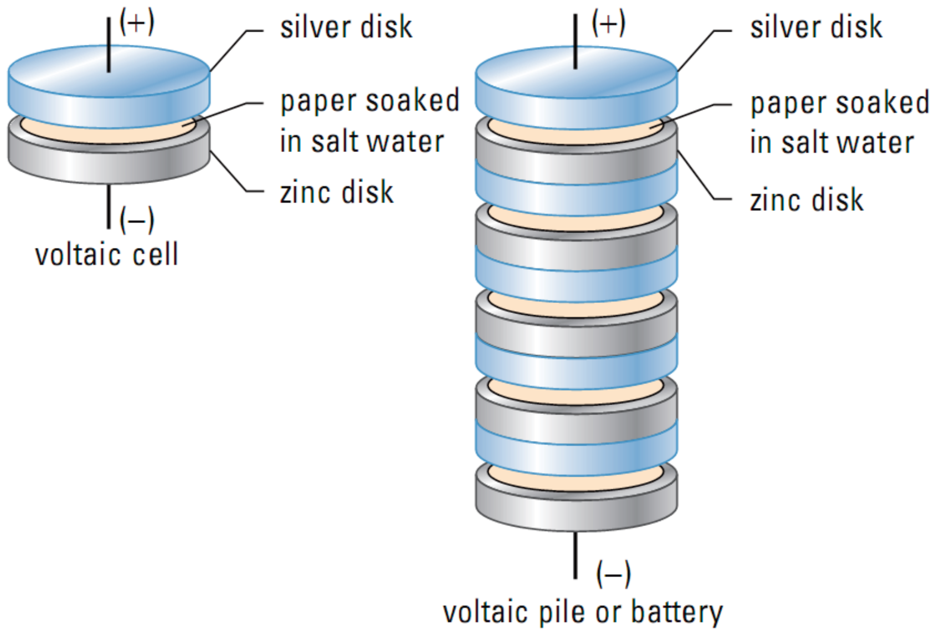
Electric Energy, Circuits and Magnetism

Grade 11 Physics

Electricity

Electric Potential Difference



Electric Potential Difference

- Voltaic Cell:
  - The previous diagram shows a voltaic cell.
  - Voltaic Pile/Battery – a stack of voltaic cell.

- The anode(+) and cathode(–) sign
  - The anode (upper path)(+)
  - The cathode (lower path)(–)
  - Chose arbitrially

Electric Potential Difference

Gravitational Potential

How much energy you carry /kg based on the height

V = IR

- Electric Potential Difference
  - The electric potential difference between any two points in a circuit is the quotient of the change in the electric potential energy of charges passing between those points and the quantity of the charge.

gh → Gravitational Potential Difference

Δh

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

change in energy

(coulombs) charge

Electric Potential Difference

- Electric Potential Difference

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

Quantity	**Symbol**	**SI unit**
electric potential difference	V	V (volt)
change in electrical potential energy	ΔE_Q	J (joule)
quantity of charge	Q	C (coulomb)

Example Problem

- Q1:
  - A battery has a potential difference of 18.0V. How much work is done when a charge of 64.0C moves from the anode to the cathode?

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

$V = 18.0V$

$Q = 64.0C$

$$\boxed{\Delta E = VC}$$

Electric Current

- Electric Current
  - Electric current is the quotient of the quantity of charge that moves past a point and the time interval during which the charge is moving.

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

Electric Current

- 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)

Example Problem

$I = \frac{Q}{\Delta t}$, $\Delta t = 2.5\,min = 150\,sec$

$V = 120V$ $\quad I = 9.60A$

- Q2:
  - The electrical system in your home operates at a potential difference of 120.0volts. A toaster draws 9.60A for a period of 2.50min to toast two slices of bread.
    - Find the amount of charge that passed through the toaster.
    - Find the amount of energy the toaster converted into heat (and light) while it toasted the bread.

a) $Q = I \cdot \Delta t$

$= 9.60A \cdot 150sec$

$= 1440\ C$

b) $V = \frac{\Delta E}{Q}$

$\Delta E = VQ$

$= 120\,V \cdot 1440\,C$

$= 172{,}800\,J$

Charge-Carrying Particles and Elementary Charge (*e*)

- Charge-Carrying Particles
  - J.J. Thomson discovered charge-carrying particle in 1897; however people are skeptical about this.

- Elementary Charge
  - Robert Andrews Millikan – Nobel Prize winner in physics in 1923.
  - Discovered elementary charge which is the charge of 1 electron or 1 proton.
  - Elementary Charge = 1.602×10^{-19} C

# of electron = 1 C ⇒ $\frac{1C}{1.602 \times 10^{-19}} = 6.24 \times 10^{18}$

Elementary Charge

- Elementary Charge
  - The amount of charge is the product of the number of elementary charge (electrons or protons) and the magnitude of the elementary charge.

$$Q = Ne$$

Elementary Charge

- Elementary Charge

1.602x10^-19

$$Q = Ne$$

constant

Quantity	Symbol	SI unit
amount of charge	Q	C (coulomb)
number of elementary charges	N	integer (pure number, no unit)
elementary charge	e	C (coulomb)

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.

