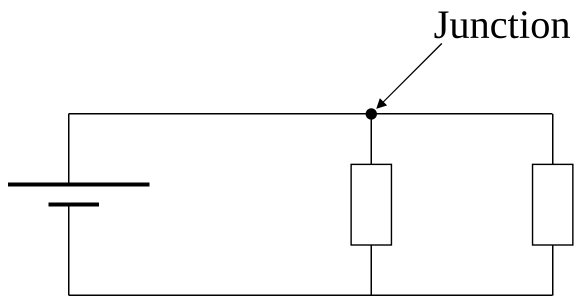
Material	*Resistivity, ρ ($\Omega \cdot$ m)
silver	1.6×10^{-8}
copper	1.7×10^{-8}
aluminum	2.7×10^{-8}
tungsten	5.6×10^{-8}
Nichrome™	100×10^{-8}
carbon	3500×10^{-8}
germanium	0.46
glass	10^{10} to 10^{14}

Series
and
Parallel Circuits

Resistors in Series and Parallel

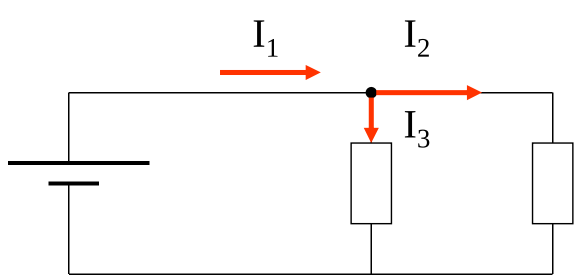


Kirchhoff's Current Rule (KCR)



At any junction, the total current into the junction equals the total current out of the junction

Kirchhoff's Current Rule (KCR)

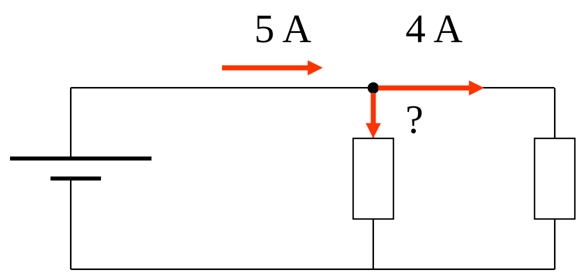


Current IN : I_1

Current OUT : I_2 and I_3

KCR: $I_1 = I_2 + I_3$

Kirchhoff's Current Rule (KCR)



Current IN : 5 A

Current OUT : 4 A and ?

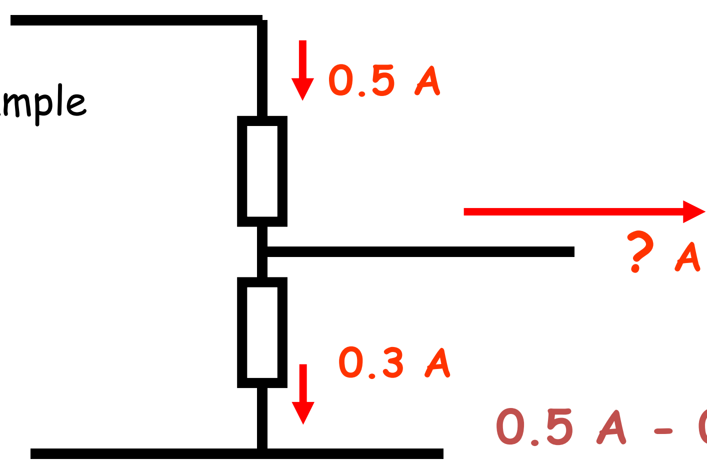
$5\text{ A} = 4\text{ A} + ?$

$? = 1\text{A}$

PUTTING IT SIMPLY

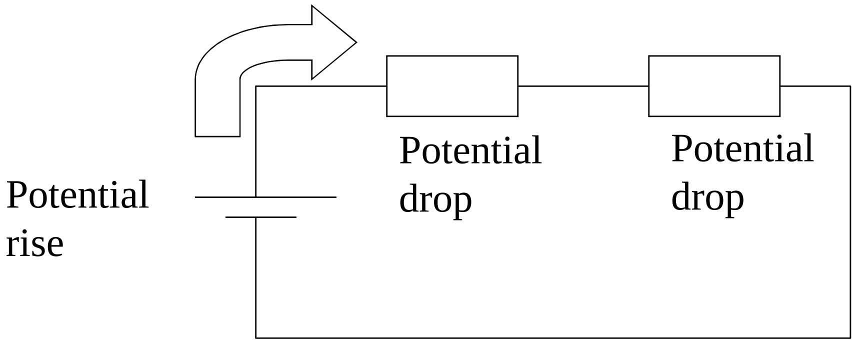
CURRENT IN **EQUALS** **CURRENT OUT**

Example



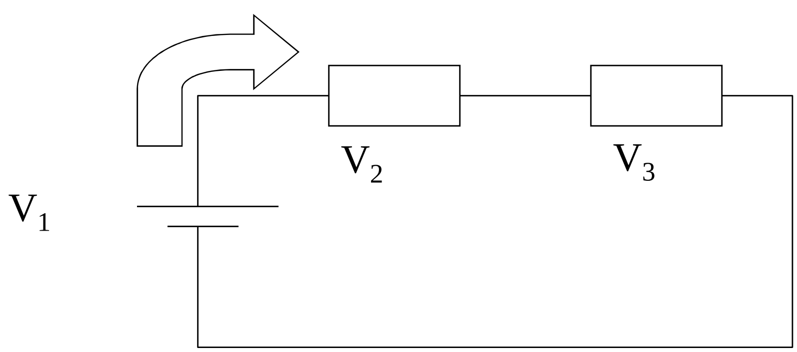
$0.5\text{ A} - 0.3\text{ A} = 0.2\text{ A}$

Kirchhoff’s Voltage Rule (KVR)



In any loop of electric circuit, the sum of potential rises equals the sum of potential drops.

