ELECTRONICS

Course Contents

- Introduction
- Electronics
  - Basics, Concepts, Numbers & Analogies
  - Magnetism & Electromagnetism,
  - Resistors, Capacitors, Inductors,
  - AC Theory,
  - Semiconductors, Transistors & Diodes.

Introduction

Introduction.

- Basic Units.
- Resistors, Resistor Network Calculations.
- Capacitors.
- Inductors.
- Diodes and Transistors.
- Operational Amplifiers.
- AC Theory.

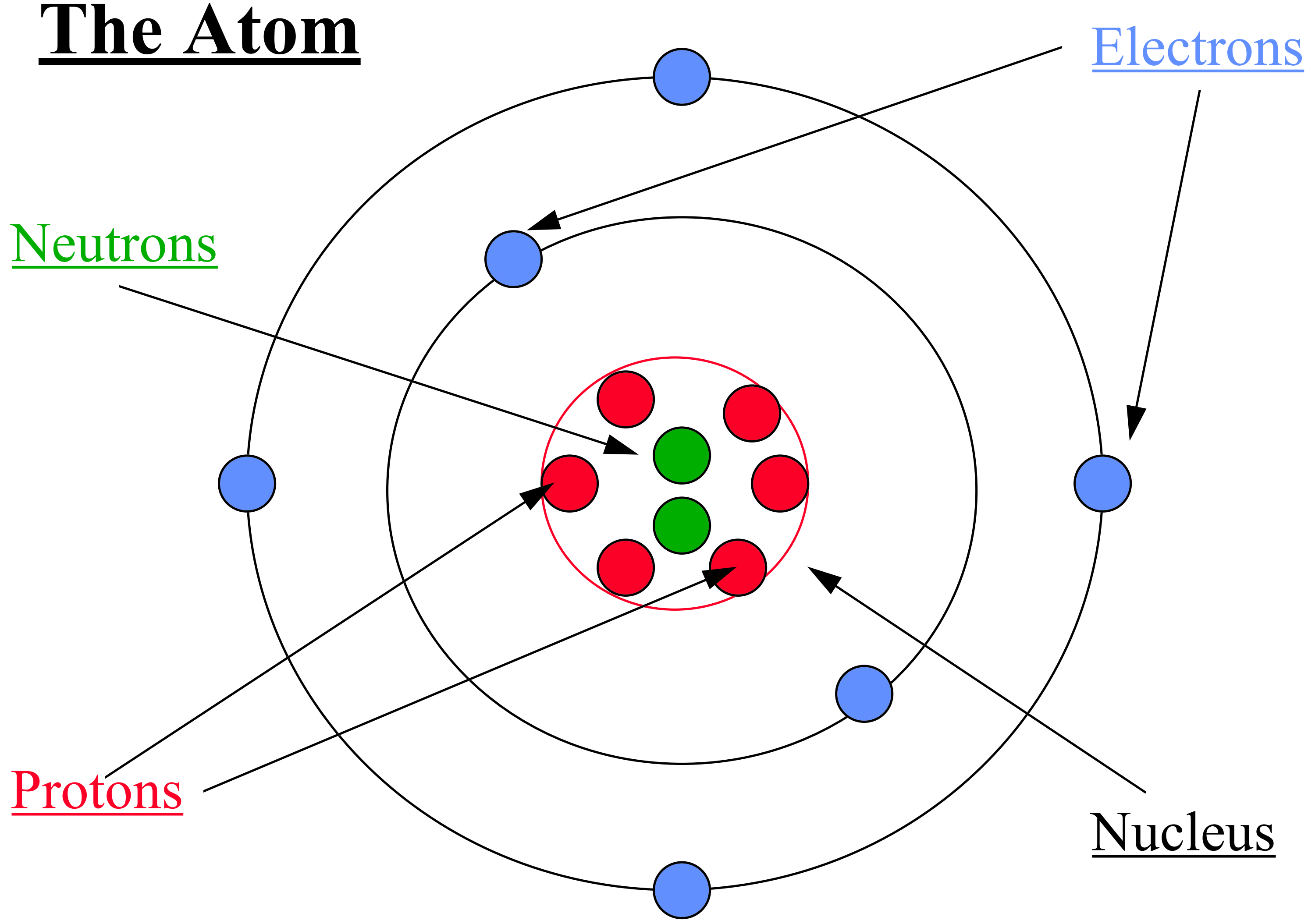
Basics

The Basics.

- This section will cover :-
- The basics and structure of atoms.
- Conductors and Insulators.
- Electrical charge

The Basics.

The Atom

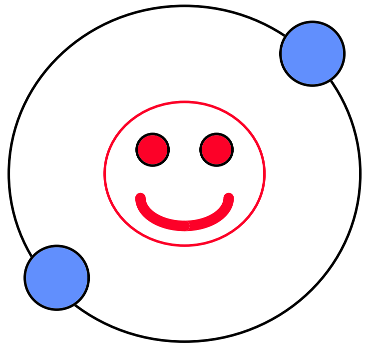


The Basics.

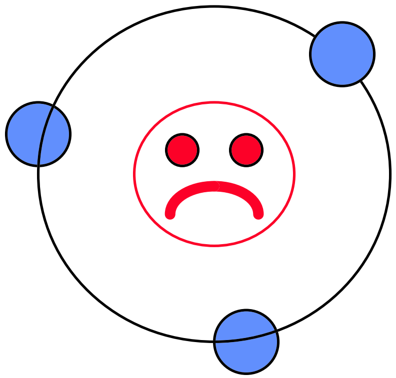
- Electrons have a negative charge.
- Protons have a positive charge.
- Neutrons are uncharged.
- The overall charges in an atom in their normal state **Cancel**.
- The atomic number is the count of protons in the nucleus.
- The atomic weight is based on the count of protons and neutrons in the nucleus.

The Basics.

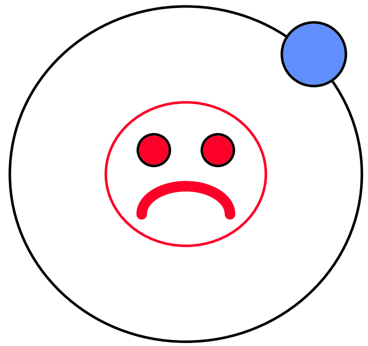
The Atom



Overall Charge
Neutral



Overall Charge
Negative



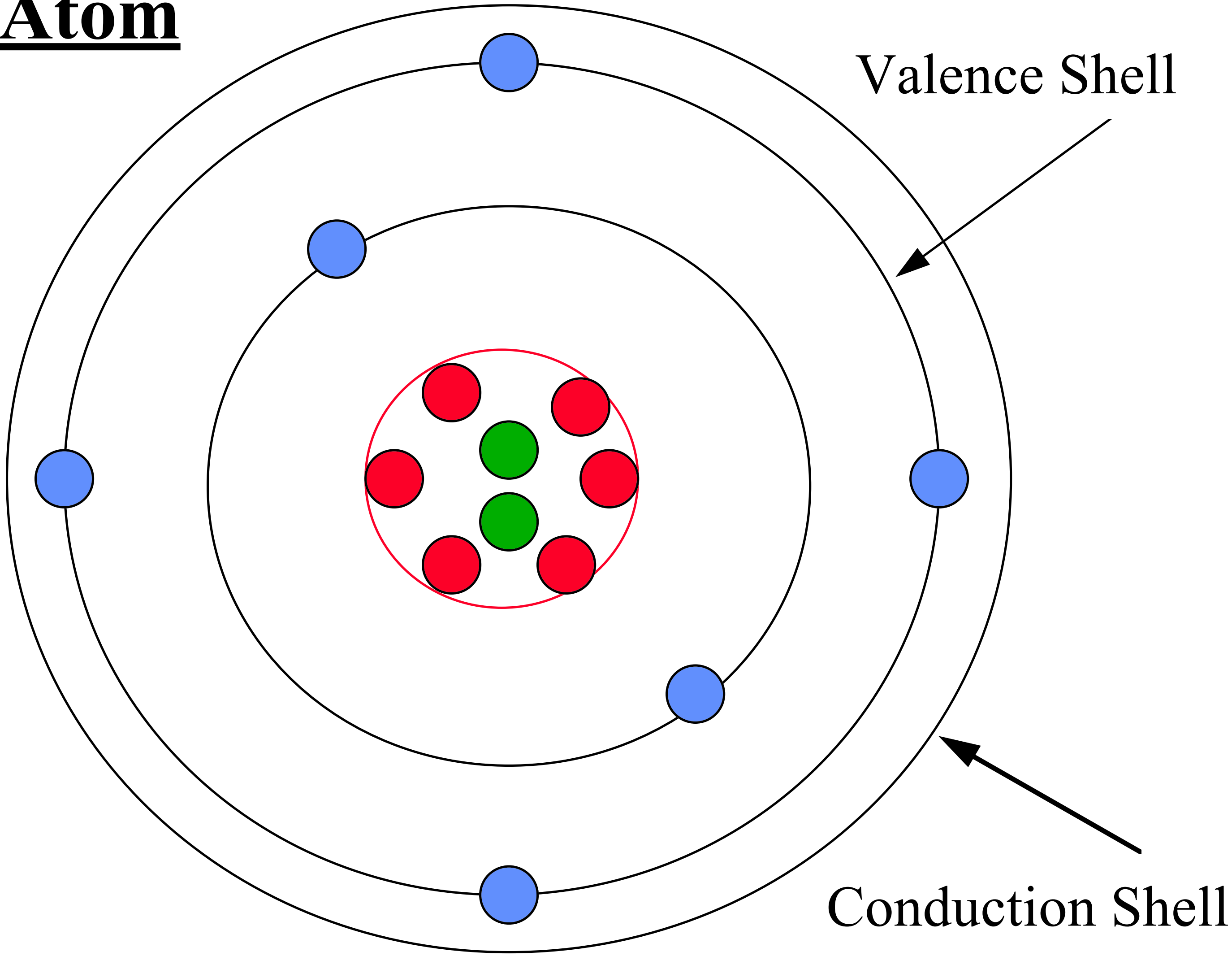
Overall Charge
Positive

Note:

All these atoms are assumed to have two protons.

The Basics.

The Atom

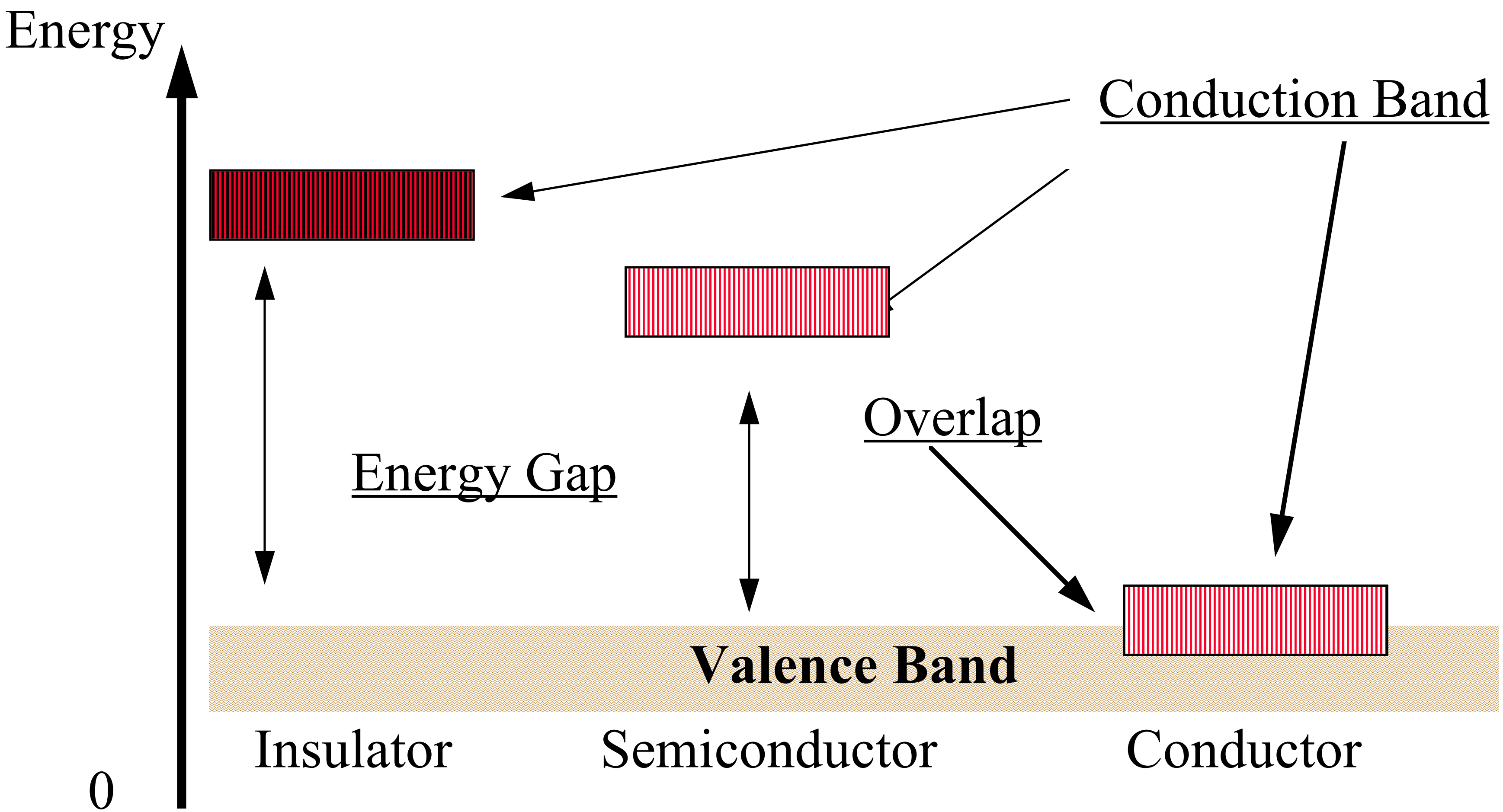


The Basics.

- The number of electrons per shell is based on the formula $2N^2$.
- Hence shell 1 can have $2*1^2 = 2$ electrons.
- Hence shell 2 can have $2*2^2 = 8$ electrons.
- Hence shell 3 can have $2*3^2 = 18$ electrons.
- The outer shell is the **valence** shell. It is this shell that defines the behavior and the way the atom will react with other atoms and can have a maximum of 8 electrons.

The Basics.

The Atom



The Basics.

- An atom with few electrons in the outer shell can have them dislodged easily and will conduct electricity.
- An atom with many electrons in the outer shell are difficult to dislodged and is an insulator.
- An atom with four electrons in the outer shell are called semiconductors (more about this special case later).

The Basics.

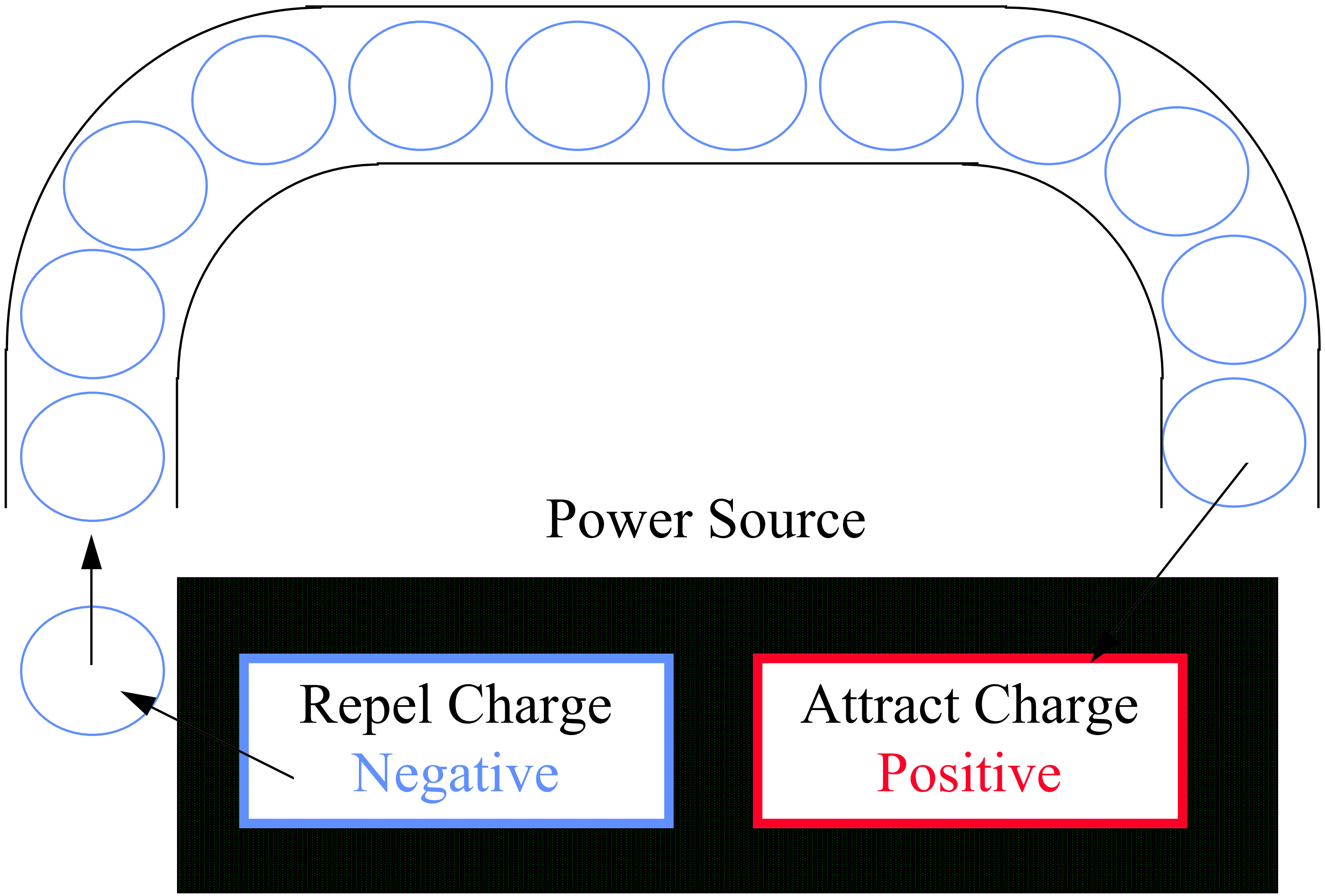
- The charge of an electron and that of a proton are equal in magnitude.
- Electrical charge is given the symbol ***Q***.
- Materials with opposite charge attract.
- Materials with same charge repel.
- The force that acts between charges is called the *electric field* .

The Basics.

- Summary:-
- The overall charge on the atom depends on the sum of Protons and Electrons and should be neutral.
- The weight of the atom is the sum of Protons and Neutrons in the nucleus..
- Electrons need sufficient energy to move into the conduction band before they can start to migrate through the material.

The Basics.

The Atom



Sources and Effects

The Basics.

Sources of e.m.f. (electromotive force) :-

- Friction giving Static electric charge.
- Chemical reactions (Battery)
- Magnetic (Conductor moving through a magnetic field [generator]).
- Energy converters
  - Heat to electricity (thermocouple).
  - Light to electricity (photocell).

The Basics.

Main effects of electric current are :-

- Magnetic effect.
- Heating effect.
- Chemical effect
- Energy converter
  - Current to Light (LED).
- Any others you can think of ?

Definitions

The Basics.

- Electrical charge is measured in **coulombs** and is abbreviated ***C***.
- A single electron has a charge of $1.6*10^{-19}$ ***C***
- One coulomb is the total charge on :-

  $6.25*10^{18}$ electrons.
- Note

$$\frac{1}{1.6*10^{-19}} = 6.25*10^{18}$$

The Basics.

- Definitions of a unit of Energy or Work :-
- Measurement unit is the Joule.
- Defined as *the work done when a force of 1 newton is exerted through a distance of 1 metre in the direction of the force*.
- or defined as *One Watt for One Second*.
- The newton is defines as *the force which when applied to a mass of 1kg, gives it an acceleration of 1* m/s^2

The Basics.

- Force = Mass * Acceleration
  - Force {Units = Newtons }
  - Mass { Units = Kilograms }
  - Acceleration { Units = metres per second per second }
- Force{N} = M{Kg} * A{m/s^2}
- Speed (v) = Distance (s) / Time (t)
- Acceleration (*f*) is the change in Speed in a time period.

$$(v_{(final)} - v_{(initial)}) / (t_{(final)} - t_{(initial)})$$

The Basics.

Summary

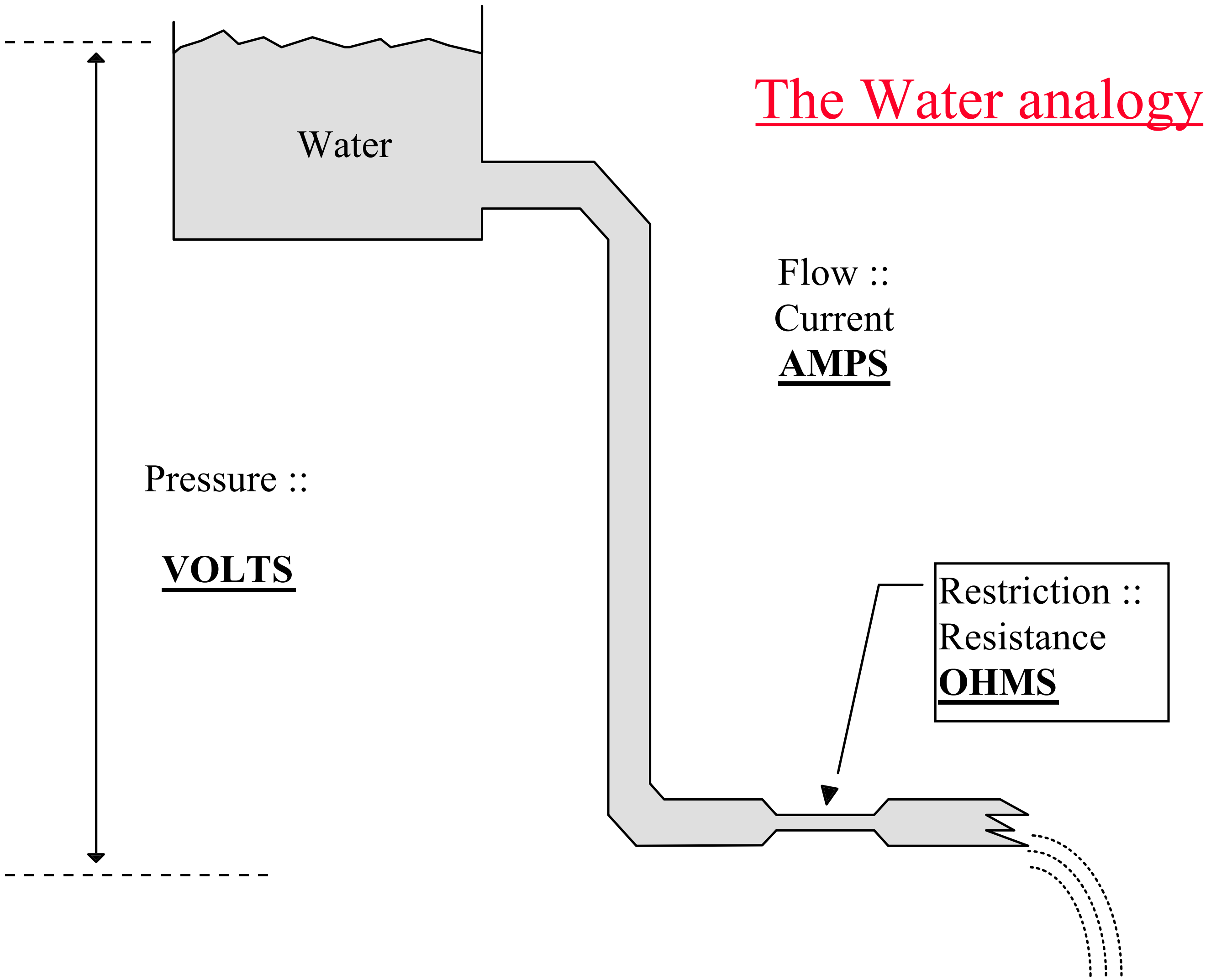
$$\text{Charge } Q = \frac{\text{Number of electrons}}{6.25*10^{18} \text{ electrons per Coulomb}}$$

$$\text{Voltage } V = \frac{\text{Energy } W \text{ (expressed in joules)}}{\text{Charge } Q \text{ (expressed in coulombs)}}$$

$$\text{Current } I = \frac{\text{Charge } Q \text{ (expressed in coulombs)}}{\text{Time } t \text{ (expressed in seconds)}}$$

Analogy Concepts

The Basics.

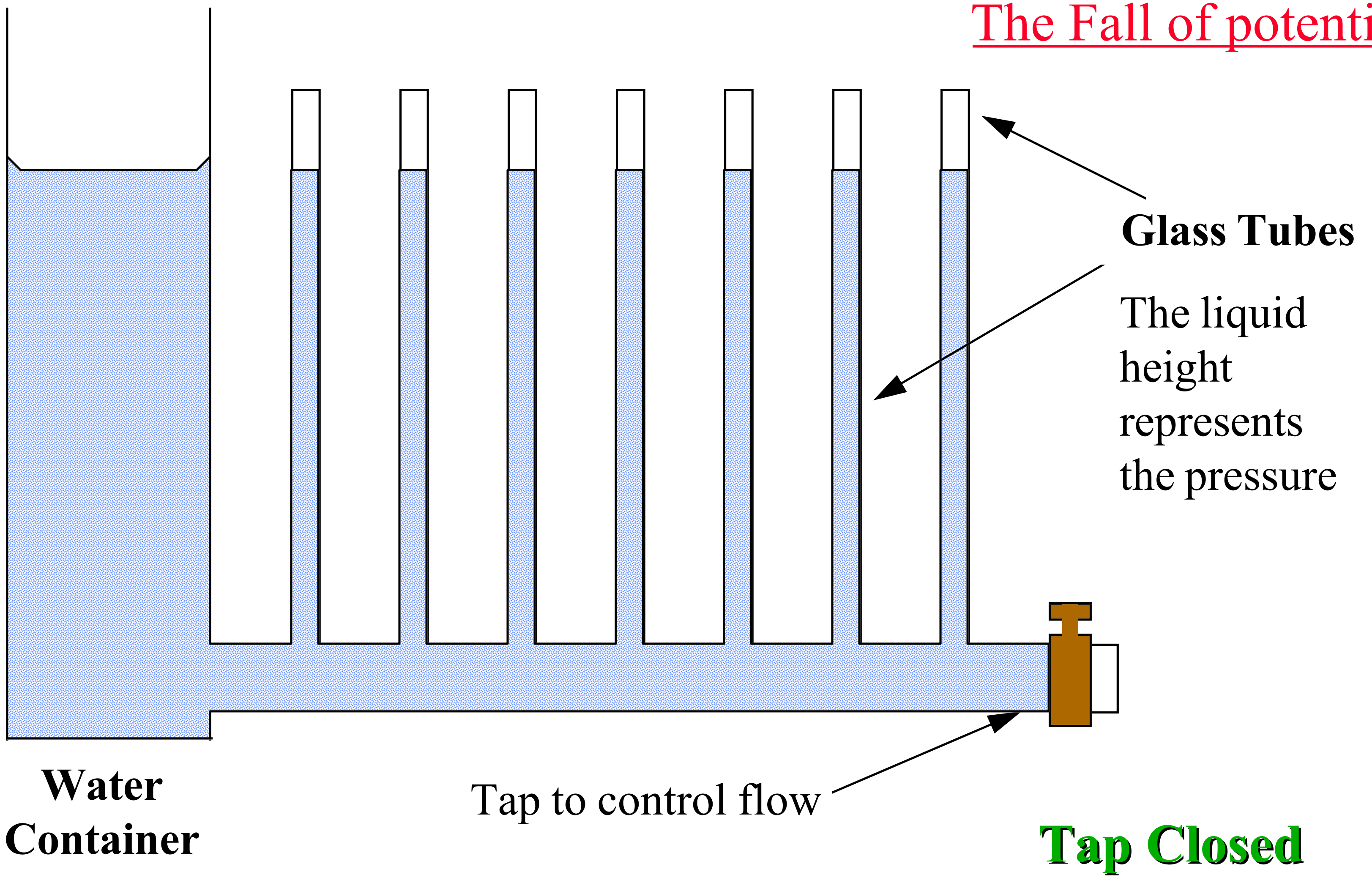


Water
The Water analogy
Flow ::
Current
AMPS
Pressure ::
VOLTS
Restriction ::
Resistance
OHMS

The Basics.

The Water analogy

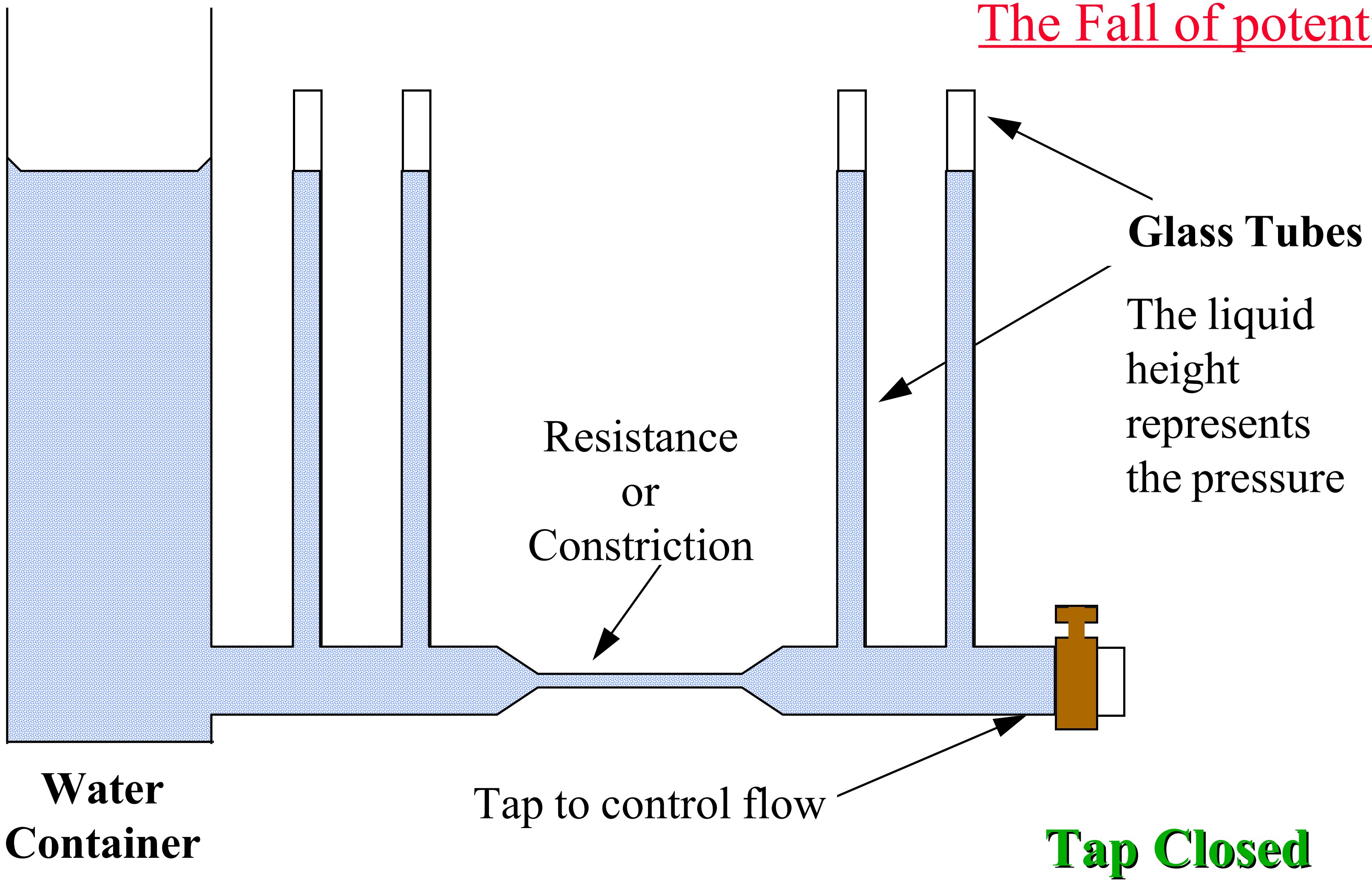
The Fall of potential



The Basics.

The Water analogy

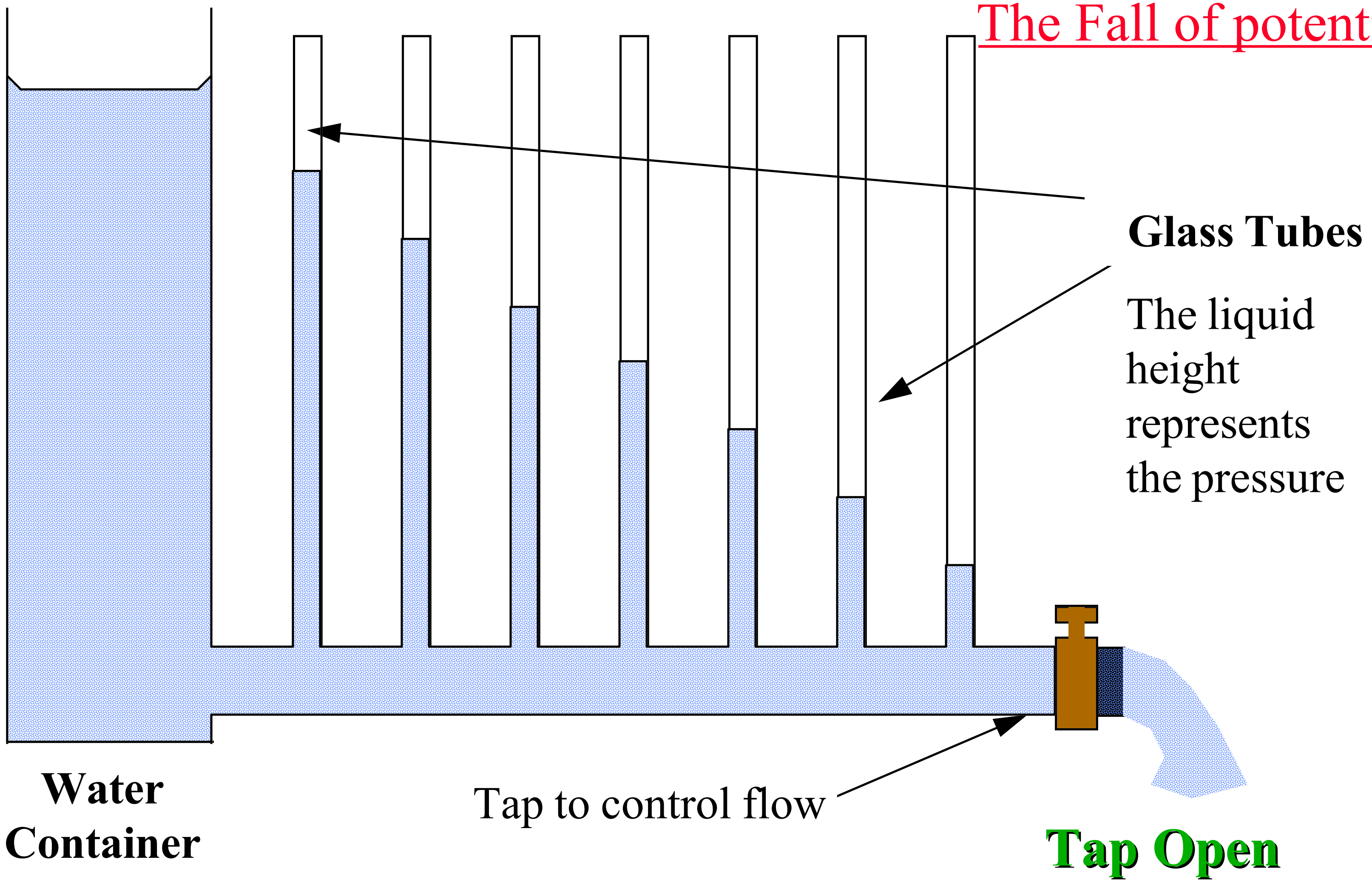
The Fall of potential



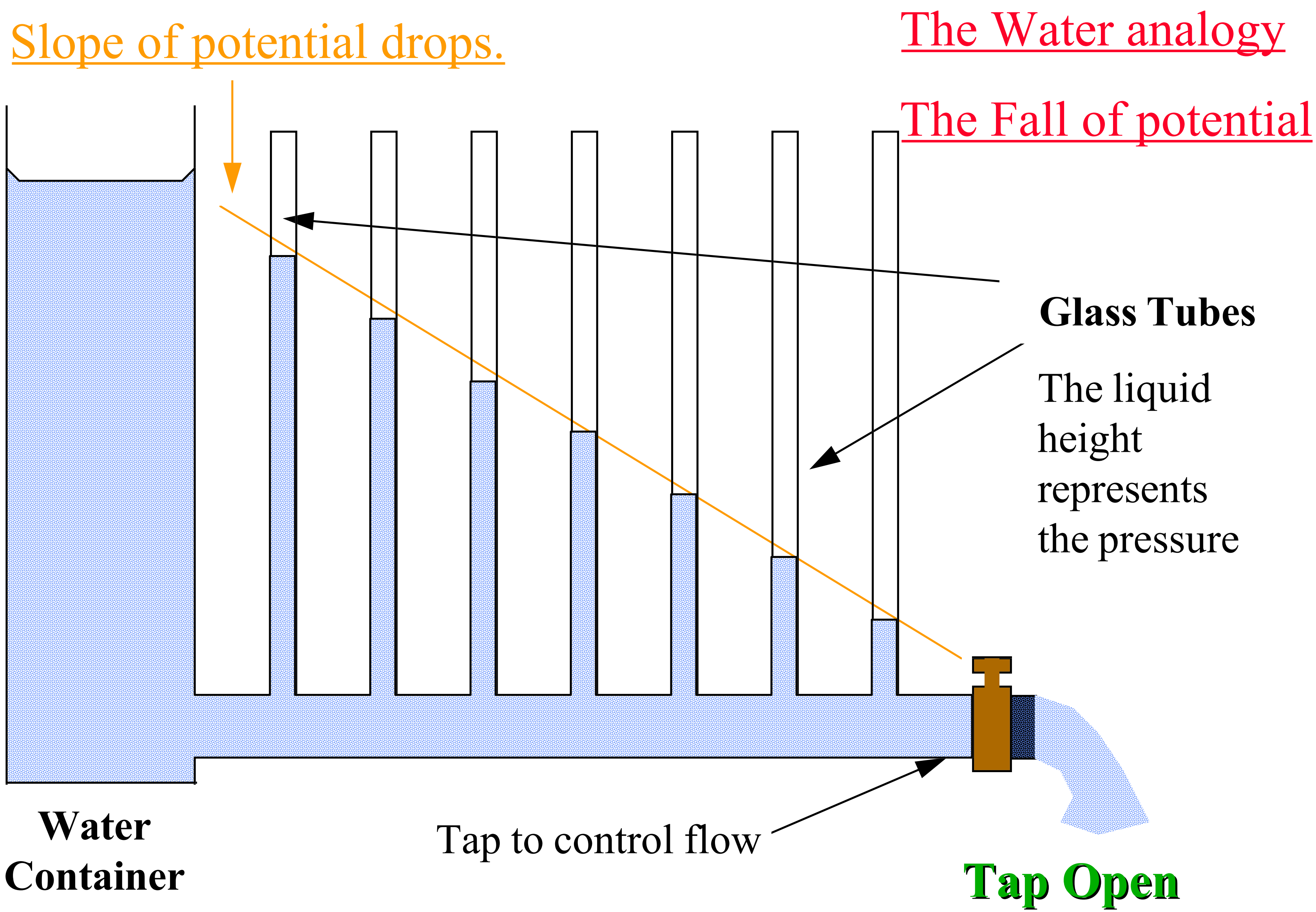
The Basics.

The Water analogy

The Fall of potential



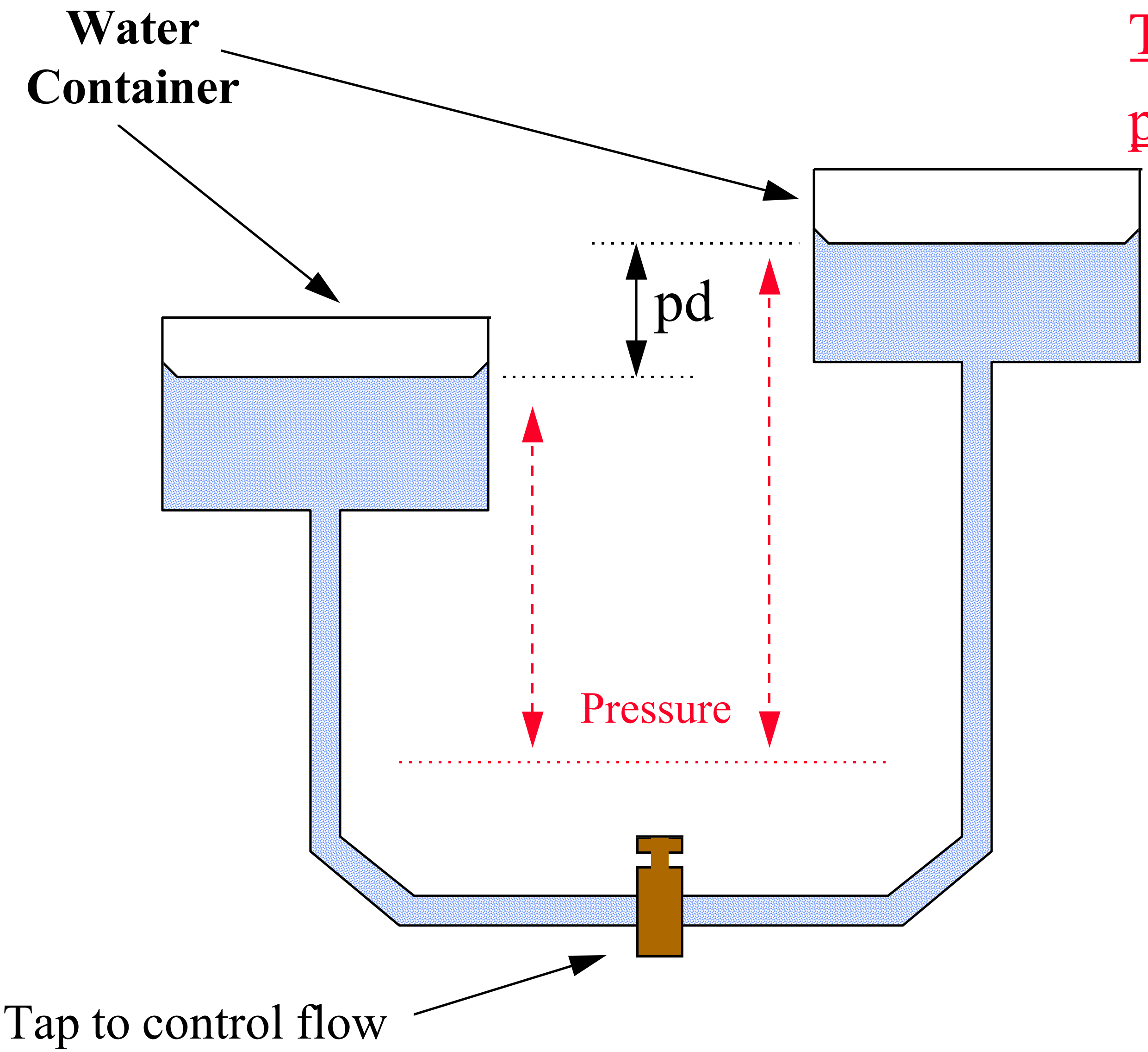
The Basics.



Slope of potential drops.
The Water analogy
The Fall of potential
Glass Tubes
The liquid height represents the pressure
Water Container
Tap to control flow
Tap Open

The Basics.

The Water analogy
potential difference.

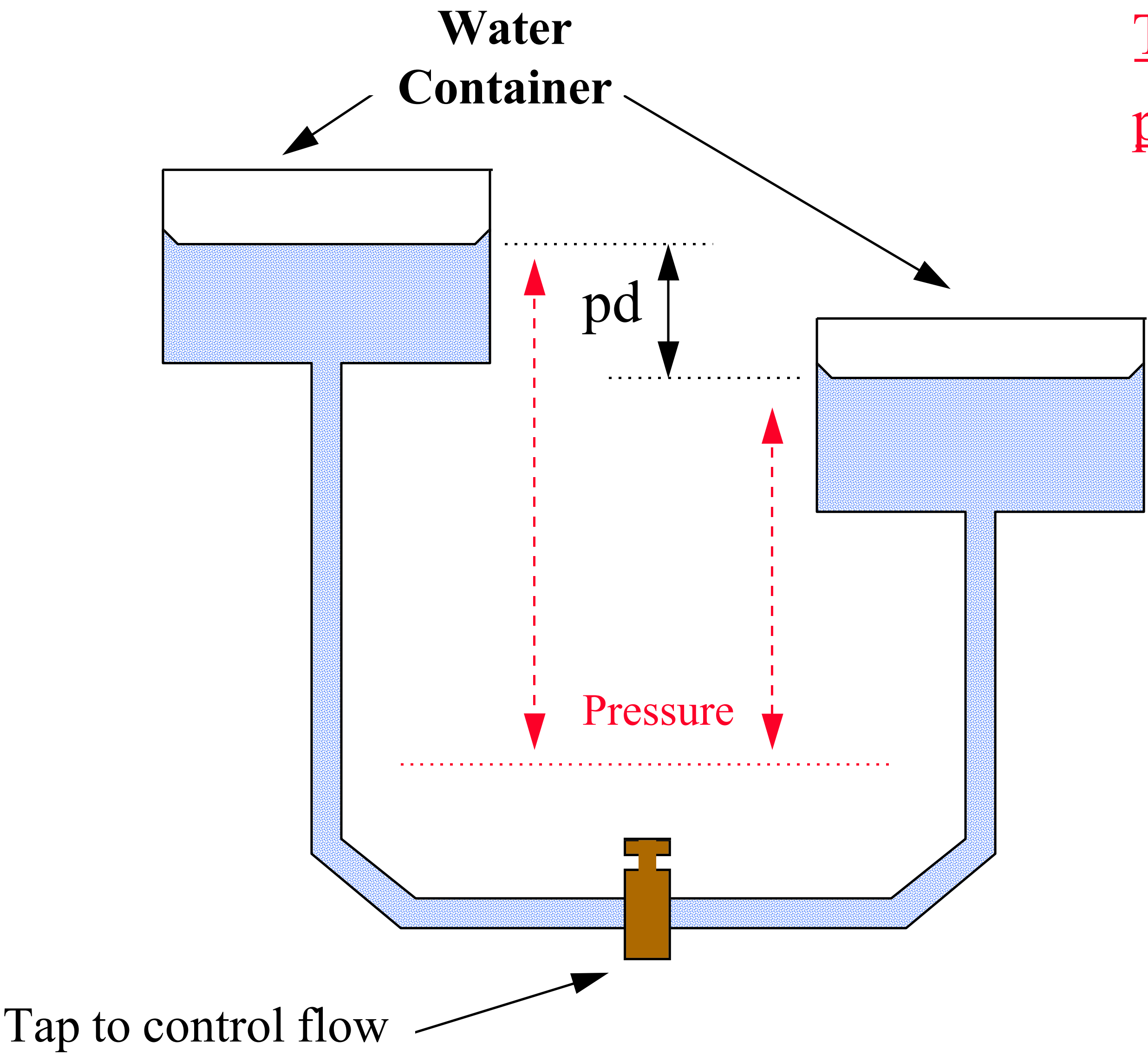


Question

When the Tap is opened which direction will the liquid flow.

The Basics.

The Water analogy potential difference.