$V = IR$

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

Resistance of a Conductor

- Resistance of a Conductor

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

Quantity	**Symbol**	**SI unit**
resistance	R	Ω (ohm)
resistivity	ρ	Ω · m (ohm metres)
length of conductor	L	m (metres)
cross-sectional area	A	m^2 (square metres)

Resistance of a Conductor

- Resistance of a Conductor

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

Gauge	Diameter (mm)	Resistance ($\times 10^{-3}$ Ω/m)
0	9.35	0.31
10	2.59	2.20
14	1.63	8.54
18	1.02	21.90
22	0.64	51.70

Material	*Resistivity, ρ (Ω · 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}

Example Problem

- Q4:
  - Calculate the resistance of a 15m length of copper wire, at 20ºC, that has a diameter of 0.050cm.

0.00050m

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

Area $= \pi R^2$

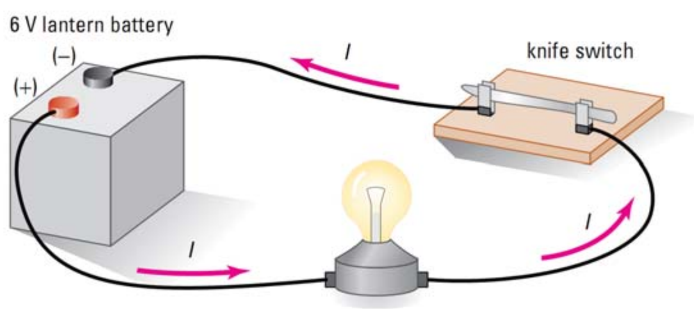
look up on chart

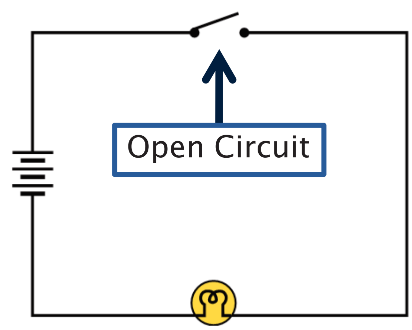
Electric Potential, Current and Resistant

- Electric Potential VS Water Potential
  - Voltage vs Steepness
- Electric Current VS Water Current
  - Charge/Time vs Volume/Time
- Electric Resistant VS Water Resistant
  - Electrical Resistance vs Rocks