Kirchhoff’s Voltage Rule (KVR)

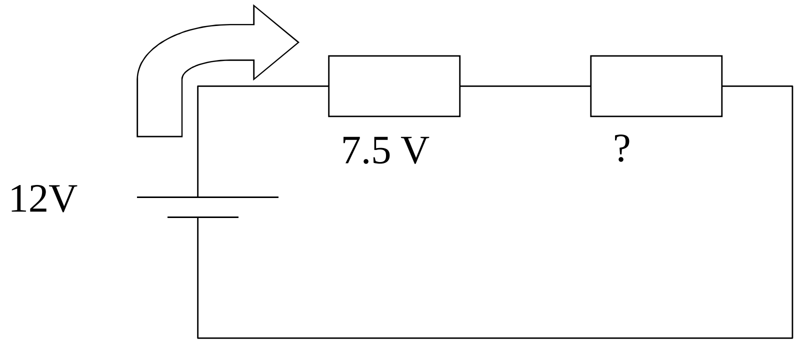


Voltage rise: V_1

Voltage drop: V_2 and V_3

KVR: $V_1 = V_2 + V_3$

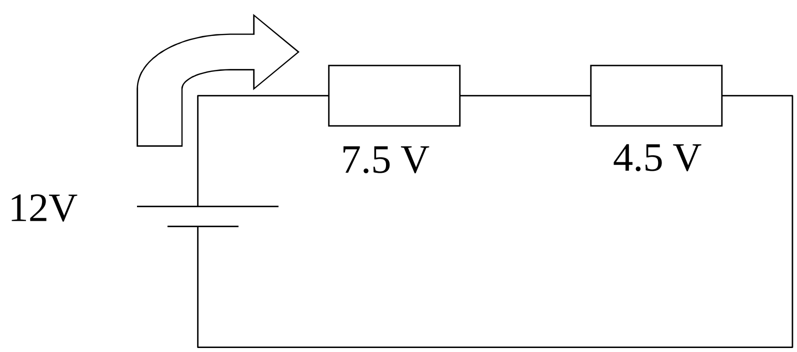
Kirchhoff's Voltage Rule (KVR)



12 V = 7.5 V + ?

? = 4.5 V

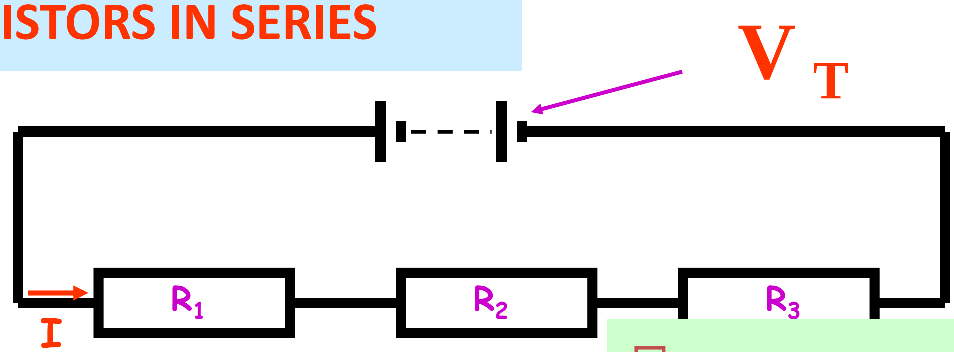
Kirchhoff's Voltage Rule (KVR)



12 V = 7.5 V + ?

? = 4.5 V

RESISTORS IN SERIES



By Kirchhoff's Voltage Rule:

? $V_T = IR_1 + IR_2 + IR_3$

$= I(R_1+R_2+R_3)$

If we apply Ohm's Law to the whole circuit, we have ? V_T= IR, where R is the total resistance

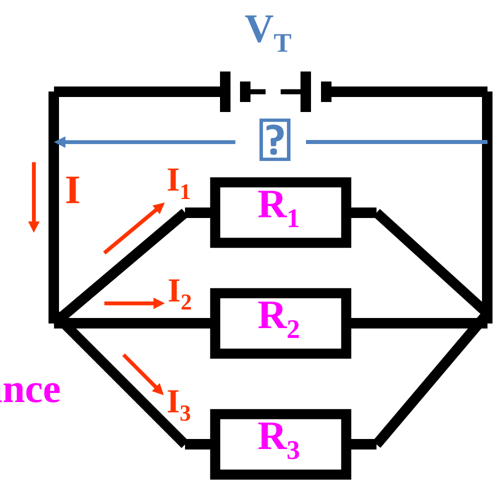
So $IR = I(R_1+R_2+R_3)$

$$R = R_1+R_2+R_3$$

RESISTORS IN PARALLEL

By Kirchoff's Current Rule

$I = I_1 + I_2 + I_3$

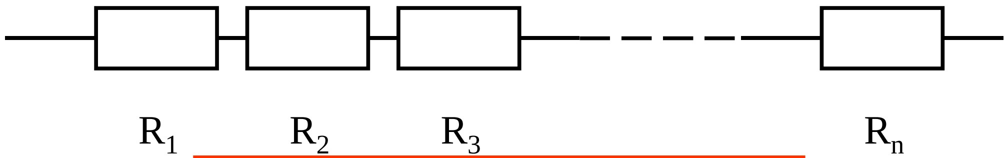


We now apply Ohm's Law to each component and to the whole circuit, letting R = the total resistance