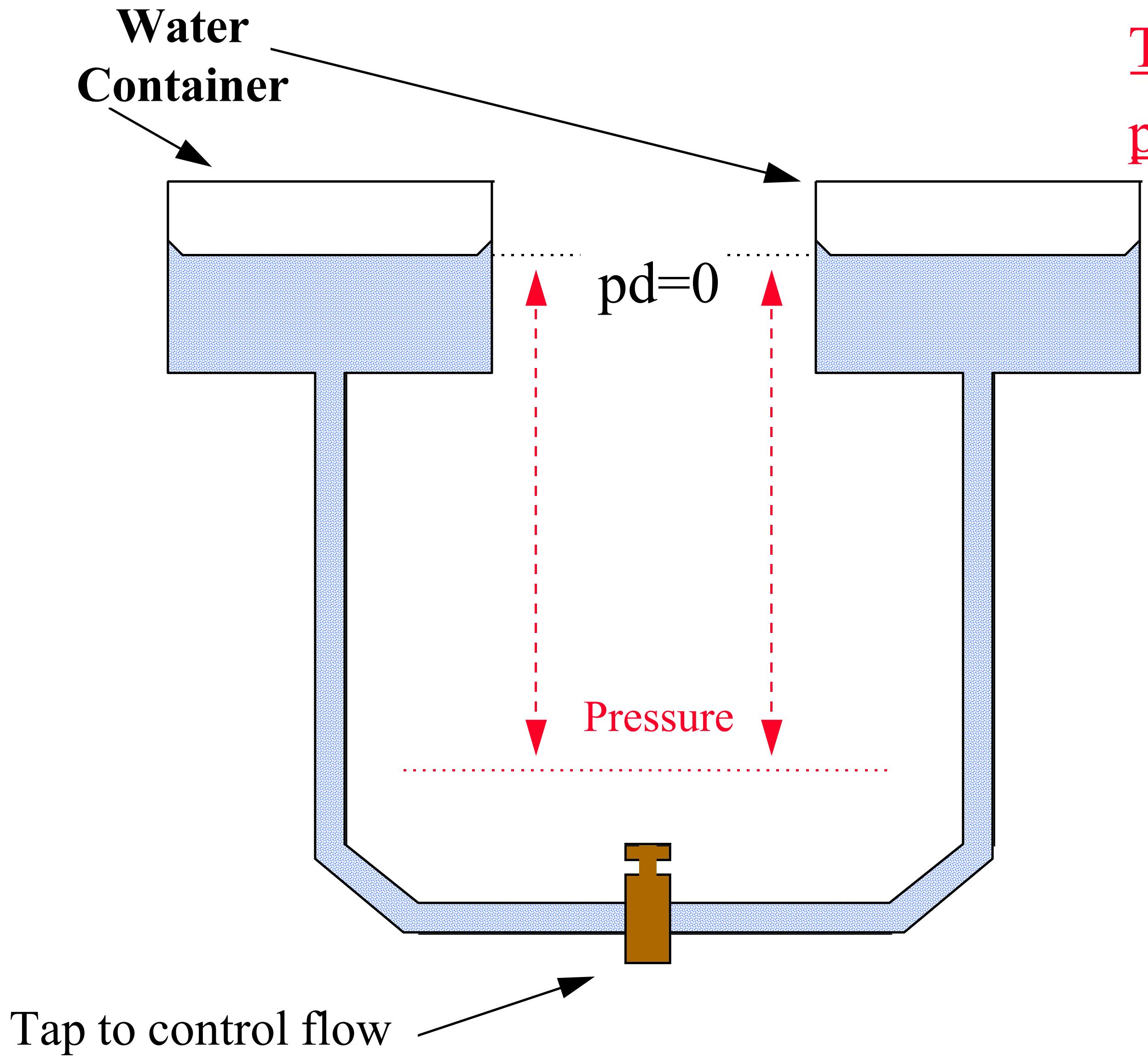


Question

When the Tap is opened which direction will the liquid flow.

The Basics.

The Water analogy
potential difference.



Question

When the Tap is opened which direction will the liquid flow.

Summary

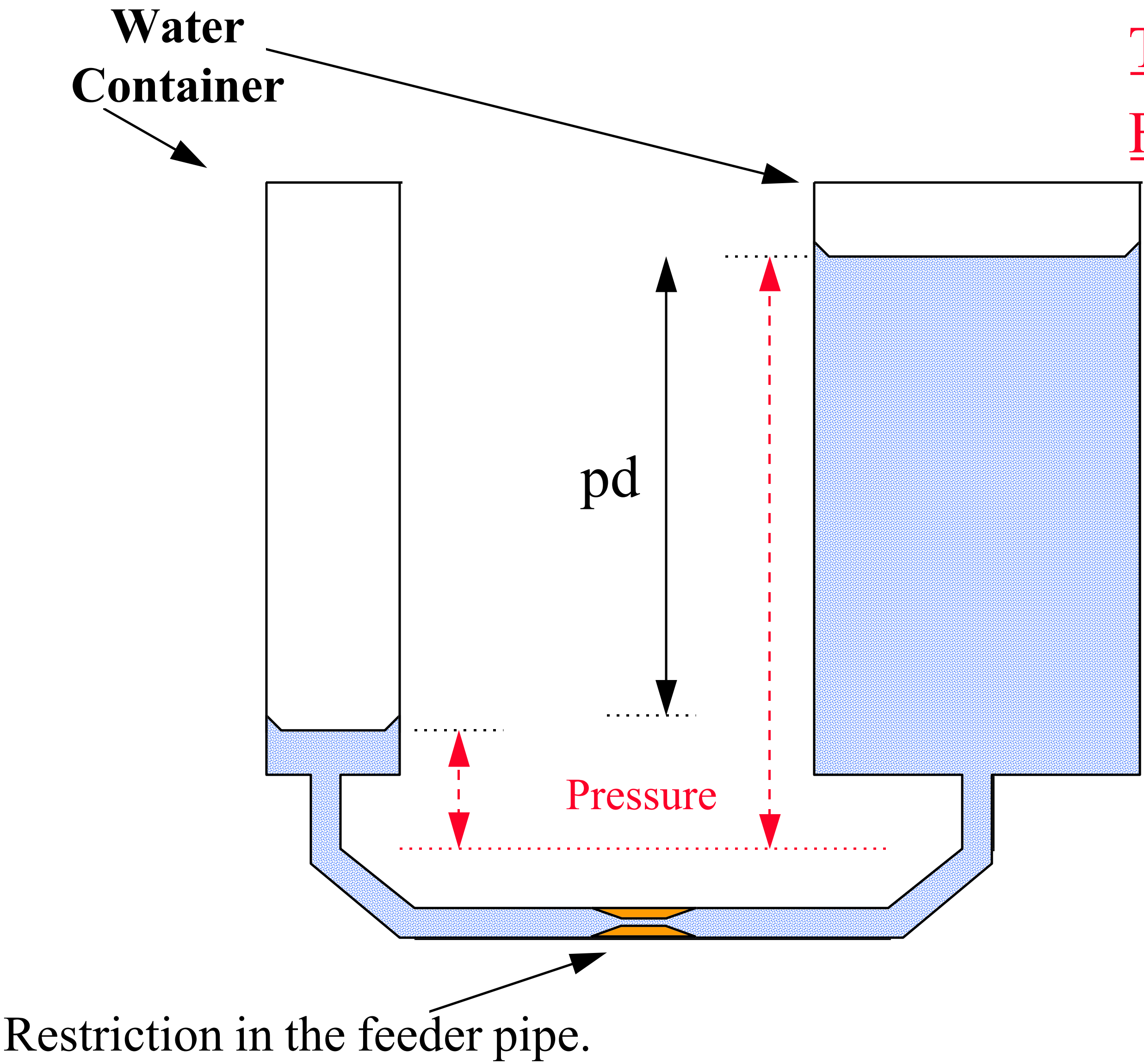
The Basics.

- For a Current to flow there must be a Pressure or Potential difference to drive that current flow.
- Whenever Current flows through a Resistance then a Pressure or Potential difference can be measured across the Resistance.
- If NO Current flows through a Resistance then the voltage or Pressure across the Resistance is Zero. (The Voltage is the same at both ends.)

The Basics.

The Water analogy

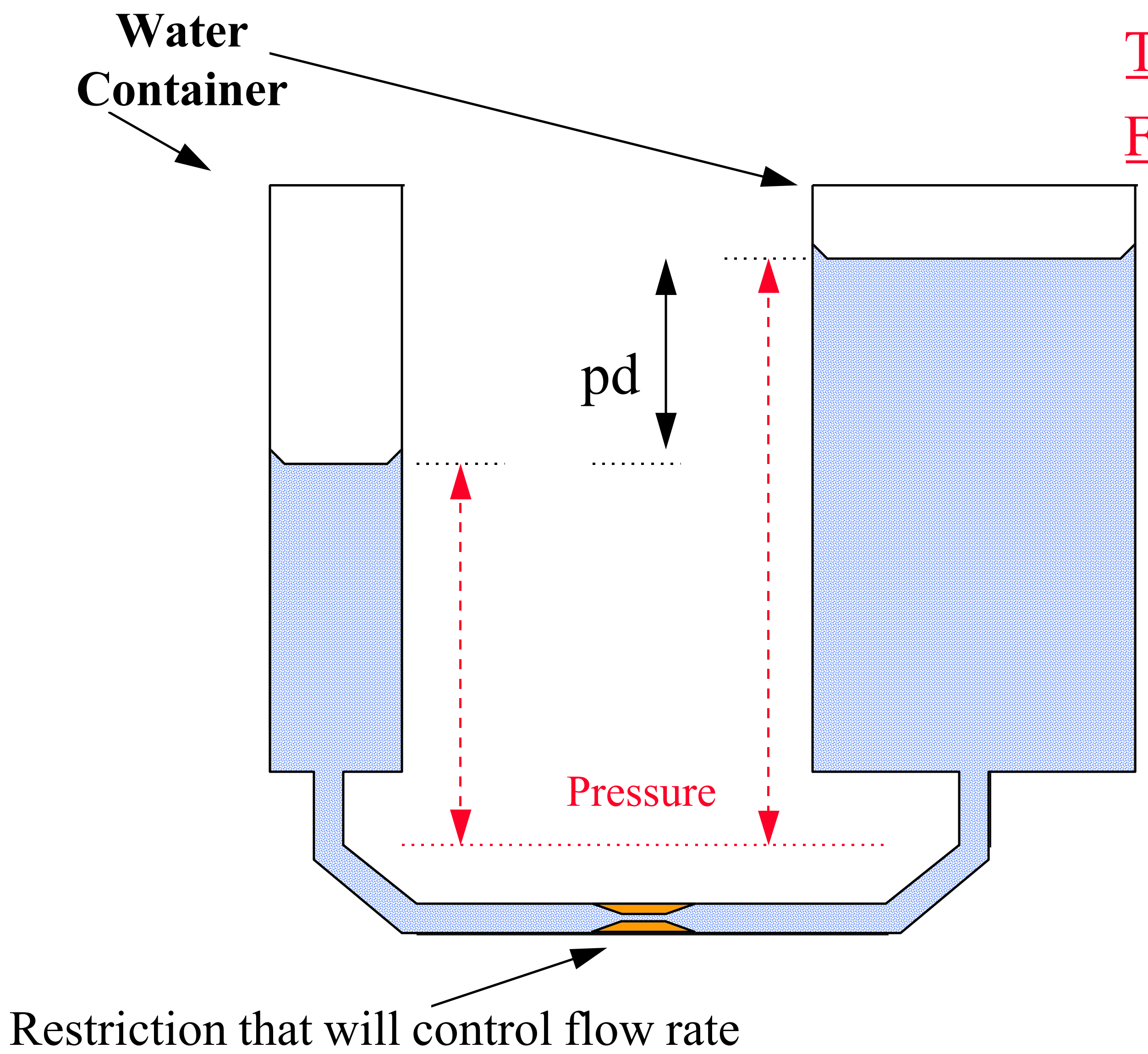
Fill Rate (Charging).



Questions

What controls the rate of flow between the tanks ?

The Basics.



The Water analogy

Fill Rate (Charging).

Questions

When does the greatest flow rate occur ?

How long does it take for the levels to be identical.

Summary

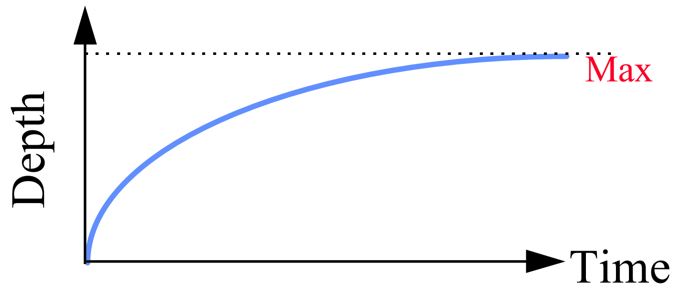
The Basics.

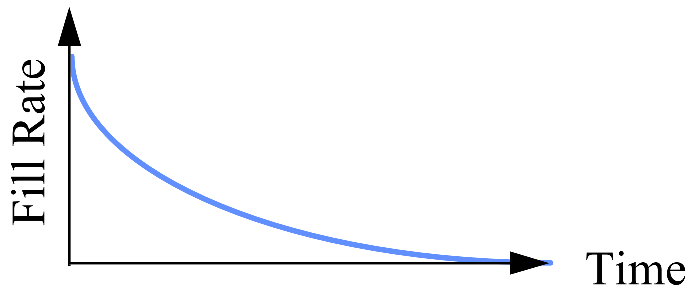
- Maximum flow rate occurs when greatest pressure difference is across restriction.
- As the container fills the pressure difference reduces and so flow rate reduces.
- The time to fill is proportional to the restriction resistance and the capacity of the container.
- Additional information:-
  The relationship of change takes an exponential form (Shape of the curve)

Summary

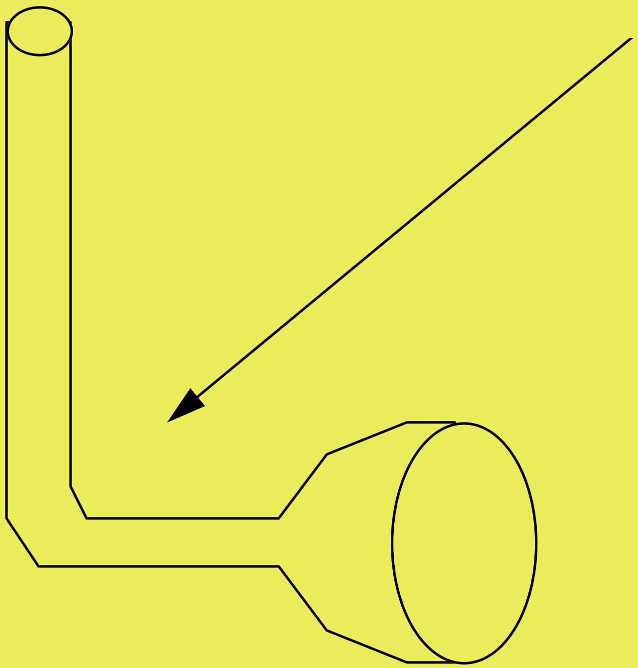
The Basics.

- Controlling factors are the capacity of the container, the potential difference between levels and the restriction resistance.
- Graphically the fill rate will take the form as follows :-



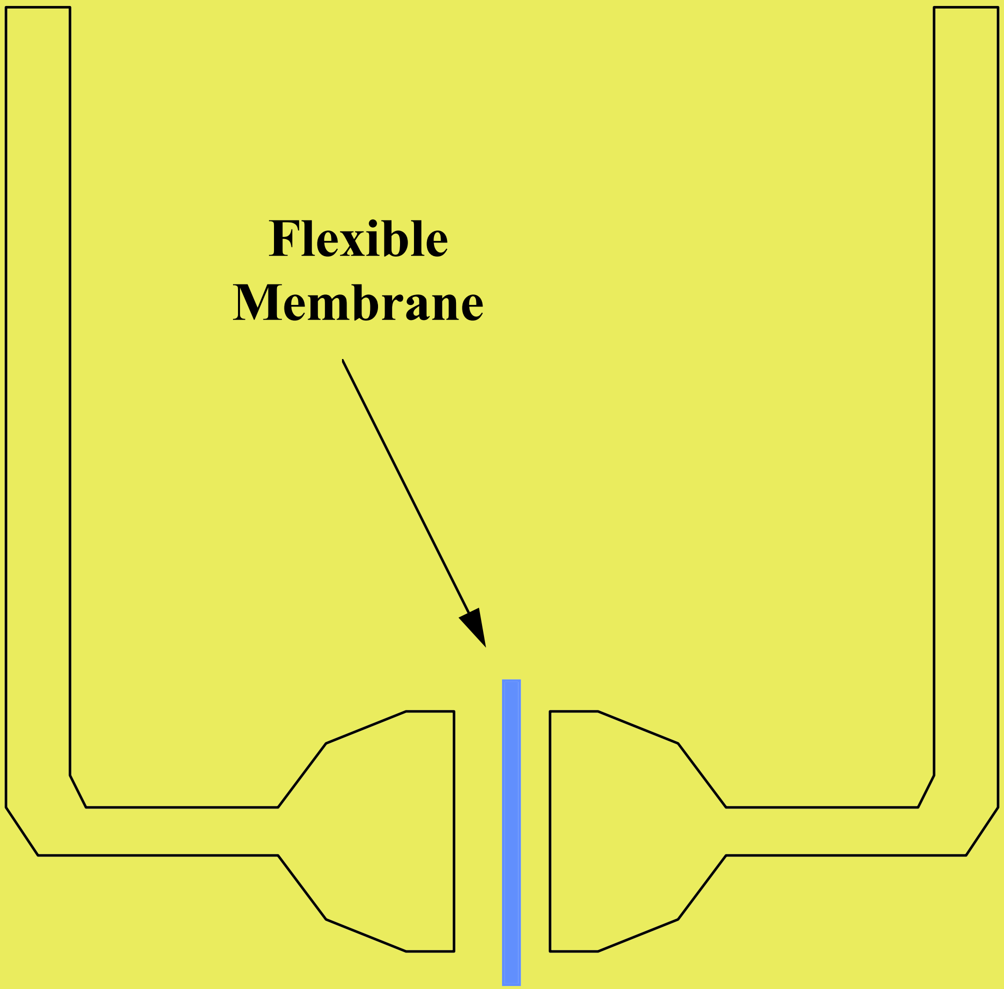


The Basics.



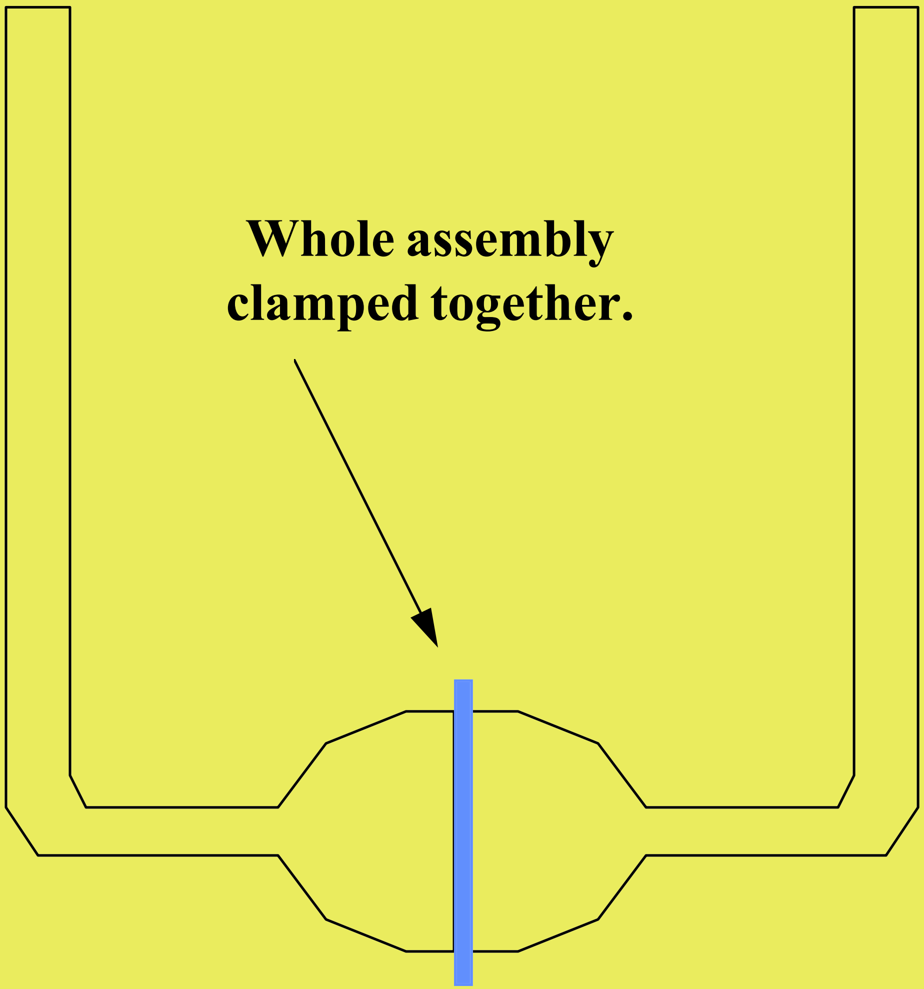
Capacitor concepts.

The Basics.



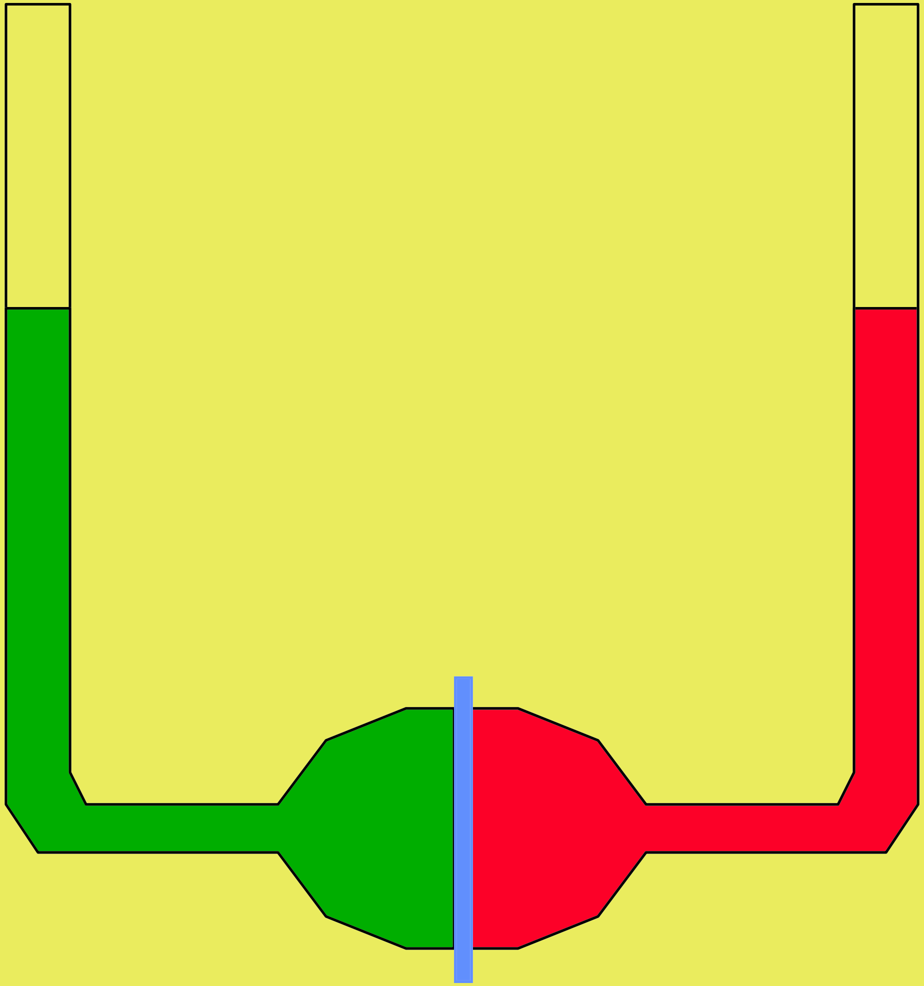
Take two containers separated by a flexible membrane.

The Basics.



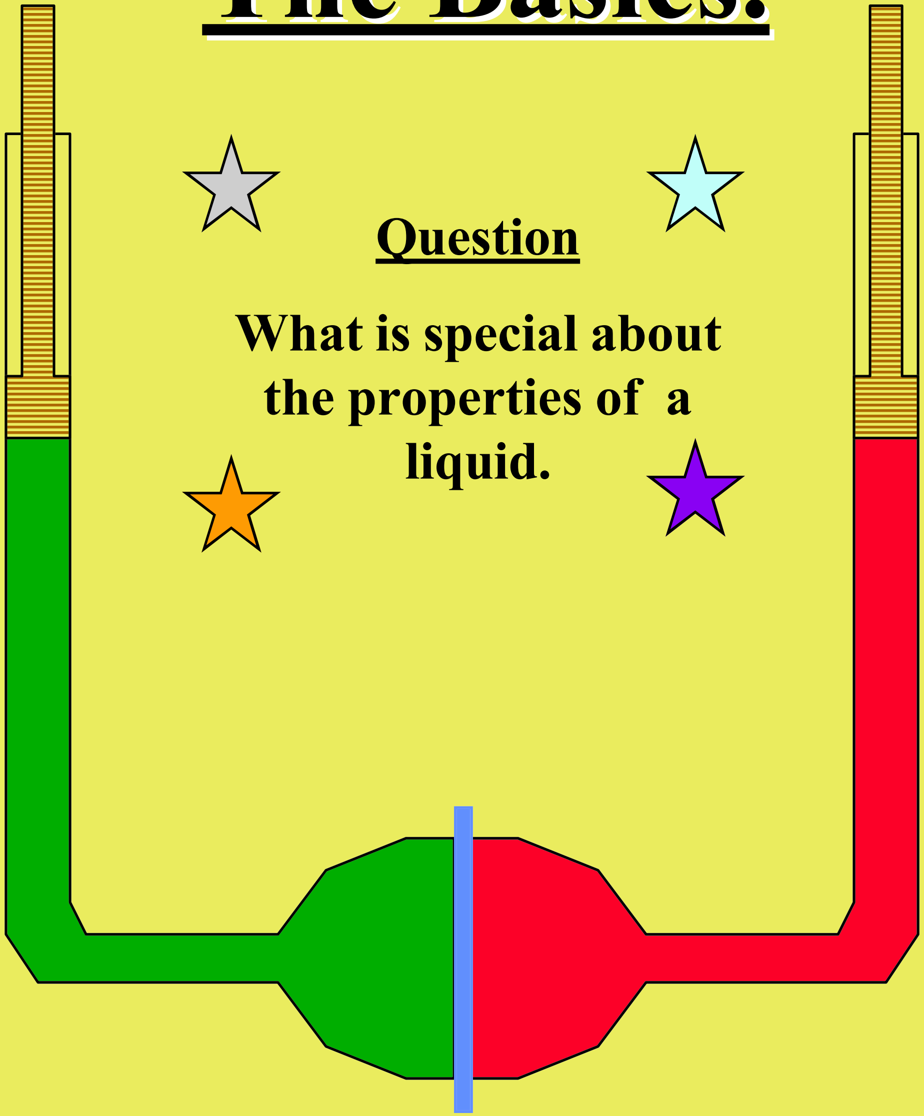
Clamp whole assembly together.

The Basics.



We now fill with our favourite coloured liquid.

The Basics.

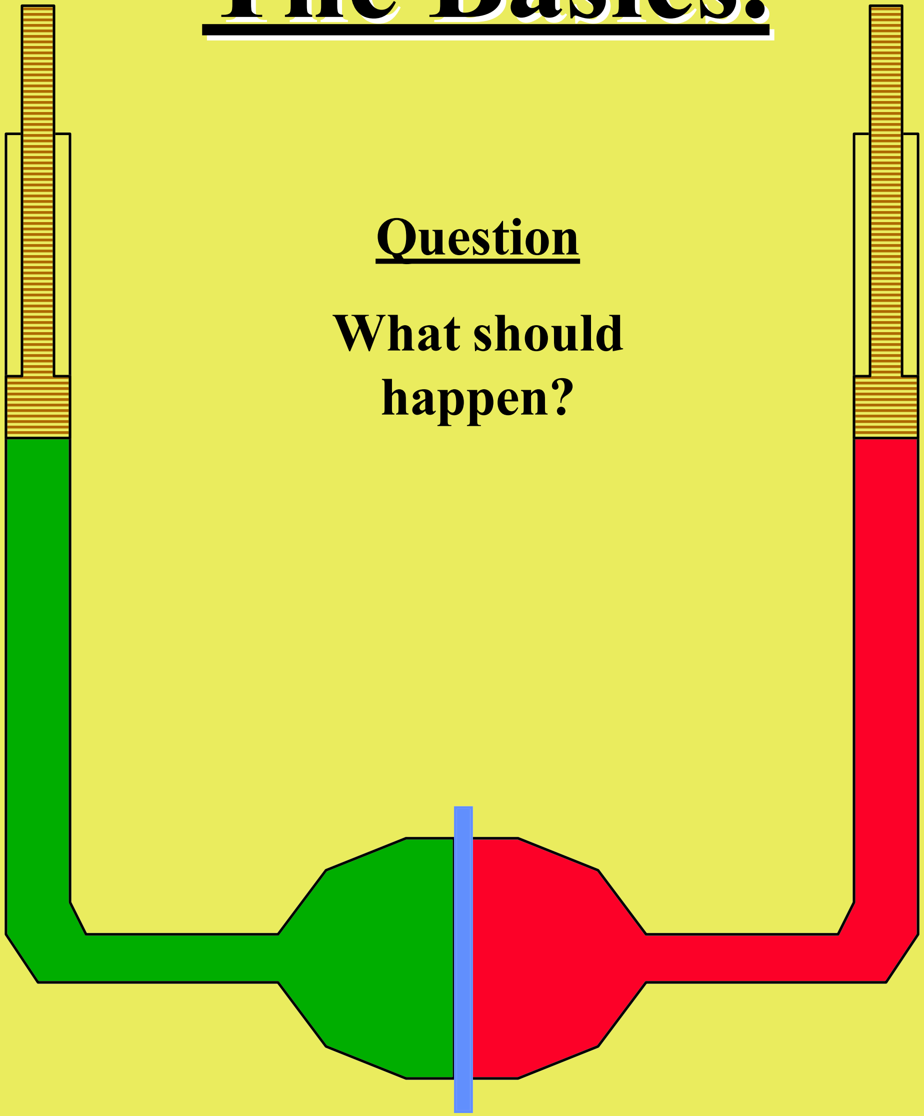


Question

What is special about the properties of a liquid.

Place plunger on top of each liquid.

The Basics.

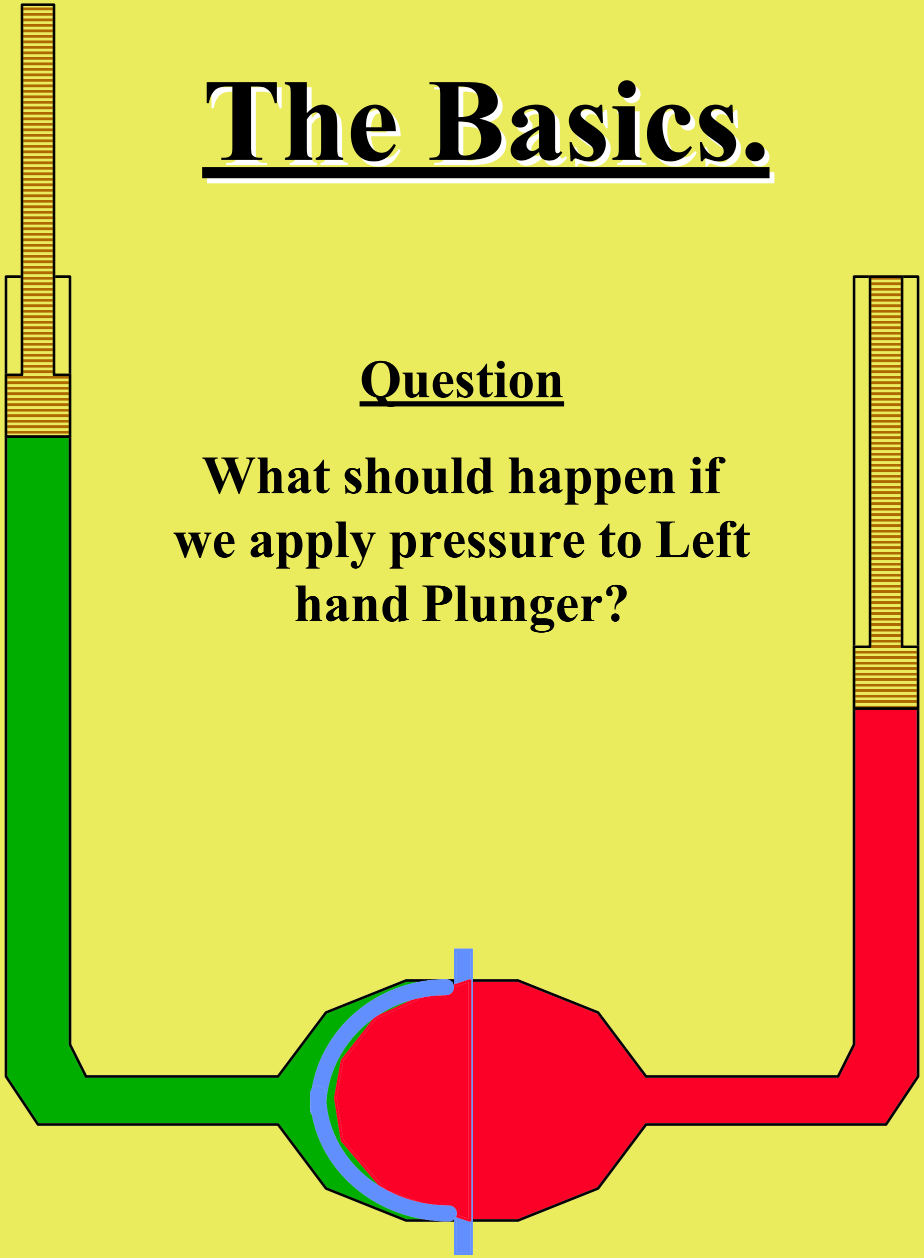


Question

What should happen?

If we apply pressure to right hand Plunger.

The Basics.

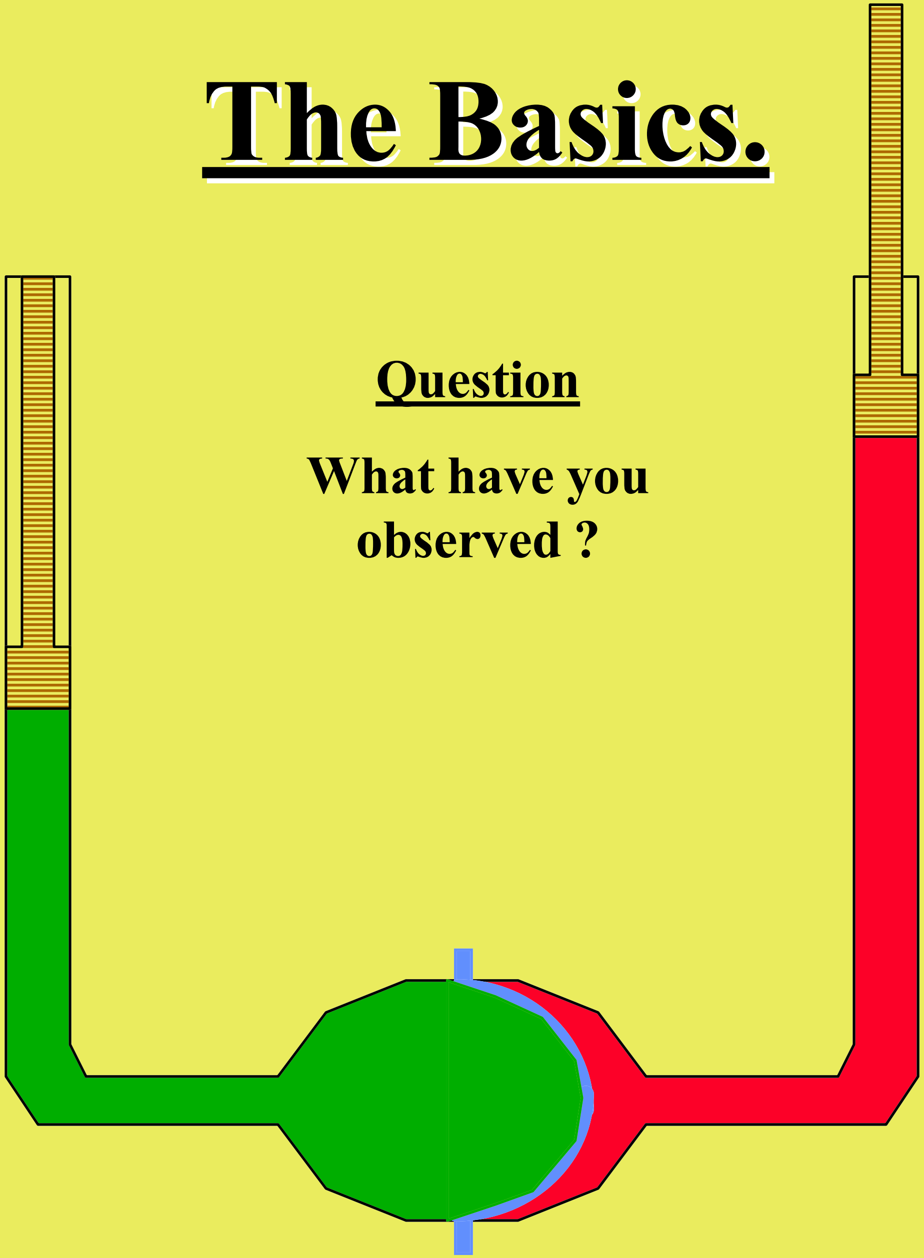


Question

What should happen if we apply pressure to Left hand Plunger?

The effect with pressure applied to right hand Plunger.

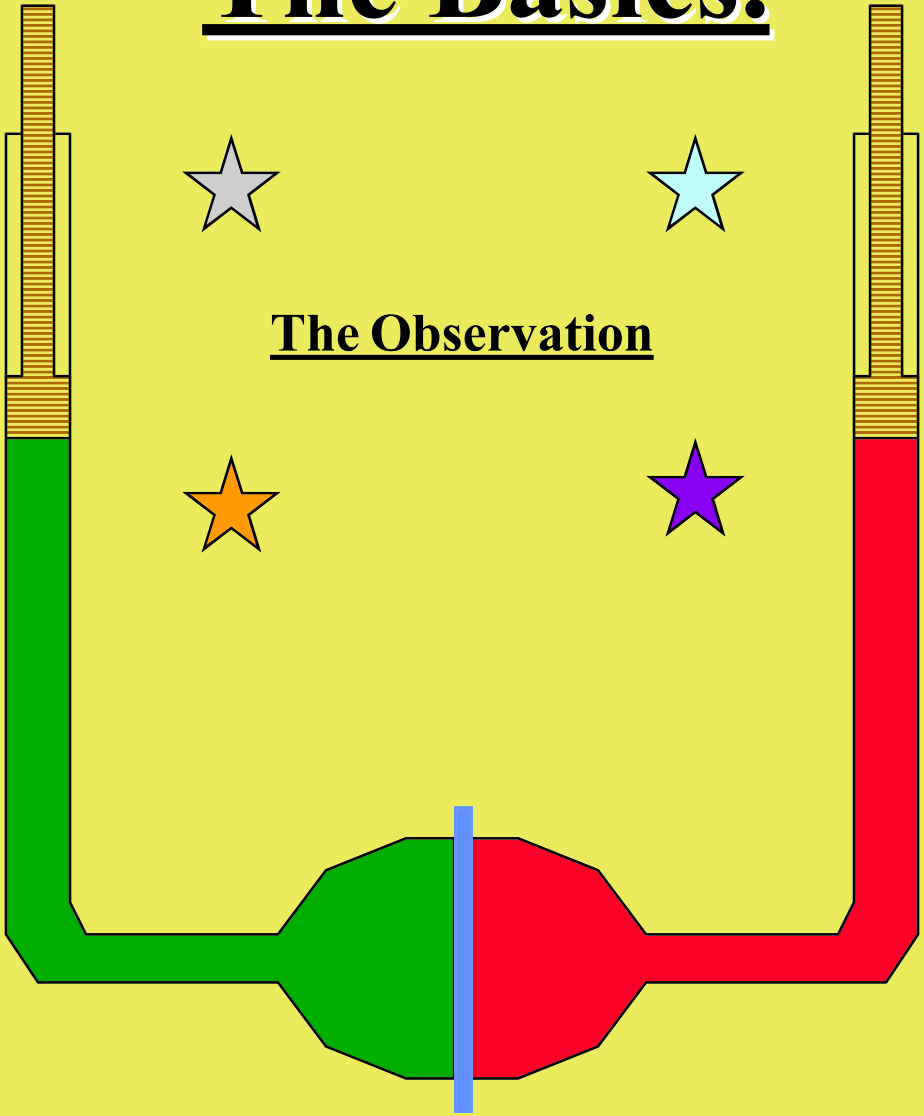
The Basics.



Question

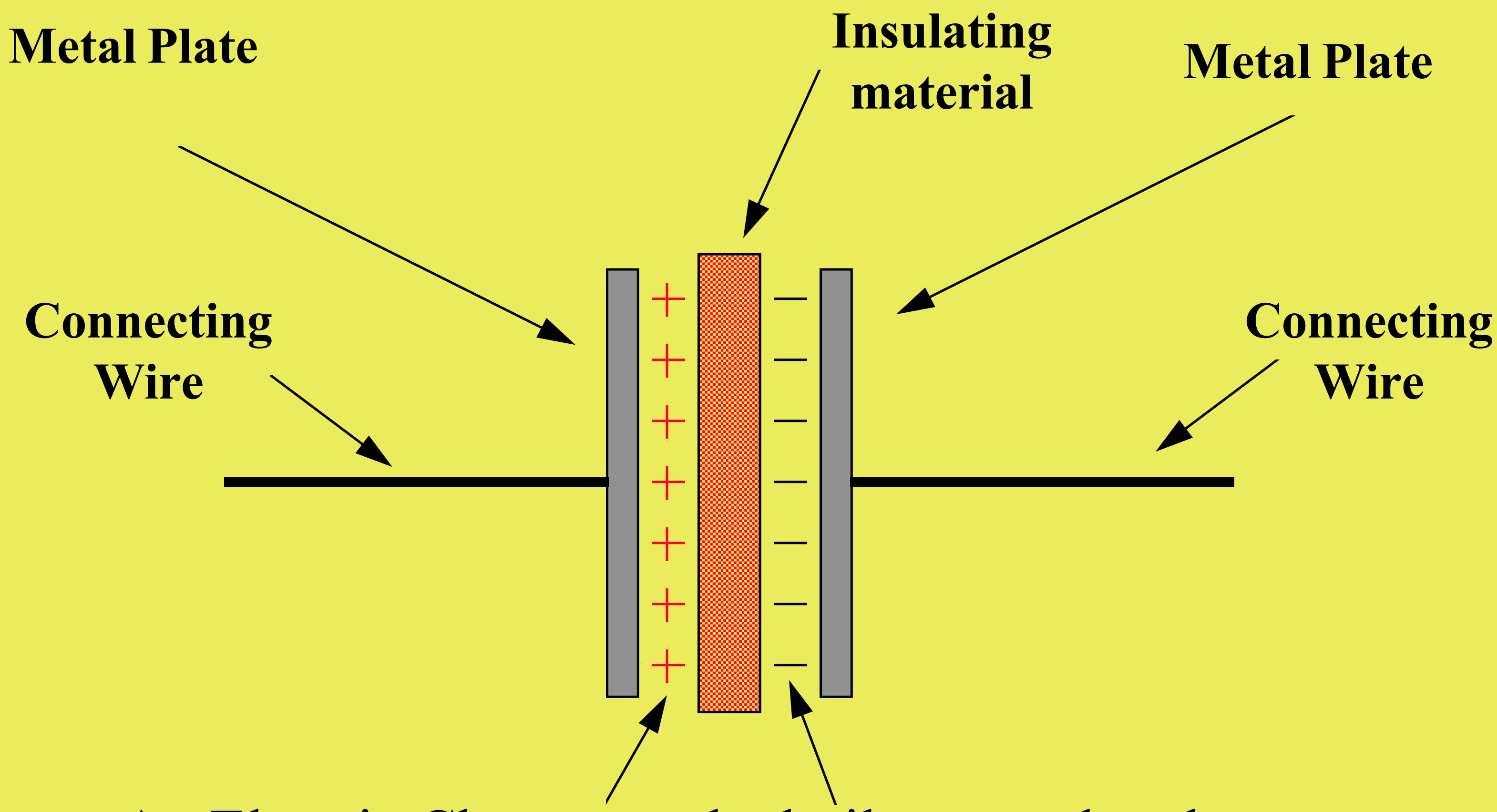
What have you observed ?

The Basics.



Energy can be transferred through the device without direct contact.

The Basics.



An Electric Charge can be built up on the plates

Capacitor concepts.

Summary

The Basics.

- The liquids never mix (The membrane acts as a liquid block).
- The insulator in the capacitor acts as a DC block.
- Energy can be transferred providing pressure is changing.
- With capacitors they enable energy to transfer when an Alternating current is applied AC.
- If an excess pressure is applied the membrane will fail, insulation will fail.

Engineering Numbers

Engineering Numbers.

• 1 Yotta	Y	=	1,000,000,000,000,000,000,000,000
• 1 Zetta	Z	=	1,000,000,000,000,000,000,000
• 1 Exa	E	=	1,000,000,000,000,000,000
• 1 Peta	P	=	1,000,000,000,000,000
• 1 Tera	T	=	1,000,000,000,000
• 1 Giga	G	=	1,000,000,000
• 1 Mega	M	=	1,000,000
• 1 Kilo	K	=	1,000
• 1 (units)		=	1
• 1 milli	m	=	0.001
• 1 micro	µ	=	0.000 001
• 1 nano	n	=	0.000 000 001
• 1 pico	p	=	0.000 000 000 001
• 1 femto	f	=	0.000 000 000 000 001
• 1 atto	a	=	0.000 000 000 000 000 001

Engineering Numbers.

• 1 **Peta**	P	=	1,000,000,000,000,000
• 1 Tera	T	=	1,000,000,000,000
• 1 Giga	G	=	1,000,000,000
• 1 Mega	M	=	1,000,000
• 1 Kilo	K	=	1,000
• 1 (units)		=	1
• 1 milli	m	=	0.001
• 1 micro	µ	=	0.000 001
• 1 nano	n	=	0.000 000 001
• 1 pico	p	=	0.000 000 000 001
• 1 femto	f	=	0.000 000 000 000 001
• 1 atto	a	=	0.000 000 000 000 000 001

NOT in common usage **YET**

Engineering Numbers.

- 1 Tera	T	=	1,000,000,000,000
- 1 Giga	G	=	1,000,000,000
- 1 Mega	M	=	1,000,000
- 1 Kilo	K	=	1,000
- 1		=	1

- 1 milli	m	=	0.001
- 1 micro	µ	=	0.000 001
- 1 nano	n	=	0.000 000 001
- 1 pico	p	=	0.000 000 000 001

Let us highlight the significant parts of these numbers.

Engineering Numbers.

• 1 Tera	T	=	1,000,000,000,000
• 1 Giga	G	=	1,000,000,000
• 1 Mega	M	=	1,000,000
• 1 Kilo	K	=	1,000
• 1		=	1
• 1 milli	m	=	0.001
• 1 micro	µ	=	0.000 001
• 1 nano	n	=	0.000 000 001
• 1 pico	p	=	0.000 000 000 001

It is also perfectly acceptable to add zeros to the end of a decimal fraction.