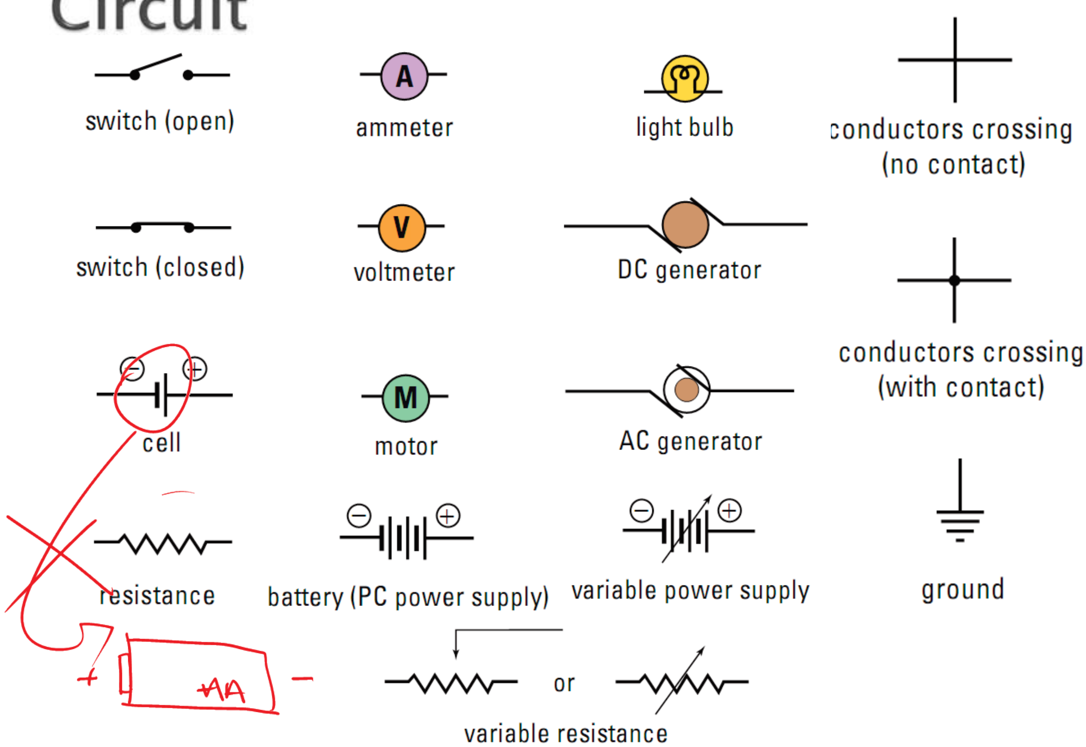
Electric Circuits

- Open Circuit
  - There is a break in the circuit (perhaps an open switch)
- Closed Circuit
  - All connections are complete.





Symbols for Elements of an Electric Circuit



Ohm's Law

- 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)

Example Problem

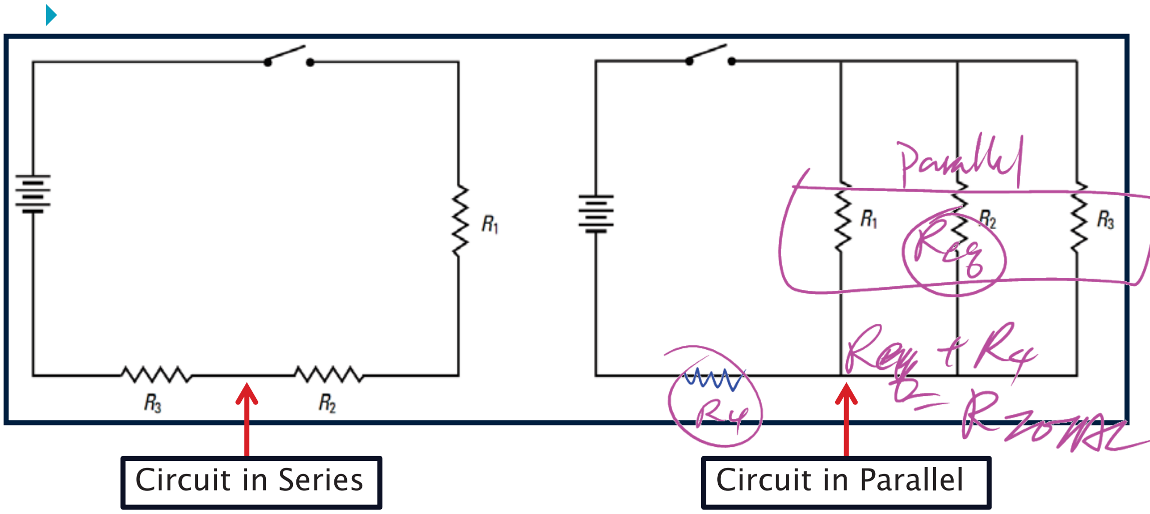
- Q5:
  - What is the resistance of a load if a battery with a 9.0V potential difference causes a current of 0.45A to pass through the load?

$V = IR$ $\quad$ $V = 9.0V$

$R = V/I$ $\quad$ $I = 0.45A$

Series and Parallel Circuits

Circuit in Series and Parallel



Circuit in Series

- Circuit in Series
  - The equivalent resistant of loads in series is the sum of the resistances of the individual loads.

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

Quantity	Symbol	SI unit
equivalent resistance	R_{eq}	Ω (ohm)
resistance of individual loads	$R_{1,2,3,\cdots N}$	Ω (ohm)

Example Problem

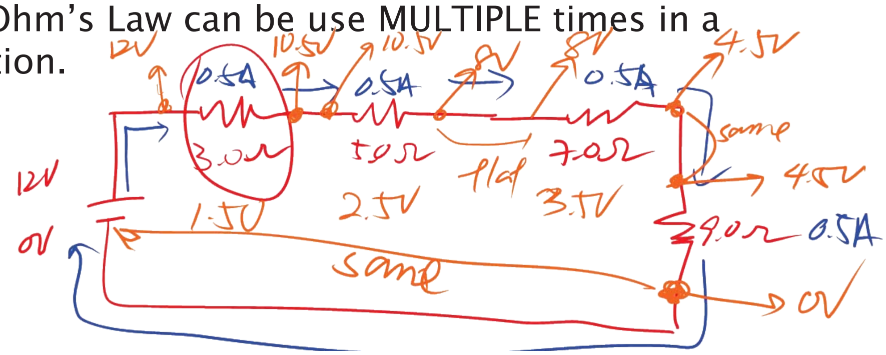
- Q5:
  - Four loads (3.0Ω, 5.0Ω, 7.0Ω and 9.0Ω) are connected in series to a 12V battery. Find
    - The equivalent resistance of the circuit
    - The total current in the circuit
    - The potential difference across the 7.0Ω load

$R_{eq} = 3+5+7+9$
$= 24\Omega$

$V = IR$
$I = V/R$
$= 12/24$
$= 0.5A$

HINT: Ohm's Law can be use MULTIPLE times in a question.