$$\frac{V}{R} = \frac{V}{R_1} + \frac{V}{R_2} + \frac{V}{R_3}$$

$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$

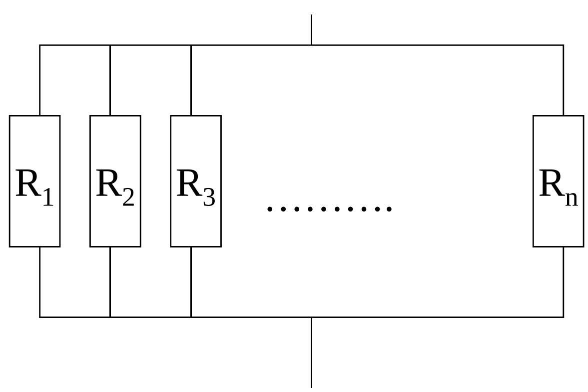
n Resistors in Series



$$\boxed{\mathbf{R_t = R_1 + R_2 + R_3 + \ldots\ldots + R_n}}$$

The total resistance increases when more resistors are added in series.

n Resistors in Parallel



$$\frac{1}{R_n} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \ldots\ldots + \frac{1}{R_n}$$

The total resistance decreases when more resistors are added in parallel.

Resistors in Series

$$R_{\text{eq}} = R_1 + R_2 + R_3 + \cdots + R_{\text{N}}$$

Resistors in Parallel

$$\frac{1}{R_{\text{eq}}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \cdots + \frac{1}{R_{\text{N}}}$$

Internal Resistance, Electromotive Force, Terminal Voltage

- Internal Resistance
  - Referring to the resistance within the battery itself
  - Like an engine itself would create friction inside. The engine needs to at least overcome the friction in itself.
  - Same as battery
- Electromotive Force (*emf* or $\mathcal{E}$)
  - With out internal resistance
    - terminal voltage = $\mathcal{E}$

Terminal Voltage and *emf*

- Terminal Voltage and *emf*
  - The terminal voltage (or potential difference across the poles) of a battery is the difference of the *emf*($\mathcal{E}$) of the battery and the potential drop across the internal resistance of the battery.

$$V_S = \mathcal{E} - V_{int}$$

Terminal Voltage and *emf*

- Terminal Voltage and *emf*

$$V_S = \mathcal{E} - V_{int}$$

If current is NOT flowing through a battery, then the potential difference across the internal resistance will be zero (V_{int}=0)

Electric Power

- Electric Power
  – Power is the product of current and potential difference.

$$P = IV$$

Quantity	Symbol	SI unit
power	P	W (watt)
current	I	A (ampere)
potential difference	V	V (volt)

Alternative Equations for Power

- Alternative Equations for Power

(use the Ohm's law to prove these equations)

$$P = \frac{V^2}{R}$$

$$P = I^2R$$

Sample Problem #1

– A battery has a potential difference of 18.0 V. How much work is done when a charge of 64.0 C moves from the anode to the cathode?

Solution:

$$W = \Delta E = Q\Delta V$$
$$W = (64.0\ C)(18.0\ V) = 1150\ J$$

Sample Problem #2

– The electrical system in your home operates at a potential difference of 120.0 volts. A toaster draws 9.60 A for a period of 2.50 min to toast two slices of bread.
  - (a) Find the amount of charge that passed through the toaster.
  - (b) Find the amount of energy the toaster converted into heat (and light) while it toasted the bread.

Solution (a)

$Q = I \times \Delta t = (9.60\ A)(150\ s)$

$Q = 1.44\ \times 10^3$ C

Solution (b)

$\Delta E = Q\Delta V$

$W = (1.44\ \times 10^3\ \text{C})(120.0\ V)W$

$= 1.72 \times 10^5\ J$

Sample Problem #3

Calculate the resistance of a 15m length of copper wire, at 20ºC, that has a diameter of 0.050cm.

Solution:

$$R = \varrho \frac{L}{A}$$

$$A = \pi \frac{d^2}{4} = \pi \frac{(5.0 \times 10^{-4} m)^2}{4} = 1.96 \times 10^{-7}\ m^2$$

$$R = (1.7 \times 10^{-8}\ \Omega m\ \times \frac{15\ m}{1.96 \times 10^{-7}\ m^2} = 1.3\ \Omega$$

Sample Problem #4

– Four loads (3.0 Ω, 5.0 Ω, 7.0 Ω and 9.0 Ω) are connected in series to a 12 V battery. Find

- (a) The equivalent resistance of the circuit
- (b) The total current in the circuit
- (c) The potential difference across the 7.0 Ω load

Solution (a)

R_s = 3.0 Ω + 5.0 Ω + 7.0 Ω + 9.0 Ω

R_s = 24 Ω
(total resistance of the circuit in series)

Solution (b)

$I = \frac{\Delta V}{R_T}$ *(Ohm's law for the circiuit)*

$I = \frac{12\ V}{24\ \Omega} = 0.50\ A$

Solution (c)

$\Delta V_{R7} = I \times R$
(Ohm's law for a load)

$\Delta V_{R7} = 0.50\ A \times 7.0\Omega = 3.5\ V$

Sample Problem #5

– A 60V battery is connected to four loads of 3.0 Ω, 5.0 Ω, 12.0 Ω and 15.0 Ω in parallel.
  - (a) Find the equivalent resistance of the four combined loads
  - (b) Find the total current leaving the battery
  - (c) Find the current through the 12.0 Ω load

Solution (a)

$R_P = (\frac{1}{3.0\ \Omega} + \frac{1}{5.0\ \Omega} + \frac{1}{12.0\ \Omega} + \frac{1}{15.0\ \Omega})^{-1}$

$R_P = 1.5\ \Omega$

(total resistance of the circuit)

Solution (b)

$I = \frac{\Delta V}{R_T}$ *(Ohm's law for the circuit)*

$I = \frac{60\ V}{1.5\ \Omega} = 40\ A$

Solution (c)