Engineering Numbers.

• 1 Tera	T	=	1,000,000,000,000
• 1 Giga	G	=	1,000,000,000
• 1 Mega	M	=	1,000,000
• 1 Kilo	K	=	1,000
• 1		=	1
• 1 milli	m	=	0.001 000 000 000
• 1 micro	µ	=	0.000 001 000 000
• 1 nano	n	=	0.000 000 001 000
• 1 pico	p	=	0.000 000 000 001

Engineering Numbers.

How could we express

98 micro units in terms of nano units ?

• 1 milli	m	=	0.001 000 000 000
• 1 micro	µ	=	0.000 001 000 000
• 1 nano	n	=	0.000 000 001 000
• 1 pico	p	=	0.000 000 000 001

Engineering Numbers.

How could we express

98 micro units in terms of nano units ?

0 9 8 0 0 0 or 98,000 n

- 1 milli m = 0.001 000 000 000
- 1 micro µ = 0.000 001 000 000
- 1 nano n = 0.000 000 001 000
- 1 pico p = 0.000 000 000 001

Engineering Numbers.

How could we express

98 micro units in terms of milli units ?

- 1 milli | m | = | 0.001 000 000 000
- 1 micro | µ | = | 0.000 001 000 000
- 1 nano | n | = | 0.000 000 001 000
- 1 pico | p | = | 0.000 000 000 001

Engineering Numbers.

How could we express

98 micro units in terms of milli units ?

0 0 0 0 9 8 or 0.098 m

- 1 milli m = 0.001 000 000 000
- 1 micro µ = 0.000 001 000 000
- 1 nano n = 0.000 000 001 000
- 1 pico p = 0.000 000 000 001

Engineering Numbers.

Let us now look the numbers greater than one.

- 1 milli m = 0.001 000 000 000
- 1 micro µ = 0.000 001 000 000
- 1 nano n = 0.000 000 001 000
- 1 pico p = 0.000 000 000 001

Engineering Numbers.

• 1 Tera	T	=	1,000,000,000,000
• 1 Giga	G	=	1,000,000,000
• 1 Mega	M	=	1,000,000
• 1 Kilo	K	=	1,000
• 1		=	1
• 1 milli	m	=	0.001 000 000 000
• 1 micro	µ	=	0.000 001 000 000
• 1 nano	n	=	0.000 000 001 000
• 1 pico	p	=	0.000 000 000 001

It is also perfectly acceptable to add zeros to the front of a decimal number without changing its value.

Engineering Numbers.

• 1 Tera	T	=	1,000,000,000,000
• 1 Giga	G	=	0,001,000,000,000
• 1 Mega	M	=	0,000,001,000,000
• 1 Kilo	K	=	0,000,000,001,000
• 1		=	0,000,000,000,001
• 1 milli	m	=	0.001 000 000 000
• 1 micro	µ	=	0.000 001 000 000
• 1 nano	n	=	0.000 000 001 000
• 1 pico	p	=	0.000 000 000 001

Let us look at numbers greater or equal to one and colour code them.

Engineering Numbers.

• 1 Tera	T	=	1,000,000,000,000
• 1 Giga	G	=	0,001,000,000,000
• 1 Mega	M	=	0,000,001,000,000
• 1 Kilo	K	=	0,000,000,001,000
• 1		=	0,000,000,000,001
• 1 milli	m	=	0.001 000 000 000
• 1 micro	µ	=	0.000 001 000 000
• 1 nano	n	=	0.000 000 001 000
• 1 pico	p	=	0.000 000 000 001

Let us look at numbers greater or equal to one and colour code them.

Engineering Numbers.

How could we express

98 Mega units in terms of Kilo units ?

• 1 Tera	T	=	1,000,000,000,000
• 1 Giga	G	=	0,001,000,000,000
• 1 Mega	M	=	0,000,001,000,000
• 1 Kilo	K	=	0,000,000,001,000
• 1		=	0,000,000,000,001

Engineering Numbers.

How could we express

98 Mega units in terms of Kilo units ?

0 | 9 8 0 0 0 | or 98000K

- 1 Tera   T   =   1,000,000,000,000
- 1 Giga   G   =   0,001,000,000,000
- 1 Mega   M   =   0,000,001,000,000
- 1 Kilo   K   =   0,000,000,001,000
- 1   =   0,000,000,000,001

Engineering Numbers.

How could we express

98 Mega units in terms of Giga units ?

•	1 Tera	T	=	1,000,000,000,000
•	1 Giga	G	=	0,001,000,000,000
•	1 Mega	M	=	0,000,001,000,000
•	1 Kilo	K	=	0,000,000,001,000
•	1		=	0,000,000,000,001

Engineering Numbers.

How could we express

98 Mega units in terms of Giga units ?

0 0 0 0 9 8 or 0.098G

•	1 Tera	T	=	1,000,000,000,000
•	1 Giga	G	=	0,001,000,000,000
•	1 Mega	M	=	0,000,001,000,000
•	1 Kilo	K	=	0,000,000,001,000
•	1		=	0,000,000,000,001

Three Digit Numbers

Three Digit Numbers.

- This is a short hand method to describe Engineering number values but never using more than three characters.
- Many engineering values have a tolerance of 10% therefore we never need more than two significant digits to express the value.
- The rest of the Three Digit Number is the multiplier or division factor .
- Example 12K = 12 times 1000 = 12000
- Example 22µ = 22 times 0.000001 = 0.000022
- **So how would we deal with a number like 1800.**

Three Digit Numbers.

- So how would we deal with a number like 1800.
- We could write 1800 as 1.8 * 1000 = 1.8K
- However 1.8K is four characters we want just three.
- A second point is that the reader could easily miss the decimal point.

Solution ...

- Use the multiplier value to identify where the decimal point would be located.
- So 1800 would be written as 1K8
- also 270,000 would be written as 0.27 * 1000000 = 0.27M
- Therefore 270,000 could be written as M27

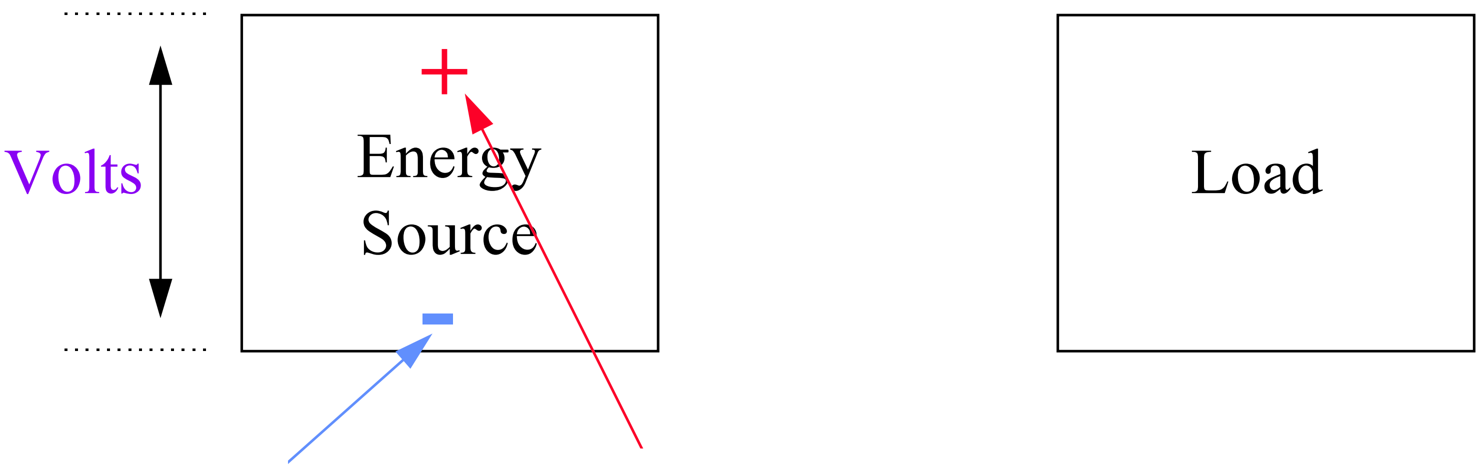
Electrical Circuits

Electrical Circuits.

All circuits consist of a Source and Load :-

Electrical Circuits.

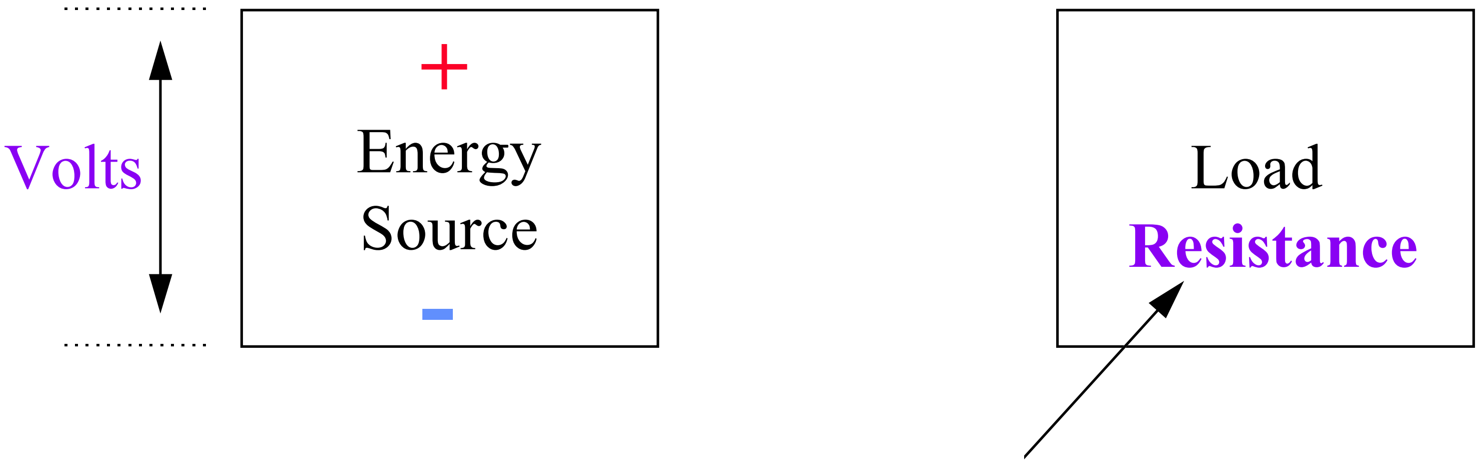
The Energy source is measured in Volts:-



Note The energy source may also be identified with polarity as well.

Electrical Circuits.

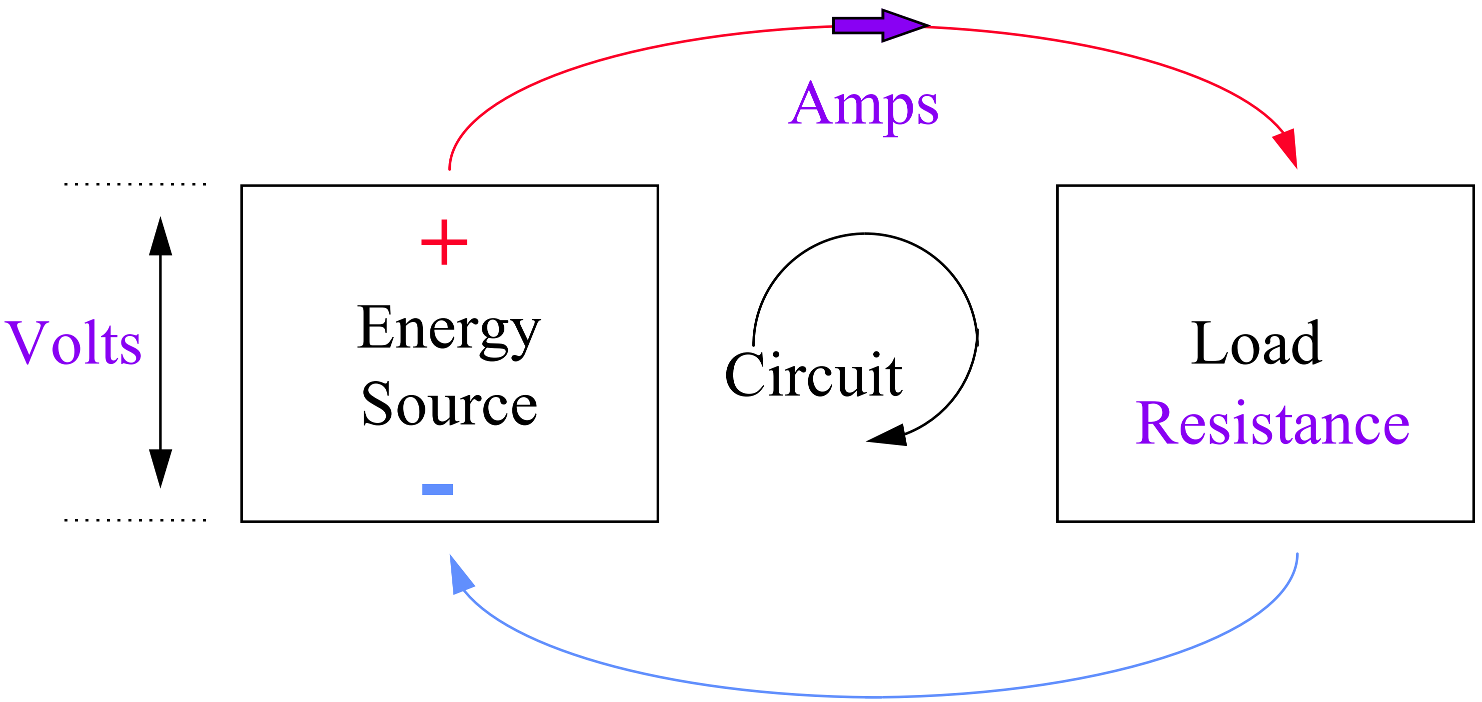
The Load presents a resistance for the Source :-



This is where all the energy that is supplied by the source will be dissipated.

Electrical Circuits.

The Source is connected to the Load :-



and Energy transferred around the circuit.

Electrical Circuits.

Summary:

- An Electrical circuit must have an Energy source and a Load.
- There must be a direct connection from source to Load and a return path back to the Source.
- The relationship between the units of Voltage, Current and Resistance is known as Ohms Law.

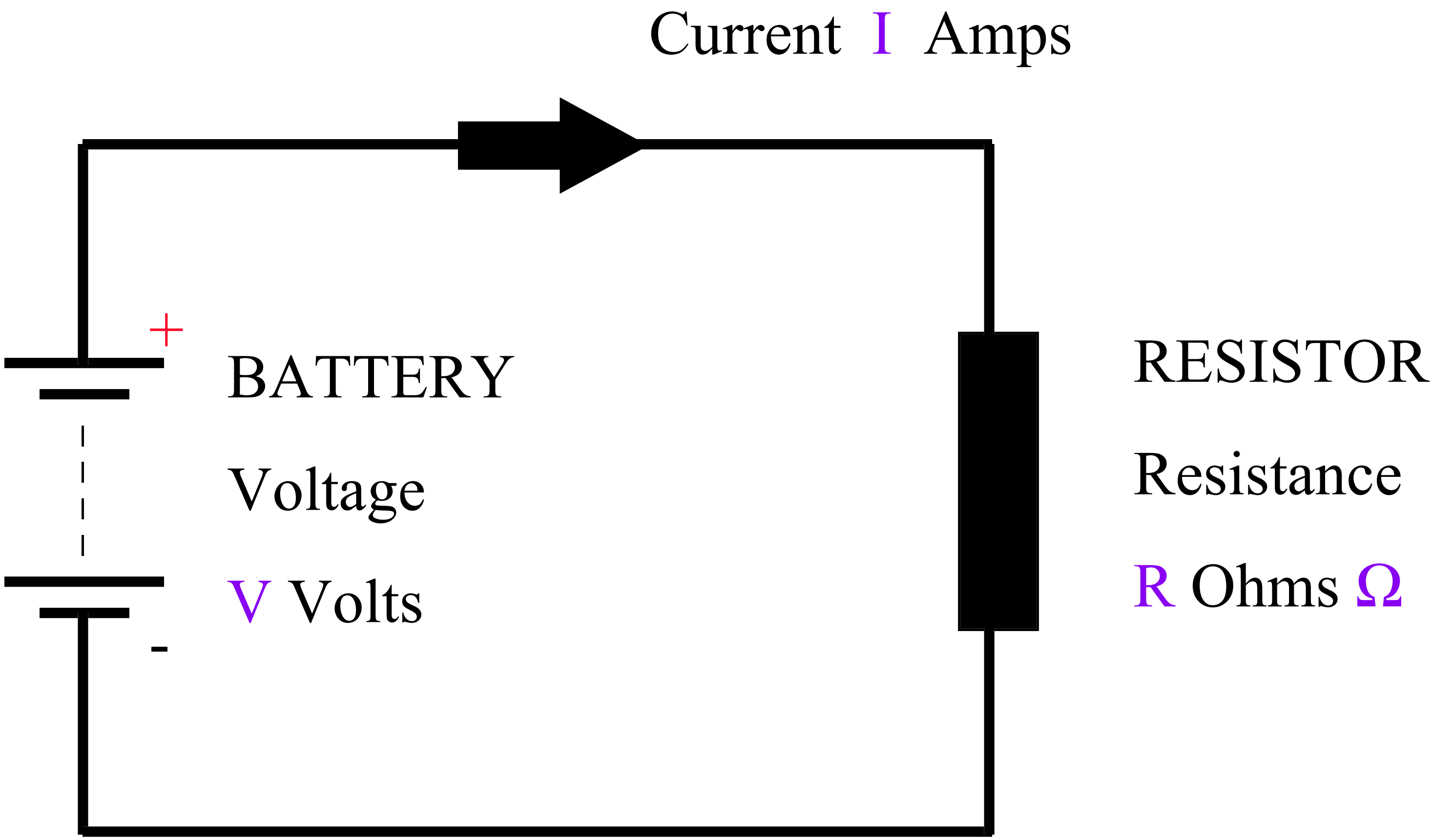
Resistors

Resistors

Ohms Law

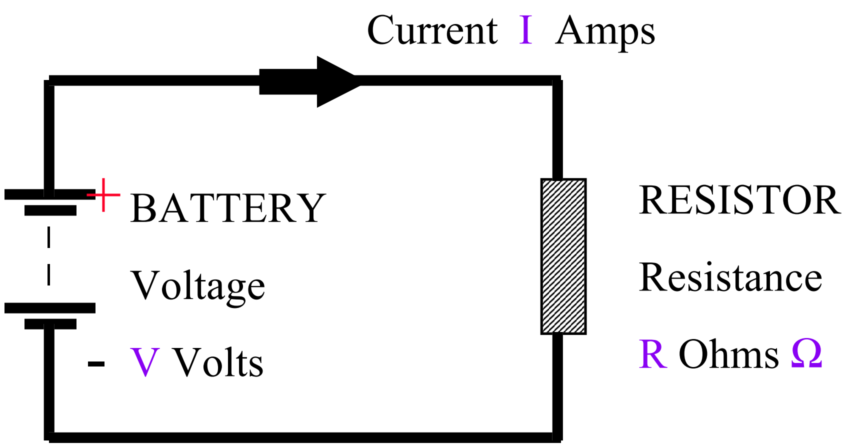
Resistors.

Ohm's Law



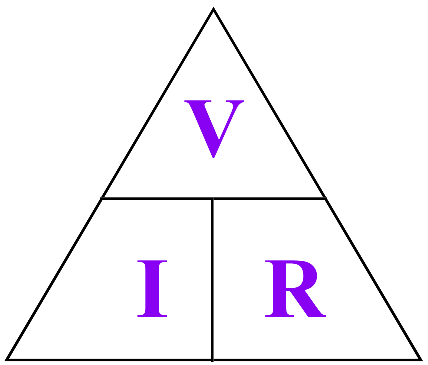
Resistors.

Ohm's Law



In the circuit : The applied Voltage **V** across resistor **R** causes a current **I** to flow. The relationship between these three quantities is known as Ohm's Law and the ratio is described as follows :-

$$\mathbf{R} = \frac{\mathbf{V}}{\mathbf{I}}$$



Where **I** is in Amps, **V** is Volts and **R** in Ohms.

Resistors.

Volts	Amps	Ohms
10V	2A	.
52V	.	13Ω
.	0.25A	500Ω
104V	5mA	.
12V	110A	.
5V	.	250Ω
9V	20mA	.
.	25μA	2KΩ

Resistors.

Volts	Amps	Ohms
10V	2A	5Ω
52V	4A	13Ω
125V	0.25A	500Ω
104V	5mA	20.8KΩ
12V	110A	0.109Ω
5V	20mA	250Ω
9V	20mA	450Ω
50mV	25µA	2KΩ

Resistors

Power

Definitions. Resistors.

Power

Power (P) is the amount of effort that can be delivered or absorbed by an entity.

Power is measured in Watts, where :-

One Watt of Power is developed when One Volt causes One Amp of current to flow in a circuit.

Watts = Volts * Amps

Energy

Energy (E) is the amount of power that can be delivered or absorbed by an entity over a specific time.

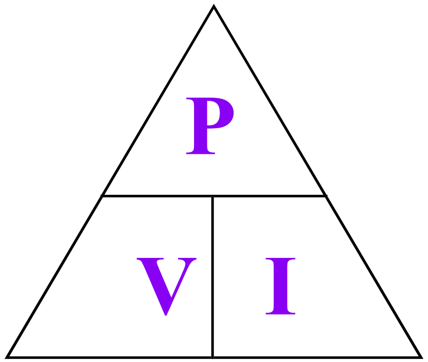
Energy is measured in Joules, where :-

One Joule = One Watt for One Second

Resistors.

Power is measured in Watts, where :-

One Watt = One Volt * One Amp



Where **I** is in Amps, **V** is Volts and **P** in Watts.

Resistors.

Volts	Amps	Watts
10V	2A	.
52V	.	13W
.	0.25A	500W
104V	5mA	.
12V	110A	.
5V	.	250W
9V	20mA	.
.	25µA	1.25µW

Resistors.

Volts	Amps	Watts
10V	2A	20W
52V	0.25A	13W
2KV	0.25A	500W
104V	5mA	0.52W
12V	110A	1.32KW
5V	50A	250W
9V	20mA	180mW
50mV	25µA	1.25µW

Resistors.

Question

Can we relate the units of

$P = V * I$ Voltage $R = V / I$

Current

Resistance

and Power

into a common relationship ?

Resistors.

(1) Power P = V*I

(2) Resistance R = V / I

Note in (3) V=I*R
or in (4) I=V/R

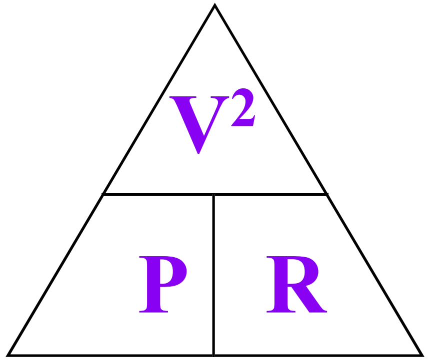
Substitute (3) in (1)

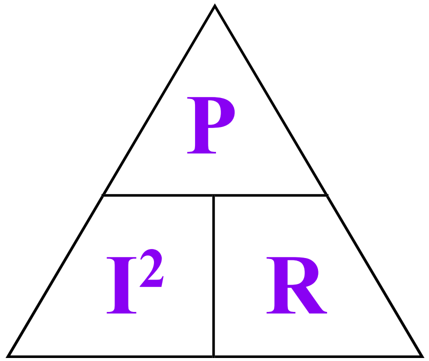
$P = I * R * I = I^2 * R$

Substitute (4) in (1)

$P = V * V/R = V^2 /R$

Where **P** is in Watts, **I** is in Amps, **V** is Volts and **R** in Ohms.





Resistors Calculations

Resistor Network Calculations.

- Series and Parallel Resistors
- Voltage divider
- Measurement loading
- Kirchhoff's laws
- Thevenin’s Theorem
- Norton’s Theorem
- Superposition Method

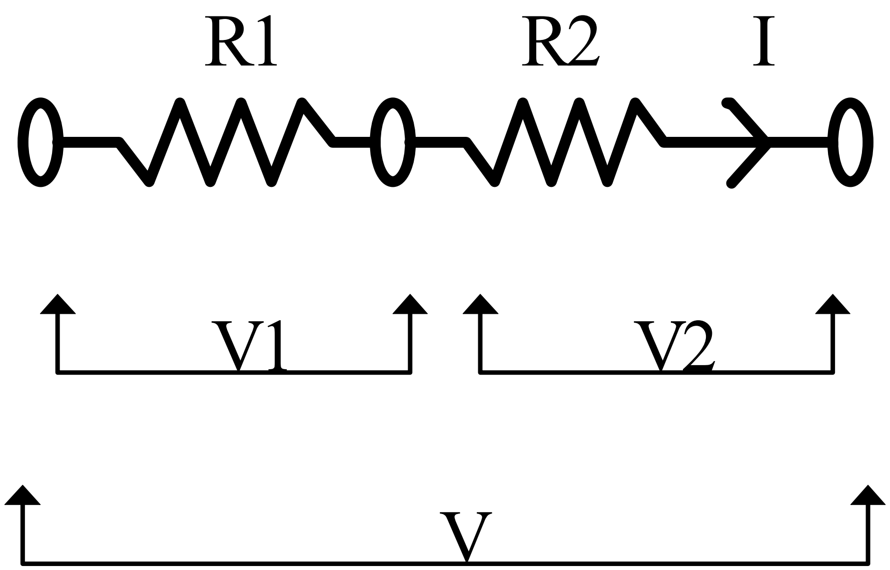
Resistors.

Series Resistor Proof

Series Connection

Resistors.

The Proof



$$\frac{V}{I} = R$$

Series Connection

Resistors.

The Proof

As “I” is Common through both R1 & R2

$$\therefore \quad V = V1 + V2$$

$$V1 = I * R1$$

$$V2 = I * R2$$

$$V = I * R(Total)$$

Series Connection

Resistors.

The Proof

∴ I * R(Total) = I * R1 + I * R2

Now divide through by "I" gives

~~I~~ * R(Total) = ~~I~~ * R1 + ~~I~~ * R2

giving :-

R(Total) = R1 + R2 + ... etc

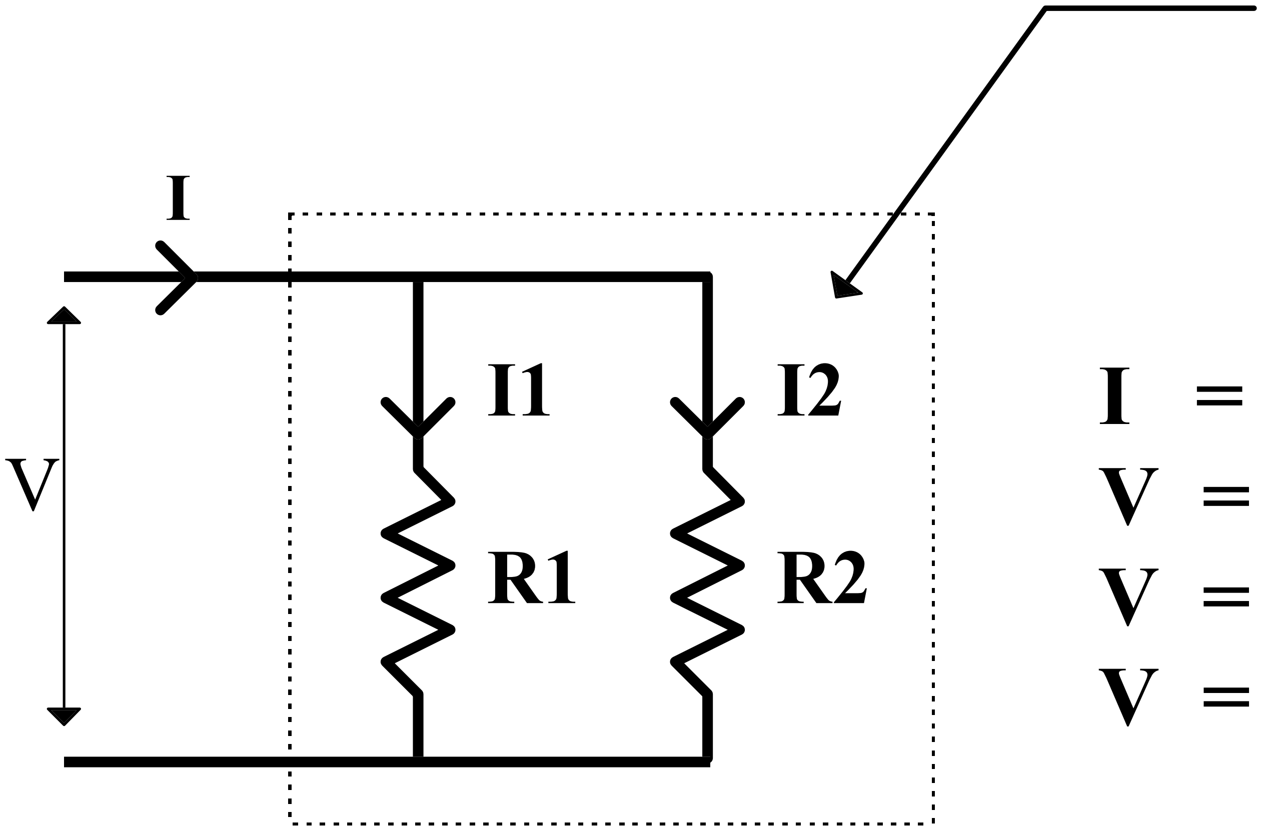
Resistors.

Parallel Resistor Proof

Parallel Connection

Resistors.

The Proof



The dotted line enclosed area is the total circuit resistance Rt

$$I = I1 + I2$$
$$V = I1 * R1$$
$$V = I2 * R2$$
$$V = I * Rt$$

Resistors.

The Proof

This Gives

$$\frac{V}{Rt} = I \quad , \quad \frac{V}{R1} = I1 \quad , \quad \frac{V}{R2} = I2$$

Parallel Connection

Resistors.

The Proof

However If **I = I1 + I2 THEN**

$$\frac{\not{V}}{Rt} = \frac{\not{V}}{R1} + \frac{\not{V}}{R2} \ldots\ldots\ldots\ldots$$

(and Dividing)
(by **V** gives)

$$\frac{1}{Rt} = \frac{1}{R1} + \frac{1}{R2} \ldots\ldots\ldots\ldots$$

etc.

Resistors.

Two Parallel Resistors

Parallel Connection

Resistors.

Two Resistors

$$\frac{1}{Rt} = \frac{1}{R1} + \frac{1}{R2}$$

Using a Common denominator (R1 * R2)

$$\frac{1}{Rt} = \frac{(R1) + (R2)}{(R1 * R2)}$$

Parallel Connection

Resistors.

Two Resistors

$$\frac{1}{R_t} = \frac{1}{R_1} + \frac{1}{R_2} \quad \text{or} \quad \frac{R_1 + R_2}{R_1 * R_2}$$

Multiply both sides by (R1 * R2)

$$\frac{1 * R_1 * R_2}{R_t} = \frac{(R_1 + R_2) * (R_1 * R_2)}{R_1 * R_2}$$

Parallel Connection

Resistors.

Two Resistors

Which gives :-

$$\frac{R1 * R2}{Rt} = \frac{(R1 + R2)}{1}$$

Multiply both sides by Rt

$$\frac{R1 * R2 * Rt}{Rt} = \frac{(R1 + R2) * Rt}{1}$$

Parallel Connection

Resistors.

Two Resistors

Which gives :-

$$\frac{R1 * R2}{1} = \frac{(R1 + R2) * Rt}{1}$$

Divide both sides by (R1 + R2)

$$\frac{R1 * R2}{(R1 + R2)} = \frac{(R1 + R2) * Rt}{(R1 + R2)}$$

Parallel Connection

Resistors.

Two Resistors

Which gives :-

$$\frac{R1 * R2}{(R1 + R2)} = \frac{Rt}{1}$$

or The Product over Sum Rule

$$Rt = \frac{R1 * R2}{(R1 + R2)}$$

Note: This is often used to evaluate two resistors in parallel.

Resistors.

Resistors Summary

Summary

Resistors.

Resistors in Series

$$Rt = R1 + R2 + R3 \quad \text{... etc...}$$

Resistors in Parallel

$$\frac{1}{Rt} = \frac{1}{R1} + \frac{1}{R2} \quad .... \quad \text{etc.}$$

or

$$Rt = \frac{R1 * R2}{(R1 + R2)}$$

The two resistor option.

Resistors.

Circuit Evaluation

Resistors.

The Circuit Evaluation process.

Step 1 , Understand what is required or being asked.

Step 2 , Understand the Circuit Connections.

Step 3 , (Repeat as required)

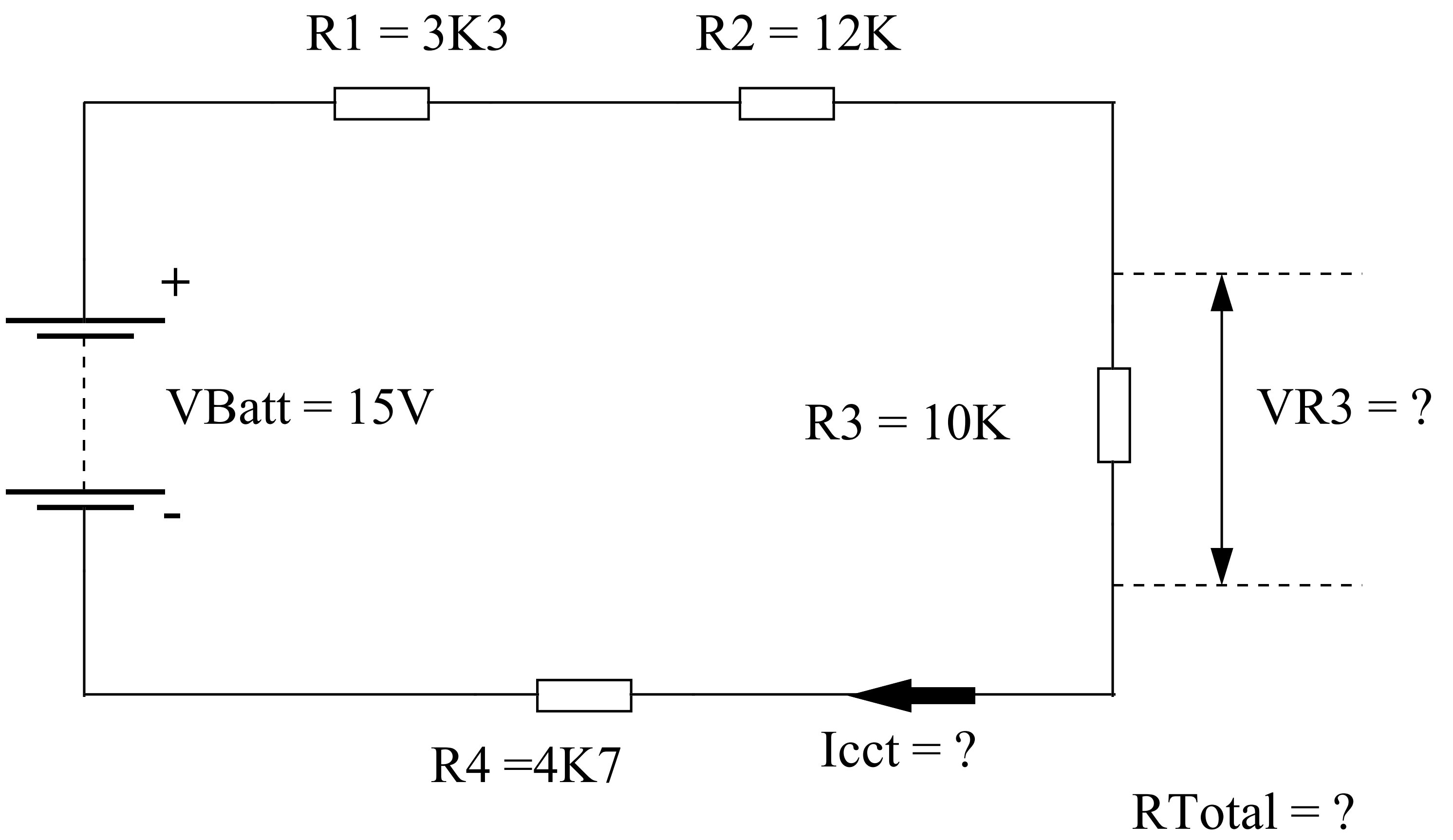
Simplify any Parallel or Series networks.

Step 4 , Answer the asked Question/s

Step 5 , Process next activity.

Resistors.

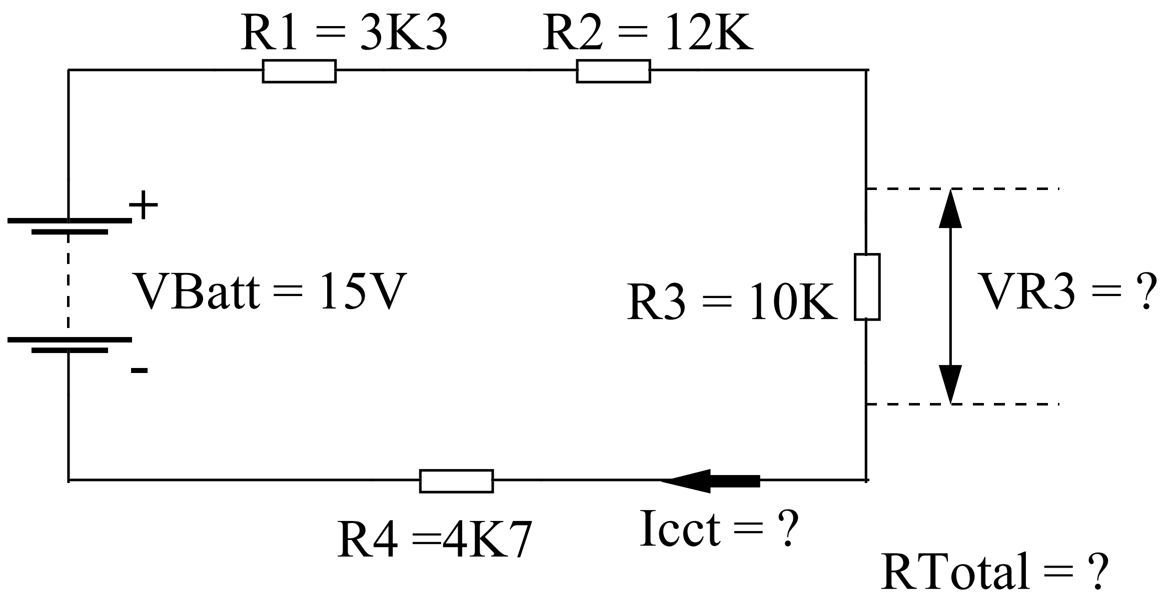
Examples



Resistors.

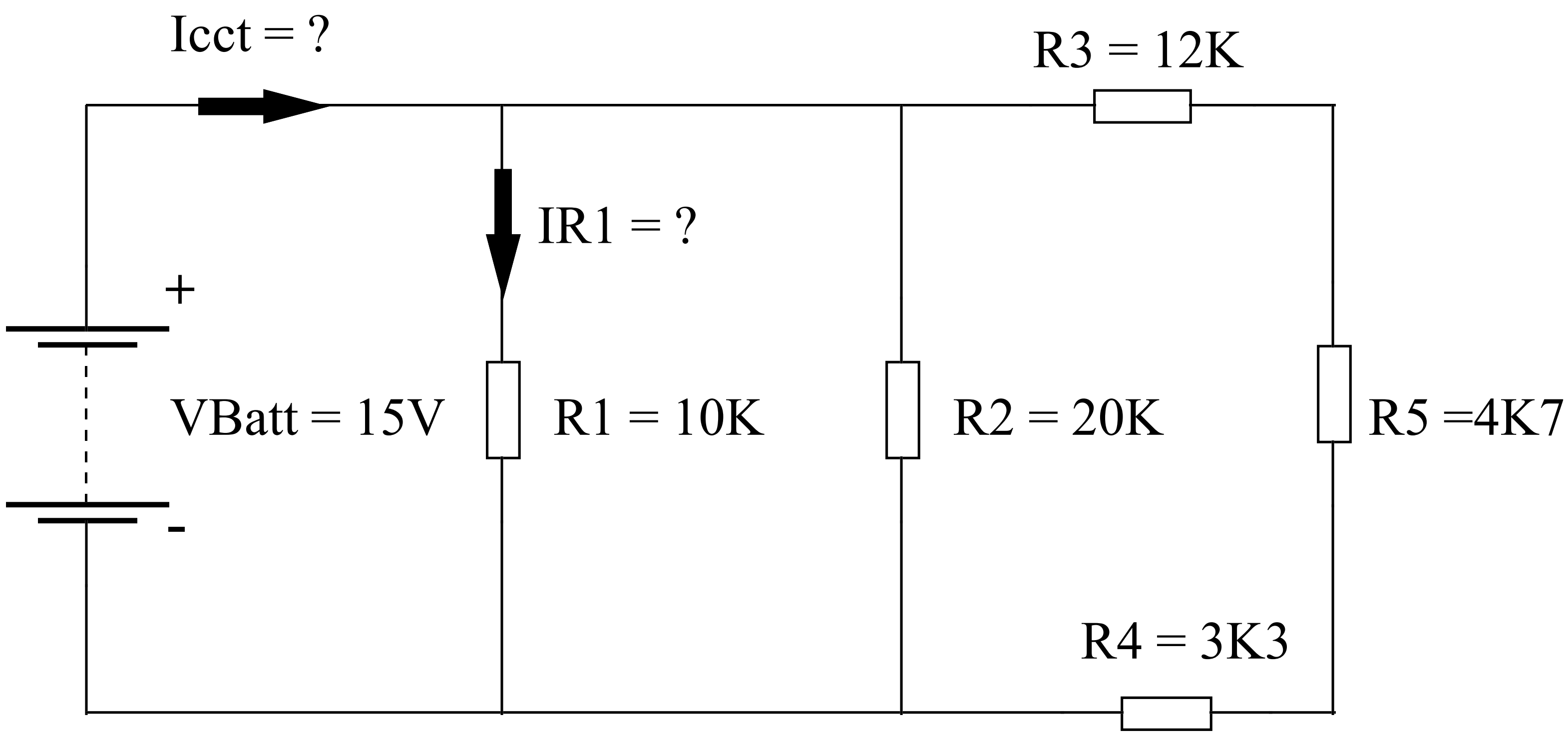
Examples

- Resistors in series RT = R1 + R2 + R3 ....
- Therefore RT = 3K3 + 12K + 10K +4K7 = 30KΩ .. ($30 * 10^3$)Ohms
- Icct = VBatt / RT , Therefore 15/30K = 0.5mA .. (15) / ($30 * 10^3$)Amps
- VR3 = I * R3 , Therefore 0.5mA * 10K = 5V .. ($0.5 * 10^{-3}$)* ($10 * 10^3$)Volts



Resistors.

Examples

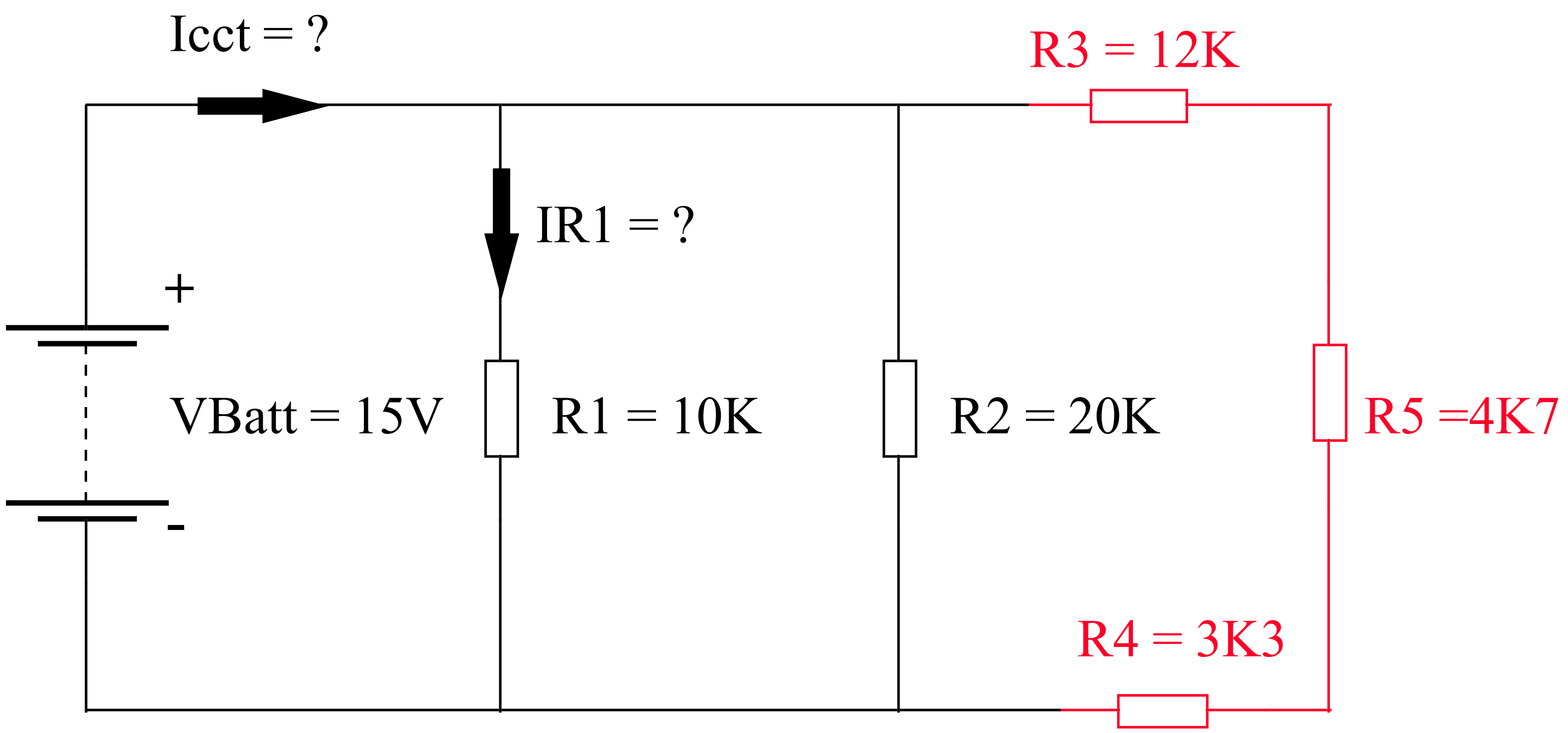


RTotal = ?

SPCA entry = (12,4.7,3.3)!20!10

Resistors.