$V=IR$



Circuit in Parallel

- Circuit in Parallel
  - The inverse of the equivalent resistance for resistors connected in parallel is the sum of the inverses of the individual resistances.

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

Quantity	**Symbol**	**SI unit**
equivalent resistance	R_{eq}	Ω (ohm)
resistance of the individual loads	$R_1, R_2, R_3, \ldots, R_N$	Ω (ohm)

Example Problem

$$\frac{1}{R_{eq}} = \frac{1}{3} + \frac{1}{5} + \frac{1}{12} + \frac{1}{15} = \frac{20}{60} + \frac{12}{60} + \frac{5}{60} + \frac{4}{60} = \frac{41}{60}$$

- Q6

$$R_{eq} = \frac{60}{41}\,\Omega$$

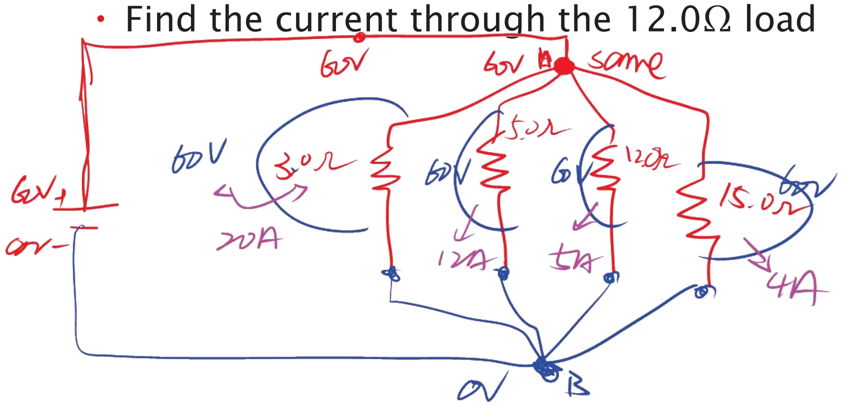
  - A 60V battery is connected to four loads of 3.0Ω, 5.0Ω, 12.0Ω and 15.0Ω in parallel.
    - Find the equivalent resistance of the four combined loads
    - Find the total current leaving the battery
    - Find the current through the 12.0Ω load

$V = IR$

$I = V/R$

$= 60V / \frac{60}{41}\Omega$

$= 41A$



Example Problem

$\frac{1}{R_{eq}} = \frac{1}{9} + \frac{1}{18} = \frac{3}{18}$

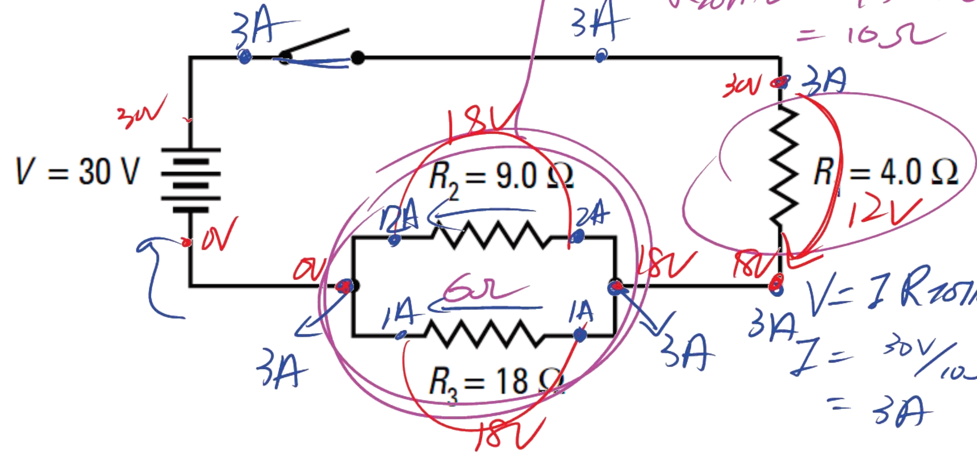
$= \frac{1}{6}$

$R_{eq} = 6\Omega$

- Q7:
  - 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.

$R_{TOTAL} = 4\Omega + 6\Omega$

$= 10\Omega$



$V = I R_{TOTAL}$

$I = 30V / 10\Omega$

$= 3A$

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

Quantity	**Symbol**	**SI unit**
terminal voltage	V_S	V (volt)
electromotive force	$\mathcal{E}$	V (volt)
internal potential drop of a battery	V_{int}	V (volt)

Example Problem

- Q8:
  - A battery with an *emf* of 9.0V has an internal resistance of 0.0500Ω. 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 4.00Ω.