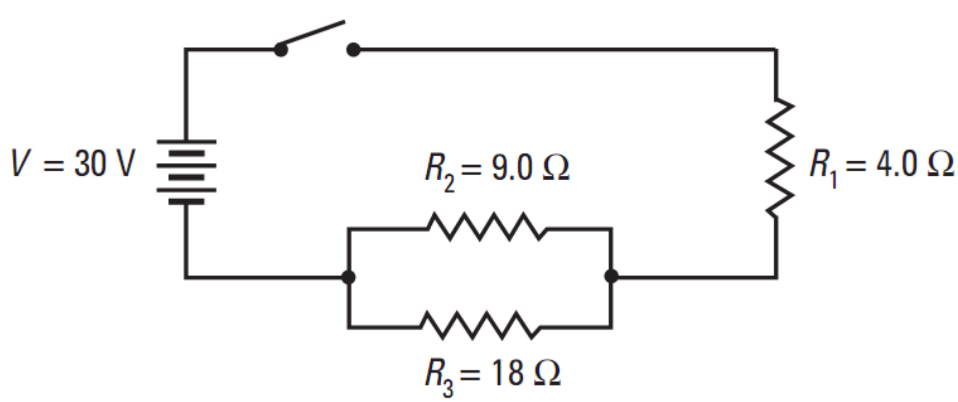
$I_{R12} = \frac{\Delta V}{R}$

(Ohm's law for a load)

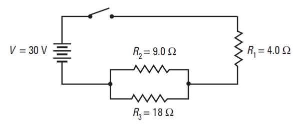
$I_{R7} = \frac{60\ V}{12\ \Omega} = 5.0\ A$

Sample Problem #6

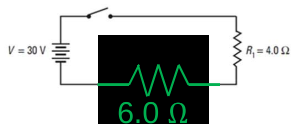
– Find the equivalent resistance of the entire circuit shown in the diagram, as well as the current through, and the potential difference across, each load.



Solution



$$R_P = \left(\frac{1}{9.0\ \Omega} + \frac{1}{18\ \Omega}\right)^{-1} = 6.0\ \Omega$$



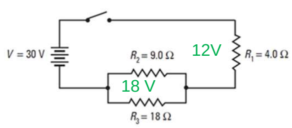
R_s = 6.0 Ω + 4.0 Ω = 10.0 Ω

$$I = \frac{\Delta V}{R_T}$$ *(Ohm's law for the circuit)*

$I = \frac{30\ V}{10\ \Omega}$ = 3.0 A *(total current, or battery current)*

I_1 = 3.0 A

$\Delta V_1 = I_1 R_1$ = (3.0 A)(4.0 Ω) = 12 V



$\Delta V_2 = \Delta V_3$ = 30 V – 12 V = 18 V

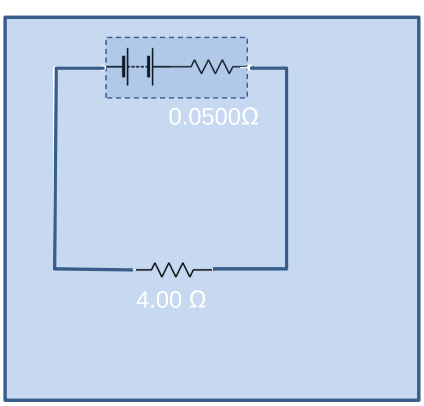
or $\Delta V_2 = \Delta V_3 = I\,Rp = (3.0\ A)(6.0\ \Omega) = 18\ V$

$$I_2 = \frac{18V}{9.0\Omega} = 2.0\ A$$

$$I_3 = \frac{18V}{18\ \Omega} = 1.0\ A$$

Sample Problem #7

– A battery with an *emf* of 9.00 V has an internal resistance of 0.0500 Ω. Calculate the potential difference lost to the internal resistance, and the terminal voltage of the battery, if it is connected to an external resistance of 4.00 Ω.



R_t = 4.00 Ω + 0.0500 Ω = 4.05 Ω

$$I = \frac{\Delta V}{R_t} = \frac{9.00\ V}{4.05\Omega} = 2.22\ A$$

$$\Delta V_{terminal} = I \times R_{ext} = 8.89\ V$$

or,

$$\Delta V_{terminal} = 9.00\ V - (2.22\ A)(0.0500\Omega)$$
$$\Delta V_{terminal} = 8.89\ V$$

Sample Problem #8

– What is the power rating of a segment of Nichrome wire that draws a current of 2.5 A when connected to a 12 V battery?

Solution:

$$P = I\,\Delta V = (2.5\ \mathrm{A})(12\ \mathrm{V}) = 30\ \mathrm{W}$$

Sample Problem #9

– In North America, the standard electric outlet has a potential difference of 120V. In Europe, it is 240V.
– (a) How does the dissimilarity in potential difference affect power output?
– (b) What would be the power output of a 100W-120V light bulb if it was connected to a 240V system?

$$P = \frac{V^2}{R}$$

Resistance of e device does not depend on the voltage or the current, if temperature does not change.

$$P_{NA} = \frac{(120V)^2}{R}$$

$$P_{EU} = \frac{(240V)^2}{R} = \frac{(2\times120V)^2}{R} = 4 \times P_{US}$$

The 100 W lightbulb would produce 400 W power if the voltage were doubled and would be burnt almost immediately.

Sample Problem #10

– An electric kettle is rated at 1500 W for a 120 V potential difference.
  - (a) What is the resistance of the heating element of the kettle?
  - (b) What will be the power output if the potential difference falls to 108 V?