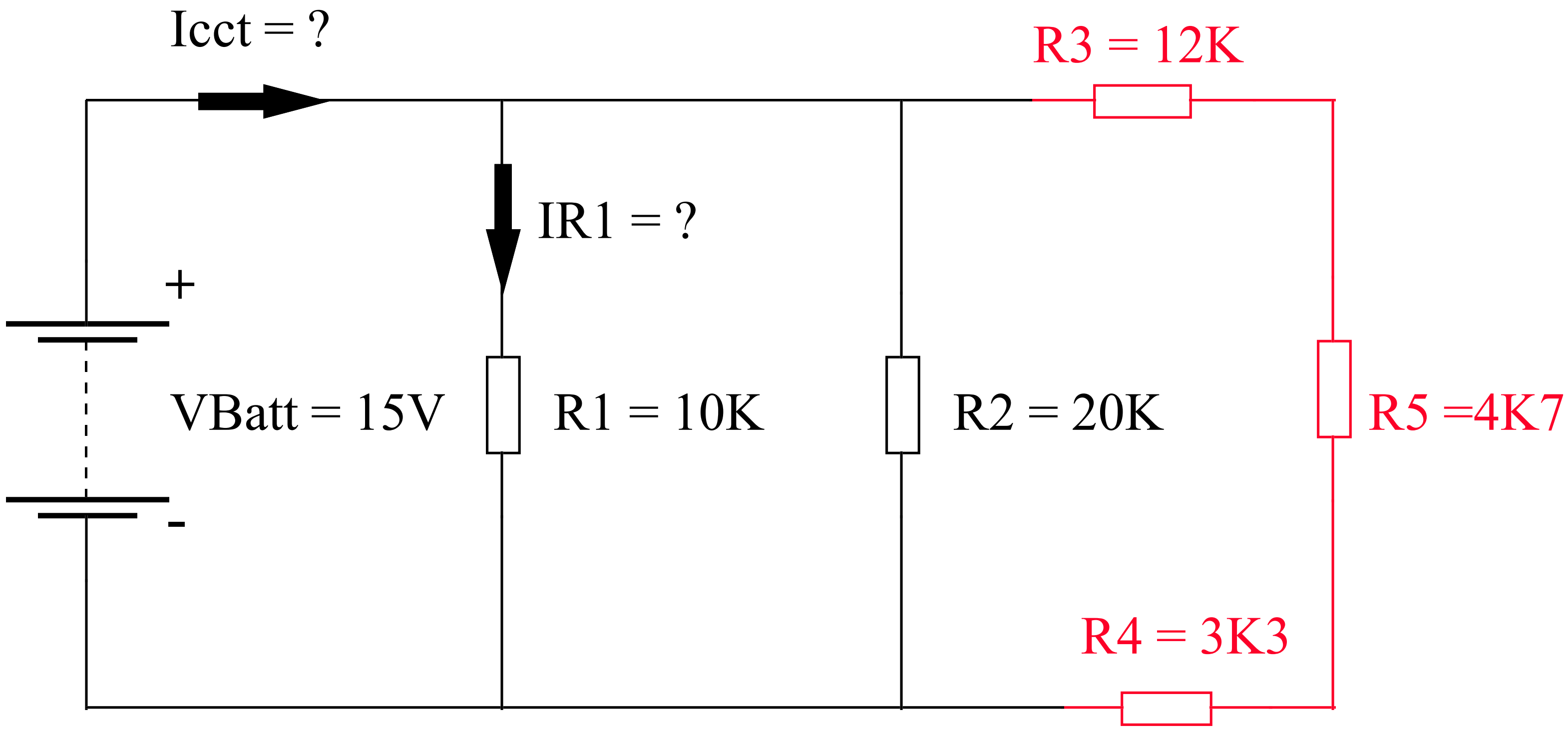
Examples



RTotal = ?

Resistors.

Examples

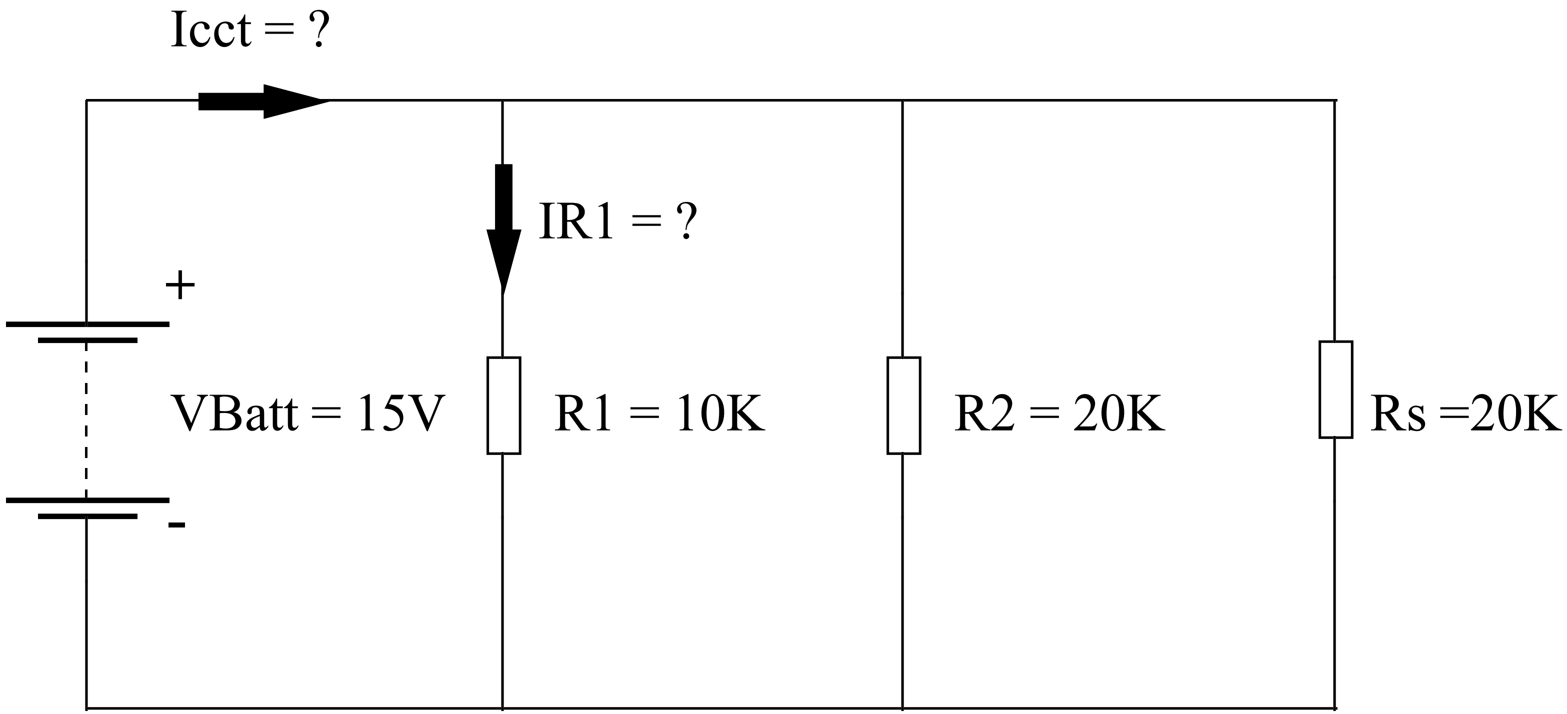


RTotal = ?

Rs = R3 + R4 + R5 = 12K + 4K7 + 3K3 = 20K Ohms

Resistors.

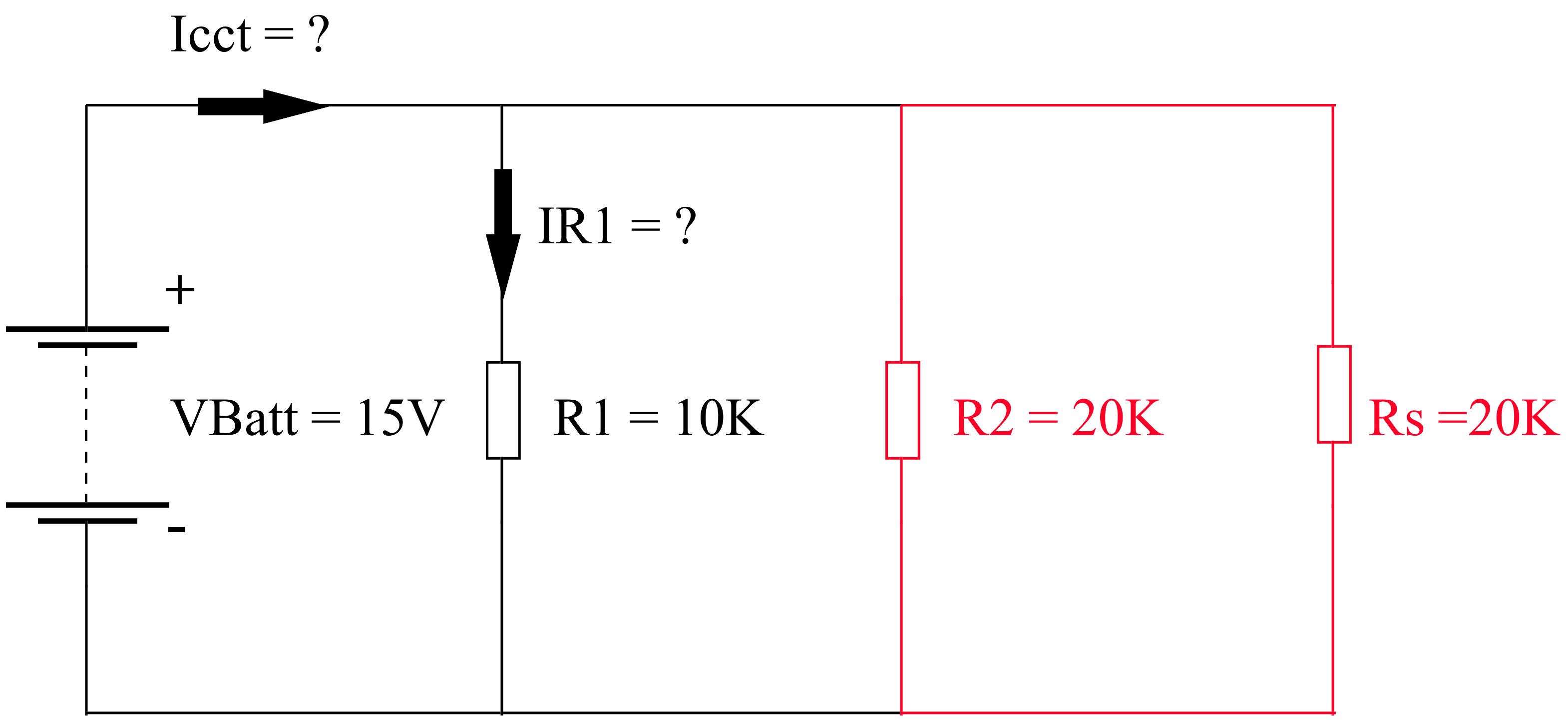
Examples



RTotal = ?

Resistors.

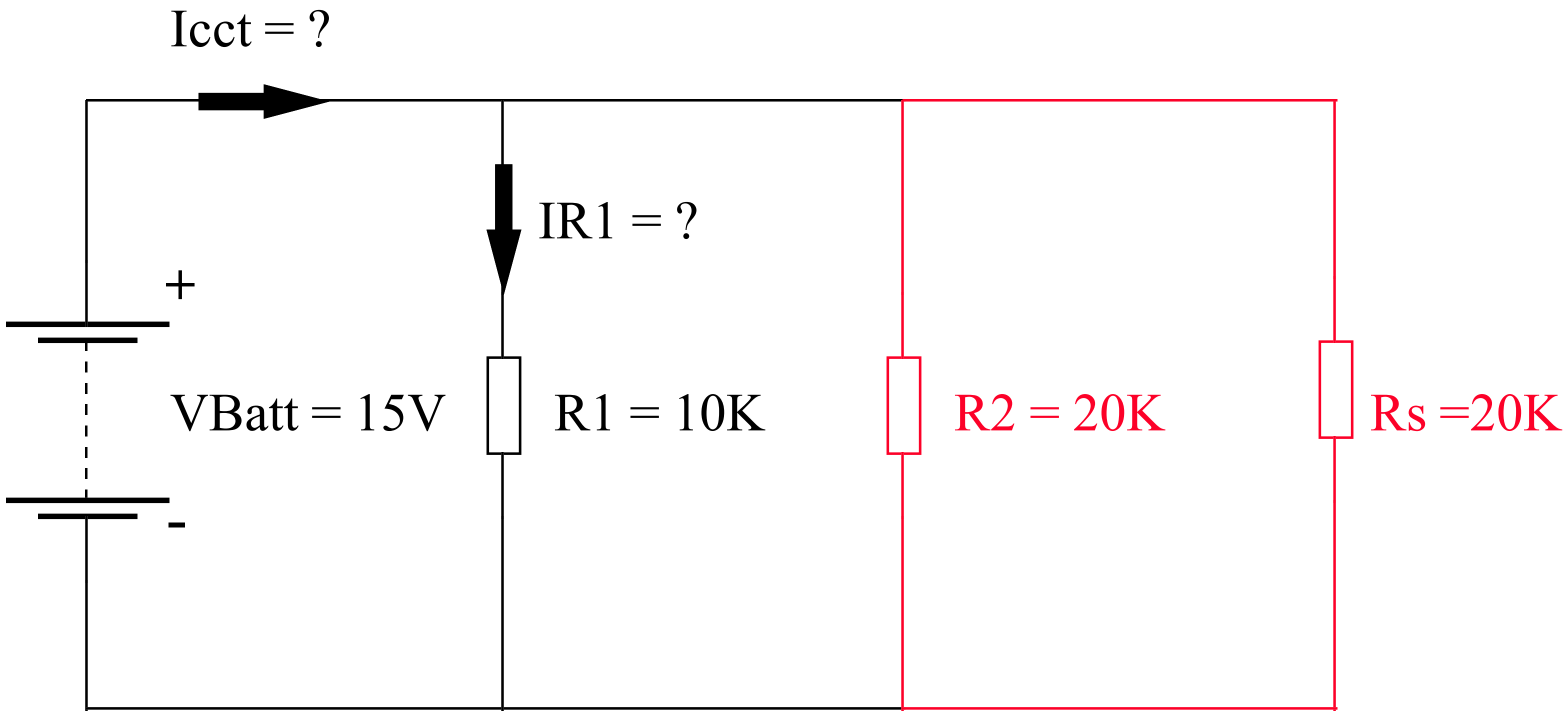
Examples



RTotal = ?

Resistors.

Examples



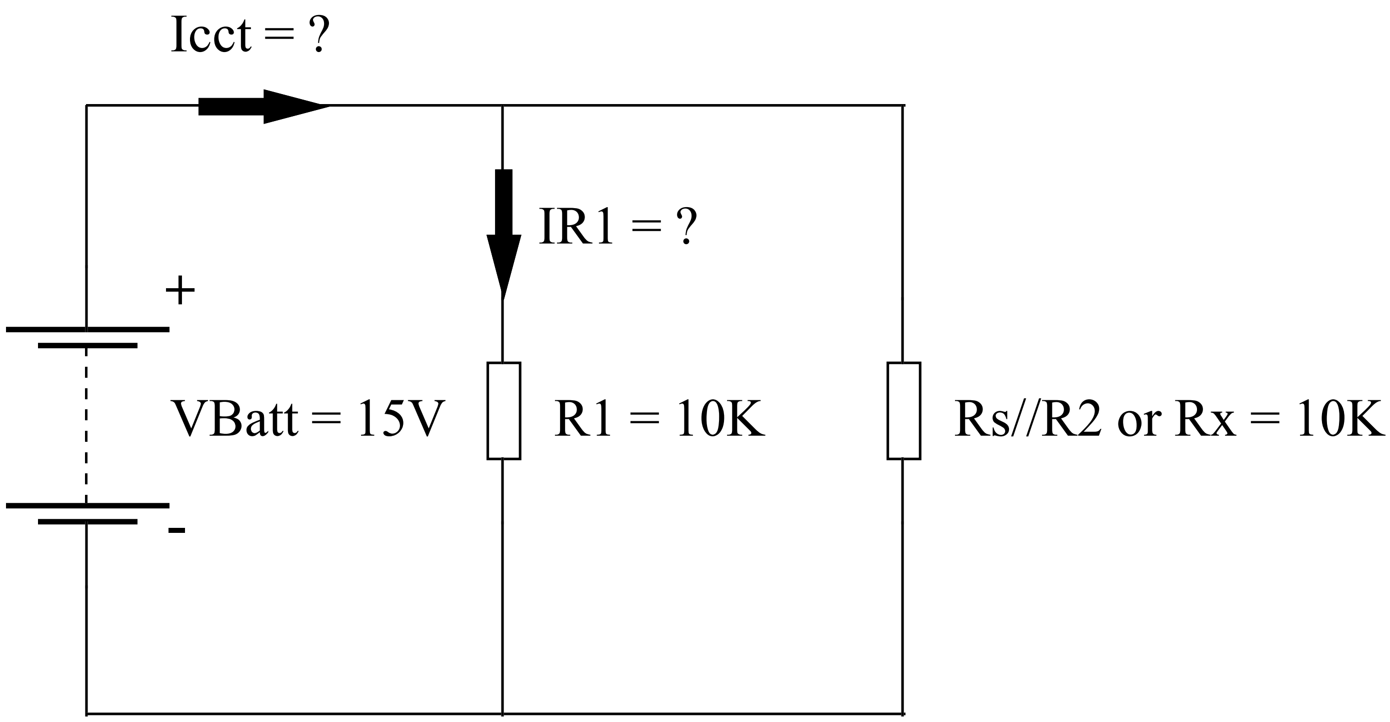
RTotal = ?

Using Product over sum rule

R2//Rs = 20K*20K / (20K+20K) = 400K / 40K = 10K

Resistors.

Examples

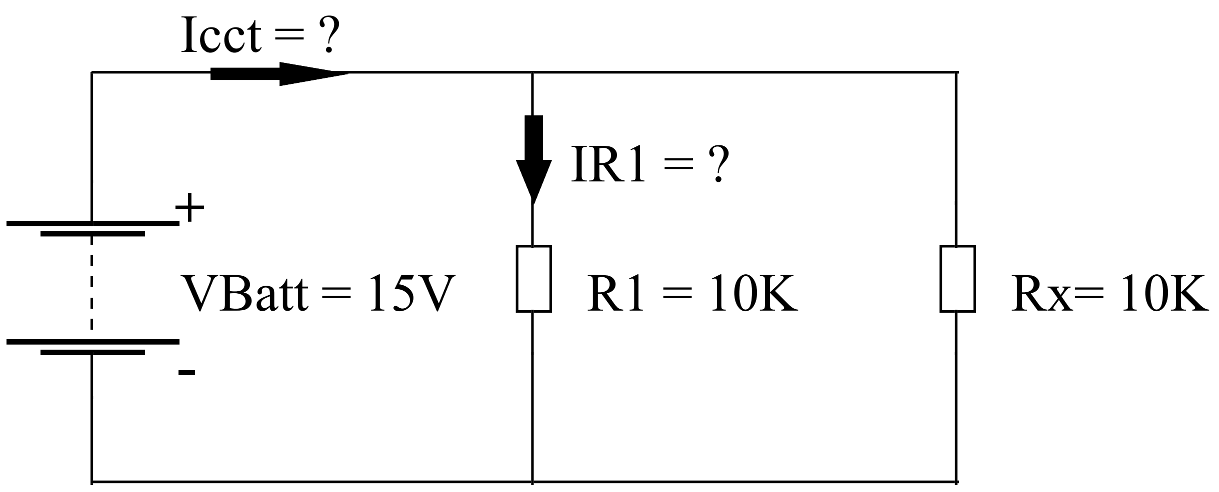


RTotal = ?

Resistors.

Examples

- Resistors in parallel R1//Rx = 10K*10K / (10K+10K) = 100K / 20K = 5K
  Again using Product over sum rule.
- Therefore RTotal = 5KΩ .. $(5 * 10^3)$Ohms
- Icct = VBatt / RTotal , Therefore 15/5K = 3mA .. (15) / $(5 * 10^3)$Amps
- IR1 = V / R1 , Therefore 15V / 10K = 1.5mA .. (15)/ $(10 * 10^3)$Amps



RTotal = 5K

Resistors Practice

Resistors.

Using Series Parallel Component Analyzer.

- This is a simple programme that will perform the analysis calculations.
- Components in series are separated by commas ie. R1,R2,R3 . . . .
- Components in Parallel are separated by the Exclamation mark ie. R1!R2!R3 . . . .
- Brackets may be used to force calculation order priority.

Resistors.

Using Series Parallel Component Analyzer.

- **Example of usage :-**
- R1= 1KΩ , R2= 200Ω and R3= 500Ω.
- R3 and R2 in series would be entered as 500,200
- R1 and R3 in Parallel would be entered as 1000!500
- R1 in series R2 all in Parallel with R3 would be entered as (1000,200)!500.

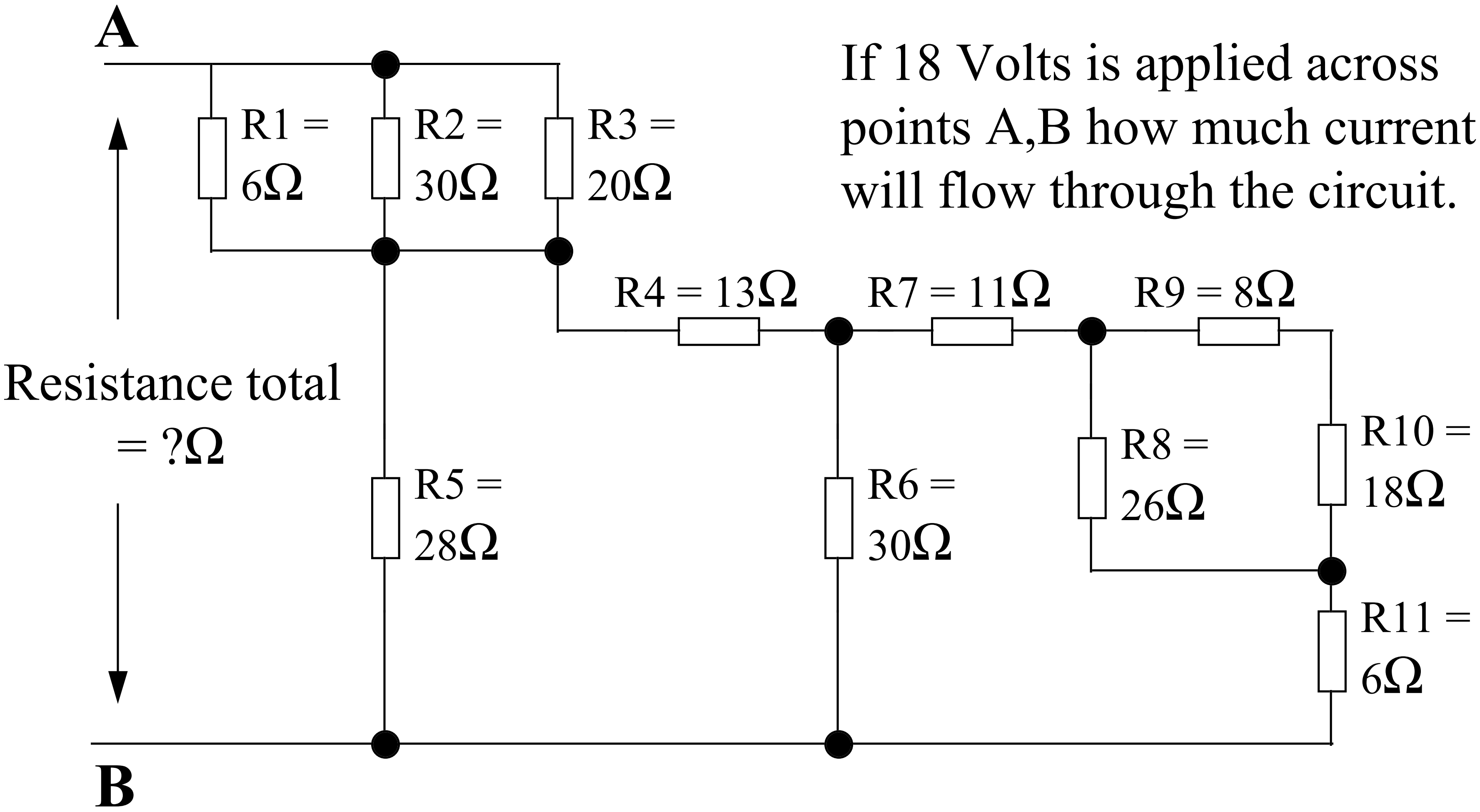
Resistors.

Using Series Parallel Component Analyzer.

- Entering Numbers :-
- 1KΩ could be entered as 1000 or 1E3
- Likewise 1μF could be entered as 0.000001 or 1E-6
- The "E" indicates the exponent format quite often used in computers.
- The normal mathematical representation of 1E6 would be written as $1*10^6$.

Resistors.

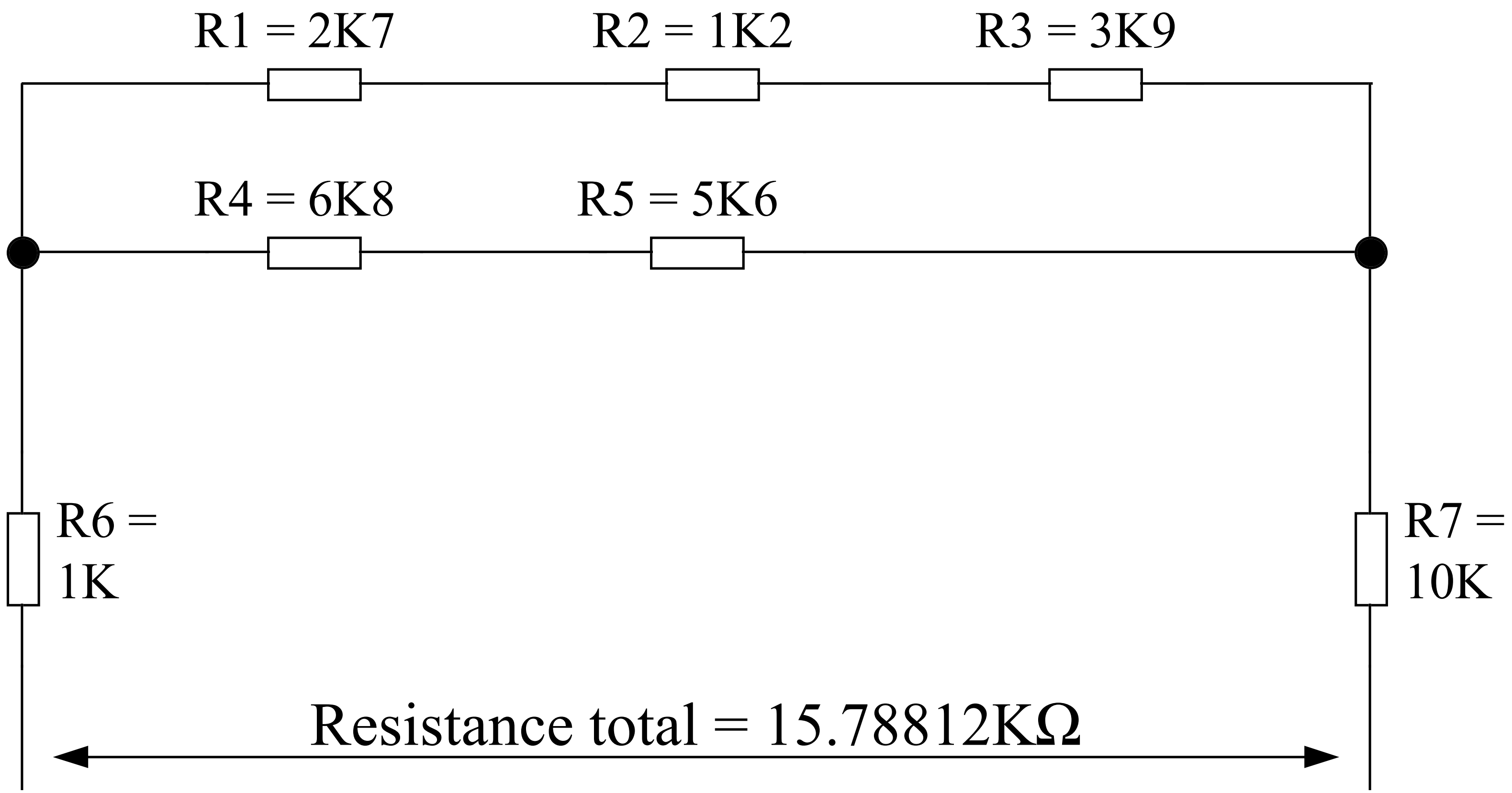
Without using calculator



If 18 Volts is applied across points A,B how much current will flow through the circuit.

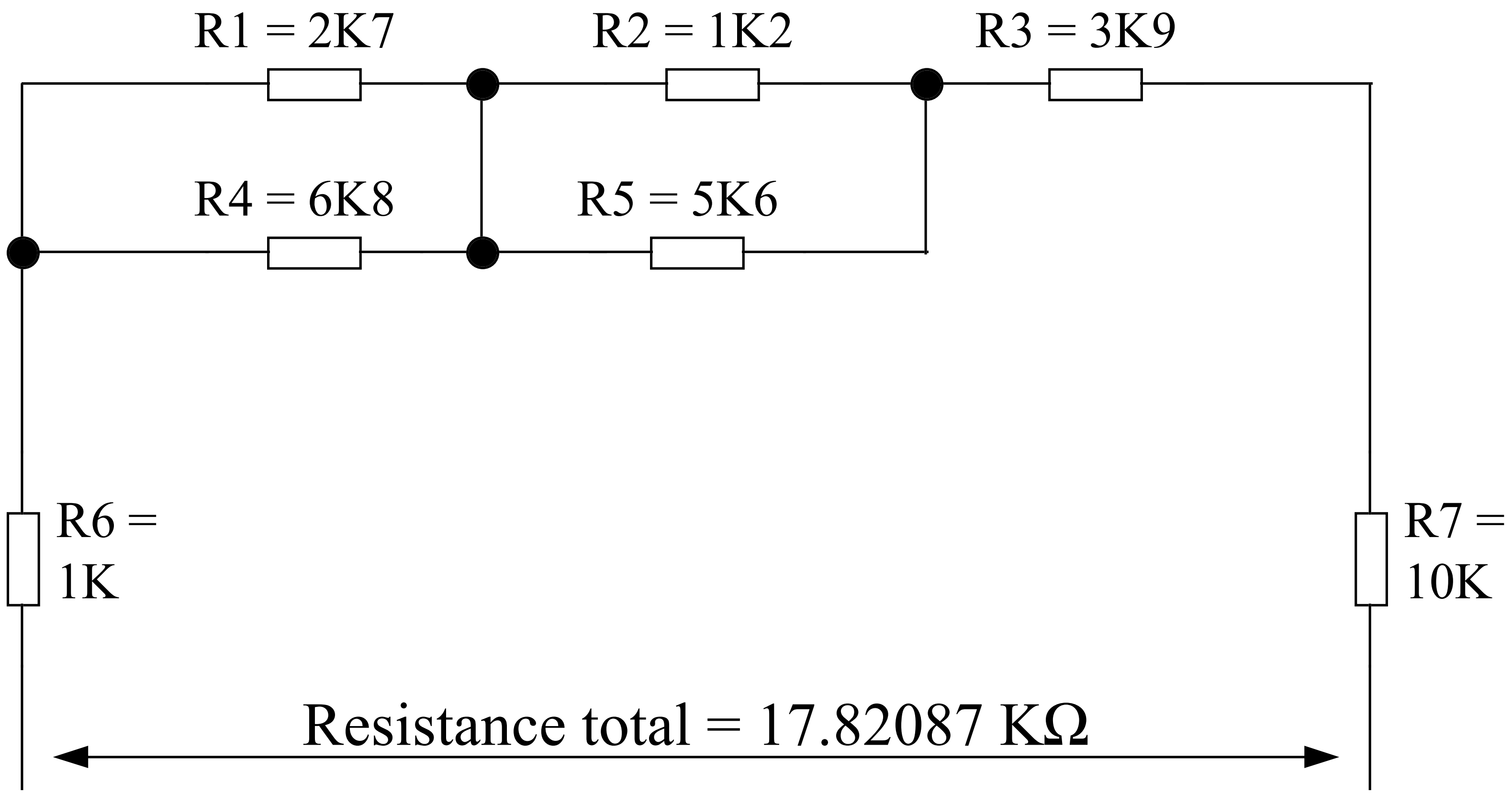
SPCA entry = (((((8,18)!26),6,11)!30),13)!28,(6!30!20)

Resistors.



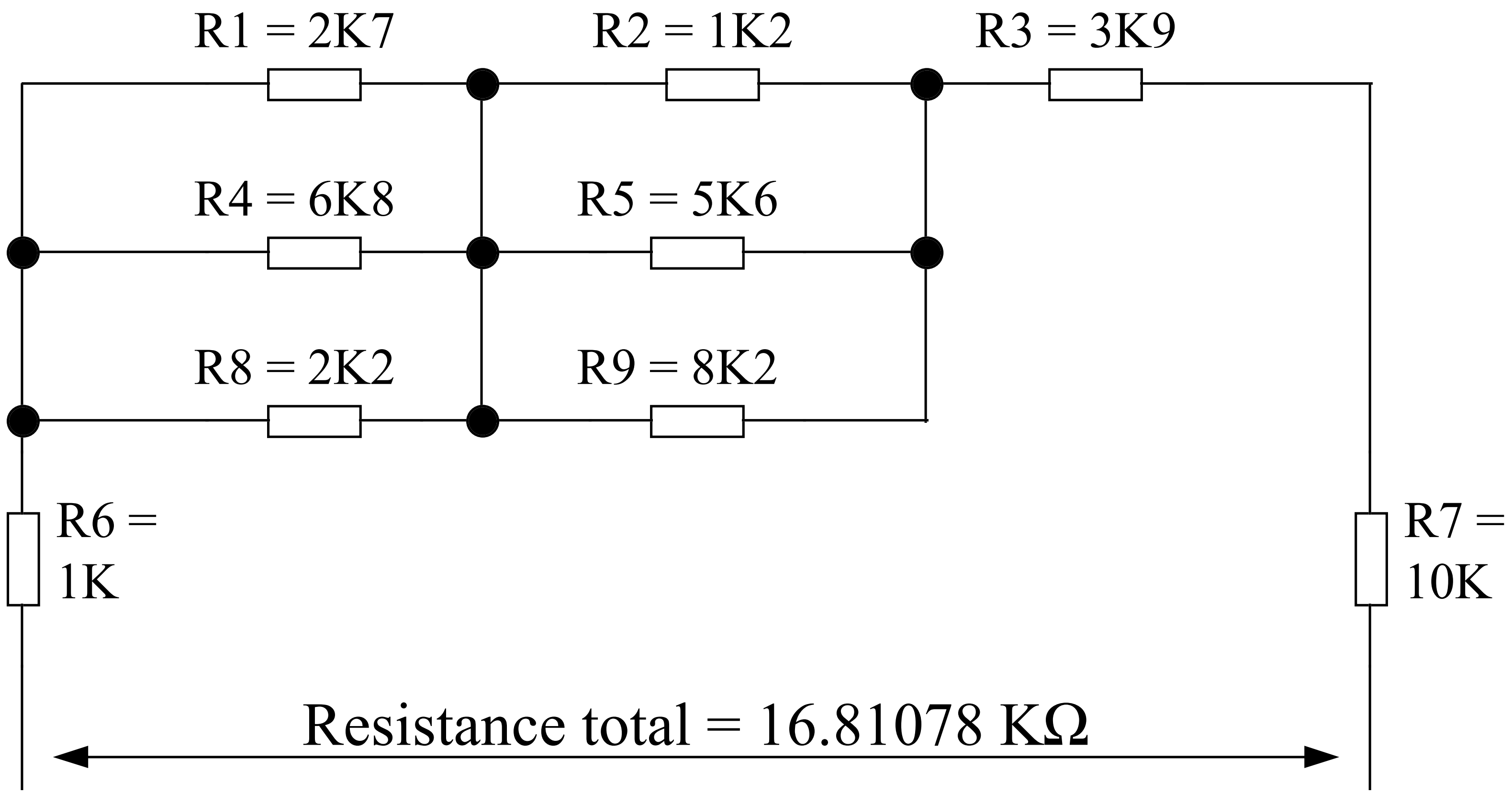
SPCA entry = 1,((2.7,1.2,3.9)!(6.8,5.6)),10

Resistors.



SPCA entry = 1,((2.7!6.8),(1.2!5.6)),3.9,10

Resistors.



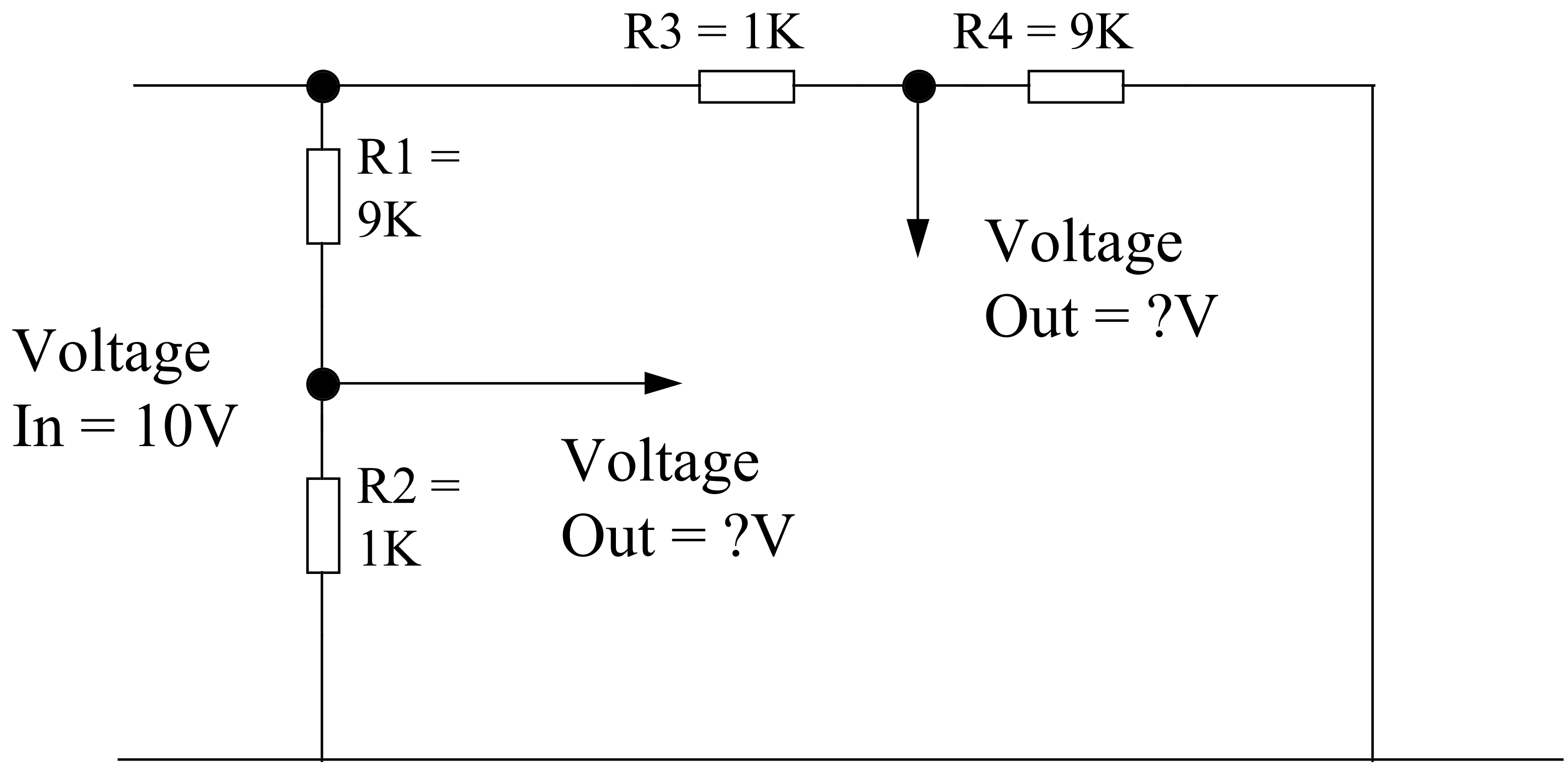
SPCA entry = 1,((2.7!6.8!2.2),(1.2!5.6!8.2)),3.9,10

Resistors

Voltage Divider

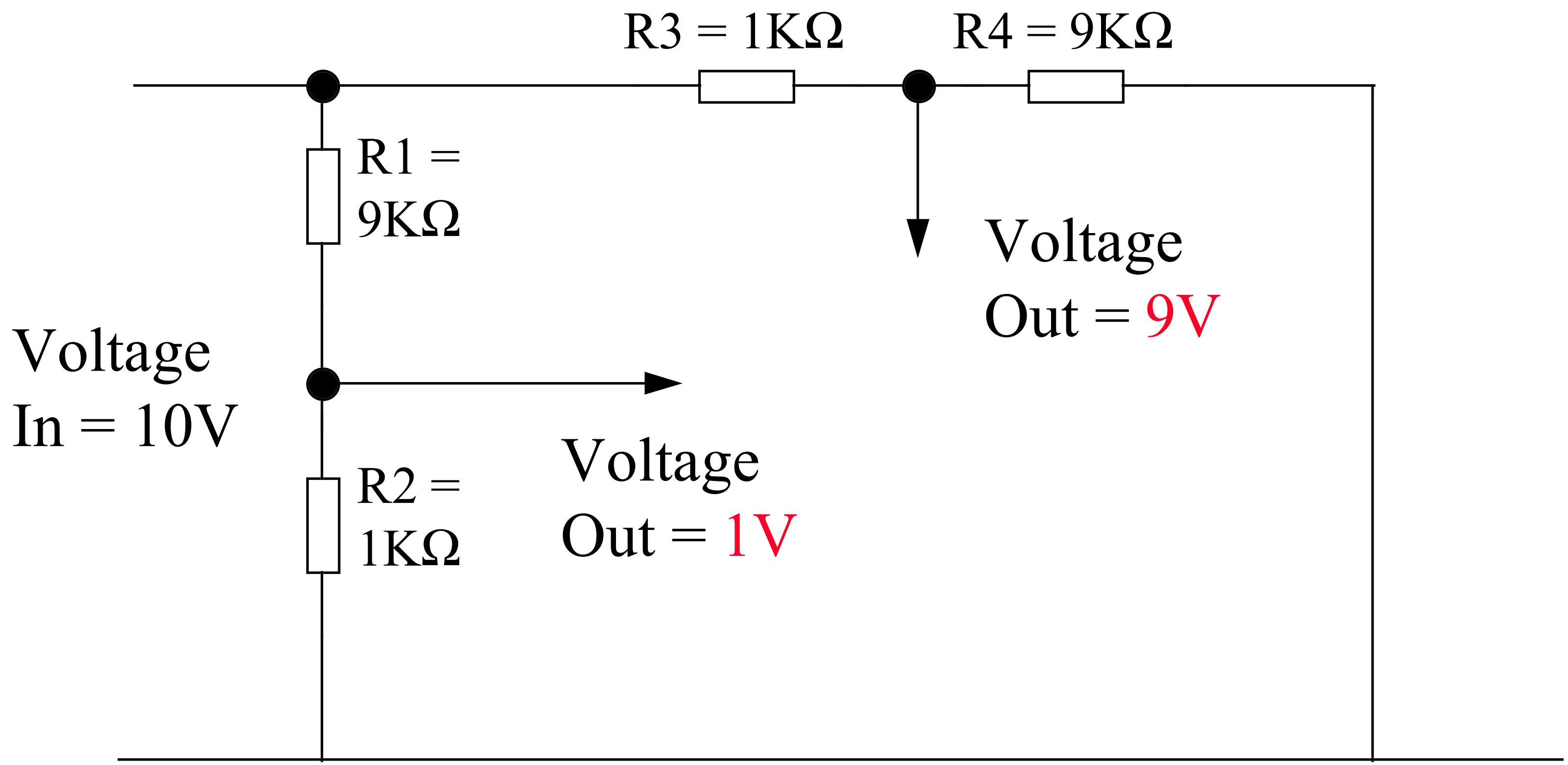
Resistors.

Voltage Dividers.



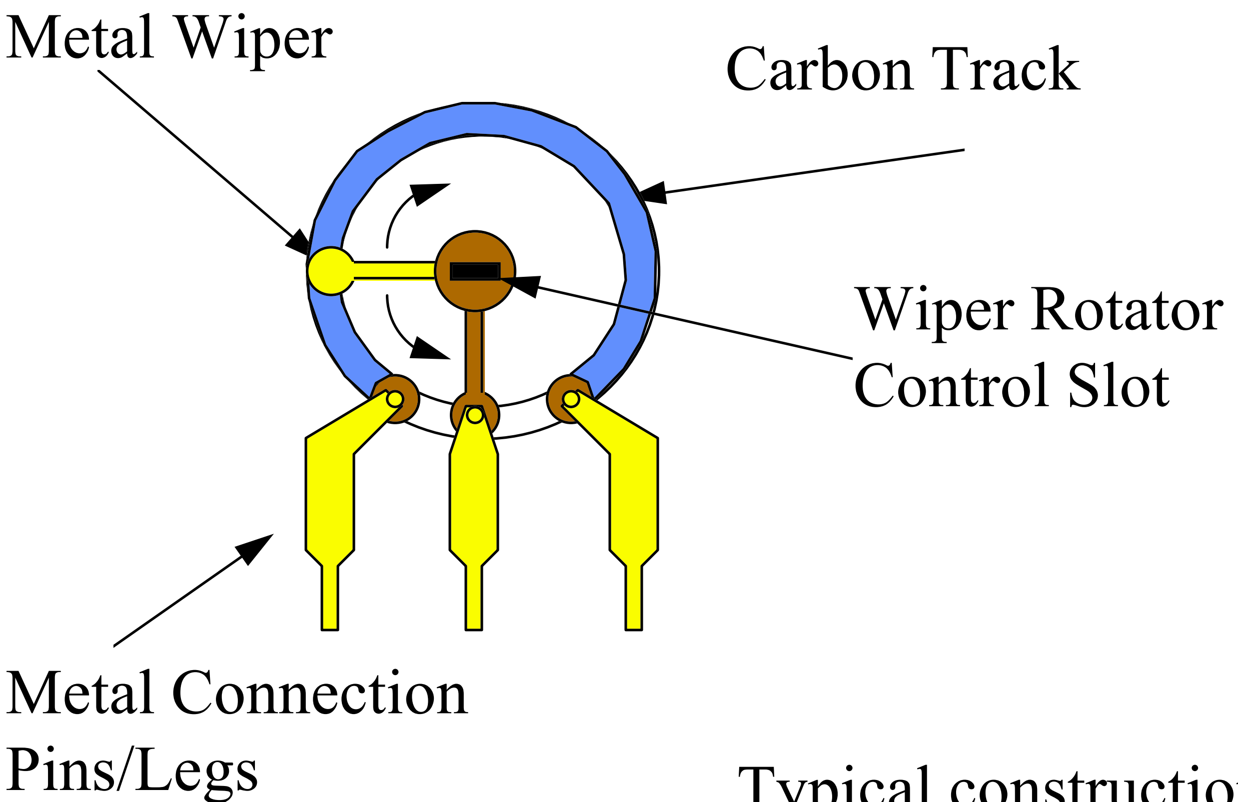
Resistors.

Voltage Dividers.



Resistors.

Variable Resistor or Potentiometer.

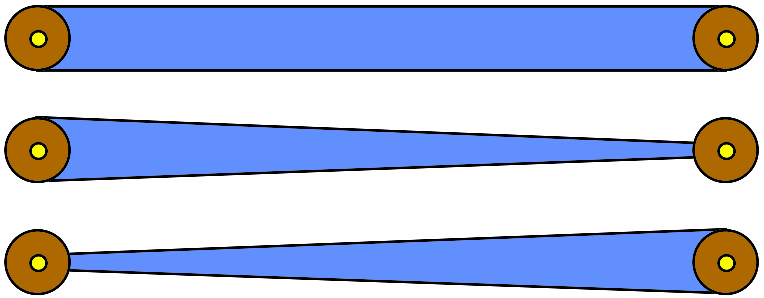


Typical construction of a
270° Potentiometer.

Resistors.

Variable Resistor or Potentiometer.