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)

Example Problem

- Q9:
  - What is the power rating of a segment of Nichrome wire that draws a current of 2.5A when connected to a 12V battery?

Power and Voltage

- Power and Voltage
  - Most of electronic appliance indicates the power used and required voltage
  - Fried appliances when travelling

Example Problem

- Q10:
  - In North America, the standard electric outlet has a potential difference of 120V. In Europe, it is 240V. Hw does the dissimilarity in potential difference affect power output? What would be the power output of a 100W-120V light bulb if it was connected to a 240V system?

Alternative Equations for Power

- Alternative Equations for Power

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

$$P = I^2R$$

Quantity	**Symbol**	**SI unit**
power	P	W (watt)
potential difference	V	V (volt)
resistance	R	Ω (ohm)
current	I	A (ampere)

Example Problem

- Q11:
  - An electric kettle is rated at 1500W for a 120V potential difference.
    - What is the resistance of the heating element of the kettle?
    - What will be the power output if the potential difference falls to 108V?

Example Problem

- Q12:
  - A family has its television set on for an average 4.0h per day. If the television set is rated at 80W and energy costs $0.070 per kWh, how much would it cost to operate the set for 30 days?

Magnetism

Magnetism

- Magnetism
  - The magnitude of the force is proportional to the inverse of the square of the distance.

$$\left|\vec{F}\right| \propto \frac{1}{d^2}$$

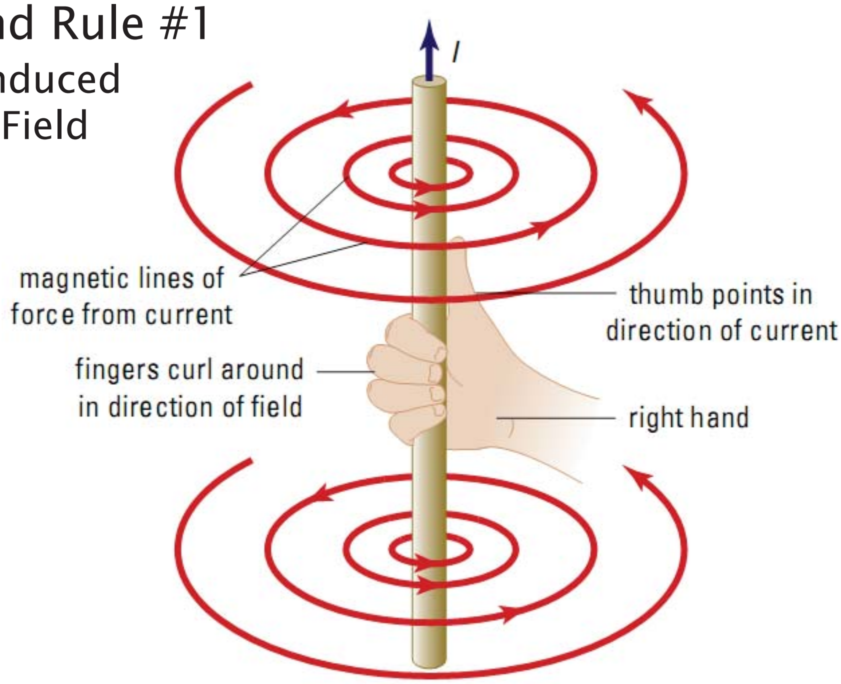
RULES FOR MAGNETIC INTERACTIONS

1. Like poles repel each other.
2. Unlike poles attract each other.
3. The force of attraction varies inversely as the square of the distance between of the poles.