Solution (a)

$$P = \frac{V^2}{R}$$

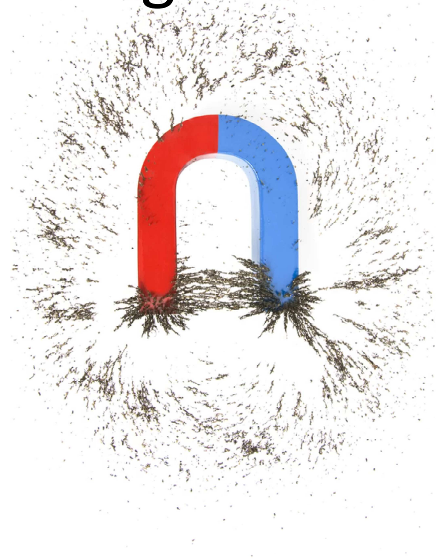
$$R = \frac{V^2}{P} = \frac{(120\,V)^2}{1500\,W} = 9.60\,\Omega$$

Solution (b)

The resistance does not change (poor assumption)

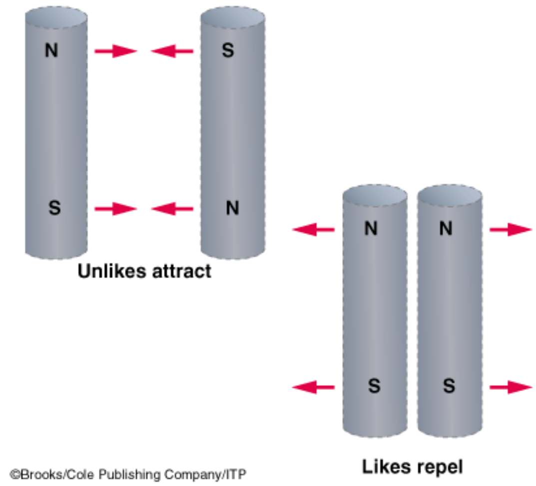
$$P = \frac{V^2}{R} = \frac{(108\,V)^2}{9.60\,\Omega} = 1210\,W$$

Magnetism

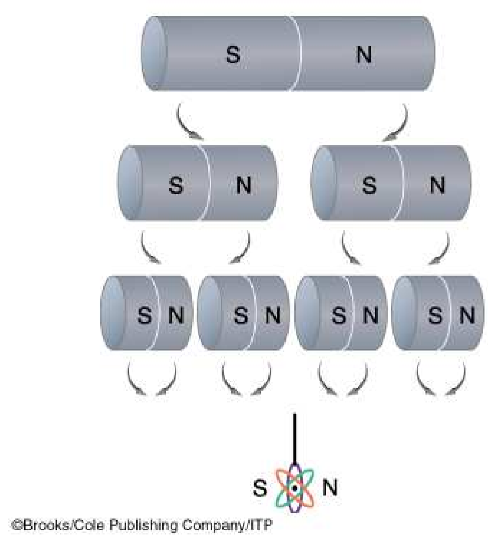


Magnets are Cool!

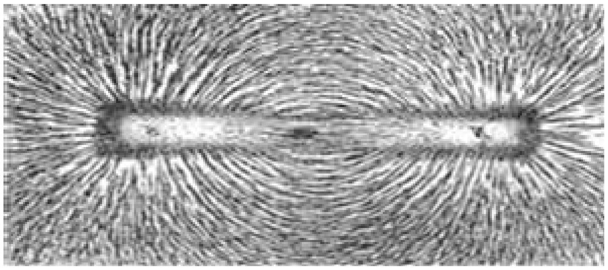
- North Pole and South Pole
  - Unlikes Attract
  - Likes Repel
- Earth's a magnet



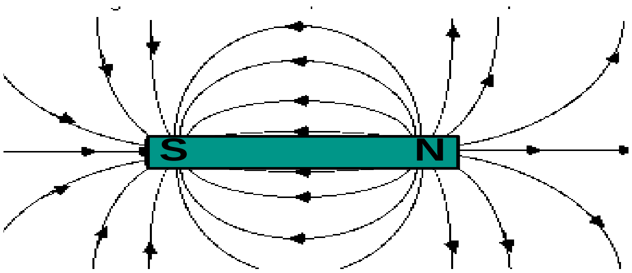
- North Pole and South Pole
  - Are inseparable



Magnetic Field Lines



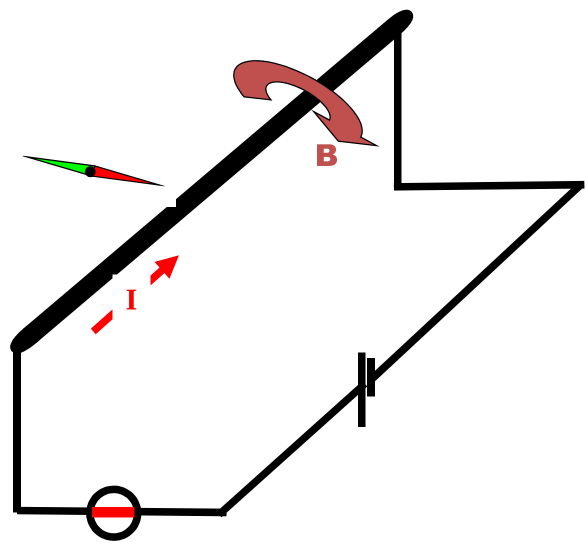
- Magnetic Field Lines
  - Arrows give direction (from N-pole to S-pole)