- This device can be used to extract some fraction of an applied voltage.
- This device can be used to limit current. (When it is used in this mode it is called a Rheostat.)
- The track can take one of three forms :-
  - Linear
  - Log
  - Anti Log

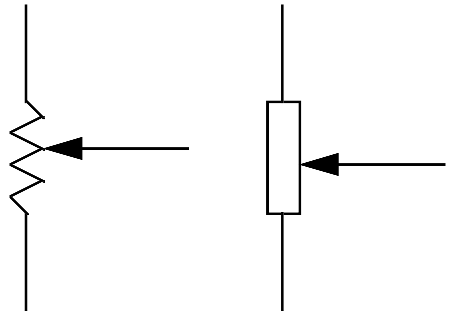


- The device's value = The total track resistance.

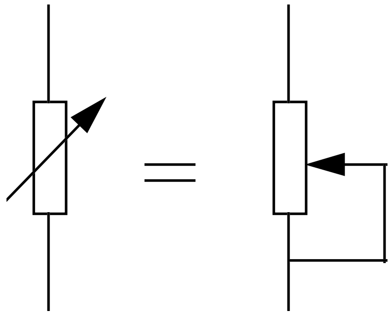
Resistors.

Variable Resistor or Potentiometer and Rheostat.

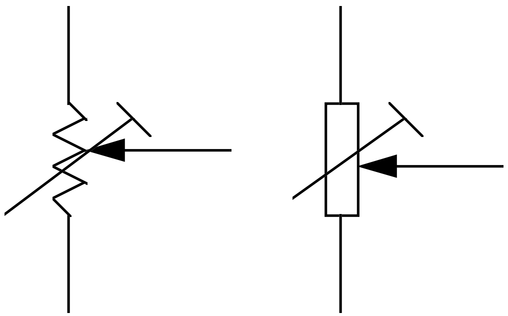
Circuit symbols



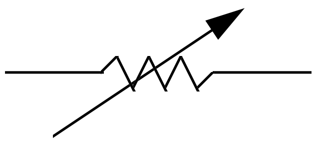
The Potentiometer



The Rheostat



The Preset Potentiometer



Resistors.

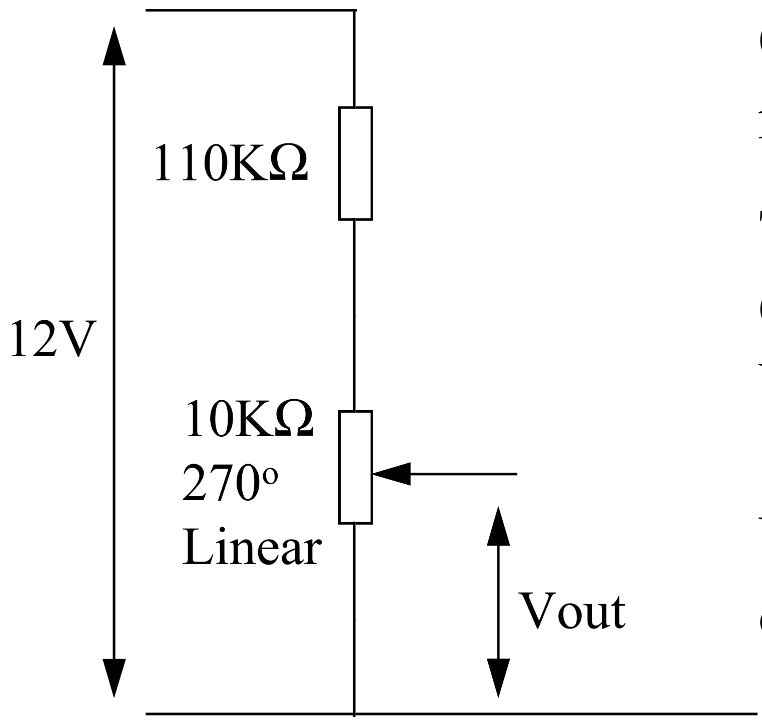
Variable Resistor or Potentiometer.

- When a Potentiometer has a linear track then the rotation angle of the wiper is proportional to the sample voltage.
- The Log and Anti Log tracks are used when a linear rotational angle is needed to represent a logarithmic value such as the volume control on an audio system.
- With audio a ten times increase in power will only give double the volume.

Resistors.

Variable Resistor or Potentiometer and Rheostat.

Example Calculation



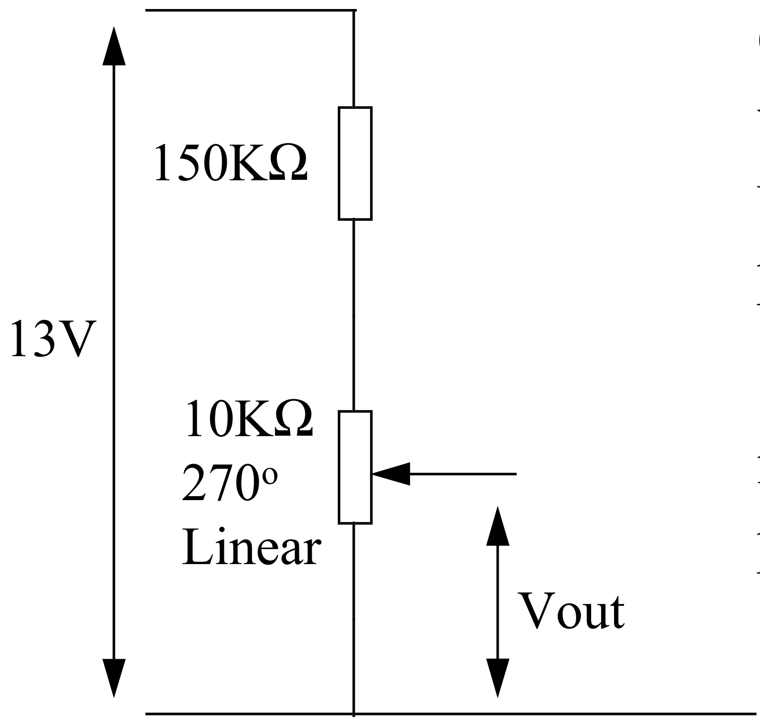
Q1. What is the voltage Vout when rotation angle is 10^o .

Total circuit resistance = 120KΩ.
Current = 12V / 120K = 100µA.
Voltage across Potentiometer = I*R = 100µA*10KΩ = 1V.
Vout = 10/270 * 1V ≅ 0.037V or 37mV.

Resistors.

Variable Resistor or Potentiometer and Rheostat.

Calculation Practice



Q2. What is the voltage "Vout" when rotation angle is stepped in 5° units across the whole range of the potentiometer.

Suggest a suitable and convenient method of resolving this calculation problem.

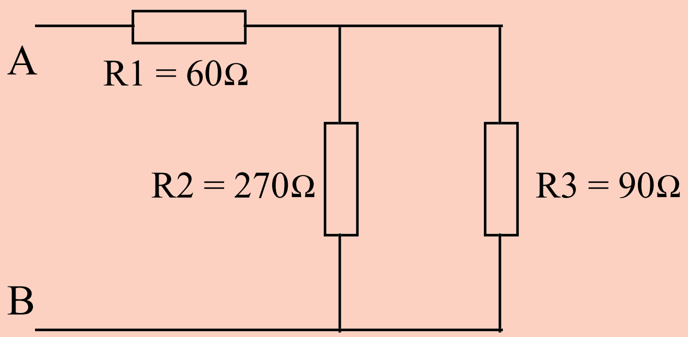
Resistors

More Example

Calculations

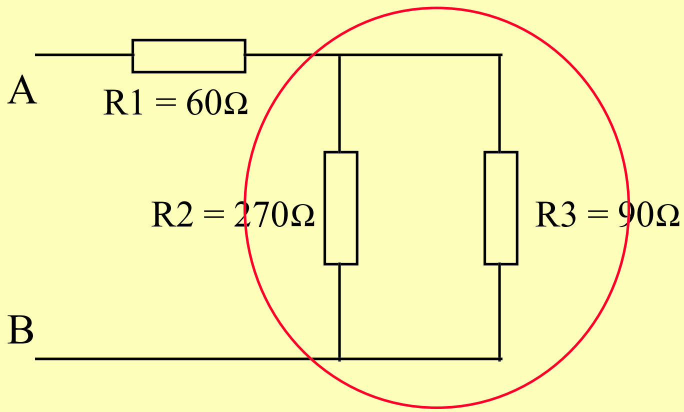
Resistors.

- Example:-
- The circuit below has 30 volts across points AB.
- What current will flow in R1?
- How much power is dissipated in R2?



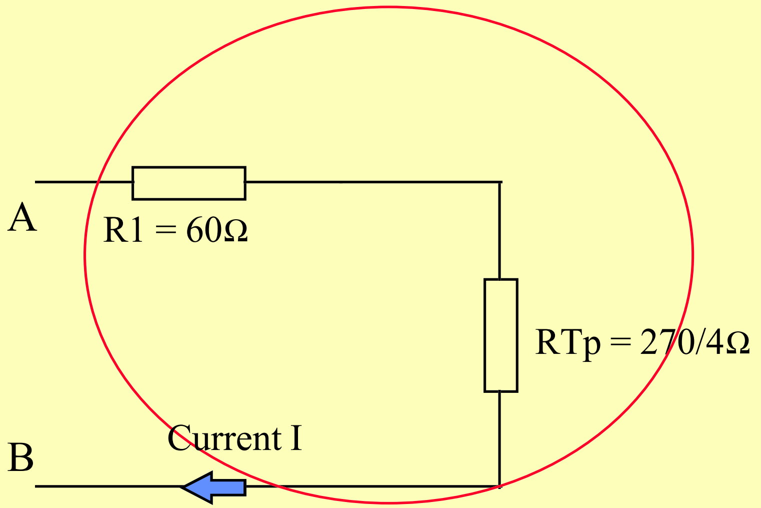
Resistors.

- Step 1 Simplify (Convert into 2 series resistors):-
- 1/RTp = 1/R2 + 1/R3 = 1/270 + 1/90 = (1 + 3)/270
- RTp = 270/4Ω.



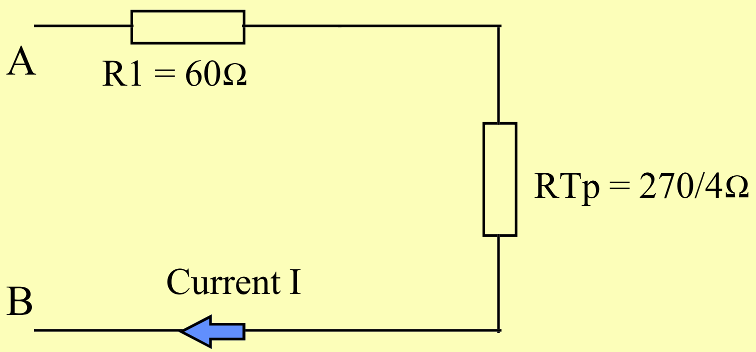
Resistors.

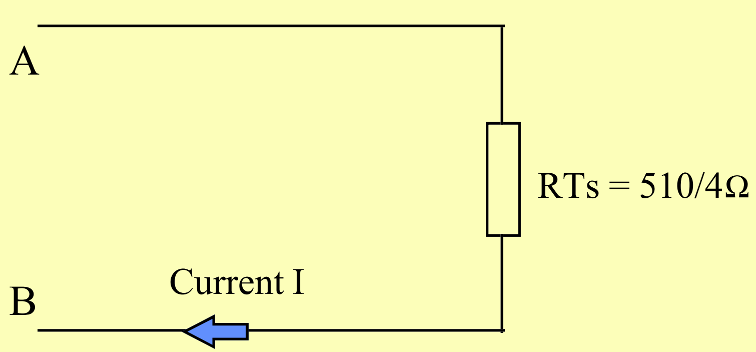
- Step 2 Simplify (Convert to single resistors):-
- $RTs = R1 + RTp = 60 + 270/4 = (240+270)/4$
- $RTs = 510/4\Omega$.



Resistors.

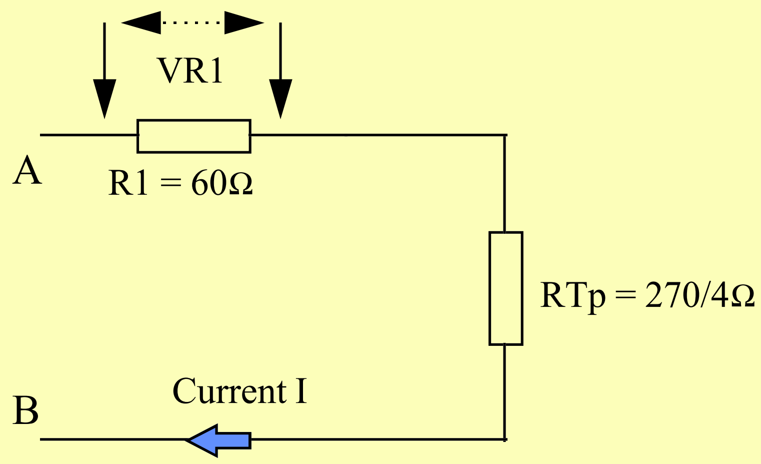
- Step 3 Calculate Current in circuit:-
- I = V/RTs = 30/(510/4) = 30*4/510 = 120/510
- I = 0.235A which also the current that flows through R1.





Resistors.

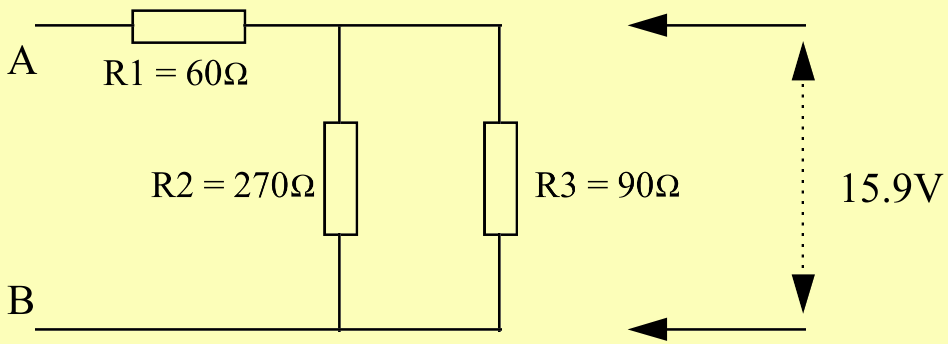
- Step 4 Calculate Voltage across Resistor R1:-
- V = I*R1 = 0.235*60 = 14.1Volts
- Voltage across Parallel Resistor section is the Applied voltage - VR1 = 30V - 14.1V = 15.9V



Resistors.

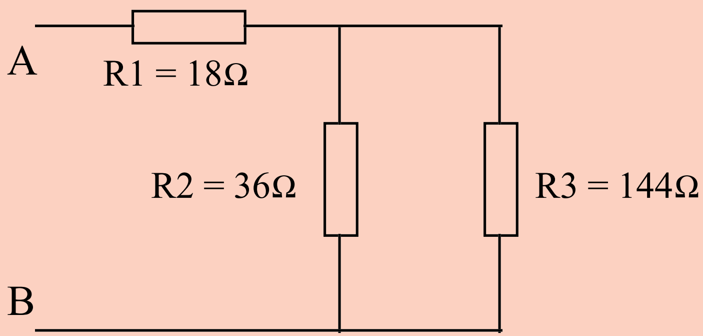
- Step 5 Calculate power in R2:-
- Voltage across Parallel section = 15.9V
- Power = V*A or V^2/R or I^2*R.
- Hence Power in R2 =

$$(15.9*15.9)/270 = 0.936\text{Watts}$$



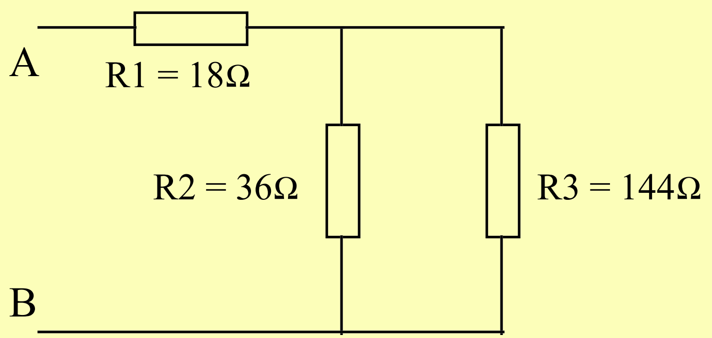
Resistors.

- Example:-
- The circuit below has 25 volts across points AB.
- What current will flow in R1?
- How much power is dissipated in R2?



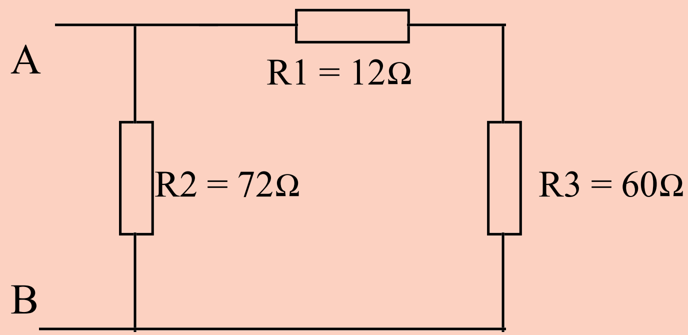
Resistors.

- Example:-
- The circuit below has 25 volts across points AB.
- What current will flow in R1?
  - Answer = 0.534 Amps
- How much power is dissipated in R2?
  - Answer = 6.57 Watts



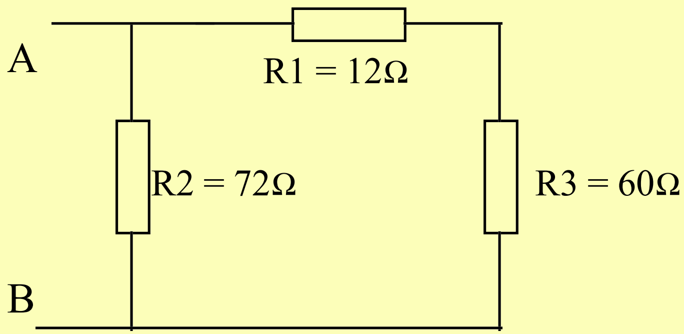
Resistors.

- Example:-
- The circuit below has 12 volts across points AB.
- What current will flow in R3?
- How much power is dissipated in R2?
- How much power is dissipated in whole circuit?



Resistors.

- Example:-
- The circuit below has 12 volts across points AB.
- What current will flow in R3?
  - Answer 1/6 Amp
- How much power is dissipated in R2?
  - Answer 1/3 Watt
- How much power is dissipated in whole circuit?
  - Answer 4 Watts



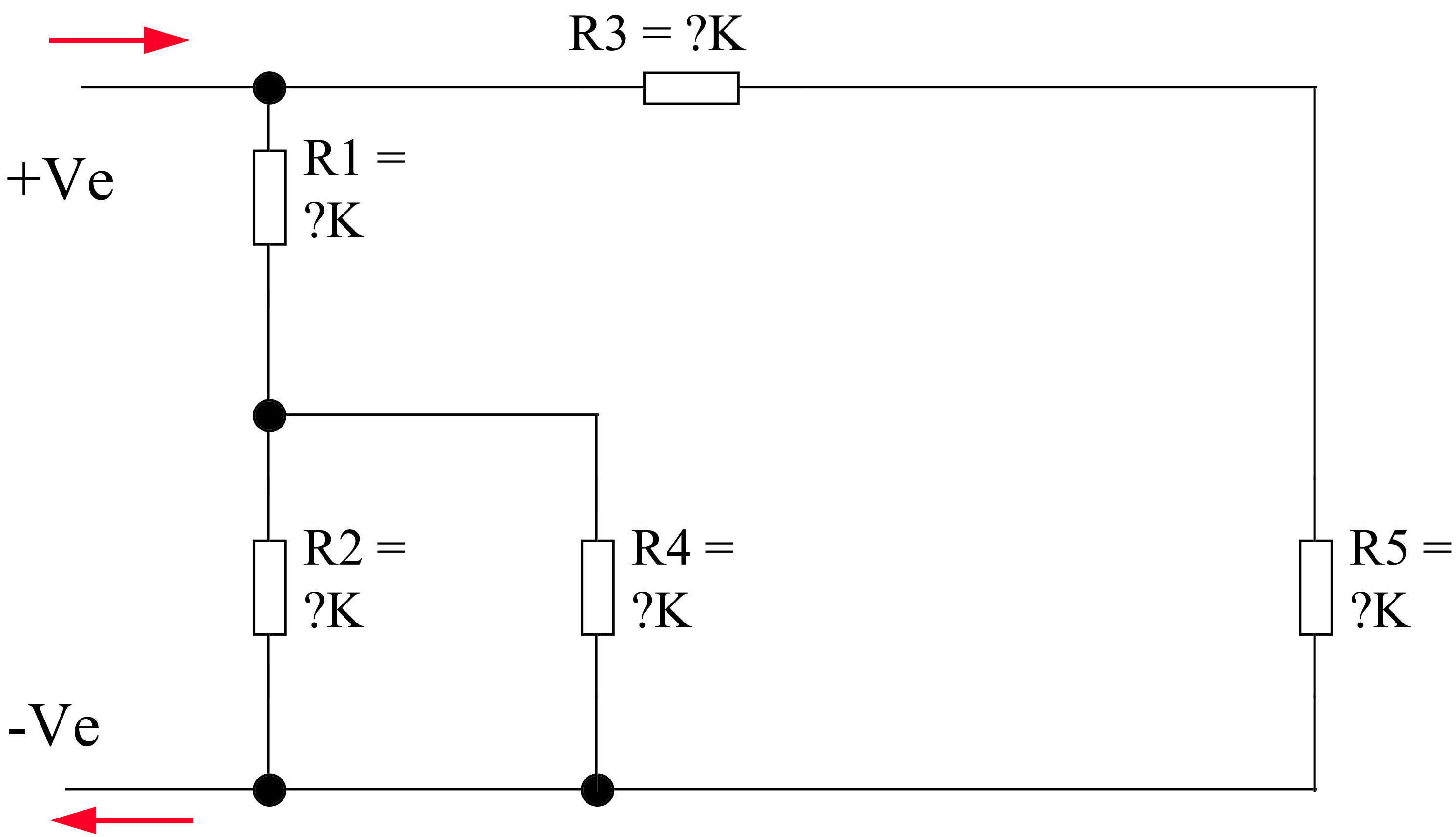
Resistors

Identifying Current flow

Example 1.

Resistors.

Current Flow Indicator

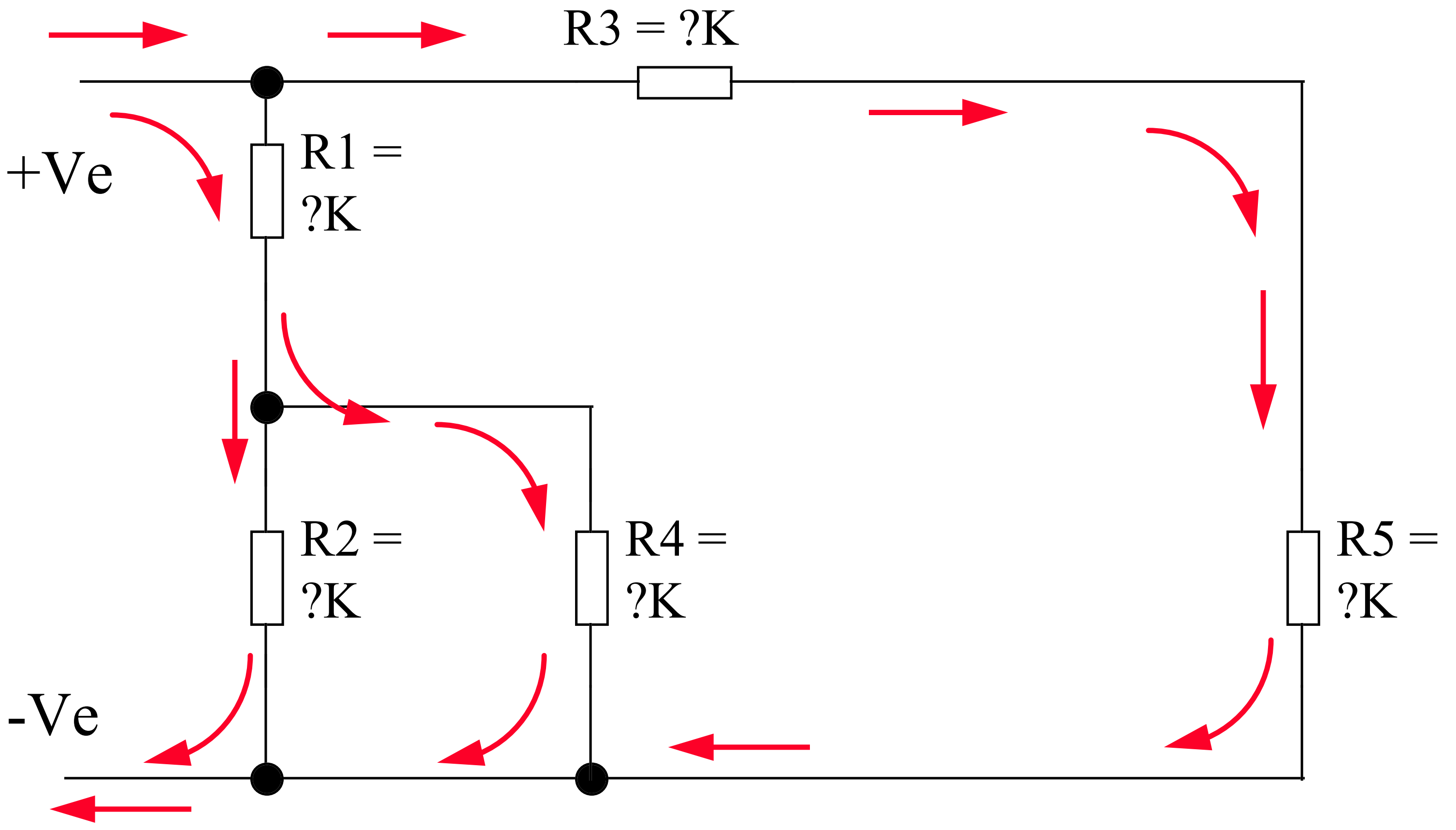


Identify Current Flow Direction in above circuit.

Example 1.

Resistors.

Current Flow Indicator

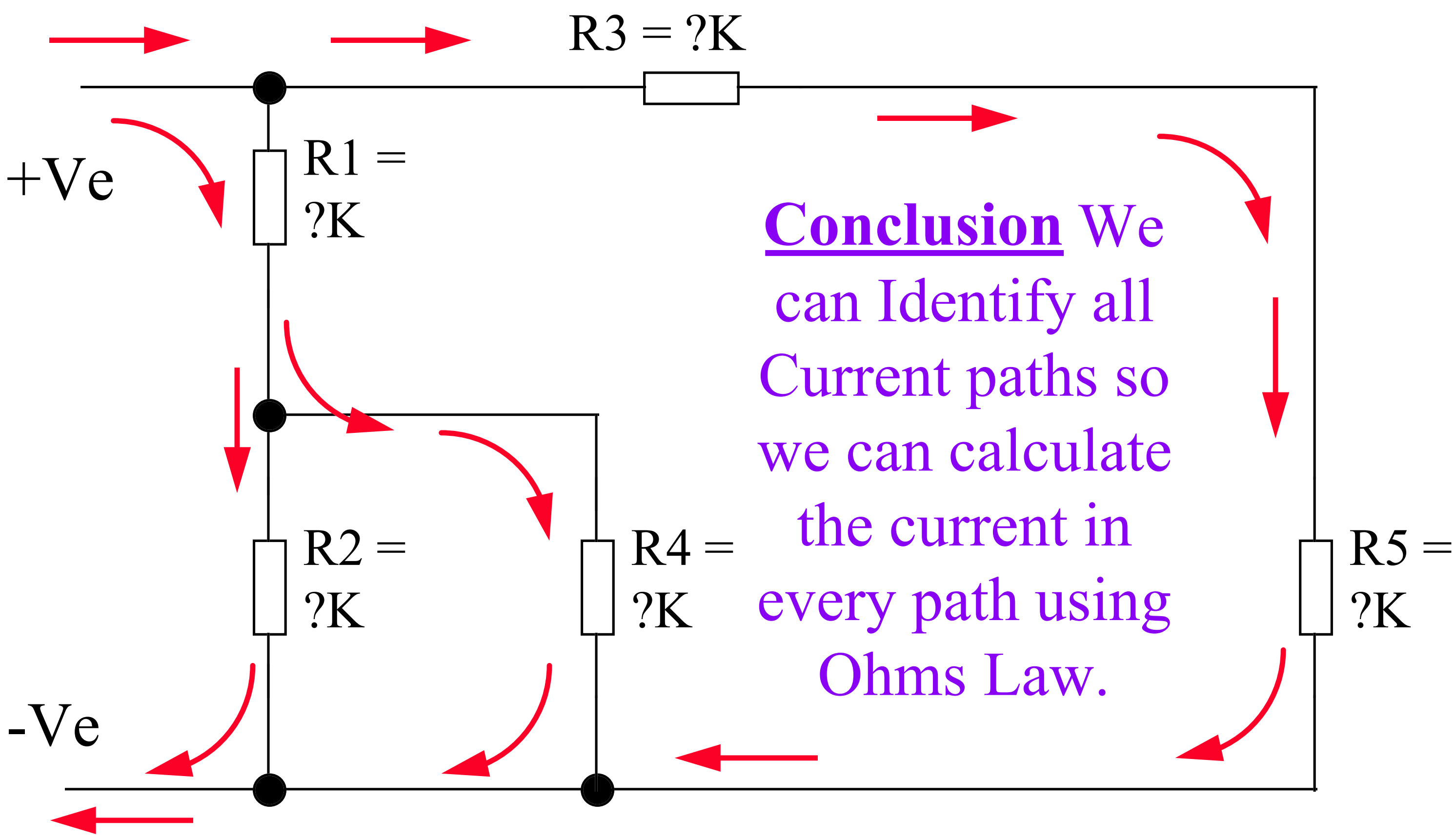


Identify Current Flow Direction in above circuit.

Example 1.

Resistors.

Current Flow Indicator



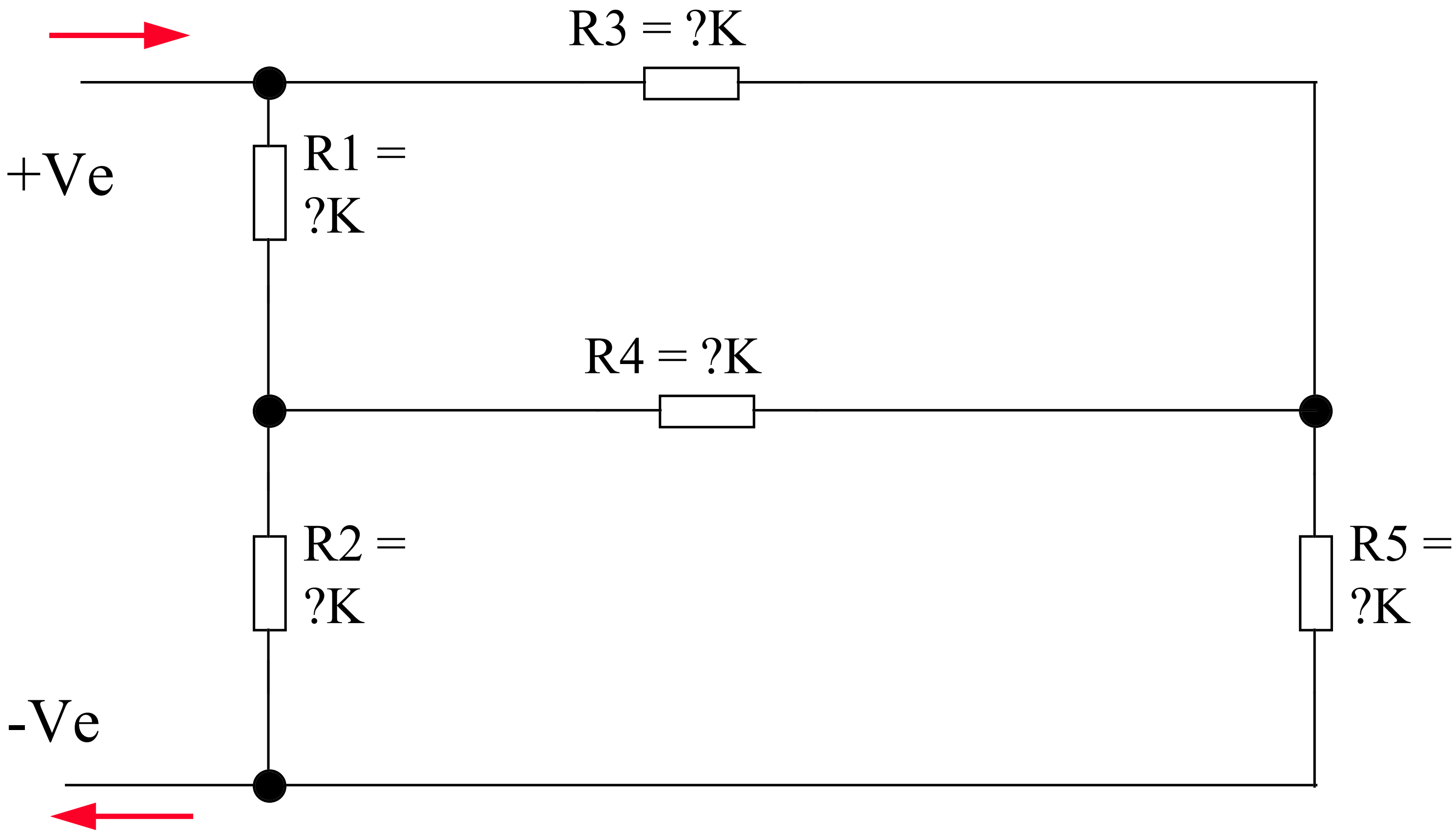
Conclusion We can Identify all Current paths so we can calculate the current in every path using Ohms Law.

Identify Current Flow Direction in above circuit.

Example 2.

Resistors.

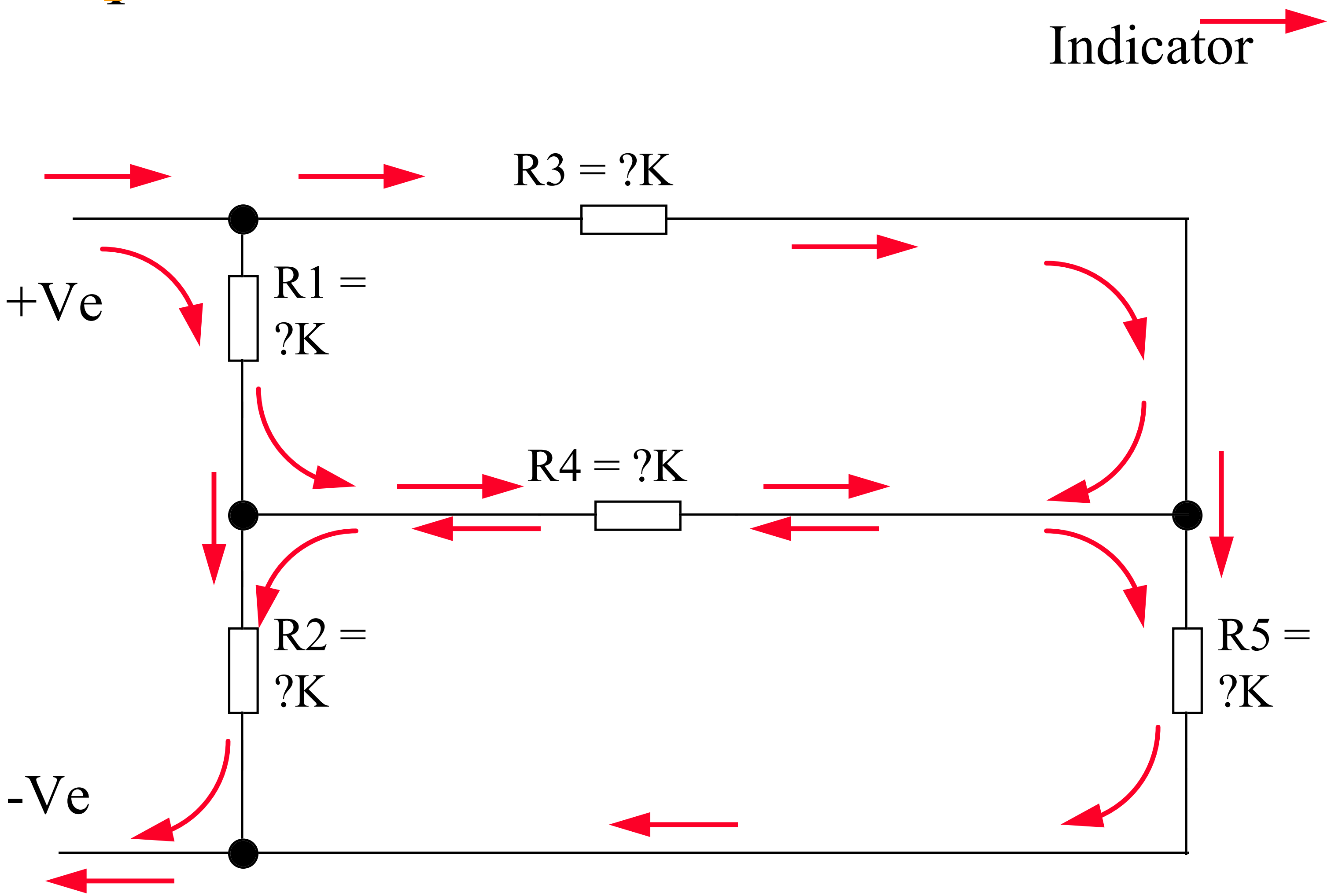
Current Flow Indicator



Identify Current Flow Direction in above circuit.

Example 2. **Resistors.**

Current Flow Indicator

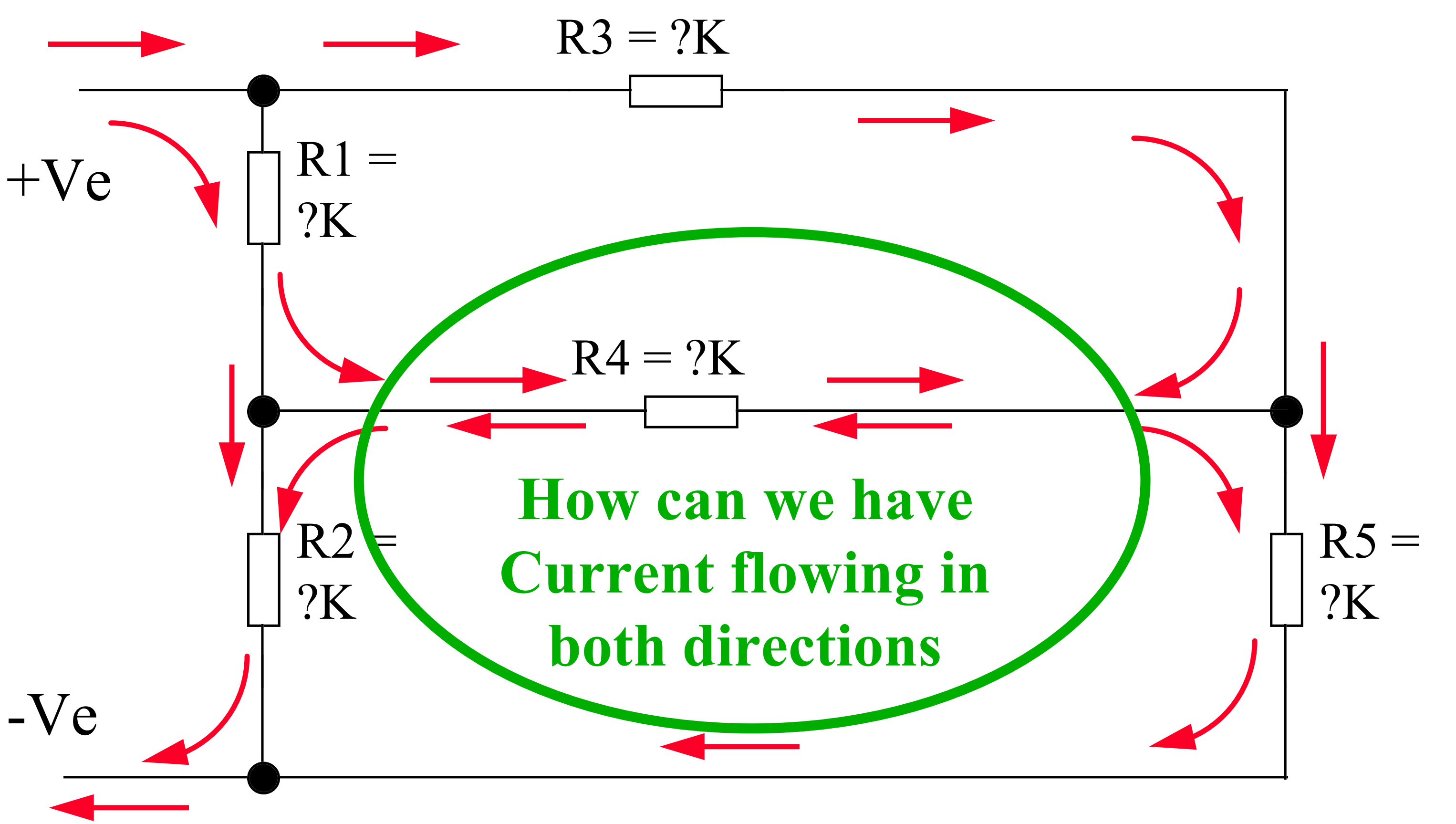


Identify Current Flow Direction in above circuit.

Example 2.

Resistors.

Current Flow Indicator

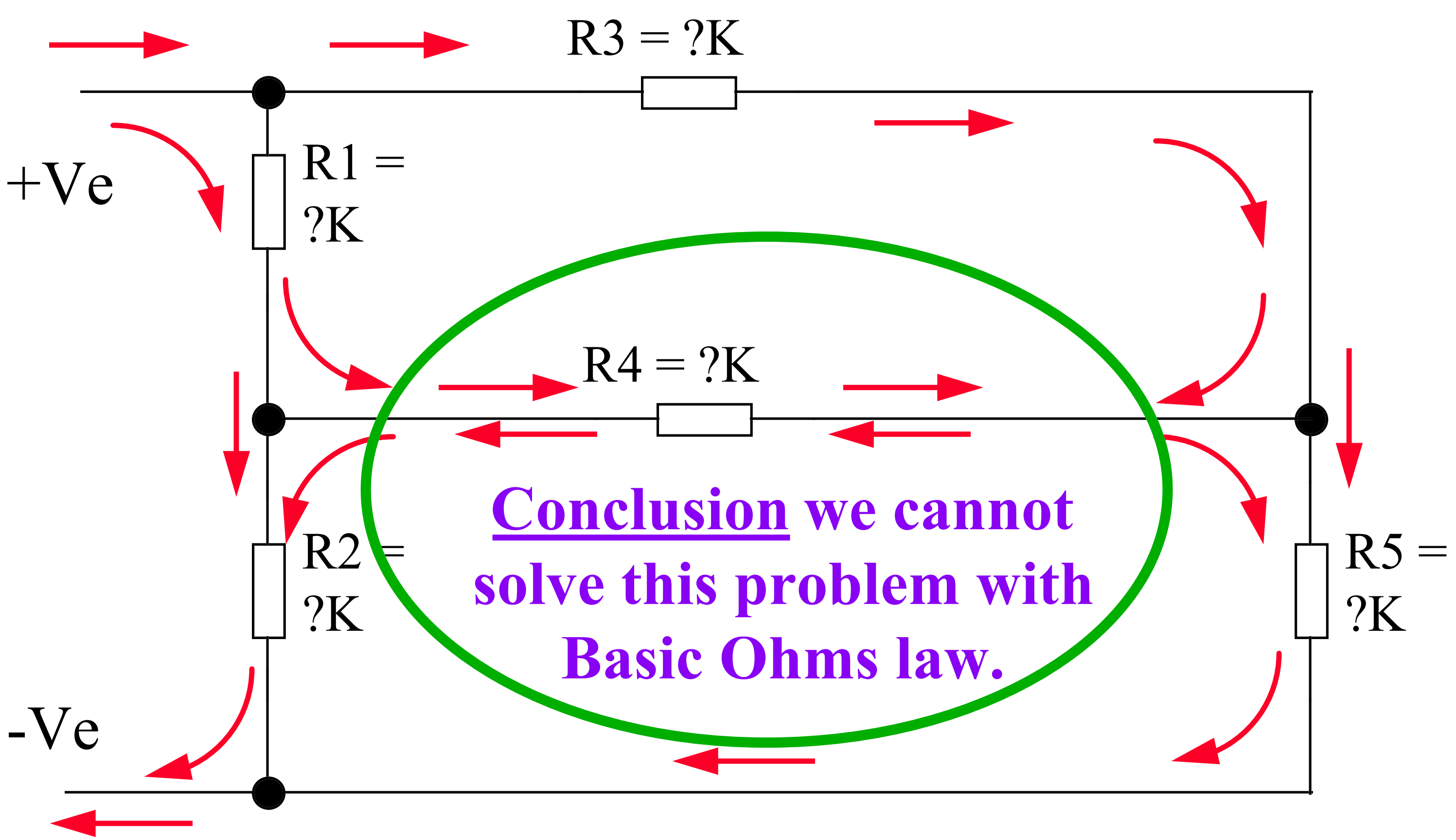


Identify Current Flow Direction in above circuit.

Example 2.

Resistors.

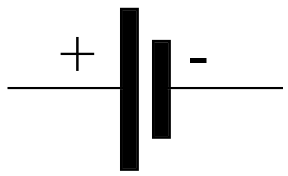
Current Flow Indicator



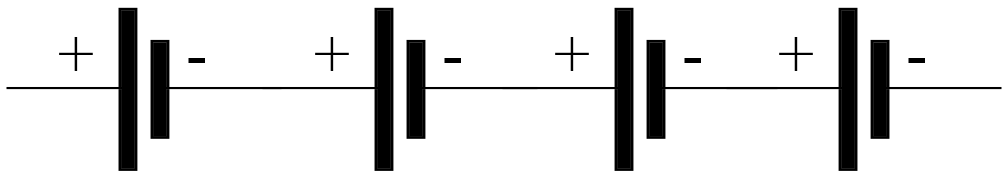
Identify Current Flow Direction in above circuit.

Cells and Batteries

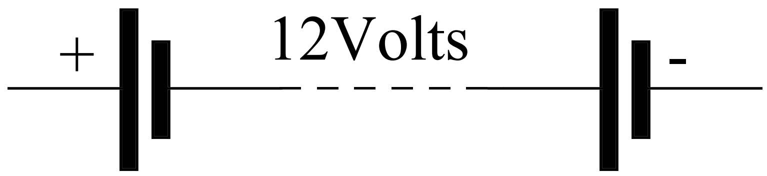
Cells and Batteries.



The Basic Cell.



Cells connected in series.

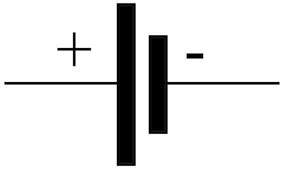


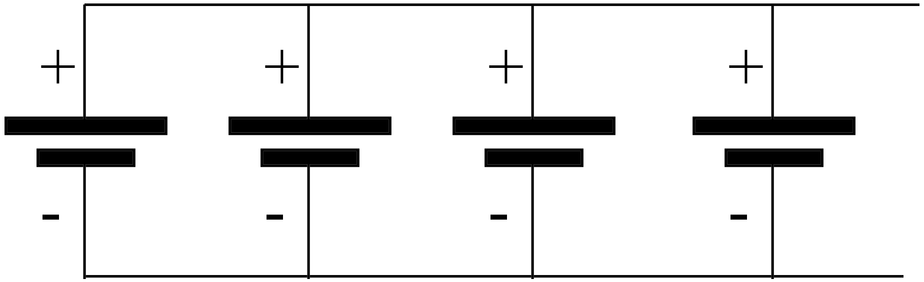
A Battery or a set of Cells connected in series.