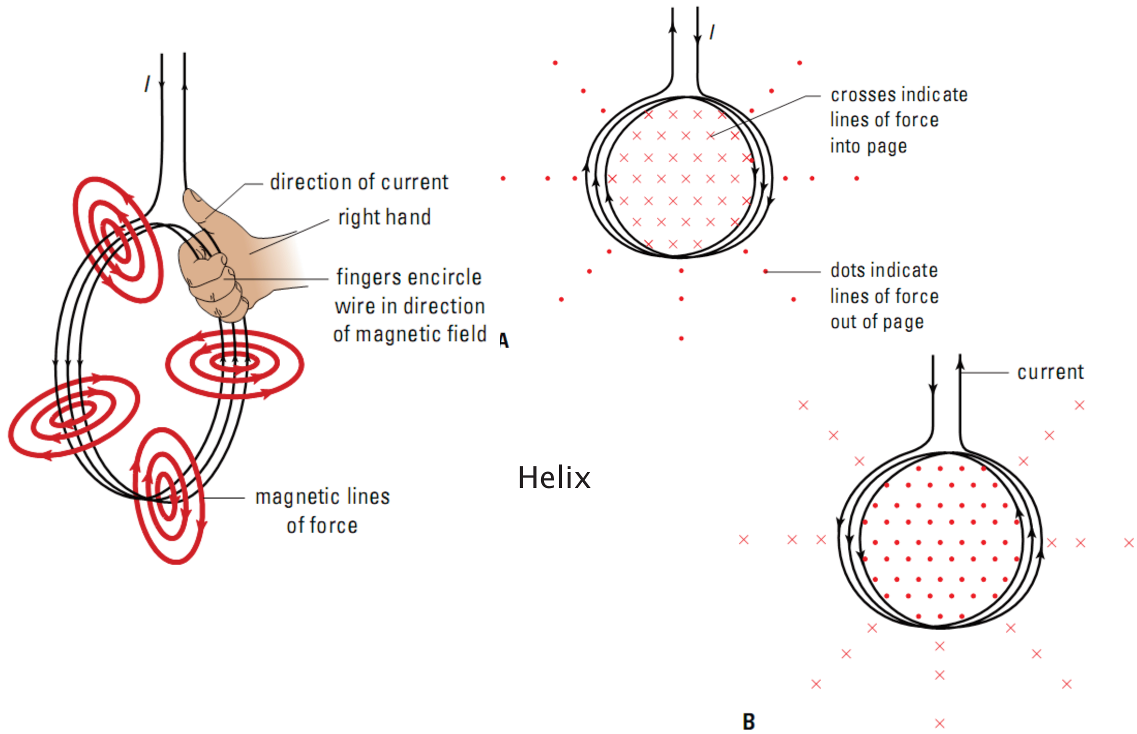
Electricity and Magnetism

Right-hand Rule #1

- Right-hand Rule #1
  - Current Induced Magnetic Field



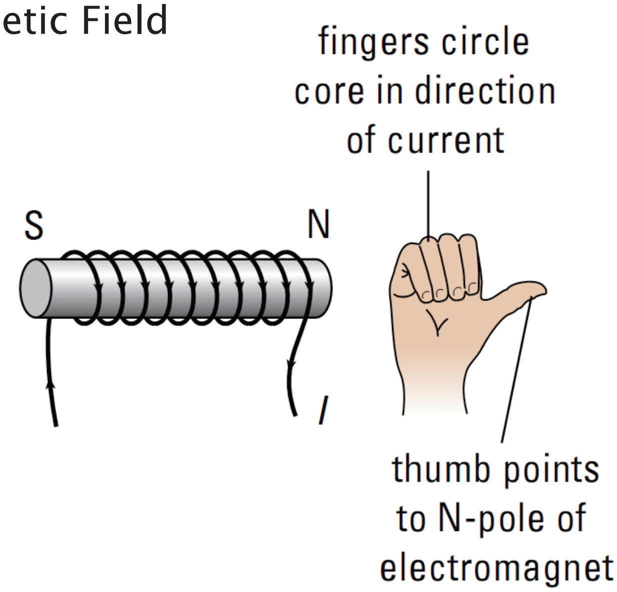
Right-hand Rule #1



Helix

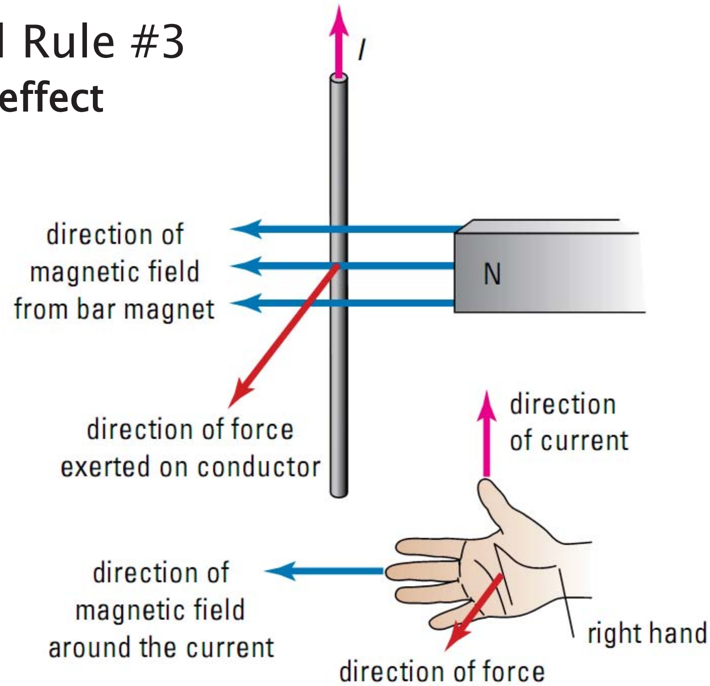
Right-hand Rule #2

- Right-hand Rule #2
  - Poles of the Magnetic Field



Right-hand Rule #3

- Right-hand Rule #3
  - The **motor effect**



Magnetic Field Strength and Magnetic Force

- Magnetic Field Strength and Magnetic Force
  - The magnetic field strength perpendicular to the conductor is the quotient of the magnetic force and the current and length of the conductor.