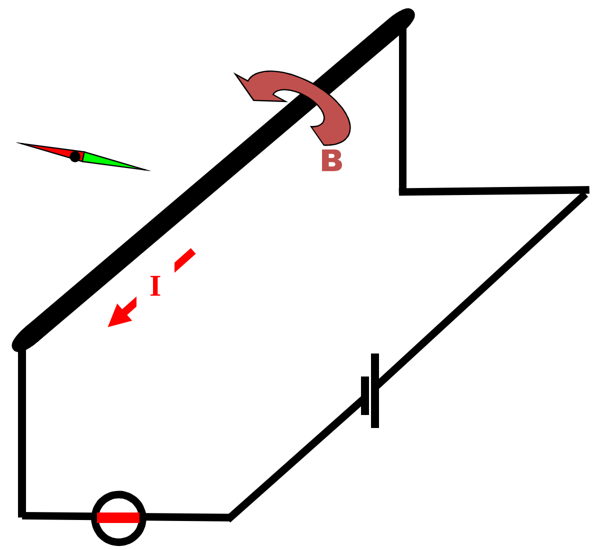


Professor Hans Christian Oersted

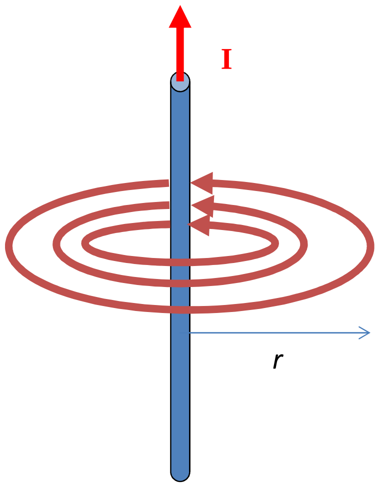
1820

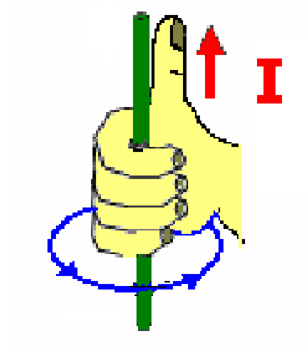
Professor Oersted was demonstrating an experiment for students when he accidentally discovered that a compass needle moved when it was close to a wire connected to a battery.


B
I


B
I

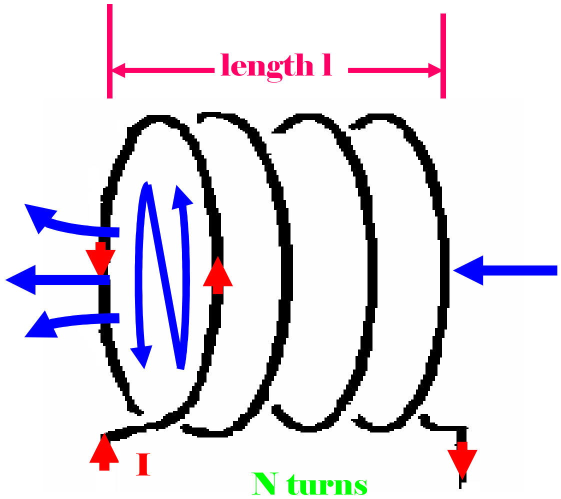
RIGHT HAND GRIP RULE:





$$B = \mu_0 \frac{I}{2\pi r}$$

$$\mu_0 = 4\pi \times 10^{-7} Tm/A$$

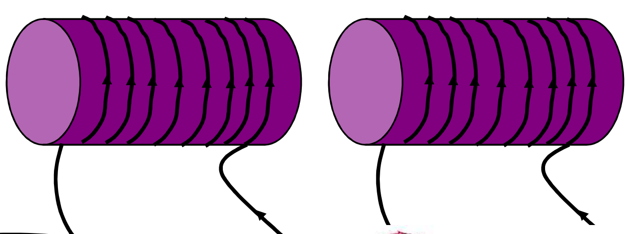


In the middle

$$\boxed{B = \frac{\mu_0 N I}{l}}$$

Magnetic field inside a solenoid is proportional to the number of turns and the electric current

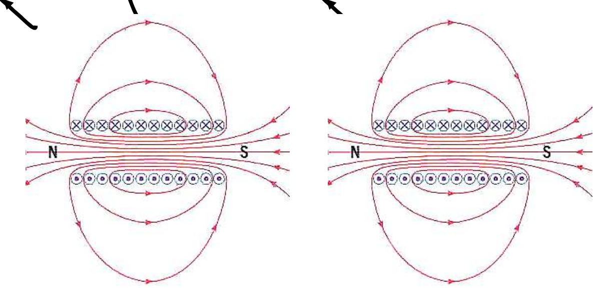
What is the net force between the two solenoids?



a)Attractive

b) Zero

b)Repulsive



Look at field lines, opposites attract.

Principles of Electromagnetism

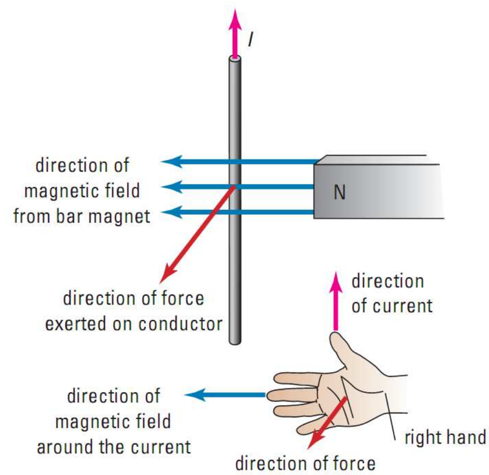
- Stationary charged particles do NOT interact with a magnetic field.
- Moving electric charges produce a magnetic field
- The direction of a magnetic field due to moving charges can be determined by using Right-Hand Rule

The Motor Principle

- Moving charges produce magnetic field
- Moving charges exert a force on an external magnet *(such as a compass needle)*
- **IMPLICATION:**
- ***(Hint: think N3LM)***

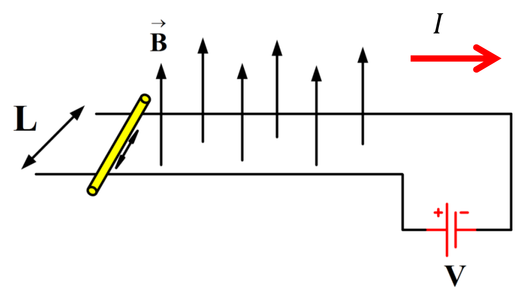
External magnetic field exerts a force on moving charges.