Note. Voltage across a Battery is the sum of the Voltages of all the Cell in the battery.

Cells and Batteries.

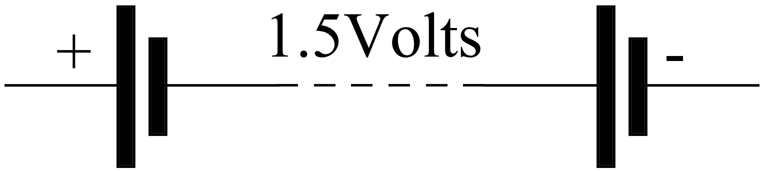
If the voltage of each cell is 1.5 volts





The Basic Cell.

Cells connected in parallel.



A Battery or a set of Cells connected in parallel.

Note. The term Battery does not imply that the cells are connected in series (just a collection of cells).

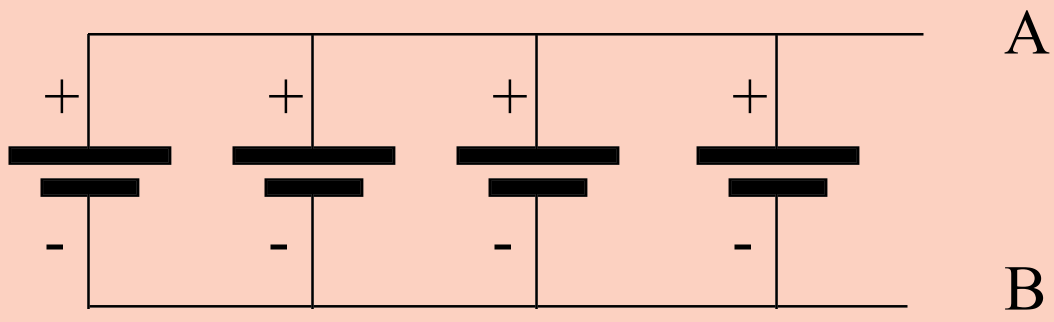
Cells and Batteries.

Battery connections

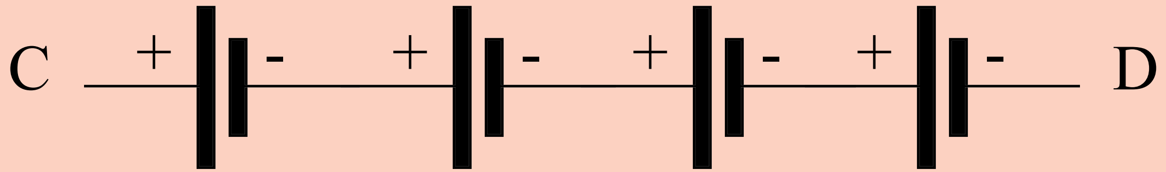
- Why might we need to connect cells in series?
- To produce an **Increased Voltage**.
- Why might we need to connect cells in parallel?
- To give an **Increased Current** capability.
- How do we calculate the voltage of cells connected in series?
- Add voltages together, however do remember to take into account Cell polarity.

Cells and Batteries.

If the voltage of each cell is 1.5 volts and they can deliver 2A.



Battery 1



Battery 2

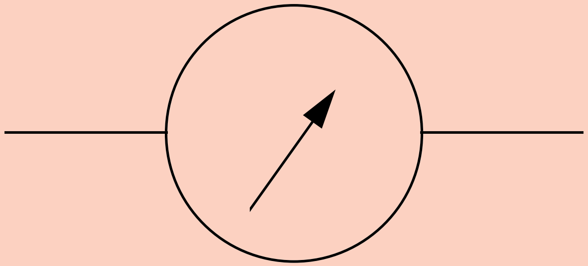
What is the current and voltage capability of the batteries shown above? Points A,B and Points C,D

Cells and Batteries.

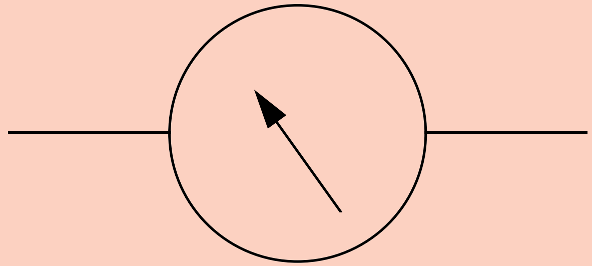
- Battery 1: As all the cells are in parallel and they are all the same voltage therefore voltage at point “AB” is 1.5Volts, however each cell can deliver 2A therefore at point “AB” the system can deliver 4*2A = 8 Amps.
- Battery 2: As all the cells are in series and they are all the same voltage therefore voltage at point “CD” is 4*1.5 = 6 Volts, however each cell can deliver 2A therefore at point “CD” the system can only deliver 2 Amps.

Meters

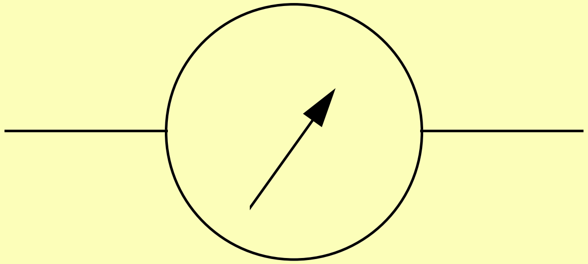
and Test Equipment



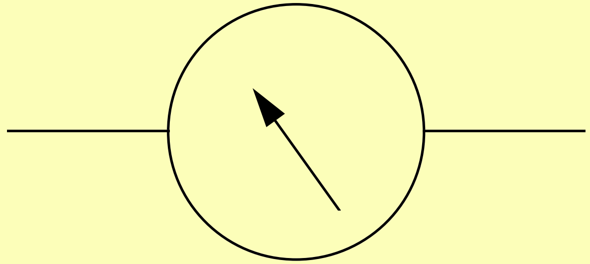
Meters.



- The typical Analogue Meter requires 1mA of current to enable its pointer to move across the meters scale. FSD (Full Scale Deflection).
- A typical Meter coil resistance is about 1000Ω.
- How do we get this Meter to measure :-
  - Voltage ?
  - Current ?
  - Resistance ?

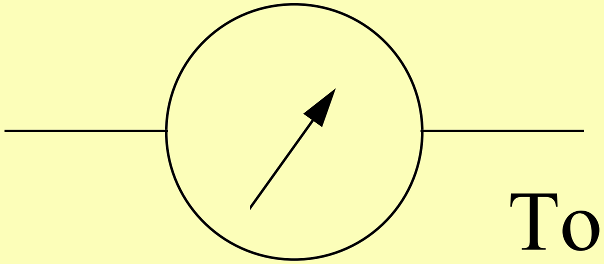


Meters.

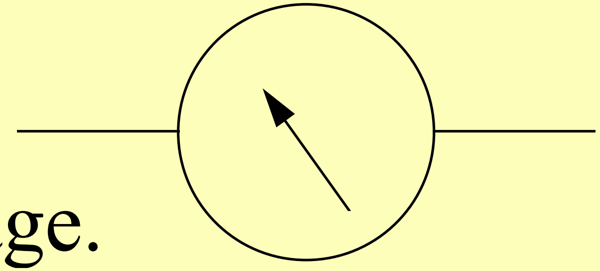


What do we know about this device ?

- Meter Voltage : V_{Meter} = Current * Resistance
- $V_{Meter} = 1mA * 1000\Omega = 1*10^{-3} * 1*10^{3}$
- V_{Meter} for Full Scale Deflection = 1 Volt
- So what do we do if we want this Meter to measure :- 100 Volts.
- Solution
- One Volt must be present across the Meter and Ninety Nine Volts lost somewhere else.



Meters.

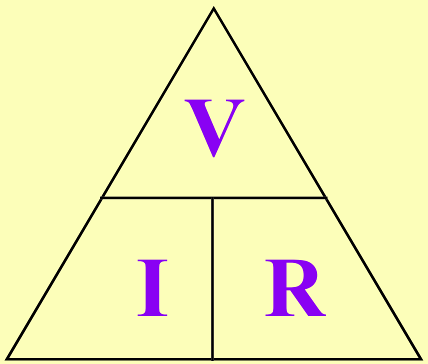


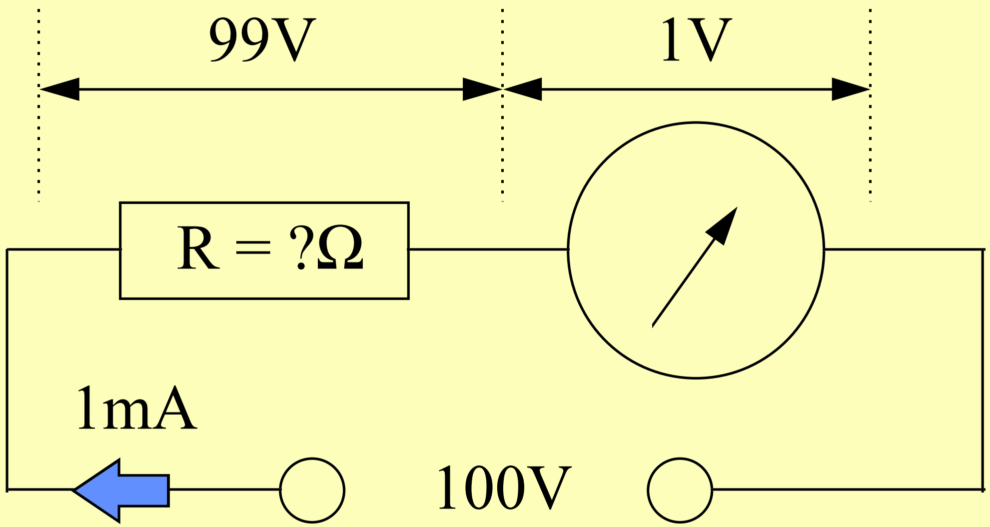
To Measure Voltage.

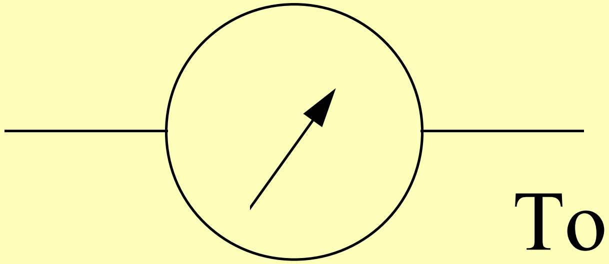
- Theory :- Resistance = Voltage / Current
- Mystery Resistance = 99 volts / 1mA

  $= 99 / (1 * 10^{-3})$

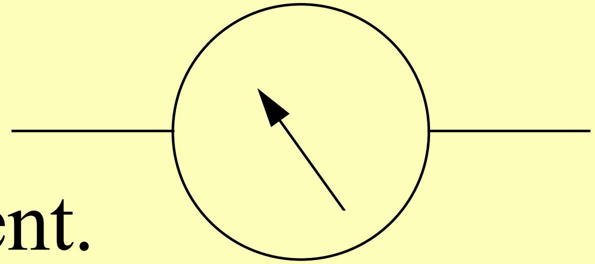
  $= 99000\Omega$ or $99K\Omega$
- Mystery Resistance needs to be $99K\Omega$





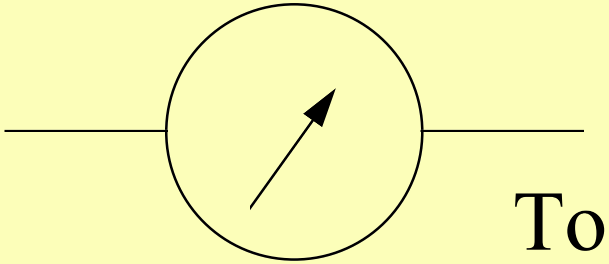


Meters.

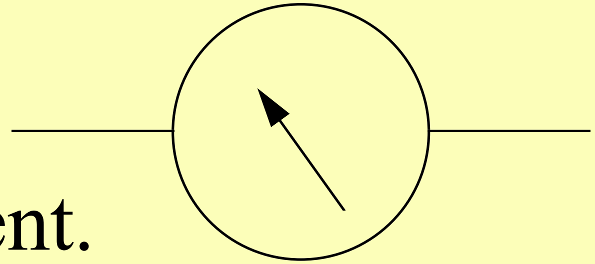


To Measure Current.

- Current for Full Scale Deflection = 1mA
- So if we want the same Meter to measure :-
  2 Amps.
- Solution
- One milli Amp must be present through the Meter and 1999mA routed elsewhere.



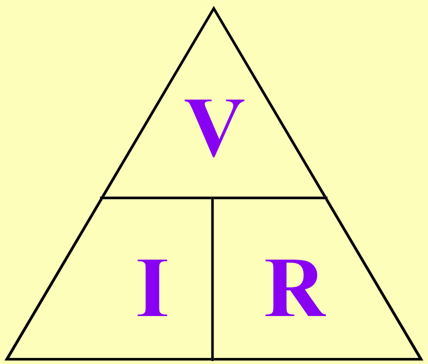
Meters.

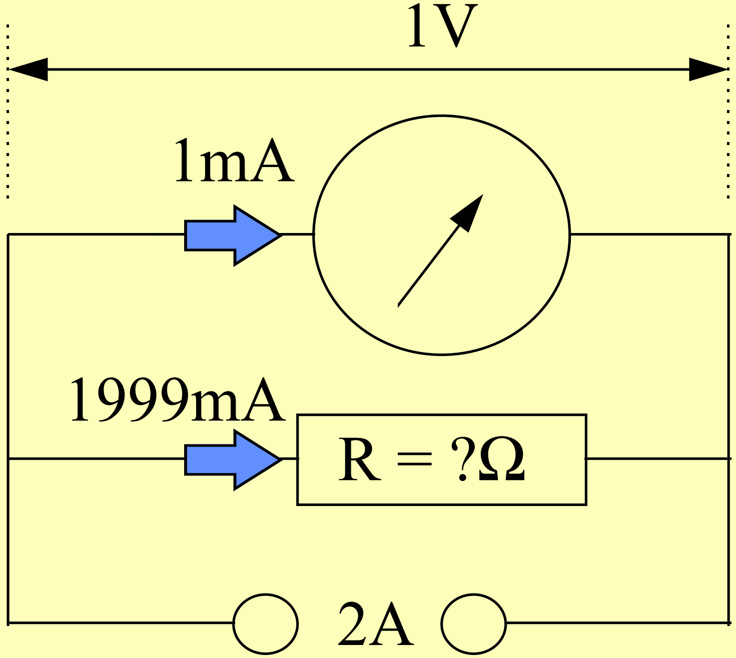


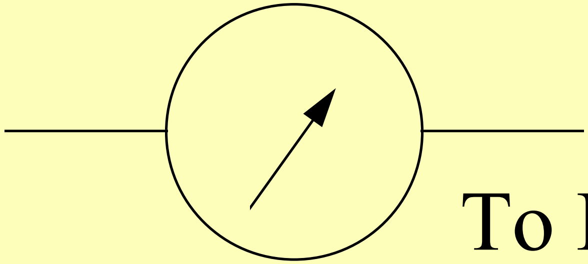
To Measure Current.

- Theory : Resistance = Voltage / Current
- Mystery Resistance = 1 volts / 1999mA

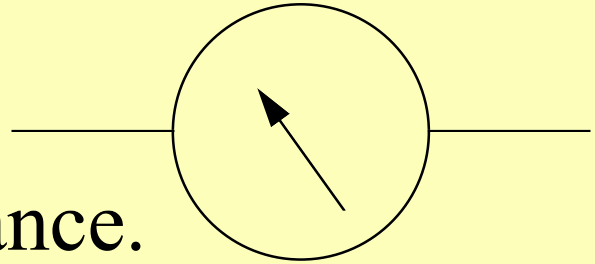
  $= 1 / 1999 * 10^{-3}$
- Mystery Resistance needs to be 0.50025Ω







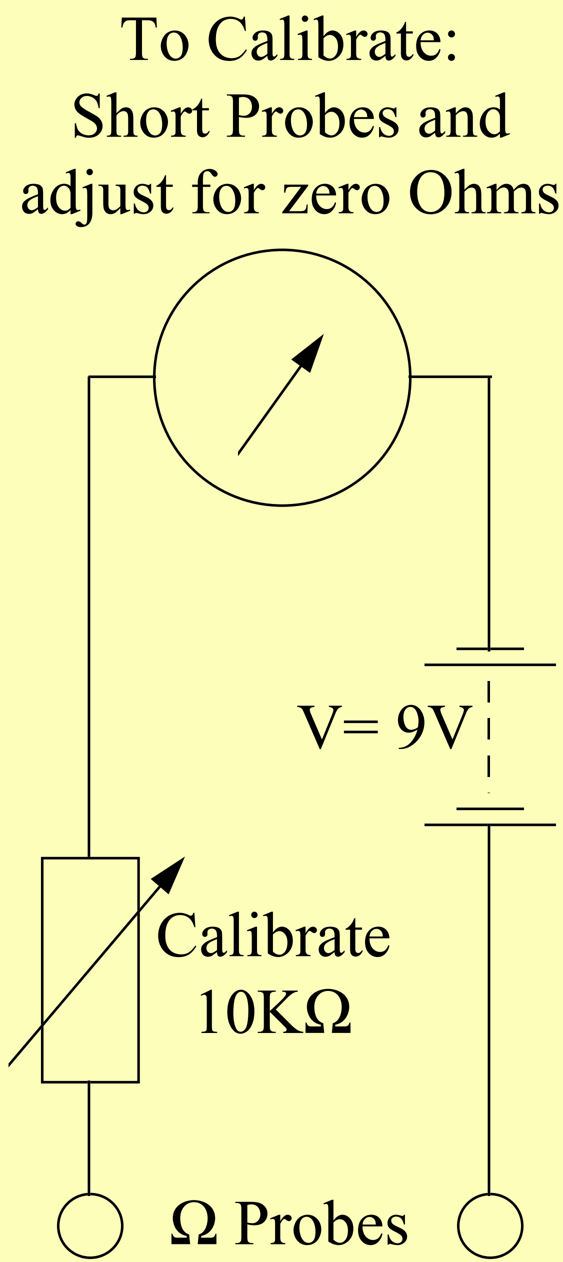
Meters.



To Measure Resistance.

- Current for Full Scale Deflection = 1mA.
- or Voltage for Full Scale Deflection = 1Volt.
- So if we want the same Meter to measure :-
  Ohms (Resistance = Volts/Amps)
- Solution
- Measure current but calibrate the scale in ohms.
- Measure Volts but calibrate the scale in ohms.
- so using current method.

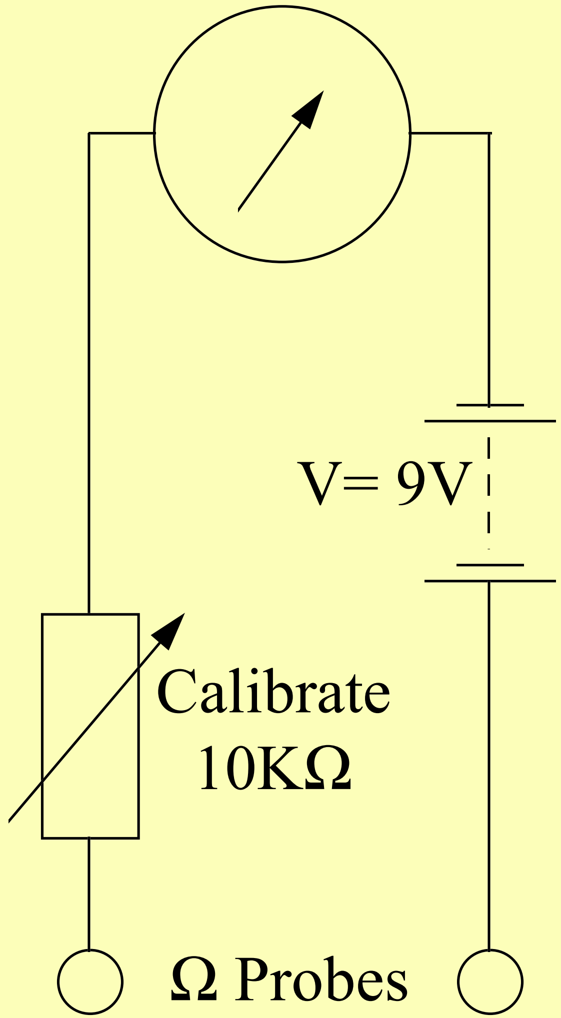
Meters.



- Using a 9V Power Source and a 10KΩ calibration variable resistor.
- @Zero Ohms : Circuit current = 1mA or 100% FSD
- Resistance = Meter + Calibrate = 9V / 1mA = 9000Ω
- Meter = 1000Ω ∴ Calibrate =8000Ω
- @1K Ohms: Circuit Resistance = 1000+(8000+1000) = 10KΩ
- @1K Ohms : Circuit current = 9V / 10KΩ = 0.9mA or 90% FSD

Meters.

To Calibrate:
Short Probes and
adjust for zero Ohms

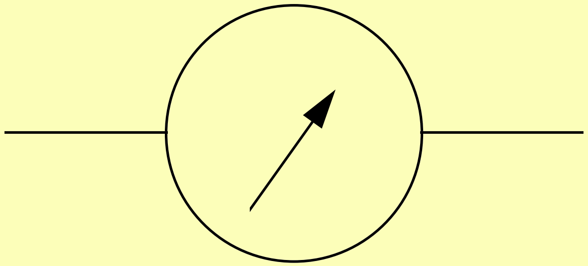


Full Calibration Table

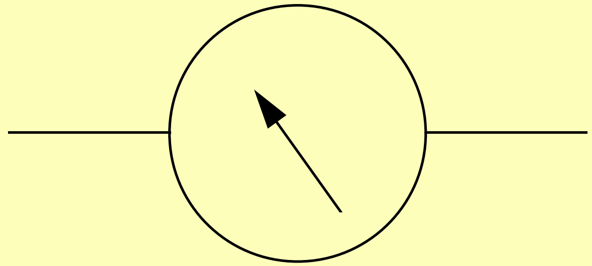
Unknown Resistance	Scale Mark
0 Ω	100.00 %
1,000 Ω	90.00%
2,000 Ω	81.82 %
5,000 Ω	64.29 %
10,000 Ω	47.37 %
20,000 Ω	31.03 %
50,000 Ω	15.25 %
100,000 Ω	8.26 %
200,000 Ω	4.31 %
500,000 Ω	1.77 %
1,000,000 Ω	0.89 %
2,000,000 Ω	0.45 %
5,000,000 Ω	0.18 %
10,000,000 Ω	0.09 %

Meters.

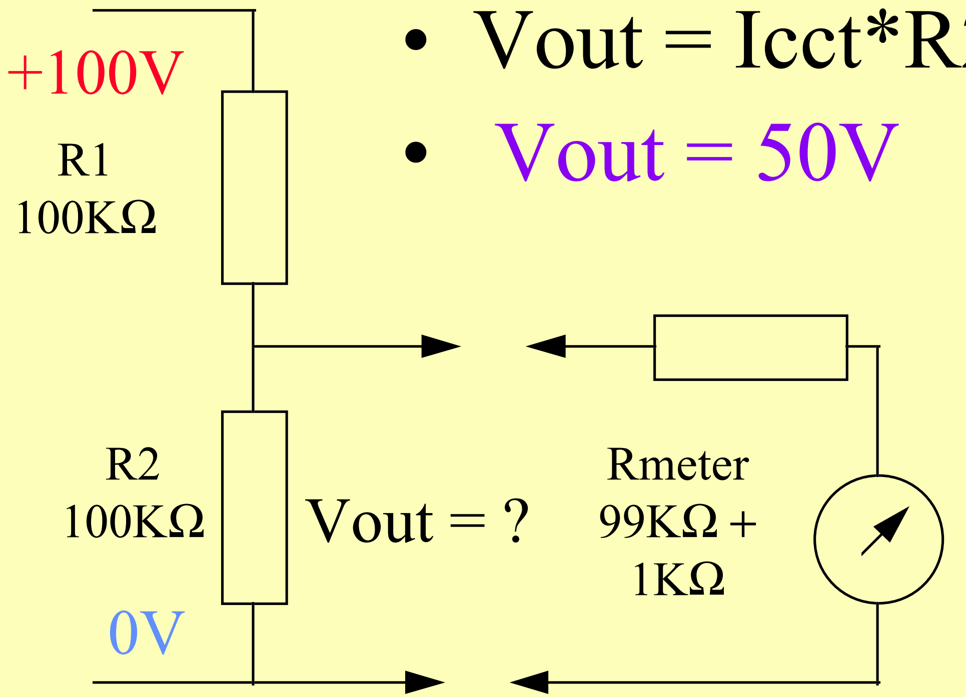
Accuracy and Loading.



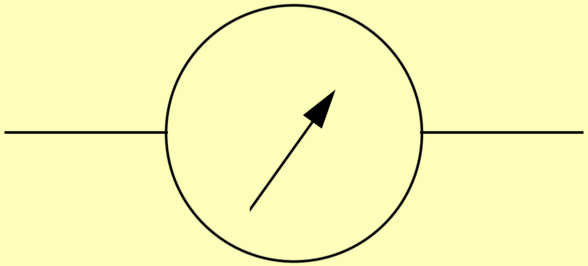
Meters.



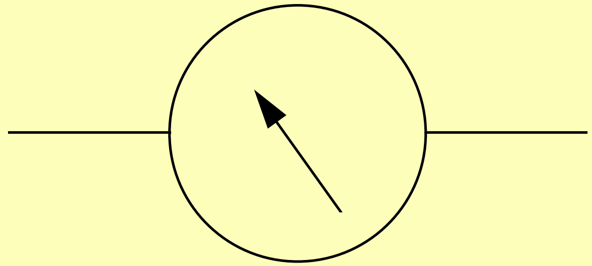
- What voltage do we expect to read ?
- RTs = 100KΩ+100KΩ = 200KΩ
- Icct = V/R = 100/200K= 0.5mA
- Vout = Icct*R2 = 0.5mA * 100KΩ
- Vout = 50V



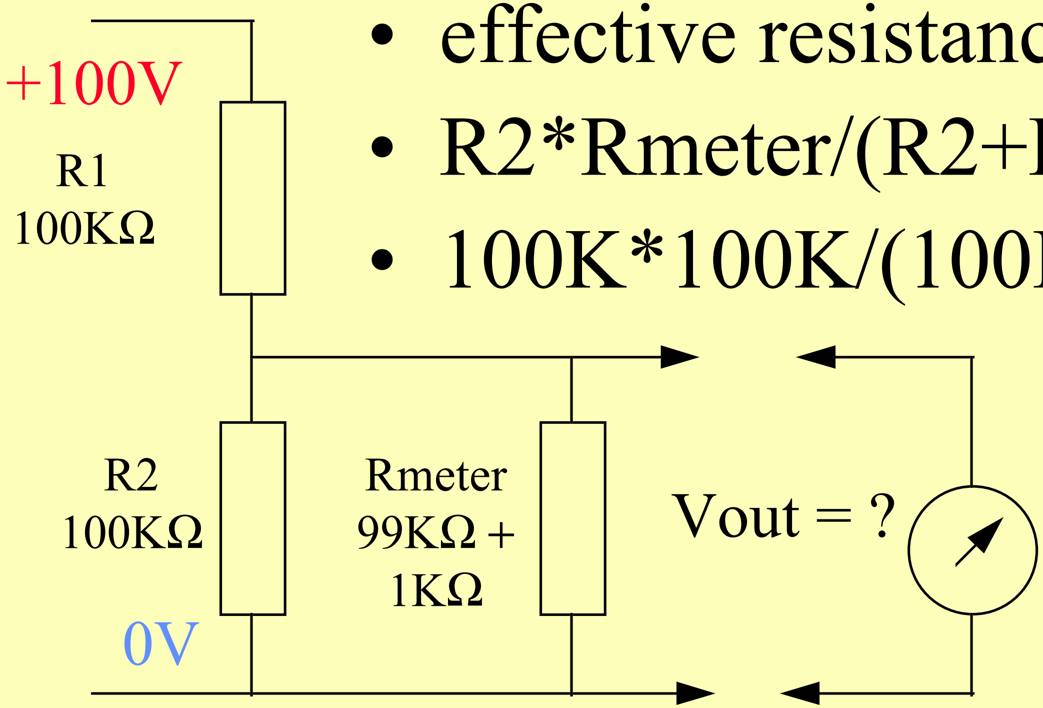
Using our "Meter" to measure voltage.

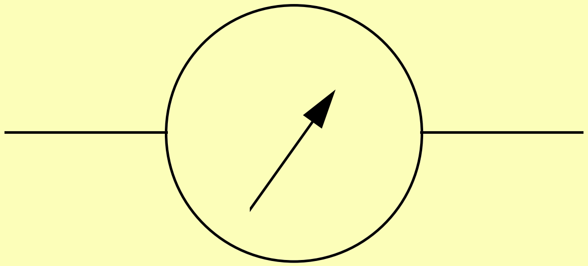


Meters.

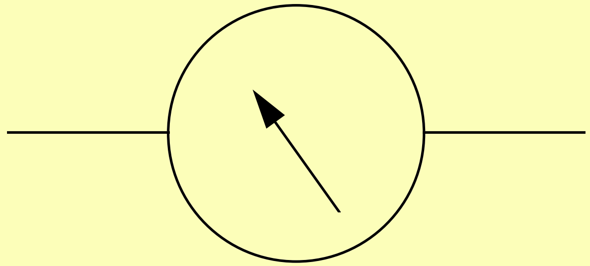


- What voltage will we read ?
- Rmeter = 99KΩ+1KΩ = 100KΩ
- Rmeter is in Parallel with R2
- effective resistance = R2!Rmeter =
- R2*Rmeter/(R2+Rmeter) =
- 100K*100K/(100K+100K)=50K Ω

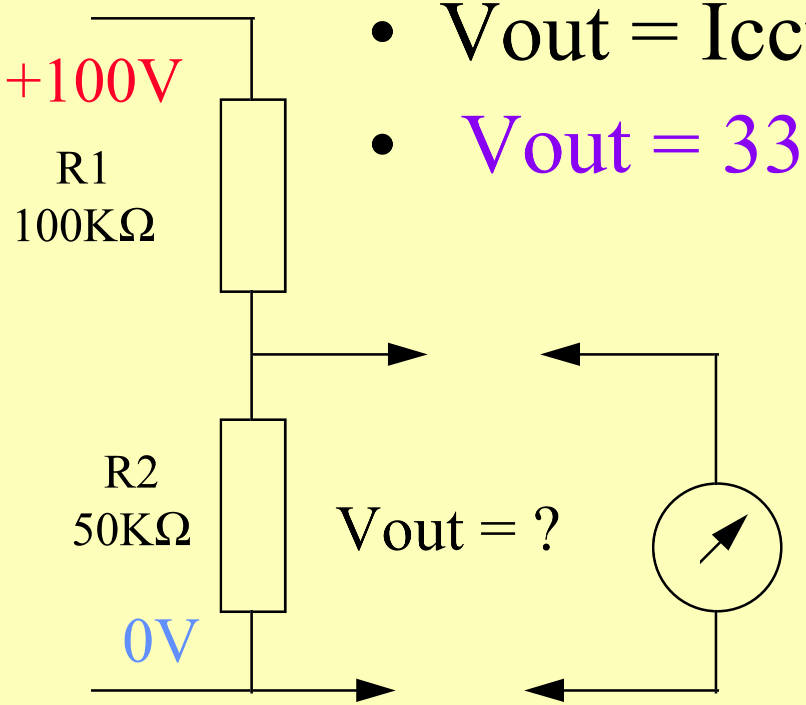


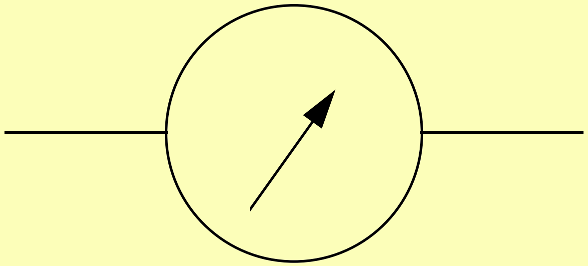


Meters.

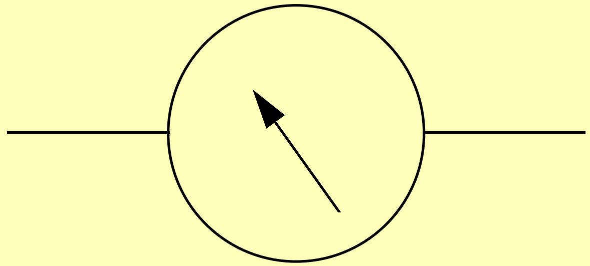


- What voltage will we read ?
- RTs = 100KΩ+50KΩ = 150KΩ
- Icct = V/R = 100/150K= 0.666mA
- Vout = Icct*R2 = 0.666mA * 50KΩ
- Vout = 33.333V





Meters.



Summary.

- By switching Shunts (Resistor in parallel) and Droppers / Multiplier (resistor in series) with the meter a range of measurements can be made (the basis of the multi-meter (needs multi scales)).
- The Impedance / Resistance of the meter can significantly effect the readings being taken.
- A scale parallax mirror can assist the accuracy of any readings taken.

Kirchhoff

Kirchhoff.

- As part of your work duties you are required to collect the daily order from canteen van.
- You are given £10 each day to pay for the order.
- A new person is looking after the van on the last day. Did they give you the correct change?

Kirchhoff.

Tea	Coffee	KitKats	Snacks	Change
Order for first four days				
5	9	3	2	£5.52
7	5	4	1	£6.07
8	8	2	3	£5.37
2	7	2	2	£6.88
Last day Order				
9	6	5	7	£1.34

Kirchhoff.

- **General Guidance.**
- To solve this type of problem if you have four unknown values.
- You need four unique equations.
- Note the equations must not be multiples of each other.
- 3 unknowns need 3 unique equations.
- 2 unknowns need 2 unique equations etc.

Kirchhoff.

Tea	Coffee	KitKats	Snacks	Change
5T	9C	3K	2S	=5.52
7T	5C	4K	1S	=6.07
8T	8C	2K	3S	=5.37
2T	7C	2K	2S	=6.88

Calculate actual cost of Goods

Kirchhoff.

Tea	Coffee	KitKats	Snacks	Change
5T	9C	3K	2S	=4.48
7T	5C	4K	1S	=3.93
8T	8C	2K	3S	=4.63
2T	7C	2K	2S	=3.12

Convert cost to pence to make calculations easier.

Draw out calculation as a table and identify the lines.

Kirchhoff.

Try to eliminate a variable and leave 3 equations.

A	5T	9C	3K	2S	=	448
B	7T	5C	4K	1S	=	393
C	8T	8C	2K	3S	=	463
D	2T	7C	2K	2S	=	312

Kirchhoff.

Try to eliminate a variable and leave 3 equations.

A	5T	9C	3K	2S	=	448
B	7T	5C	4K	1S	=	393
C	8T	8C	2K	3S	=	463
D	2T	7C	2K	2S	=	312

Action 1 Subtract D from A
Action 2 Subtract (B*2) from A
Action 3 Subtract (B*3) from C

Kirchhoff.

A	5T	9C	3K	2S	=	448
D	2T	7C	2K	2S	=	312
A-D	3T	2C	1K	0S	=	136

Action 1 Subtract D from A
Action 2 Subtract (B*2) from A
Action 3 Subtract (B*3) from C

Kirchhoff.

A	5T	9C	3K	2S	=	448
B*2	14T	10C	8K	2S	=	786
A-2B	-9T	-1C	-5K	0S	=	-338

Action 1 Subtract D from A
Action 2 Subtract (B*2) from A
Action 3 Subtract (B*3) from C

Kirchhoff.

C	8T	8C	2K	3S	=	463
B*3	21T	15C	12K	2S	=	1179
C-3B	-13T	-7C	-10K	0S	=	-716

Action 1 Subtract D from A
Action 2 Subtract (B*2) from A
Action 3 Subtract (B*3) from C

Kirchhoff.

E	3T	2C	1K	0S	=	136
F	-9T	-1C	-5K	0S	=	-338
G	-13T	-7C	-10K	0S	=	-716

Start a new table from processed values.

Kirchhoff.

Try to eliminate another variable and leave 2 equations.

E	3T	2C	1K	0S	=	136
F	-9T	-1C	-5K	0S	=	-338
G	-13T	-7C	-10K	0S	=	-716

Kirchhoff.

Try to eliminate another variable and leave 2 equations.

E	3T	2C	1K	0S	=	136
F	-9T	-1C	-5K	0S	=	-338
G	-13T	-7C	-10K	0S	=	-716

Action 1 Add (E*5) to F
Action 2 Add (E*10) to G

Kirchhoff.

Try to eliminate another variable.

5*E	15T	10C	5K	0S	=	680
F	-9T	-1C	-5K	0S	=	-338
5E-F	6T	9C	0K	0S	=	342

Action 1 Add (E*5) to F

Action 2 Add (E*10) to G

Kirchhoff.

Try to eliminate another variable.

10*E	30T	20C	10K	0S	=	1360
G	-13T	-7C	-10K	0S	=	-716
10E+G	17T	13C	0K	0S	=	644

Action 1 Add (E*5) to F
Action 2 Add (E*10) to G

Kirchhoff.

H	6T	9C	0K	0S	=	342
J	17T	13C	0K	0S	=	644

Start a new table from processed values.

Kirchhoff.

H	6T	9C	0K	0S	=	342
J	17T	13C	0K	0S	=	644

Action 1 Multiply H * 13
Action 2 Multiply J * 9
Action 3 Subtract (13*H) from (9*J)

Kirchhoff.

H*13	78T	117C	0K	0S	=	4446
J	17T	13C	0K	0S	=	644

Action 1 Multiply H * 13
Action 2 Multiply J * 9
Action 3 Subtract (13*H) from (9*J)

Kirchhoff.

H*13	78T	117C	0K	0S	=	4446
J*9	152T	117C	0K	0S	=	5796

Action 1 Multiply H * 13
Action 2 Multiply J * 9
Action 3 Subtract (13*H) from (9*J)

Kirchhoff.

J*9	152T	117C	0K	0S	=	5796
H*13	78T	117C	0K	0S	=	4446
9*J-13H	75T	0C	0K	0S	=	1350

Action 1 Multiply H * 13
Action 2 Multiply J * 9
Action 3 Subtract (13*H) from (9*J)

Kirchhoff.

K	75T	0C	0K	0S	=	1350

Start a new table from processed values.

As we have only one Variable the process is complete.

Kirchhoff.

- So 75 Teas = 1350 pence.
- Therefore a tea = 1350/75 or 18 pence
- Substitute in equation "H"
- Where 6 Teas + 9 Coffees = 342 pence.
- (6 * 18= 108) from 342 = 234p
- Therefore a coffee = 234/9 or 26 pence

Kirchhoff.

- Substitute in equation “E”
- Where 3 Teas + 2 Coffees + 1 KitKat = 136.
- (3*18= 54) + (2*26=52) from 136 pence
- 54 + 52 + 1 KitKat = 136 pence
- 106 + 1 KitKat = 136 pence
- 1 KitKat = 136 pence -106 pence.
- Therefore a KitKat is 30 pence.

Kirchhoff.

- Substitute in equation “D”
- Where 2 Teas, 7 Coffees, 2 KitKat, 2 Snacks is 312 pence.
- (2*18= 36) + (7*26=182) + (2*30 =60) from 312 pence
- 36 + 182 + 60 + 2 Snacks = 312 pence
- 278 + 2 Snacks = 312 pence
- 2 Snacks = 312 - 278 pence = 34 pence.
- Therefore a Snack = 34/2 which is 17 pence.

Kirchhoff.

- So did you get the correct change.
- How much does 9 Teas, 6 Coffees, 5 KitKat and 7 Snacks cost?
- (9*18 = 162) + (6*26 = 156) + (5*30 =150) and (7 *17= 119) which gives:-
- 162 + 156 + 150 + 119 = 587 pence
- Change from £10 = 1000-587 = £4.13
- If you were given £1.34 change then the driver owes you £4.13 - £1.34 = £2.79.

Kirchhoff.

Practice Example.

Kirchhoff.

X	Y	Z	Value
1	2	3	=14
2	3	1	=11
3	1	2	=11

Calculate values of X,Y and Z

Kirchhoff.

- Solution
- X = 1
- Y = 2
- Z = 3

Kirchhoff.

Back to Electronics.

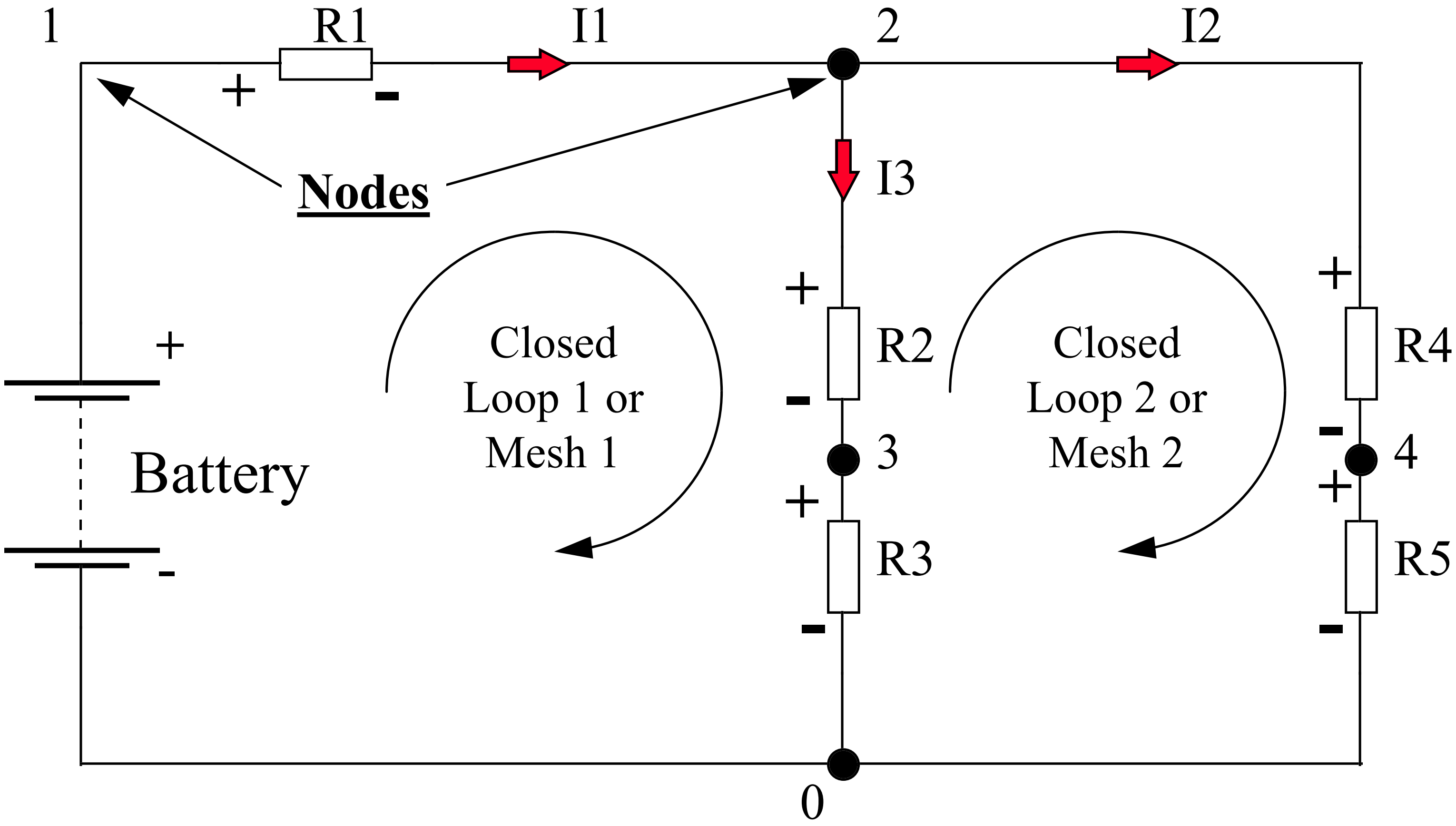
Kirchhoff.

Kirchhoff's Laws (Circuit Analysis)

- Circuits are made up of Components and Interconnection.
- Each Connection point is called a Node.
- The sections between two nodes is a Net.
- A complete interconnected ring of components is a Closed Loop or Mesh.
- Only complete Loop can operate as current needs to flow around circuit to work.

Kirchhoff.

Kirchhoff's Laws



Kirchhoff.

Kirchhoff's Laws

Number 1.

The algebraic sum of all the voltages around a closed loop is zero. (or Sum of Voltage sources equals Sum of Voltage drops)

eg. Vbatt -VR1 - VR2 - VR3 = 0

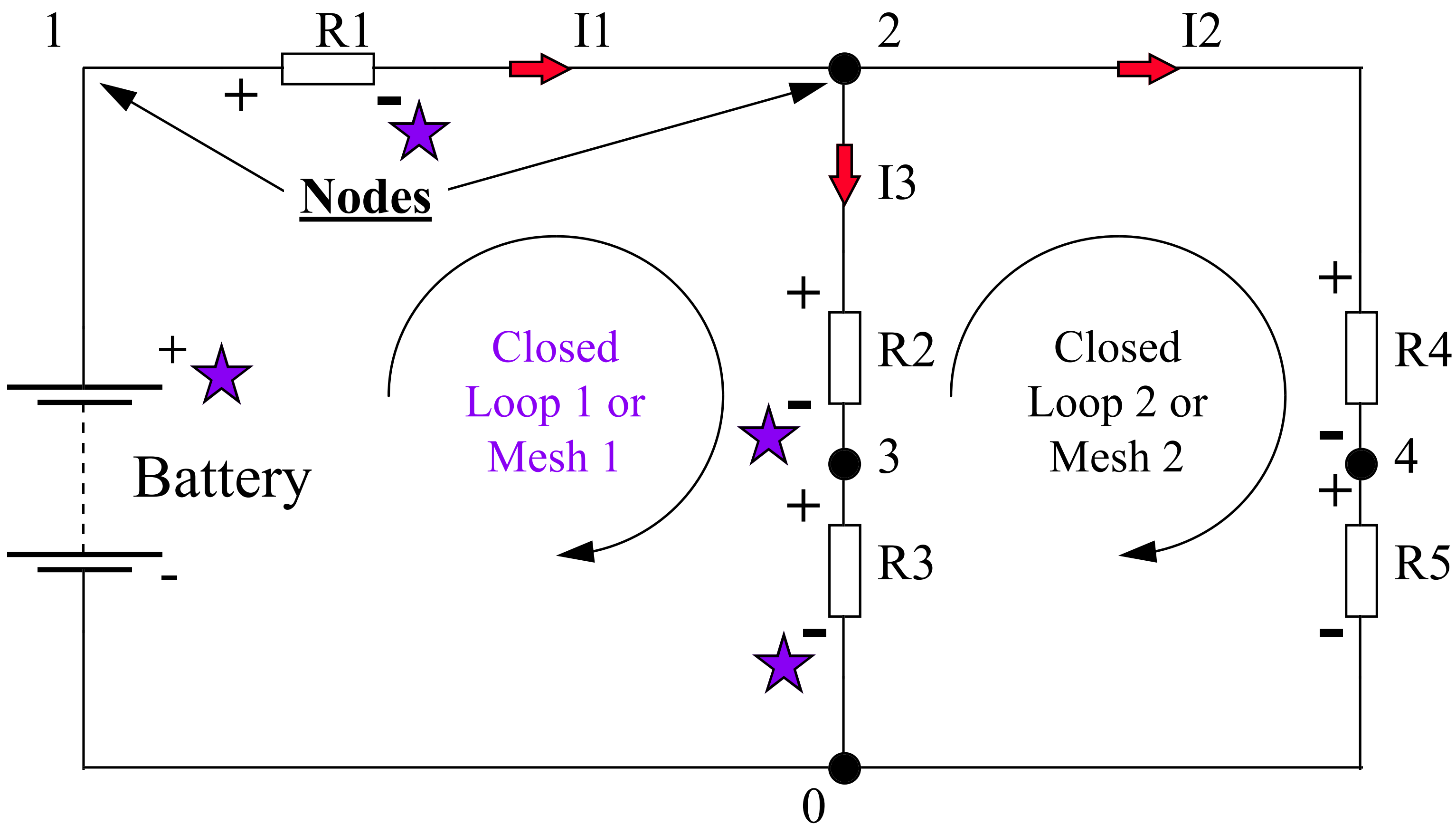
Number 2.