$$B_{\perp} = \frac{F}{IL}$$

$$L = n\ell$$

Magnetic Field Strength and Magnetic Force

- Magnetic Field Strength and Motor Force

$$B_{\perp} = \frac{F}{IL}$$

$$L = n\ell$$

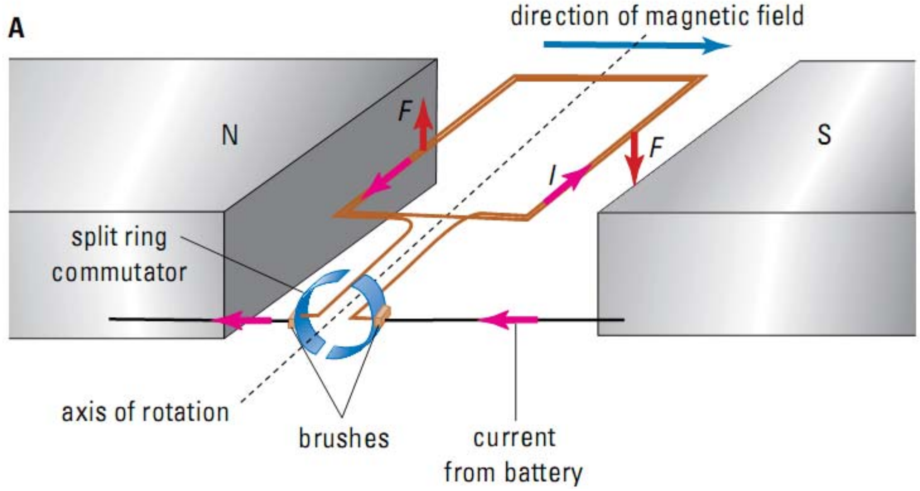
Quantity	Symbol	SI unit
magnetic field strength	B	tesla (T)
"perpendicular to"	$\perp$	
motor force	F	newton (N)
current	I	amp (A)
length of conductor	L	metre (m)
number of coil turns	n	no unit
length of each turn	ℓ	metre (m)

Example Problem

- Q1:
  - A length of straight conductor carries a current of 4.8A into page at right angels to a magnetic field. The length of the conductor that lies inside the magnetic field is 25cm (0.25m). If this conductor experiences a force of 0.60N to the right, what is the magnetic field strength acting on the current?

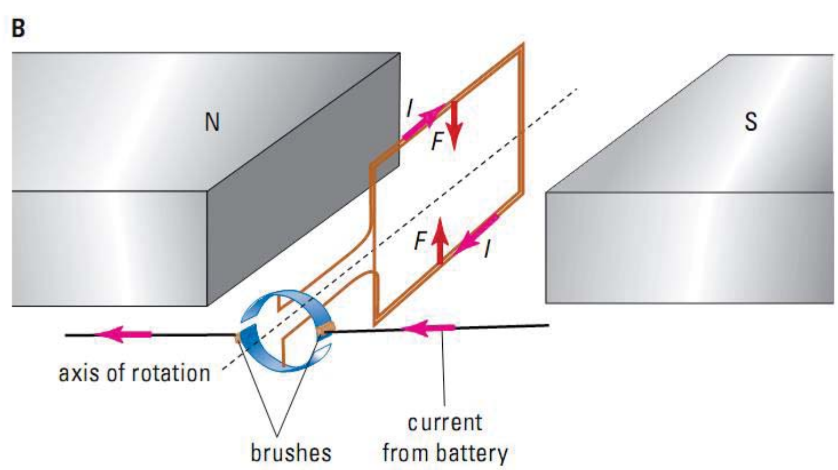
DC Motor

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



DC Motor

- DC Motor
  - The direction of the magnetic pole is important
  - Notice that the direction of the current is changed
  - A different magnetic pole.