The Motor Principle



Magnetic Force on current Carrying Conductor

- $F_M = BIL\sin\theta$



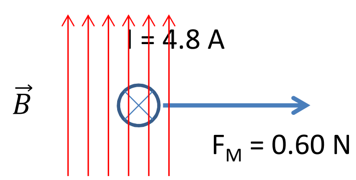
F_M – the magnetic force, in newtons
B – the magnetic field, in teslas
I – the electric current, in amperes
L – the length of the conductor in magnetic field, in meters
Θ – the angle between L and B

Sample Problem #1

– A length of straight conductor carries a current of 4.8 A into page at right angels to a magnetic field. The length of the conductor that lies inside the magnetic field is 25cm If this conductor experiences a force of 0.60 N to the right, what is the magnetic field strength acting on the current?

Solution

- $F_M = BIL \sin\theta$



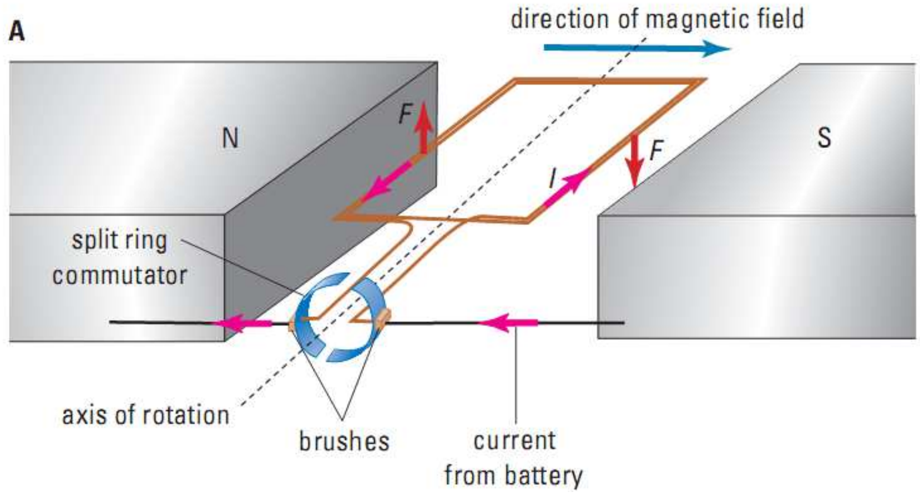
RHR : $\vec{B}\ is\ up$

$$sin\theta = 1$$

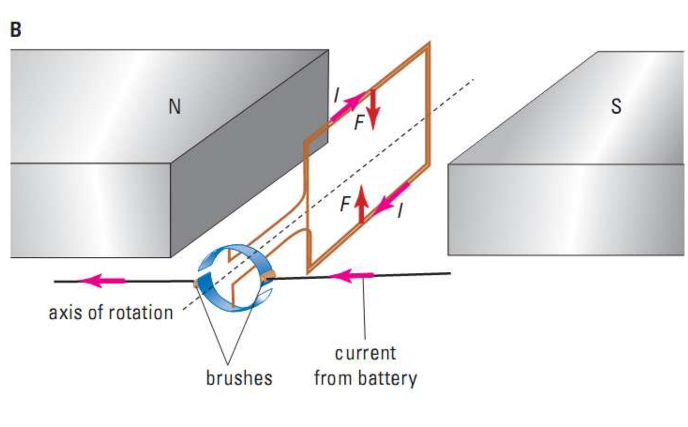
$$\boldsymbol{B = \frac{F}{IL} = \frac{0.60\ N}{(4.8\ A)(0.25m)} = 0.50\ T}$$

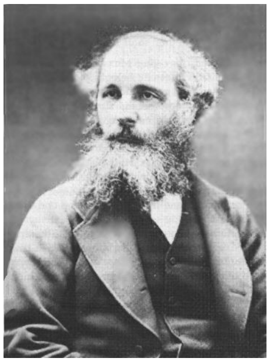
DC Motor

- DC Motor
  - The direction of the magnetic pole is important

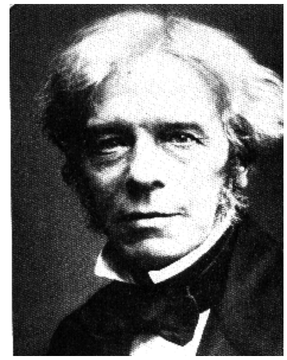


DC Motor





James Clerk Maxwell



Michael Faraday

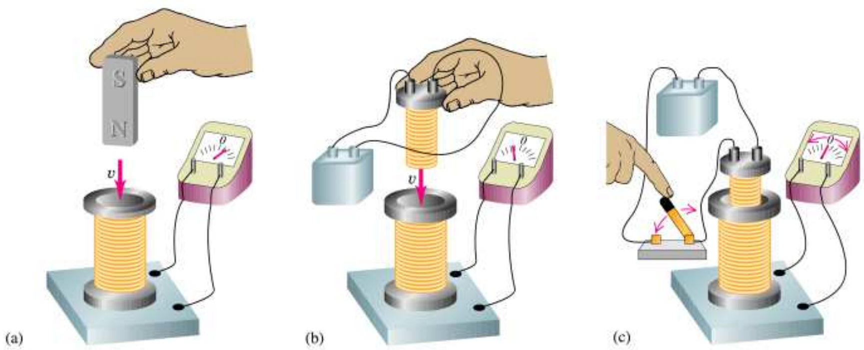
Electromagnetic Induction

Electromagnetism

- **Electricity and magnetism are different facets of *electromagnetism***
  - **a moving electric charge produces magnetic fields**
  - **changing magnetic field creates electric field**
- **This connection first elucidated by Faraday and Maxwell**
- **Einstein saw electricity and magnetism as frame-dependent facets of *unified* electromagnetic force**