The sum of the currents flowing into a junction(node) equals the sum of the currents flowing out of that junction.

eg. I1 = I2 + I3 ...

Kirchhoff.

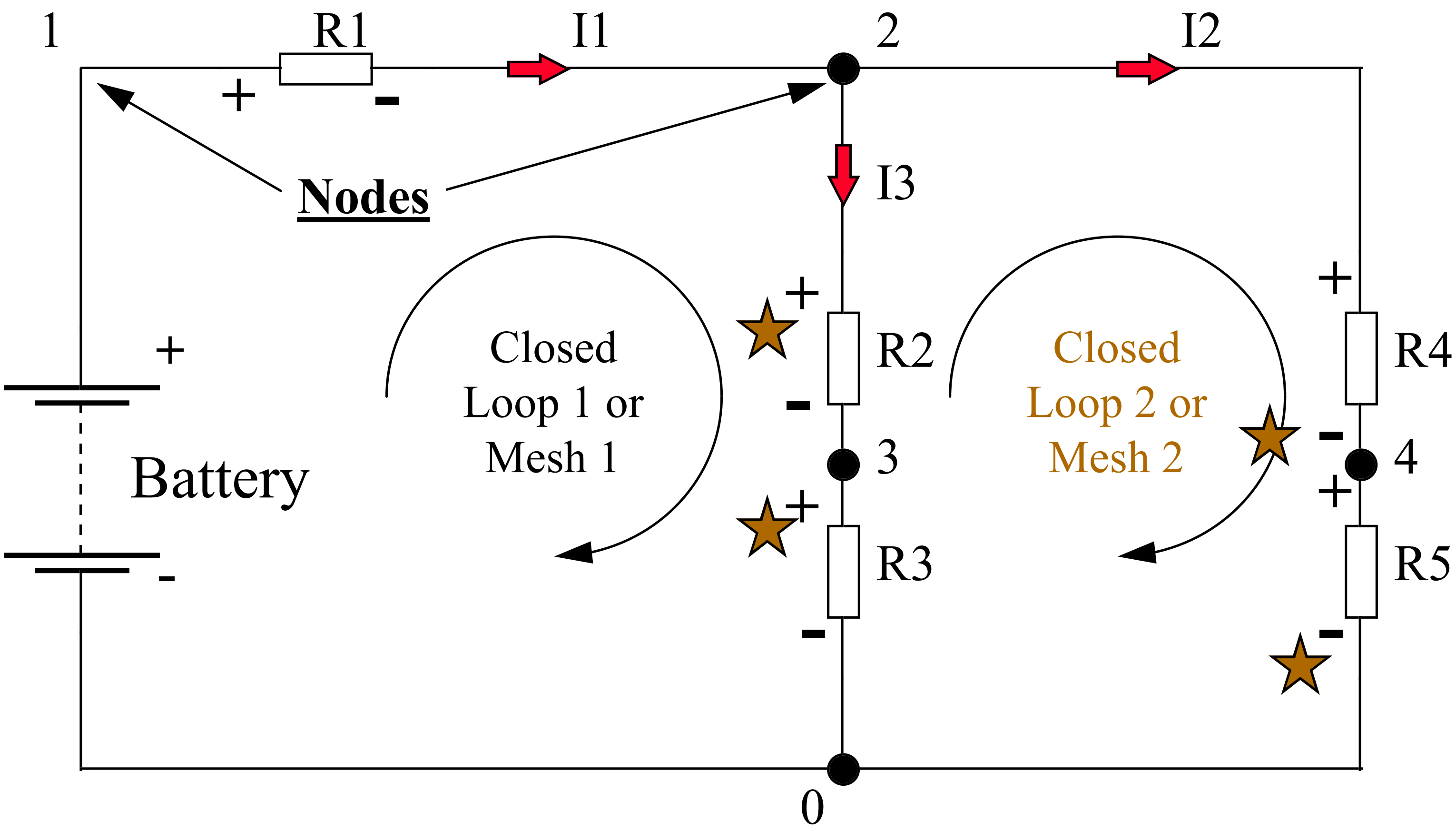
Kirchhoff's Laws



Battery - VR1 - VR2 - VR3 = 0

Kirchhoff.

Kirchhoff's Laws



VR2 + VR3 - VR4 - VR5 = 0

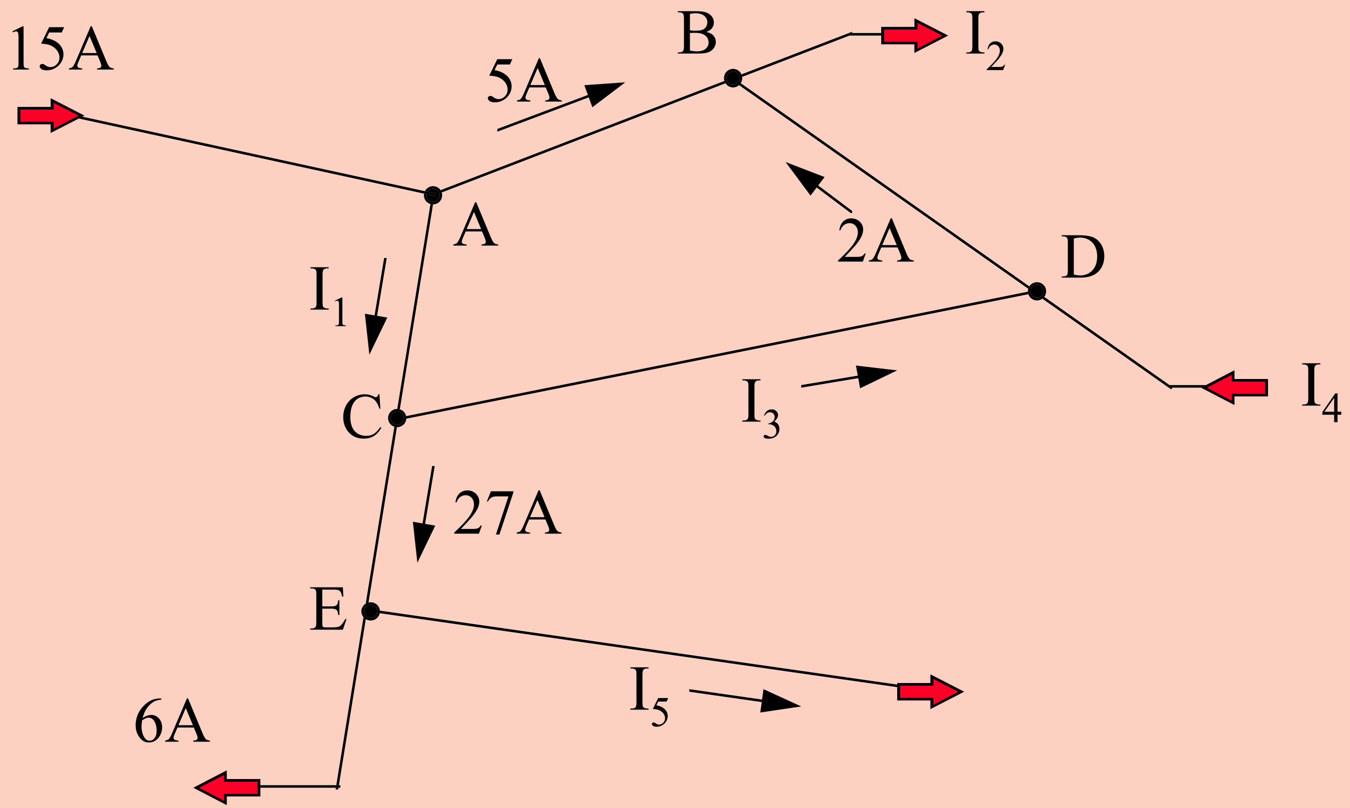
Kirchhoff.

Kirchhoff's Laws (The basic Steps)

- Step 1 , Identify the Nodes and Loops.
  - Ensure all components included.
  - Keep loop count to absolute minimum.
- Step 2 , Identify presumed polarity on components (this is to ensure the equations are correct, the actual direction will be identified once the equations are solved).
- Step 3 , Solve equations.

Kirchhoff.

- Example:-
- Determine the value of the unknown currents.



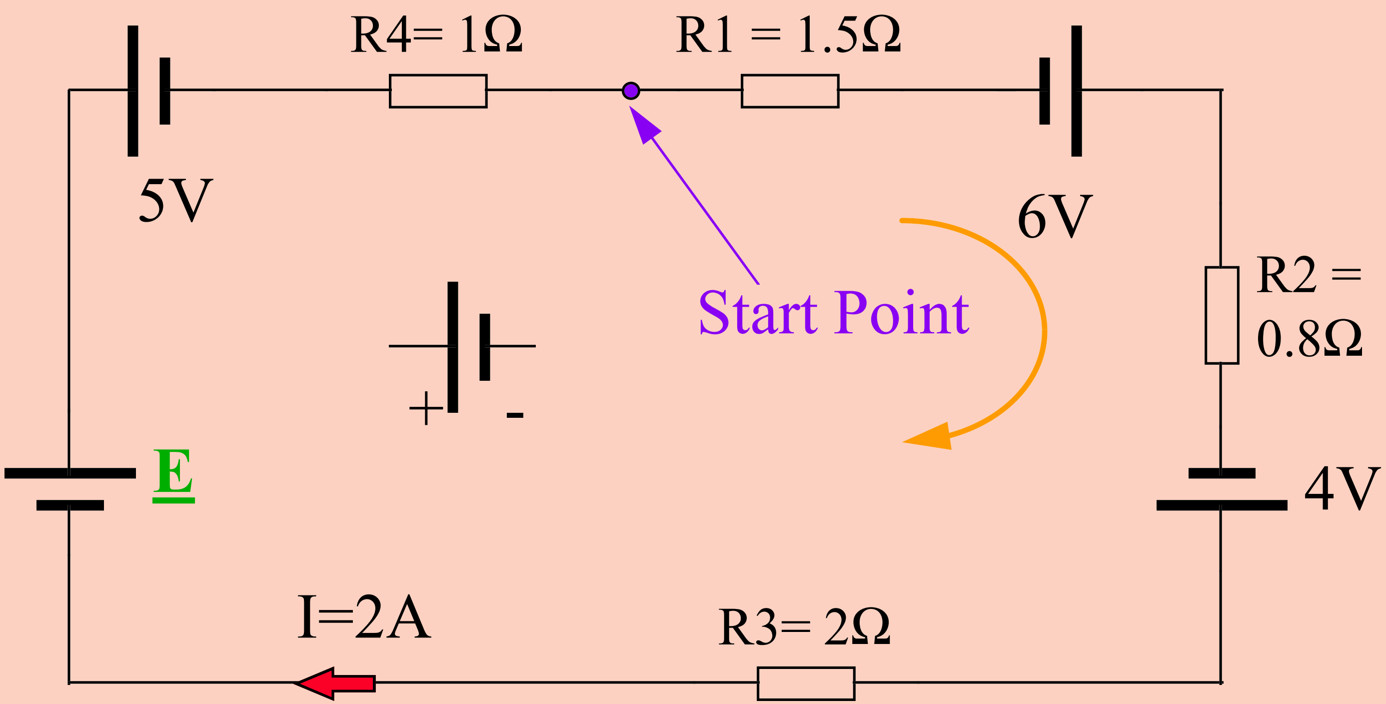
Example:-

Kirchhoff.

- Junction A: $15 = 5 + I_1$ therefore $I_1 = 10A$
- Junction B: $5 + 2 = I_2$ therefore $I_2 = 7A$
- Junction C: $I_1 = 27 + I_3$ or $10 = 27 + I_3$
- or $10 - 27 = I_3$ therefore $I_3 = -17A$
- Junction D: $I_3 + I_4 = 2$ or $-17 + I_4 = 2$
- or $I_4 = 2 + 17$ therefore $I_4 = 19A$
- Junction E: $I_5 = 27 - 6 = 21A$

Example:- **Kirchhoff.**

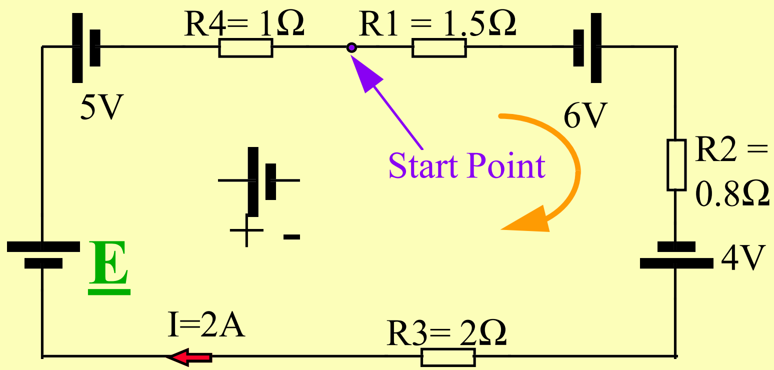
- Determine the value of the e.m.f **E** in volts.



Example:-

Kirchhoff.

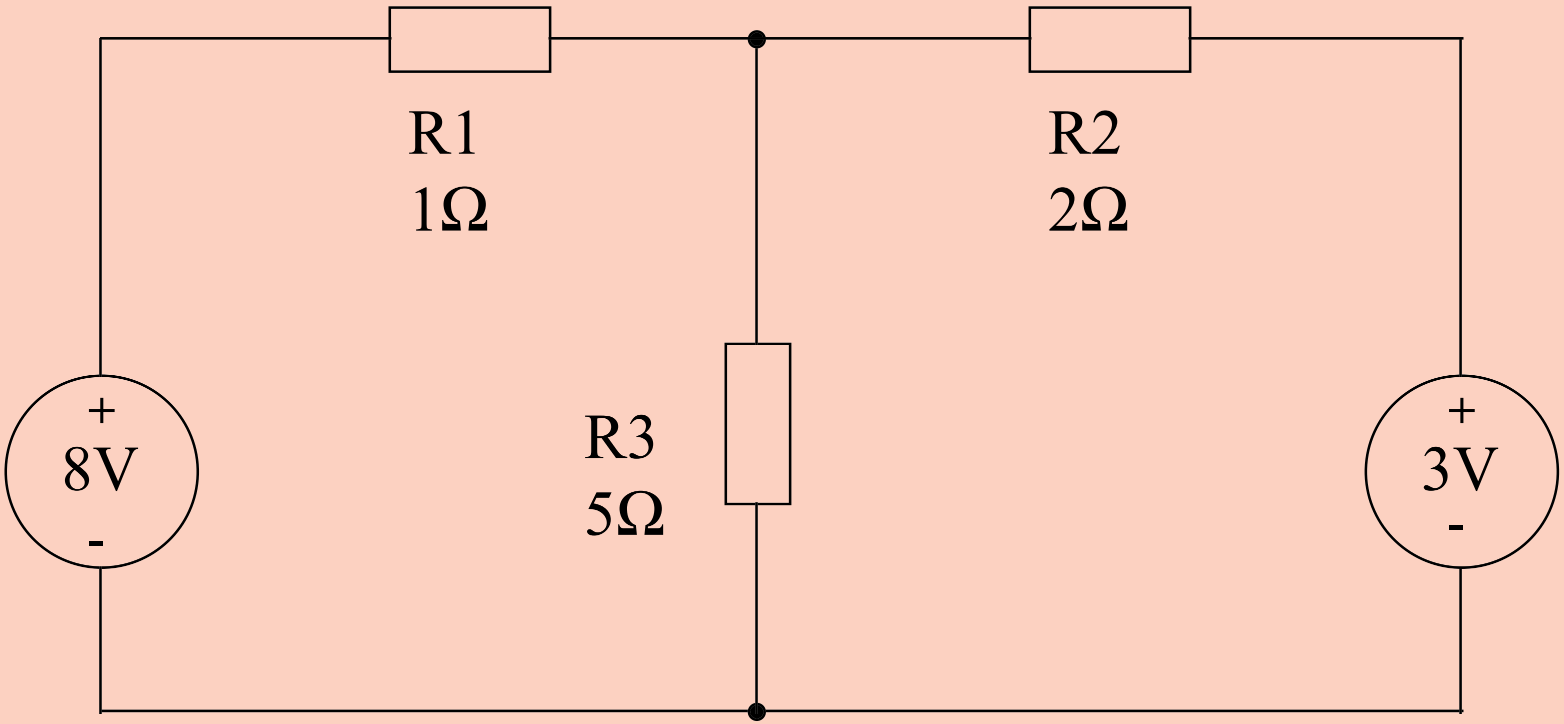
- Calculate sum of e.m.f = 6 + 4 + E - 5 Volts
- = 5 + E Volts
- Note current in circuit = I Volt Drop = I*R
-
- Calculate sum of Volt drops= 1.5I + 0.8I +2I + 1I Volts
- = 5.3I Volts
-
- Note that I = 2 Amps therefore :-
- Volt drops = 5.3*2 = 10.6 Volts
- From Kirchhoff . . . Sum of Voltages = Sum of Drops
- So 5 + E = 10.6
- or E = 10.6 - 5
- Therefore E = 5.6 Volts



Example:

Kirchhoff.

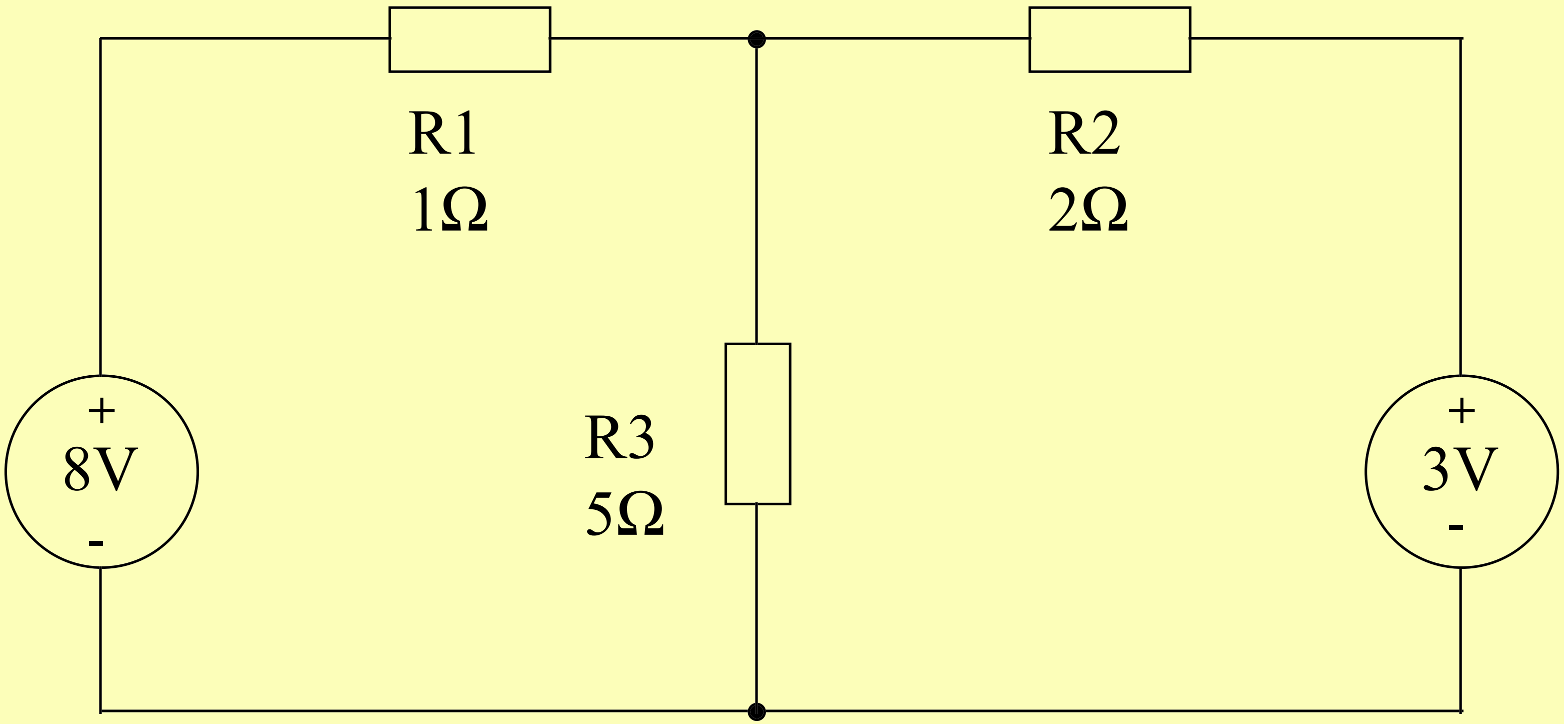
- Calculate
  - The current flowing in R3.
  - The voltage developed across R3.



Solution:

Kirchhoff.

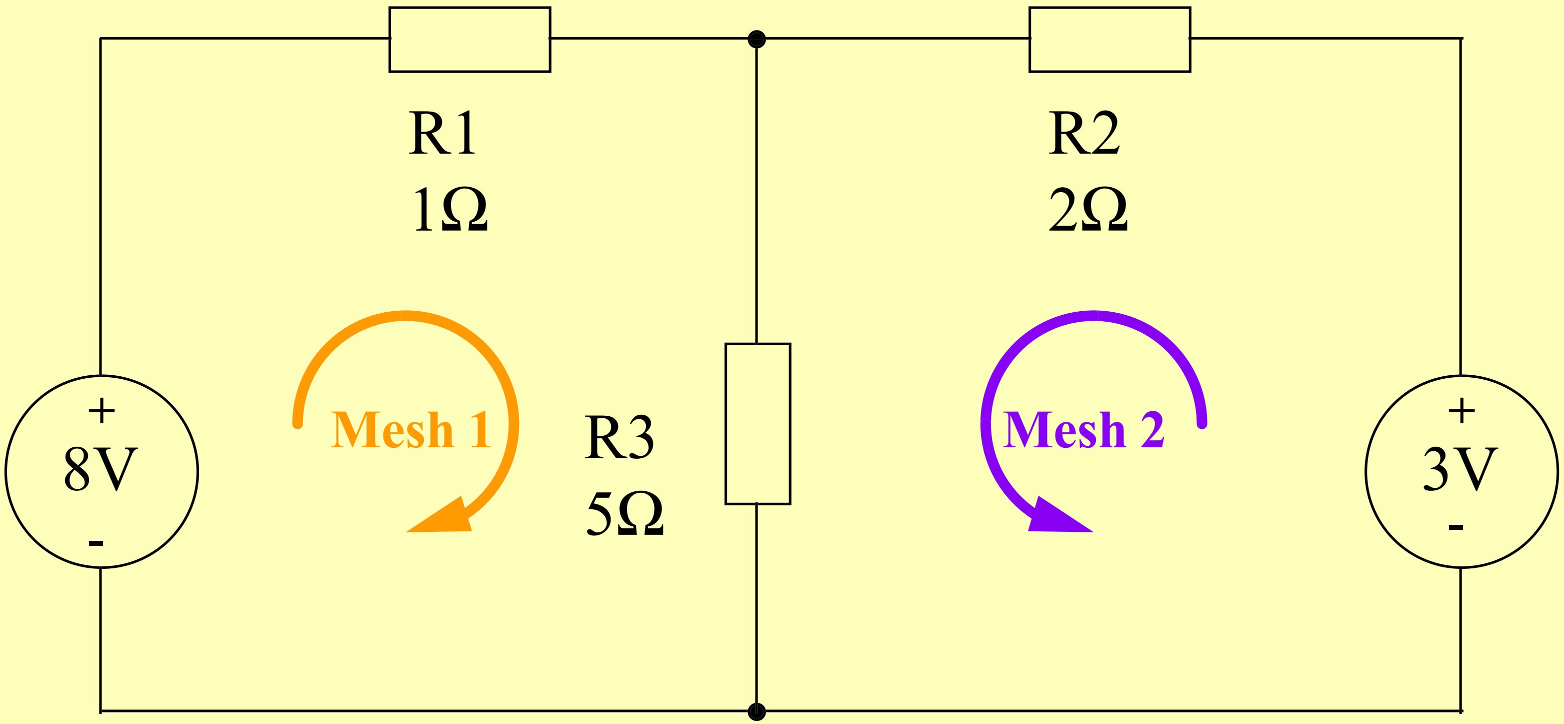
- **Getting Started** :-
- Let us consider the circuit shown below and identify where the Closed Loops are.



Solution:

Kirchhoff.

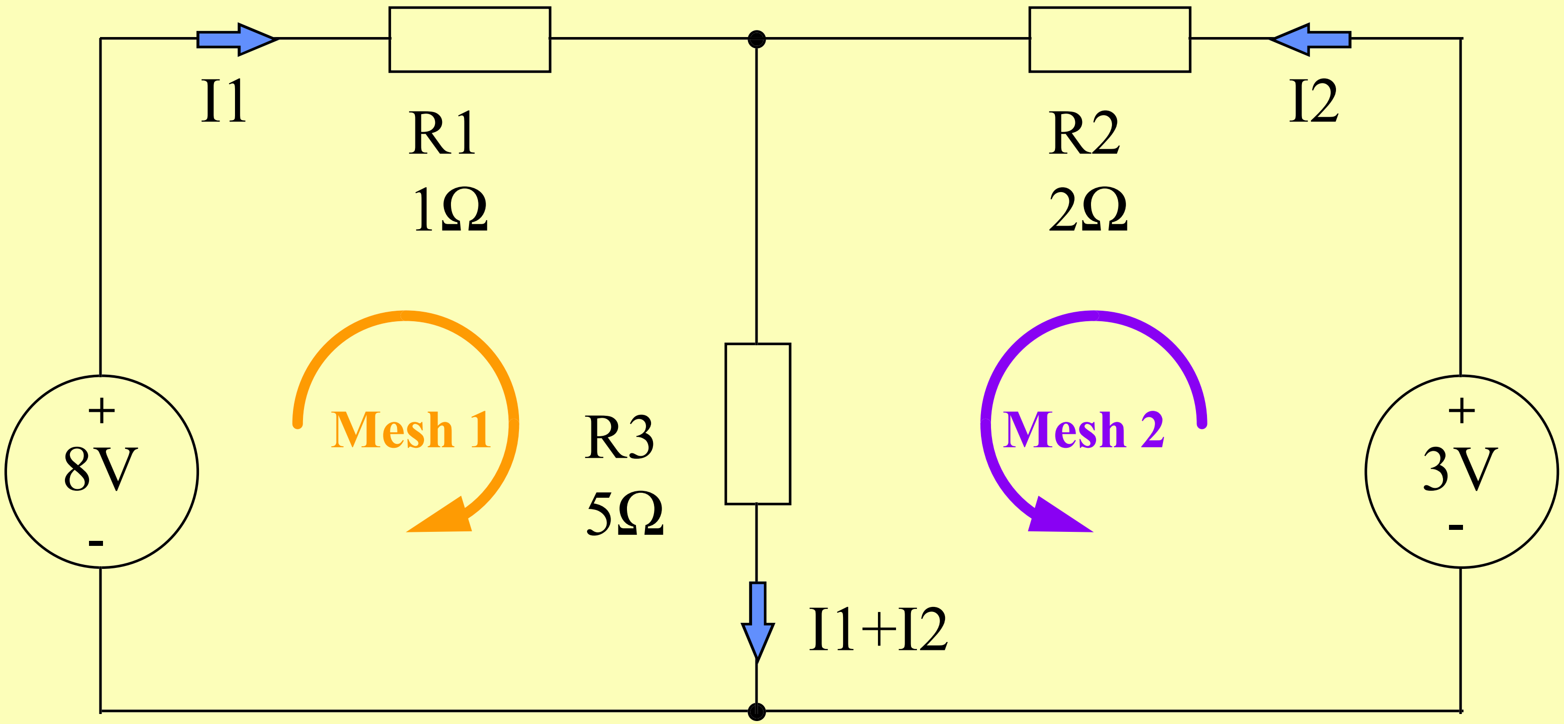
- Now annotate the current flows around the circuit.



Solution:

Kirchhoff.

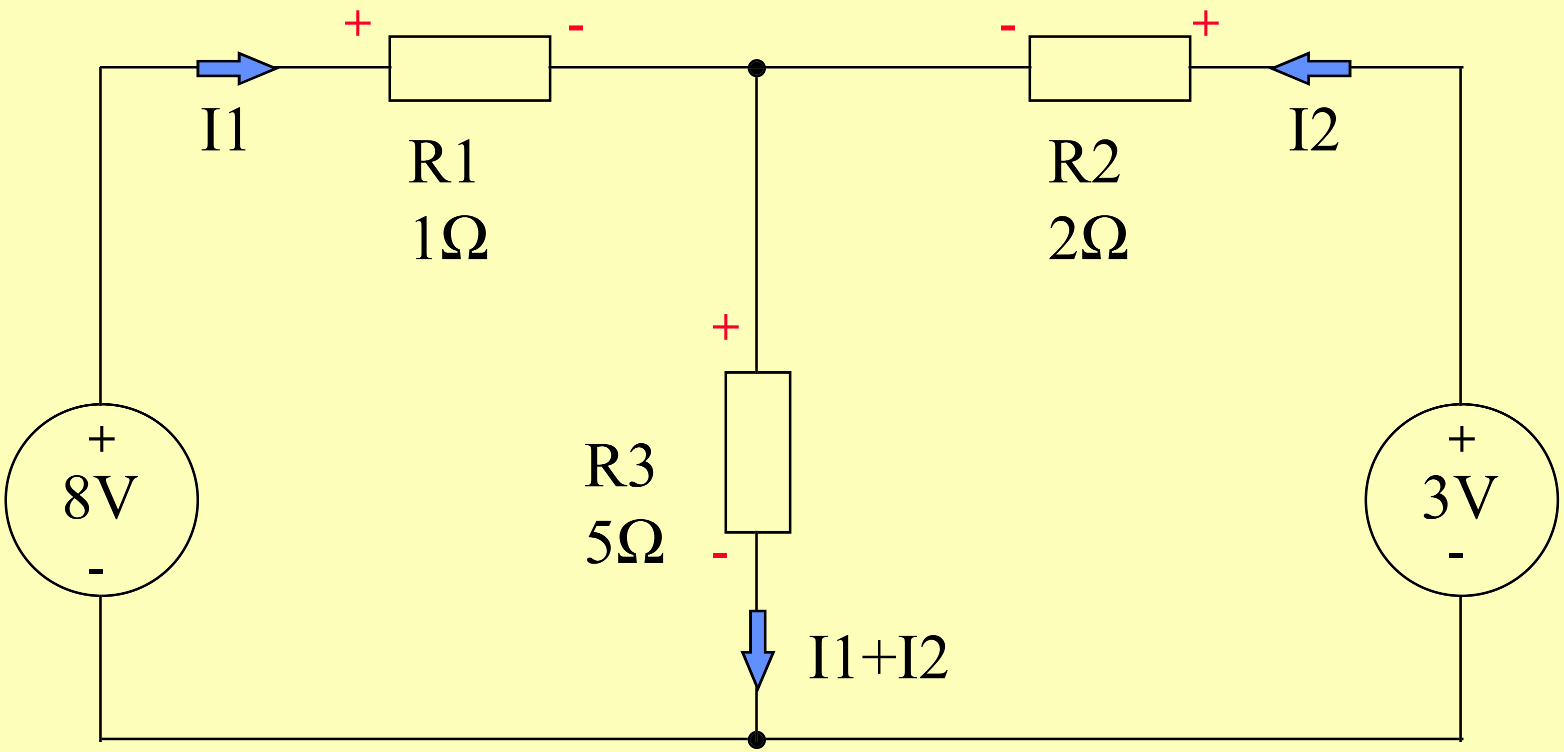
- Annotate with assumed polarities of the circuit - observing the Voltage drops and Voltage sources.



Solution:

Kirchhoff.

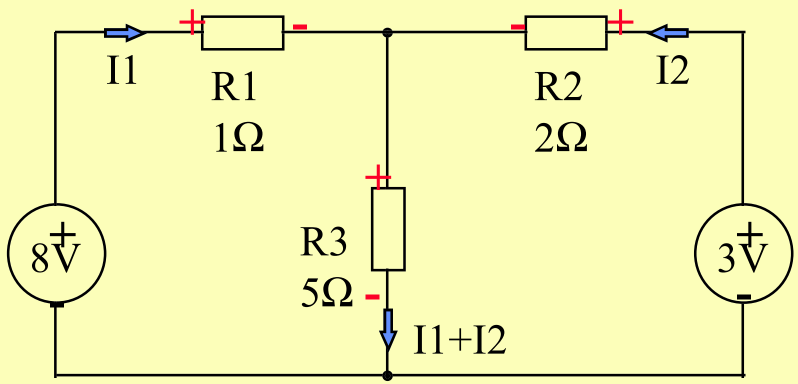
- Develop the voltage equations for Mesh 1 and Mesh 2.



Solution:

Kirchhoff.

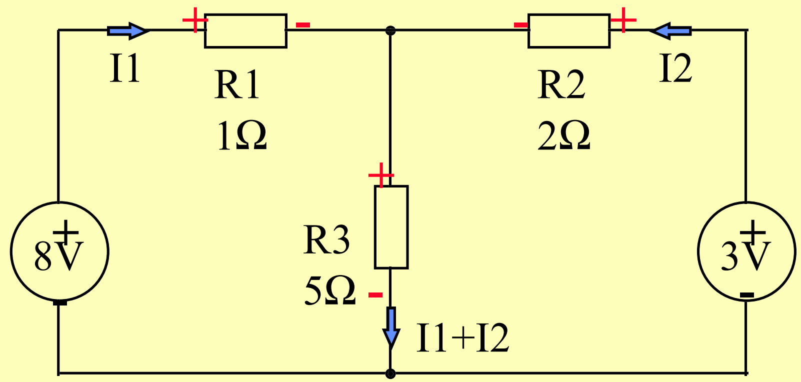
- 8Volts - (R1*I1 + R3*(I1+I2))Volts = 0
- 3Volts - (R2*I2 + R3*(I1+I2))Volts = 0
- Expand the equations:-
- 8 - (R1*I1 + R3*I1 + R3*I2) = 0
- 3 - (R2*I2 + R3*I1 + R3*I2) = 0
- Re-arrange the equations:-
- R1*I1 + R3*I1 + R3*I2 = 8
- R2*I2 + R3*I1 + R3*I2 = 3



Solution:

Kirchhoff.

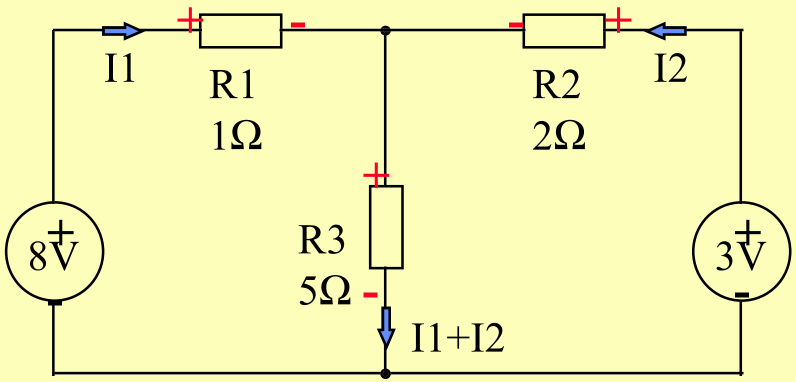
- Substitute in Resistance values:-
- 1I1 + 5I1 + 5I2 = 8
- 2I2 + 5I1 + 5I2 = 3
- Giving
- 6I1 + 5I2 = 8
- 5I1 + 7I2 = 3



Solution:

Kirchhoff.

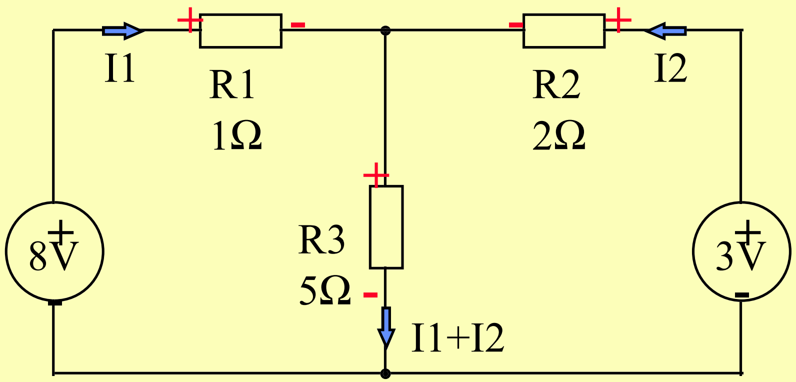
- 6I1 + 5I2 = 8 (Equation "A")
- 5I1 + 7I2 = 3 (Equation "B")
- Multiply Eqn A * 5 and Eqn B * 6 this gives:-
- 30I1 + 25I2 = 40 (Equation "C")
- 30I1 + 42I2 = 18 (Equation "D")
- Subtract Eqn "D" from Eqn "C"
- 0I1 - 17I2 = 22
- Therefore
- I2 = -22/17 Amps
- or I2 = -1.294 Amps



Solution:

Kirchhoff.

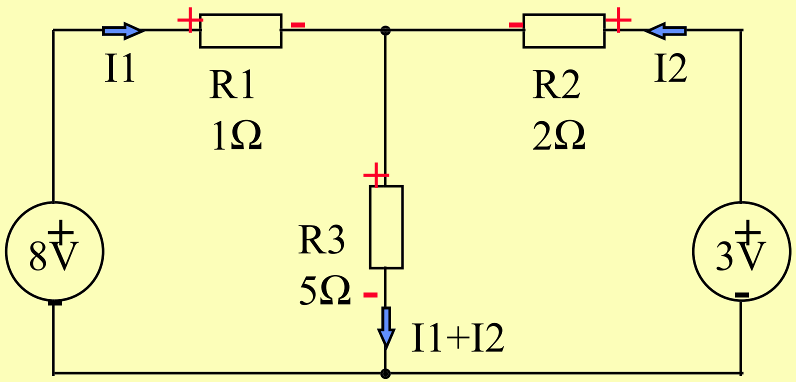
- Substitute (I2 = -22/17) in Equation “A”
- 6I1 + 5*(-22/17) = 8 or
- 6I1 + (-110/17) = 8 or
- 6I1 = 8 + (110/17)
- 6I1 = (8 *17)/17+ (110/17)
- 6I1 = (136)/17+ (110/17)
- 6I1 = 136/17+ 110/17
- 6I1= 246/17
- Therefore
- I1 = 246/(17*6) Amps
- I1 = 246/102 Amps
- or I1 = 2.411 Amps



Solution:

Kirchhoff.

- Current in R3 = I1 + I2
- I1 = 246/102 Amps and I2 = -22/17 Amps
- Therefore
- IR3 = 246/102 + (-22/17) = 246/102 - 132/102 A
- IR3 = (246-132)/102 = 114/102 = 1.117Amps
- Voltage across R3 = I*R or IR3 * 5
- VR3 = 114/102 * 5 = 570/102 = 5.588 Volts



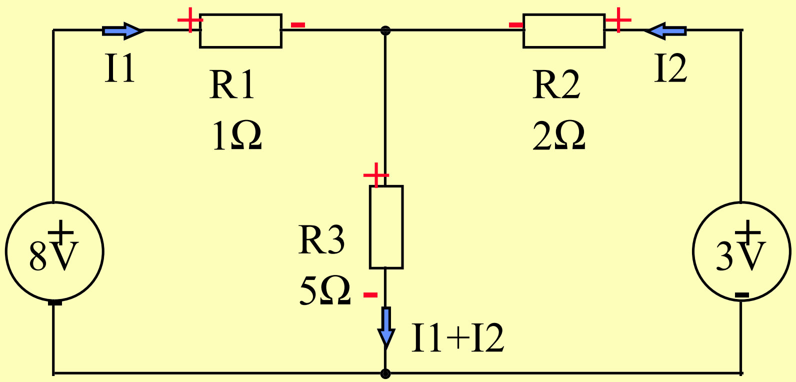
Solution:

Kirchhoff.

- Current in R3 = I1 + I2
- I1 = 246/102 Amps and I2 = -22/17 Amps
- Therefore
- IR3 = 246/102 + (-22/17) = 246/102 - 132/102 A
- IR3 = (246-132)/102 = 114/102 = 1.117Amps
- Voltage across R3 = I*R or IR3 * 5
- VR3 = 114/102 * 5 = 570/102 = 5.588 Volts

Note:

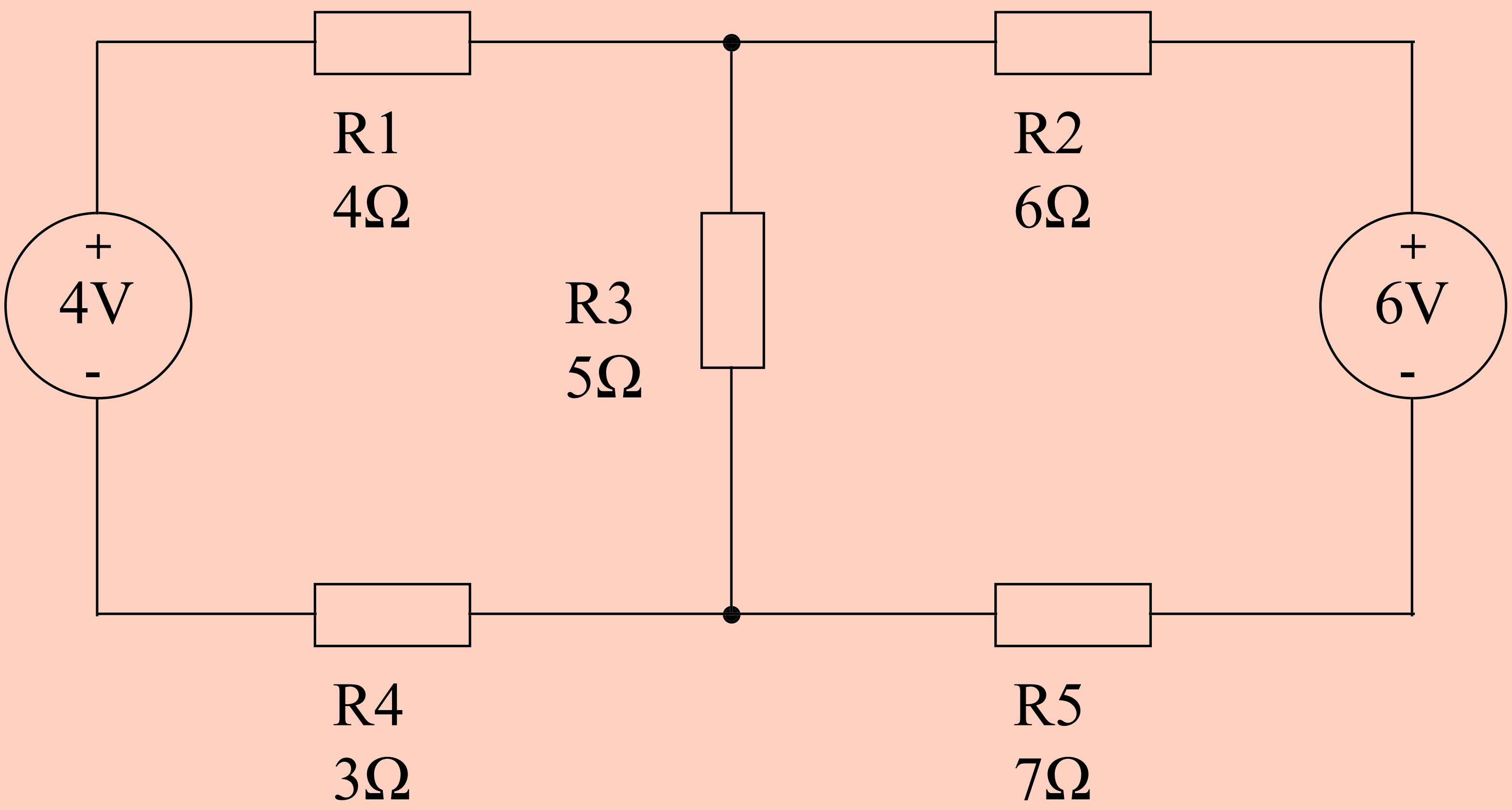
If you convert to decimals during the calculation process you will get slightly different results.



Practice:

Kirchhoff.

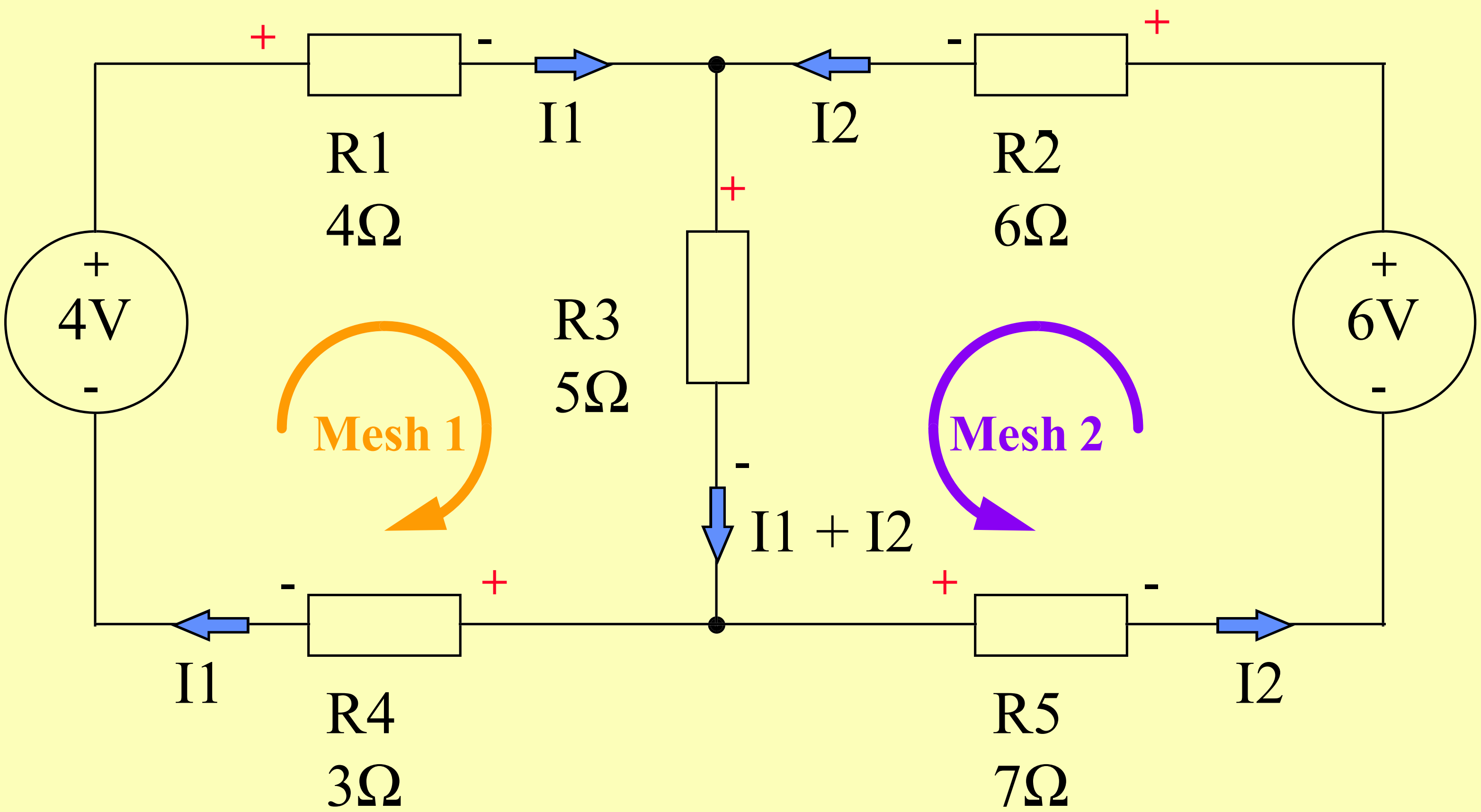
- Calculate showing all working.
  - The current flowing in R3.
  - The voltage developed across R3.