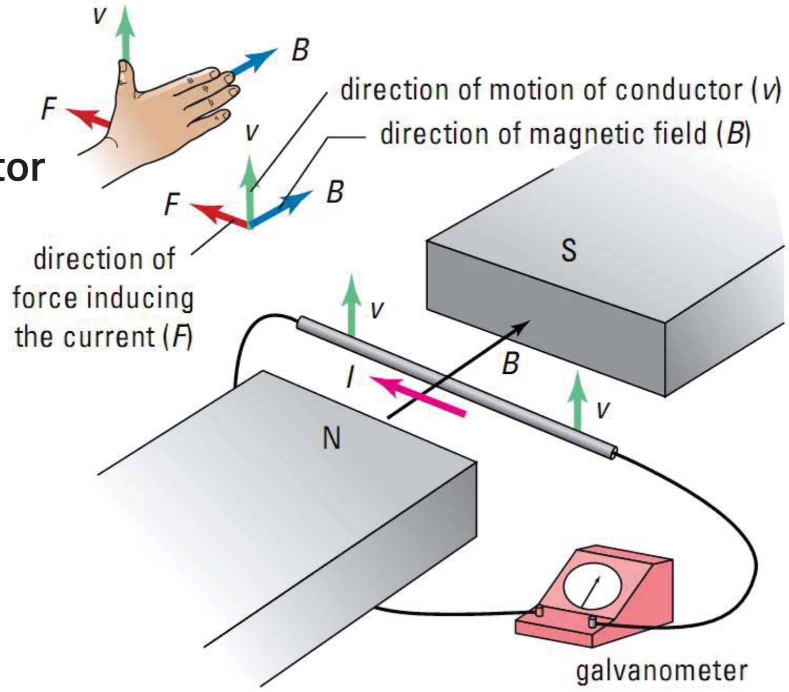
Electromagnetic Induction

Electromagnetic Induction

- Electromagnetic Induction
  - Current induces changing magnetic field strength
  - Does changing magnetic field strength induces current?
  - DOES IT????? Or DOES IT NOT???????

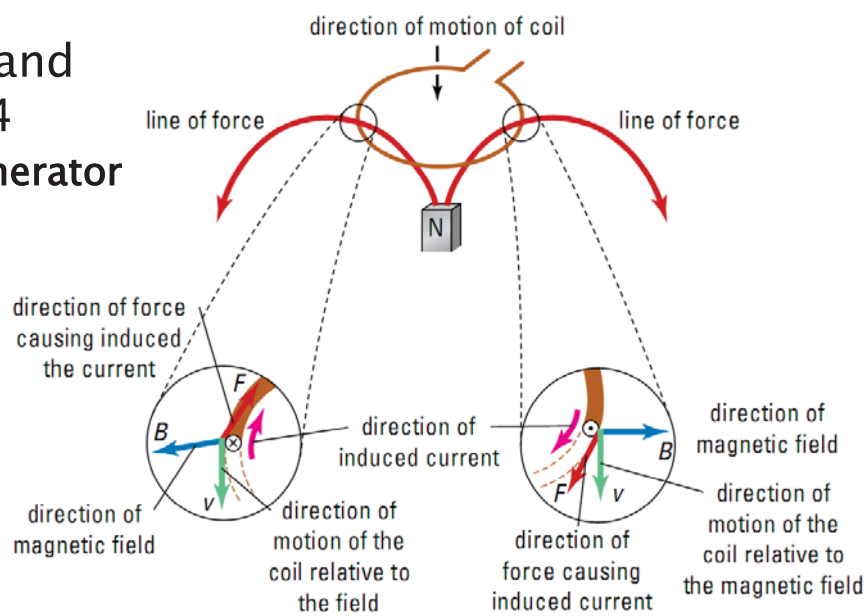
Right-hand Rules #4

- Right-hand Rules #4
  - The **generator effect**



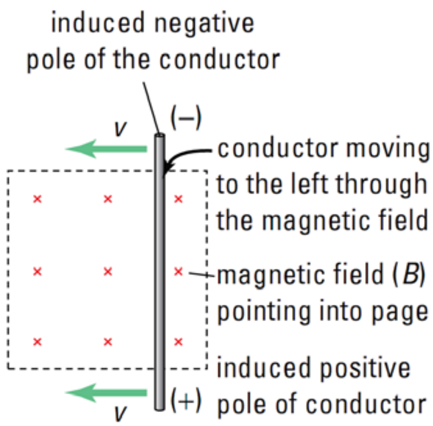
Right-hand Rules #4

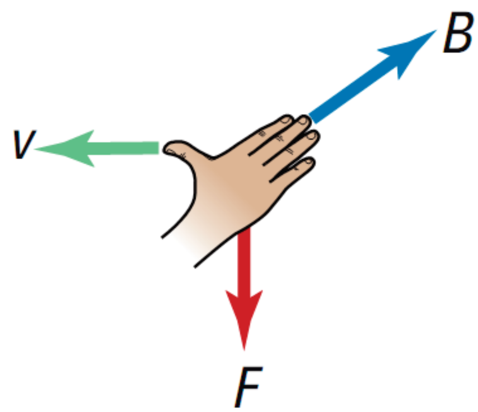
- Right-hand Rules #4
  - The **generator effect**



Conductor through Magnetic Field

- Conductor through Magnetic Field
  - Causes the conductor to have a polarity difference in charges similar to a battery.





Lenz's Law

- Lenz's Law
  - When a conductor interacts with a magnetic field, there must be an induced current that opposes the interaction, because of the law of conservation of energy.
  - Video!