Induced Current

- The next part of the story is that a *changing magnetic field* produces an electric current in a loop surrounding the field
  - called electromagnetic induction, or Faraday’s Law



Faraday’s Law of Electromagnetic Induction (1831):

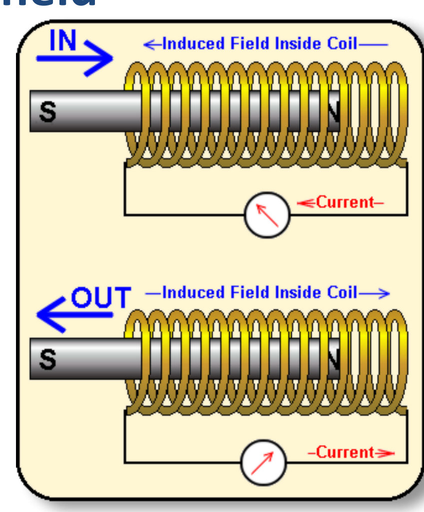
An electric current is induced in a conductor wherever the magnetic field in the region of the conductor changes with time

The factors affecting the magnitude of induced current are :

- Number of turns in the induction coil
- The rate of change of the inducing magnetic field

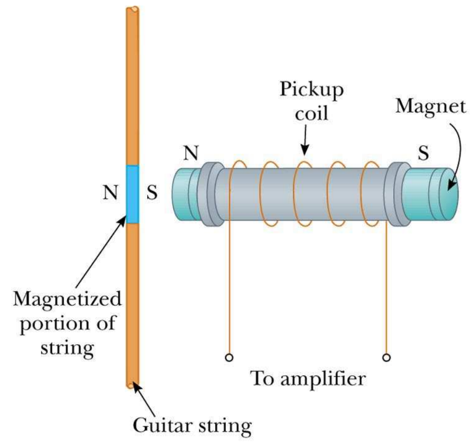
The Lenz's Law

- **The induced current flows in such a direction that the induced magnetic field it creates <u>opposes</u> the action of the inducing magnetic field**

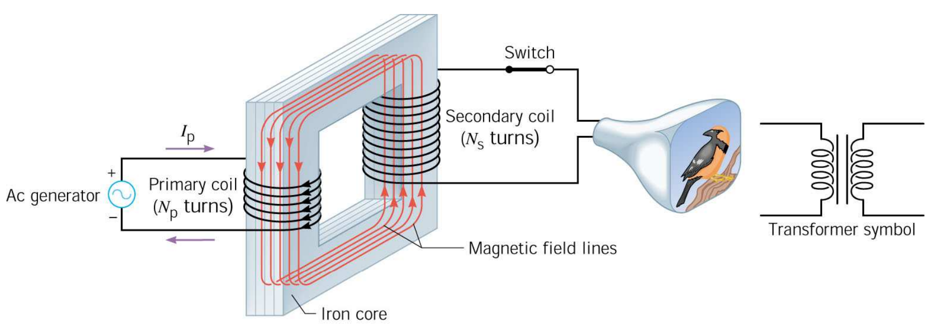


Applications of Faraday's Law – Electric Guitar

- A vibrating string induces an emf in a coil
- A permanent magnet inside the coil magnetizes a portion of the string nearest the coil
- As the string vibrates at some frequency, its magnetized segment produces a changing flux through the pickup coil
- The changing flux produces an induced emf that is fed to an amplifier



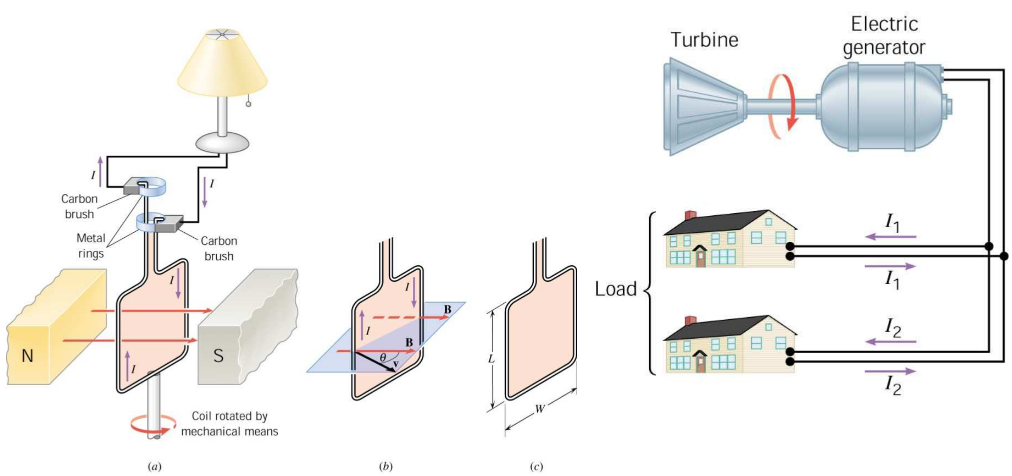
The Transformer



The voltage on the secondary depends on the number of turns on the primary and secondary.

Step-up→ the secondary has more turns than the primary
Step-down→ the secondary has less turns than the primary

Electric Generators



When a coil is rotated in a magnetic field, an induced current appears in it. This is how electricity is generated. Some external source of energy is needed to rotate the turbine which turns the coil.

The End