Practice:

Kirchhoff.

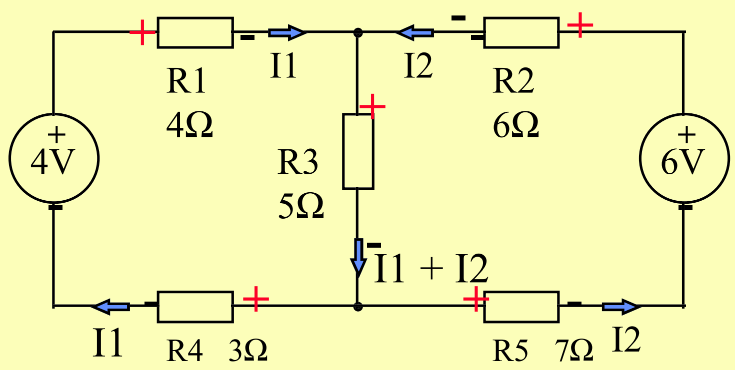
- Develop the voltage equations for Mesh 1 and Mesh 2.



Solution:

Kirchhoff.

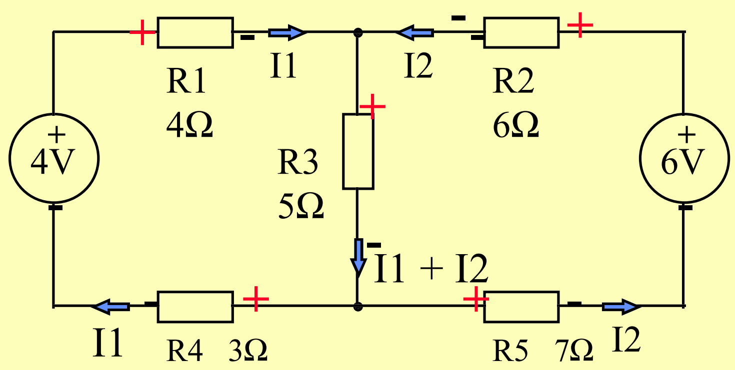
- 4Volts - (R1*I1 + R3*(I1+I2)+R4*I1) = 0
- 6Volts - (R2*I2 + R3*(I1+I2)+R5*I2) = 0
- Expand the equations:-
- 4 - (R1*I1 +R3*I1 +R3*I2 +R4*I1) = 0
- 6 - (R2*I2 +R3*I1 +R3*I2 +R5*I2) = 0
- Re-arrange the equations:-
- 4 = R1*I1 +R3*I1 +R3*I2 +R4*I1
- 6 = R2*I2 +R3*I1 +R3*I2 +R5*I2



Solution:

Kirchhoff.

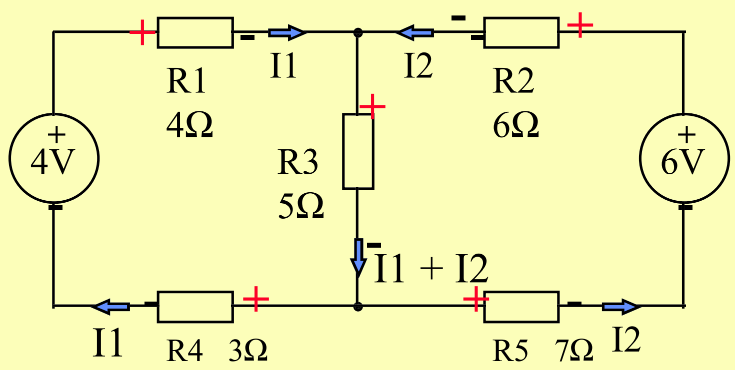
- Substitute in Resistance values:-
- 4 = 4*I1 +5*I1 +5*I2 +3*I1 = 4I1+5I1+5I2+3I1
- 6 = 6*I2 +5*I1 +5*I2 +7*I2 = 6I2+5I1+5I2+7I2
- Giving
- 4 = 12I1 + 5I2
- 6 = 5I1 + 18I2
- or
- 12I1 + 5I2 = 4
- 5I1 + 18I2 = 6



Solution:

Kirchhoff.

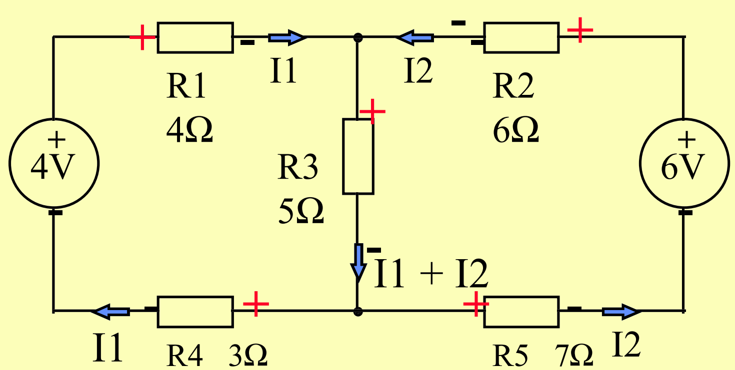
- Define the equations
- 12I1 + 5I2 = 4 (Equation “A”)
- 5I1 + 18I2 = 6 (Equation “B”)
- Multiply Eqn A * 5 and Eqn B * 12 this gives:-
- 60I1 + 25I2 = 20 (Equation “C”)
- 60I1 + 216I2 = 72 (Equation “D”)
- Subtract Eqn “D” from Eqn “C”
- 0I1 - 191I2 = -52
- Therefore
- I2 = -52/-191 or 52/191 Amps
- or I2 = 0.272 Amps



Solution:

Kirchhoff.

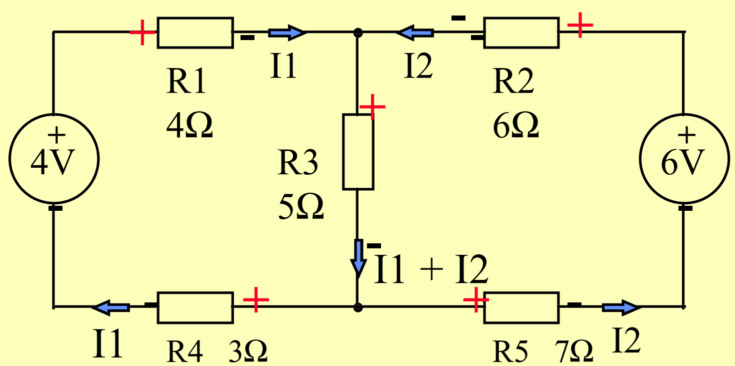
- Substitute (I2 = 52/191) in Equation "A"
- 12I1 + 5*(52/191) = 4 or
- 12I1 + (260/191) = 4 or
- 12I1 = 4 - (260/191)
- 12I1 = (4 *191)/191 - (260/191)
- 12I1 = (764)/191 - (260/191)
- 12I1= 504/191
- Therefore
- I1 = 504/(191*12) Amps
- I1 = 504/2292 Amps
- or I1 = 0.2198 Amps



Solution:

Kirchhoff.

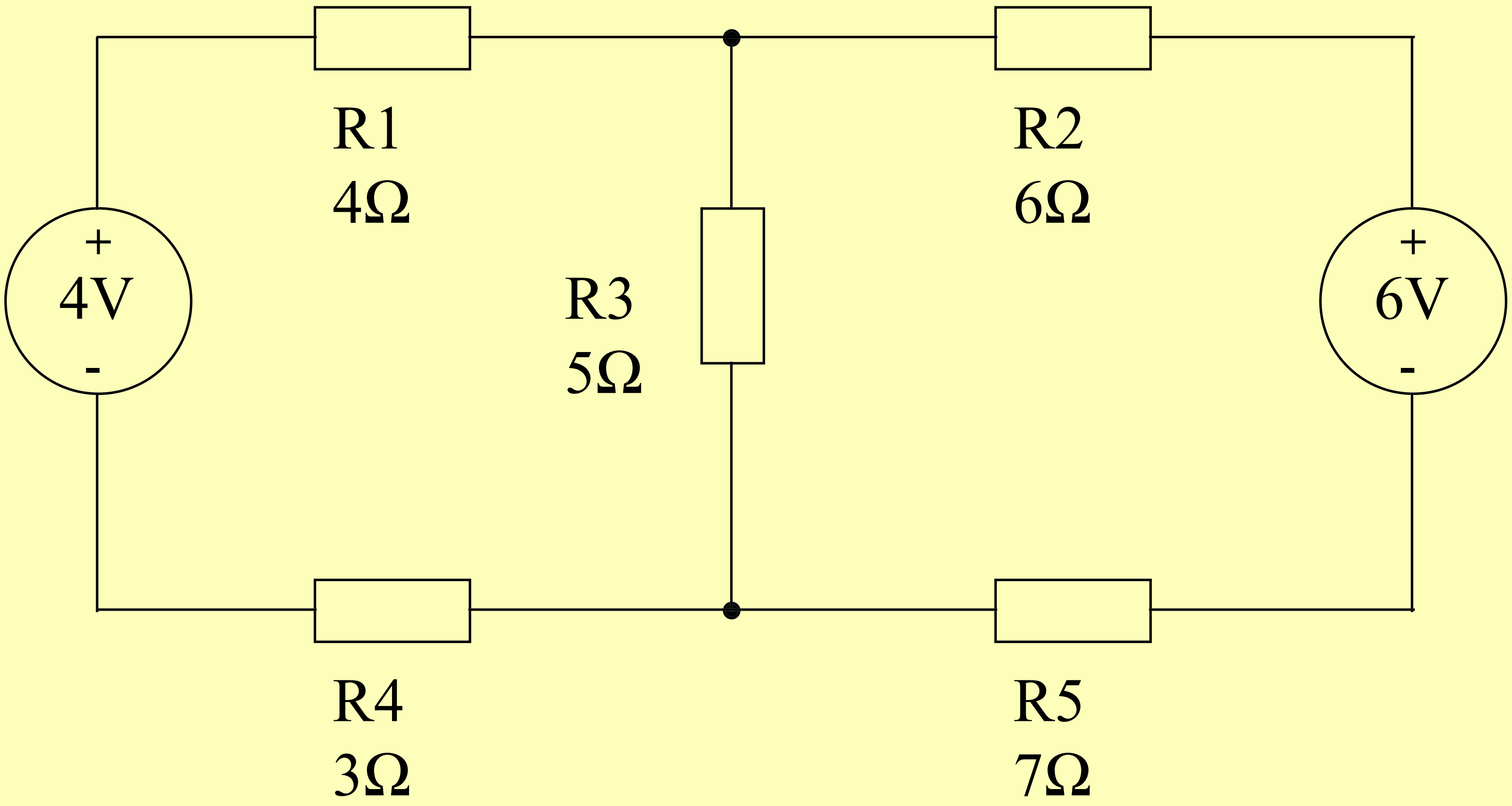
- Current in R3 = I1 + I2
- I1 = 504/2292 Amps and I2 = 52/191 Amps
- Therefore
- IR3=504/2292 +52/191 = 504/2292 +624/2292 A
- IR3=(502+624)/2292 = 1126/2292 = 0.4912Amps
- Voltage across R3 = I*R or IR3 * 5
- VR3 = 1126/2292 * 5 = 5630/2292= 2.456 Volts



Practice:

Kirchhoff.

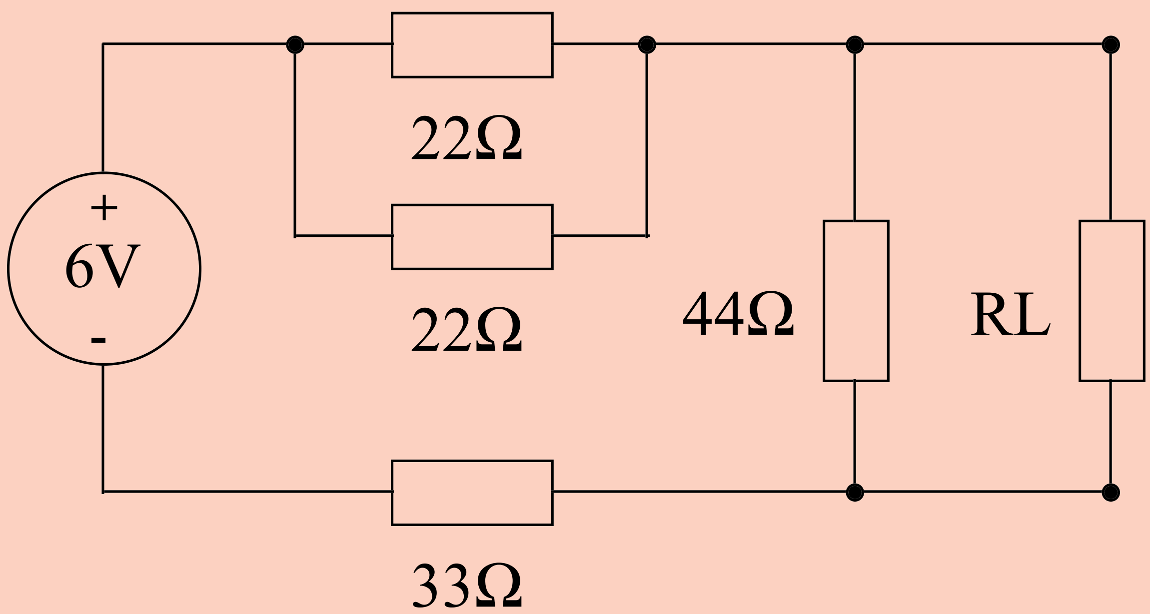
- Calculate showing all working.
  - The current flowing in R3 = 0.4912Amps.
  - The voltage developed across R3 = 2.456 Volts.



Practice:

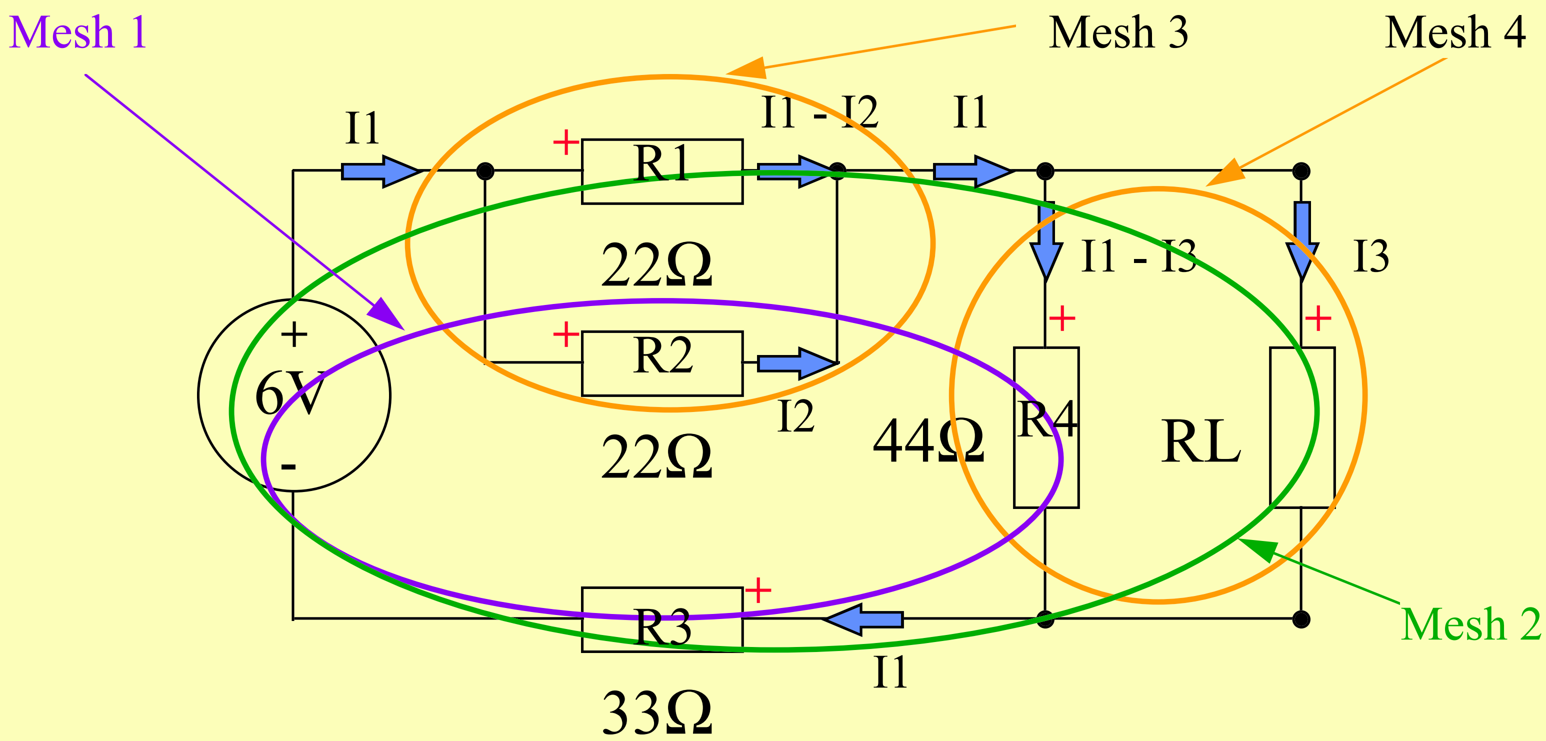
Using Kirchhoff.

- Calculate showing all working (RL = 11Ω).
  - The current flowing in RL.
  - The voltage developed across RL.



Practice: **Using Kirchhoff.**

- Calculate showing all working (RL = 11Ω).
  - The current flowing in RL.
  - The voltage developed across RL.



Solution:

Kirchhoff.

- Step 1. Identify the unique mesh circuits
- Mesh 1
- 6Volts - (R2*I2 + R4*(I1-I3) + R3*I1) = 0
- Mesh 2
- 6Volts - (R1*(I1-I2) + RL*I3 + R3*I1) = 0
- Mesh 3
- R2*I2 - R1*(I1-I2) = 0
- Mesh 4
- R4*(I1-I3) - RL*I3 = 0

Solution:

Kirchhoff.

- Expand the equations:-
- 6 - (R2*I2 + R4*I1 - R4*I3 + R3*I1) = 0
- 6 - (R1*I1 - R1*I2 + RL*I3 + R3*I1) = 0
- R2*I2 - R1*I1 + R1*I2 = 0
- R4*I1 - R4*I3 - RL*I3 = 0
- Re-arrange the equations:-
- R4*I1 + R3*I1 + R2*I2 - R4*I3 = 6
- R1*I1 + R3*I1 - R1*I2 + RL*I3 = 6
- -R1*I1 + R2*I2 + R1*I2 = 0
- R4*I1 -R4*I3 - RL*I3 = 0

Solution:

Kirchhoff.

- Substitute in Resistance values:-
- 44I1 + 33I1 + 22I2 - 44I3 = 6
- 22I1 + 33I1 - 22I2 + 11I3 = 6
- -22I1 + 22I2 + 22I2 = 0
- 44I1 - 44I3 - 11I3 = 0
- Giving
- 77I1 + 22I2 - 44I3 = 6 (Eqn A)
- 55I1 - 22I2 + 11I3 = 6 (Eqn B)
- -22I1 + 44I2 = 0 (Eqn C)
- 44I1 - 55I3 = 0 (Eqn D)

Solution:

Kirchhoff.

- Add Eqn A to Eqn B to give Eqn E :-
- 77I1 + 22I2 - 44I3 = 6 (Eqn A)
- 55I1 - 22I2 + 11I3 = 6 (Eqn B)
- 132I1 -33I3 = 12 (Eqn E)
- Mult Eqn D by 3 to give Eqn F :-
- 132I1 -33I3 = 12 (Eqn E)
- 132I1 -165I3 = 0 (Eqn D*3)
- and subtract gives
- 132I3 = 12
- Therefore I3 = 12/132 = 0.0909 A
- Voltage across RL = RL*I3 = 12/132 * 11 = 1Volt

Solution:

Kirchhoff.

- Substitute I3 in Eqn D :-
- 44I1 - 55I3 = 0 (Eqn D)
- 44I1 - 55*(12/132) = 0 or
- 44I1 = 55*12/132 = 660/132 amps
- Therefore
- I1 = 660/(132*44) = 660/5808 = 0.1136A
- Substitute I1 in Eqn C :-
- -22I1 + 44I2 = 0 (Eqn C)
- -22 *(660/5808) + 44I2 = 0 or
- 22 *(660/5808) = 44I2 = 14520/5808 amps
- Therefore
- I2 = 14520/(5808*44) = 14520/255552 = 0.0568A

Solution:

Kirchhoff.

- Conclusion

- Current in RL = I3
- Voltage across RL = R*I = RL*I3

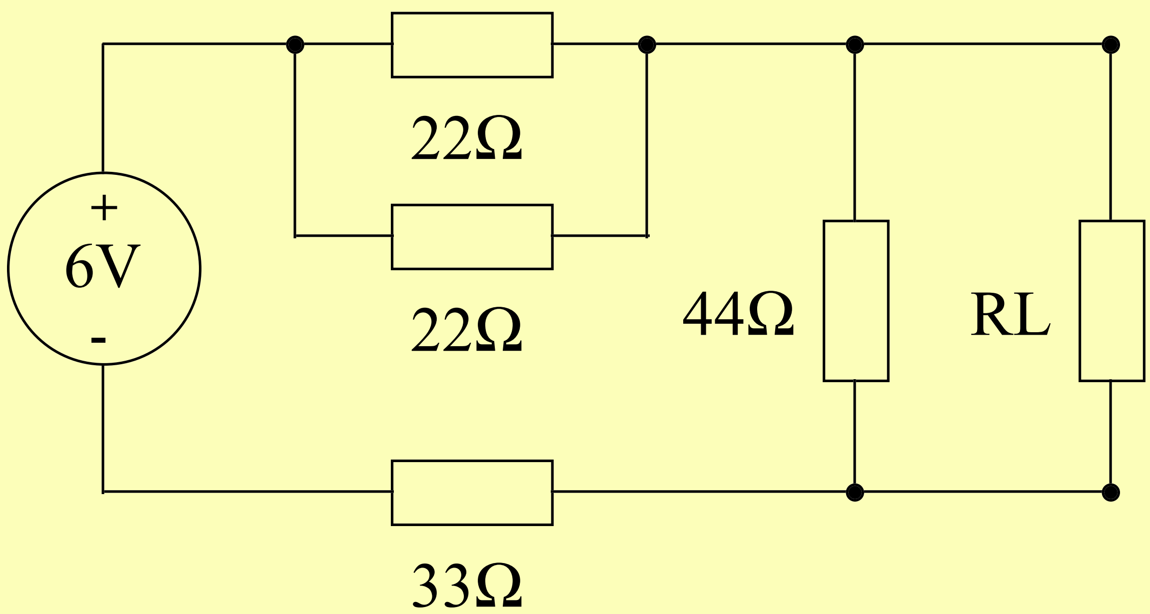
- RL = 11Ω and I3 = 12/132 Amps or = 0.0909 A

- Therefore
- Voltage across RL = 12/132 * 11 = 1Volt

Practice:

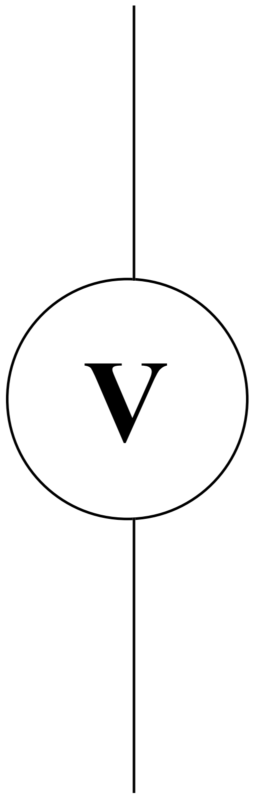
Using Kirchhoff.

- Calculate showing all working (RL = 11Ω).
  - The current flowing in RL. (12/132 Amps)
  - The voltage developed across RL. (1 volt)

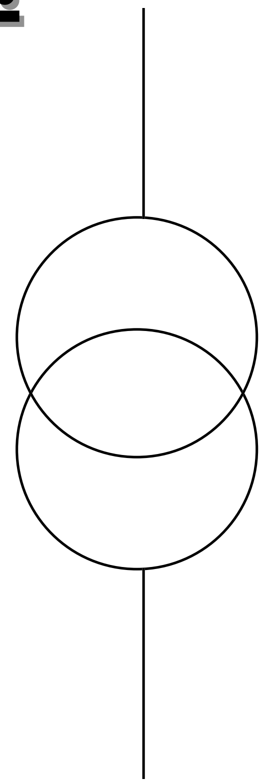


Circuit Analysis Symbols

Circuit Analysis.



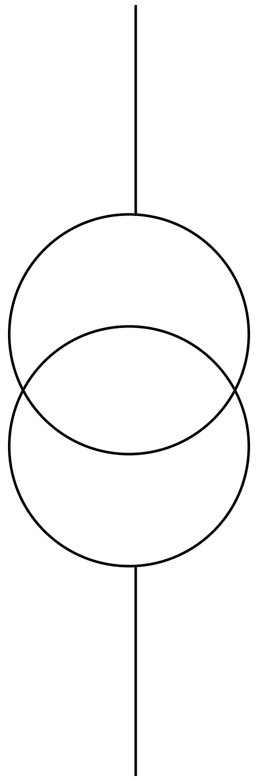
The Voltage Source



The Constant
Current Source

Symbols used to assist with the analysis of circuits.

Circuit Analysis.



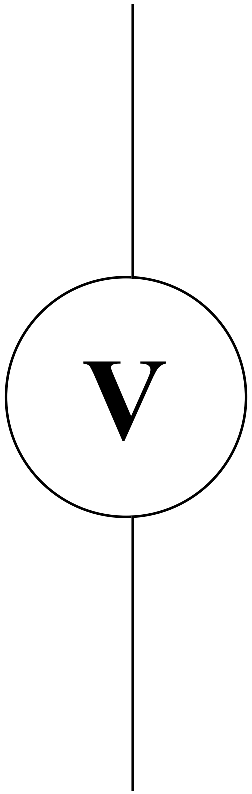
The Constant
Current Source

When you use a Current source in a calculation it is acceptable to assume that it has Infinite resistance.

A **Current Source** is therefore treated as an **Open Circuit**.

Symbols used to assist with the analysis of circuits.

Circuit Analysis.



The Voltage Source

When you use a Voltage source in a calculation it is acceptable to assume that it has NO resistance.

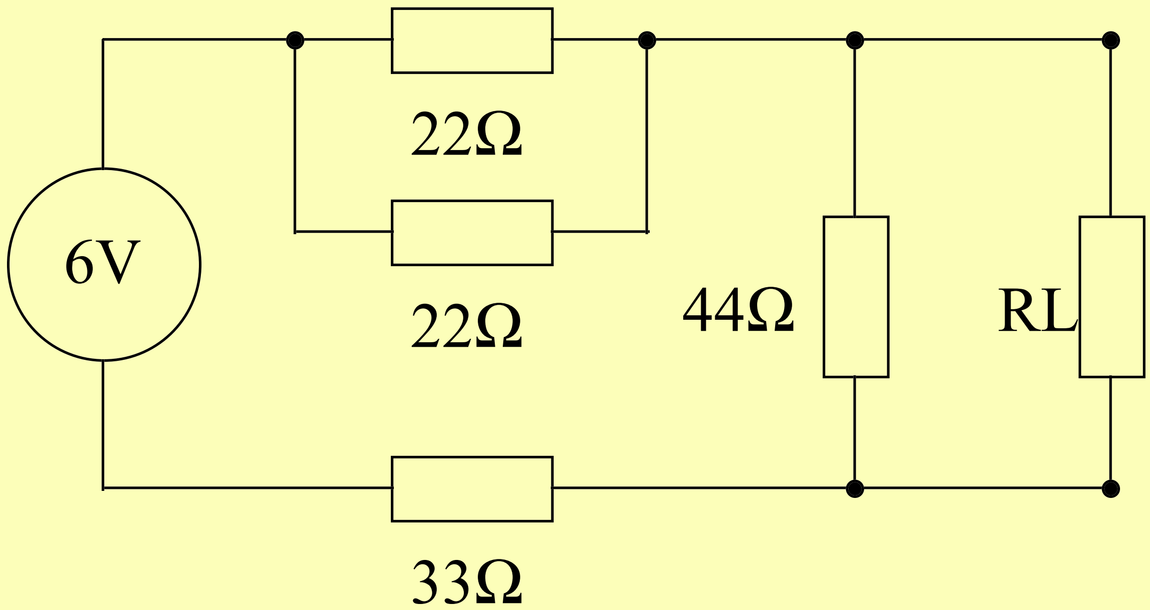
A **Voltage Source** is therefore treated as a **SHORT Circuit**.

Symbols used to assist with the analysis of circuits.

Resistance Evaluation

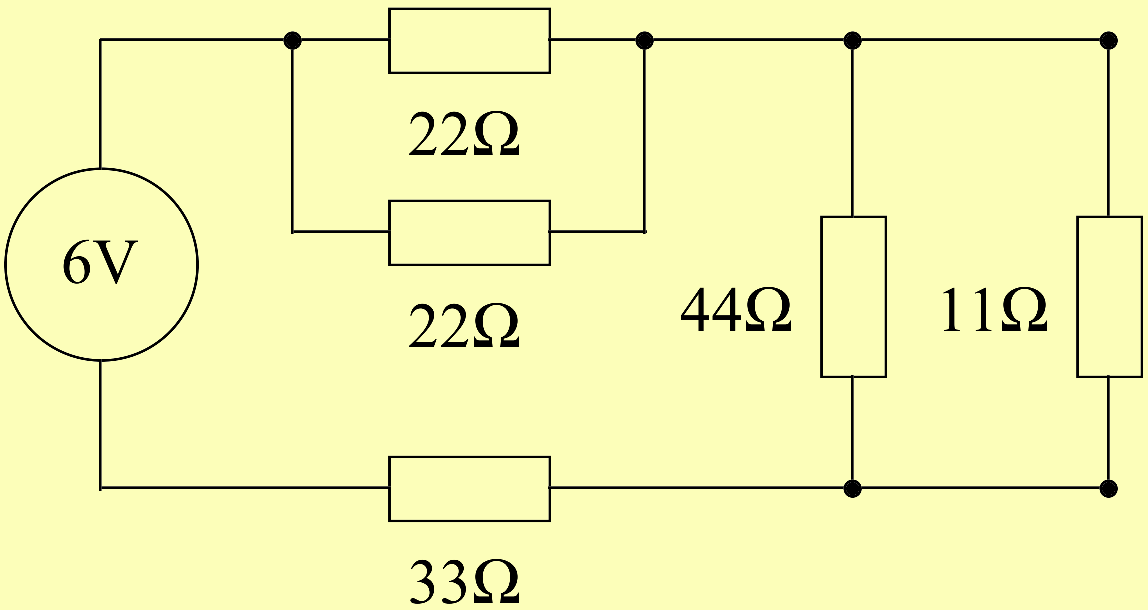
Resistance Evaluation.

- Calculation exercise:
- Assume RL = 11Ω then
  - Calculate the Current through RL.
  - Calculate the Voltage across RL.



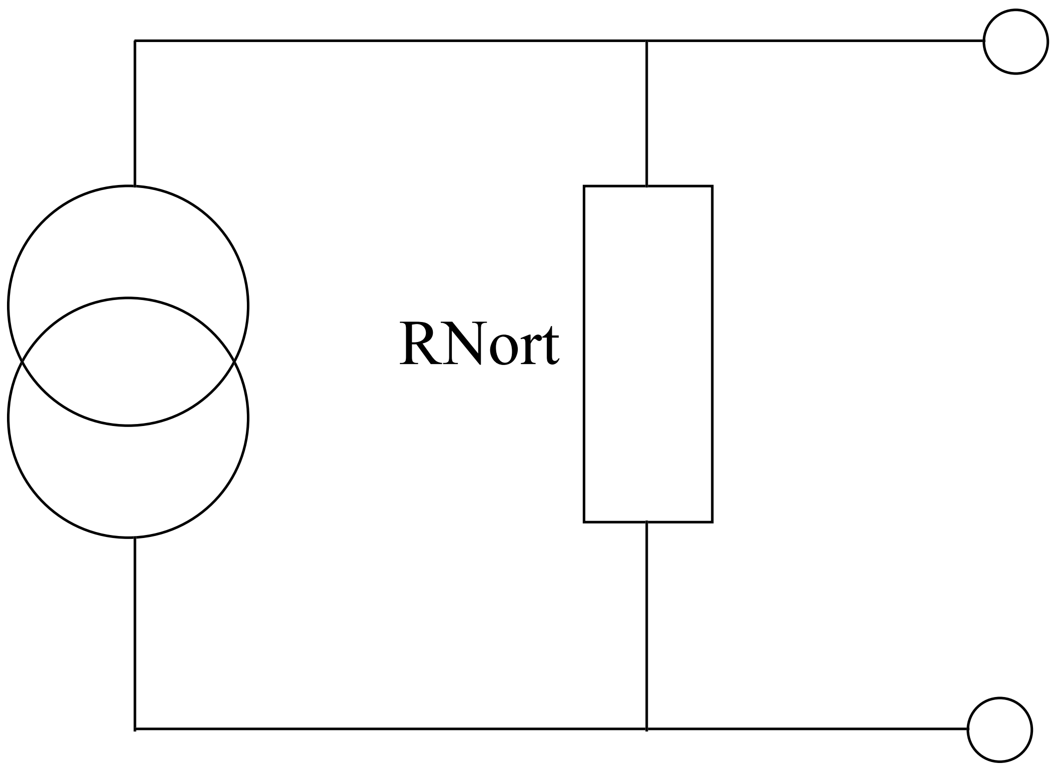
Resistance Evaluation.

- Rcct = (22!22)+(44!11)+33
- Rcct = (22*22/(22+22))+(44*11/(44+11))+33
- Rcct = (11)+(8.8)+33 = 52.8Ω
- Icct = V/R = 6/52.8 = 0.1136A
- V across RL section = I*R = 6/52.8 * 8.8 = 1 Volt
- I through RL = V/R = 1/11 = 0.09 Amps



Norton

Norton.



The Norton equivalent Circuit.

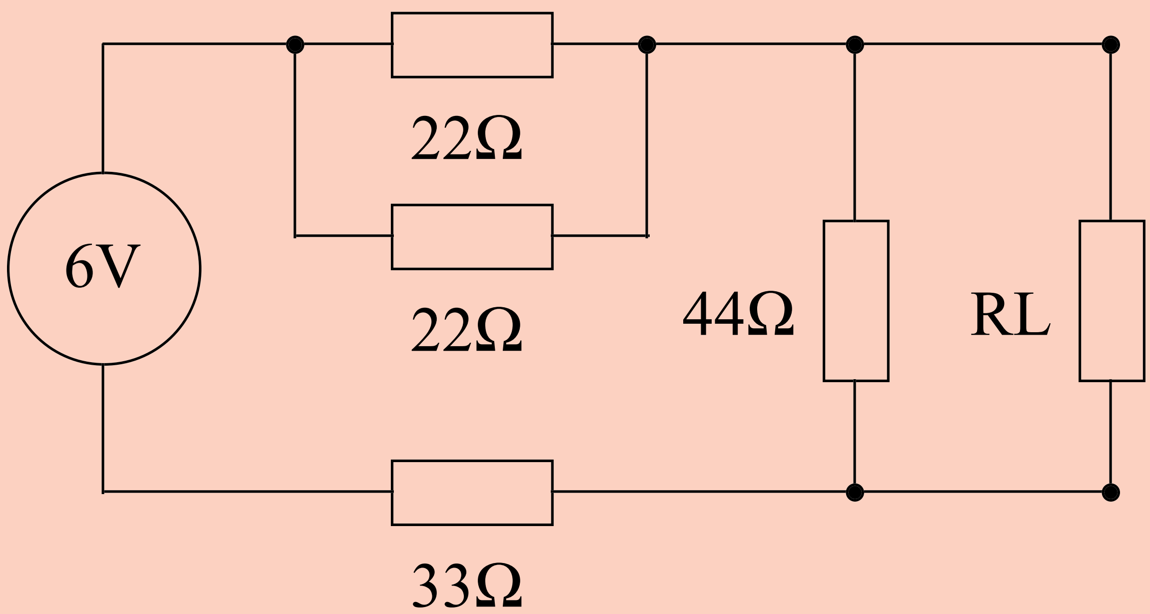
Norton.

- The Norton Process:
- Replace the load of the circuit you want to find its Norton equivalent with a **Short Circuit**.
- Determine the Current through the terminal points where the load was connected (INort).
- Determine the Resistance looking into the terminal points where the load was connected (RNort).
  (Replace all voltage sources with a short circuit)
  (Replace all current sources with an open circuit)
- Redraw circuit using the calculated INort and RNort to replace the original circuit.

Example:

Norton.

- Calculate the Norton equivalent for the circuit shown below.
- RL = 11Ω : Calculate the Current through RL :-
  - using the Norton equivalent circuit.
  - using circuit below.



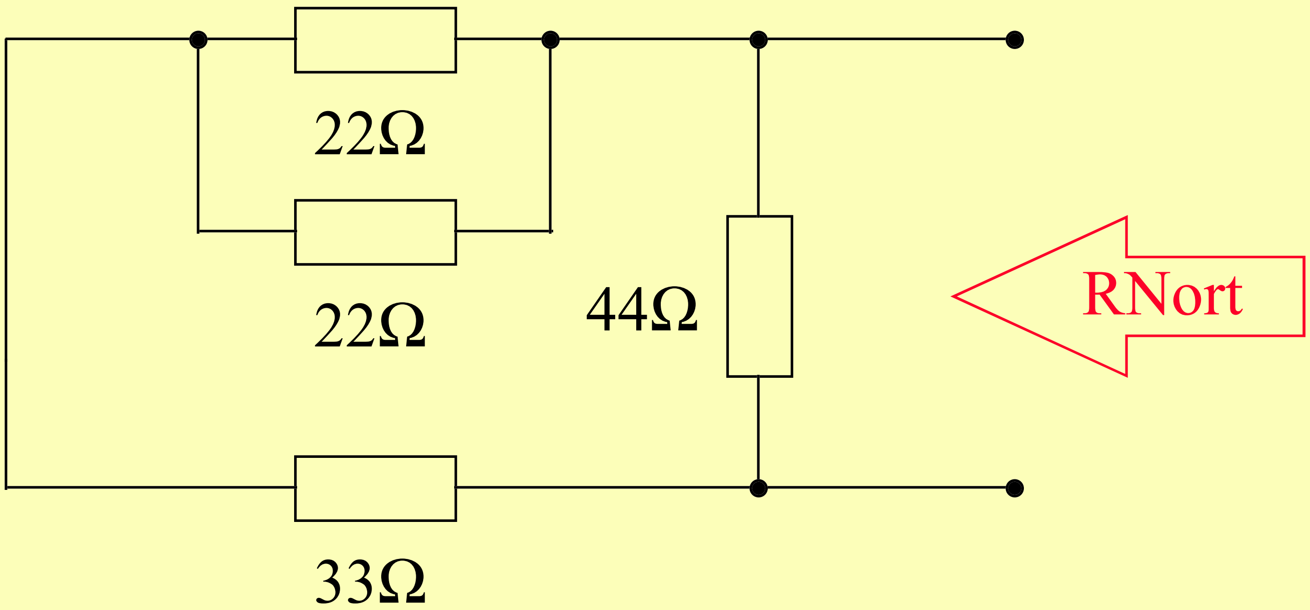
Part 1:

Norton.

- Calculate RNort = (22!22 + 33) ! 44
- first part 22!22 = 22*22/(22+22) =11Ω
- second part (22!22 + 33) = (11 +33) = 44Ω
- overall 44!44 = 44*44/(44+44) = 22Ω

! = In Parallel

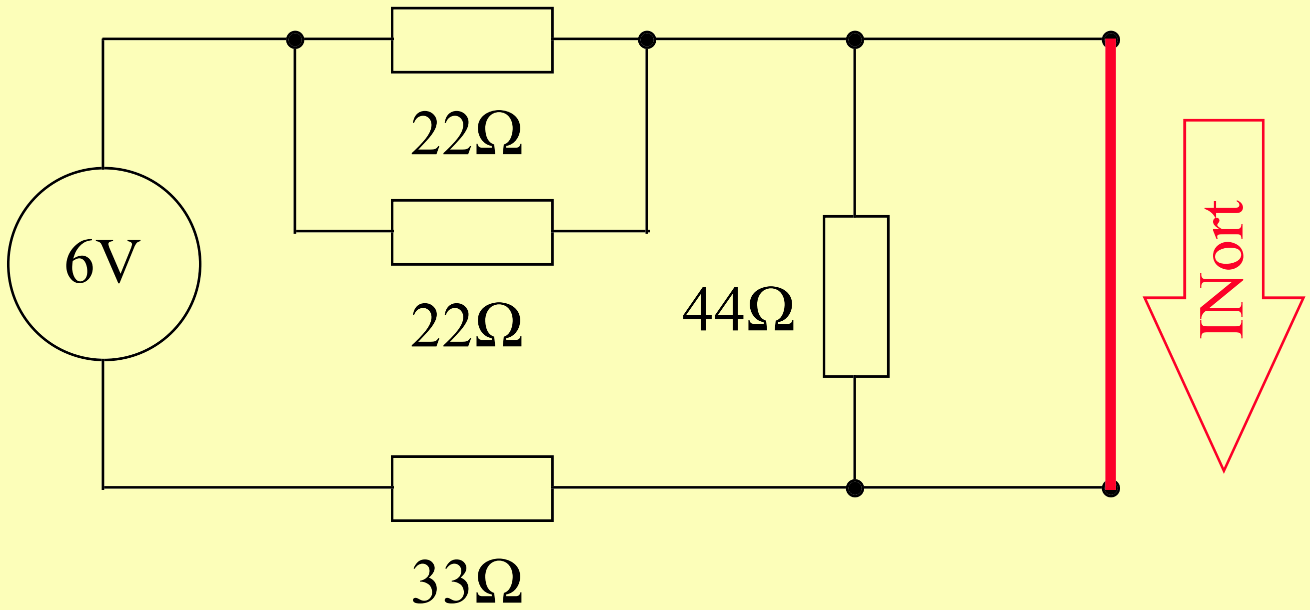
+ = In Series



Part 1:

Norton.

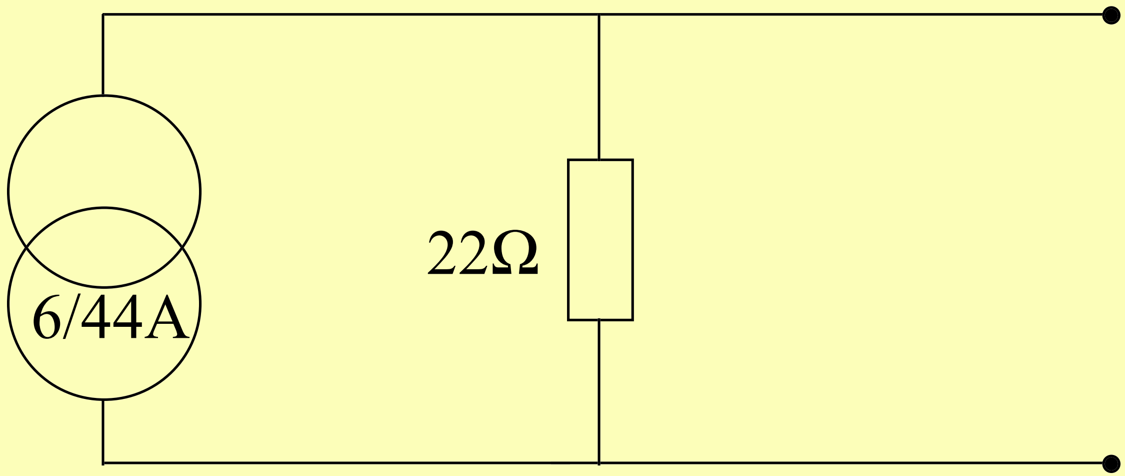
- Calculate Rcct = (22!22+33)
- first part   22!22 = 22*22/(22+22) =11Ω
- overall   (22!22+33) = (11+33) = 44Ω
- Circuit Current I = V/R = 6/44 Amps
- INort = 6/44 Amps



Part 1:

Norton.

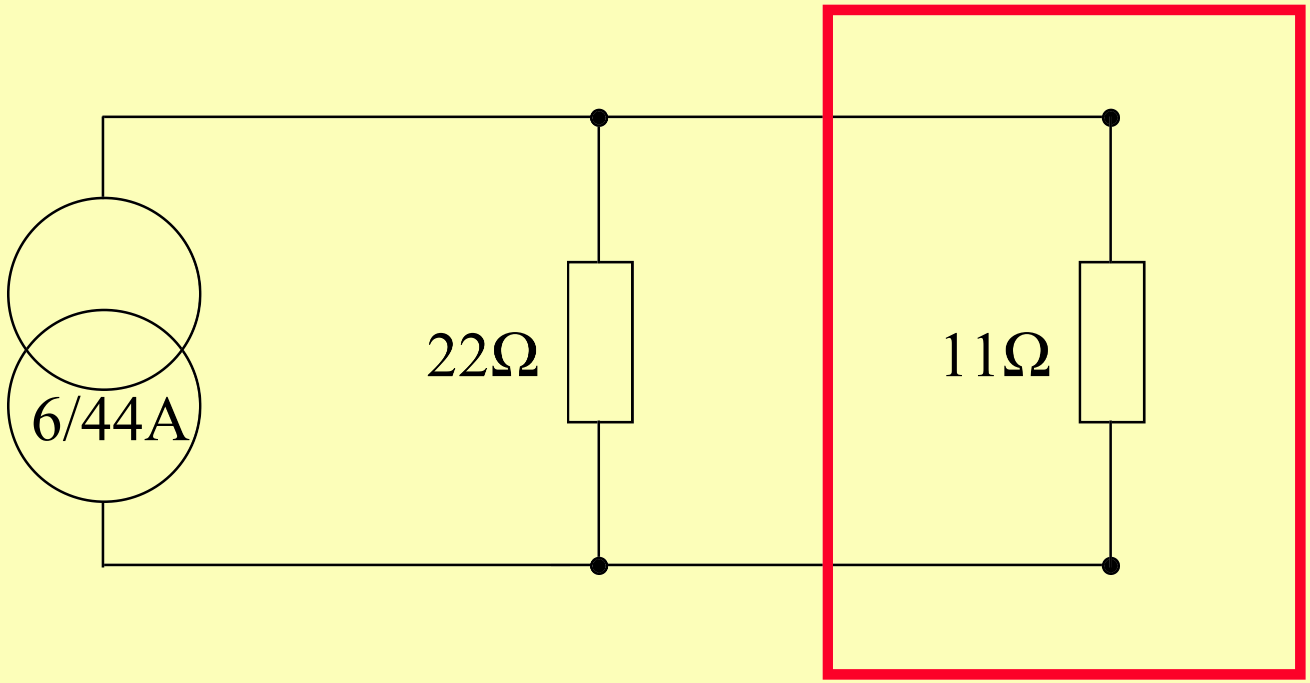
- Equivalent Norton Circuit
- RNort = 22Ω
- INort = 6/44 or 0.136 Amps



Part 2:

Norton.

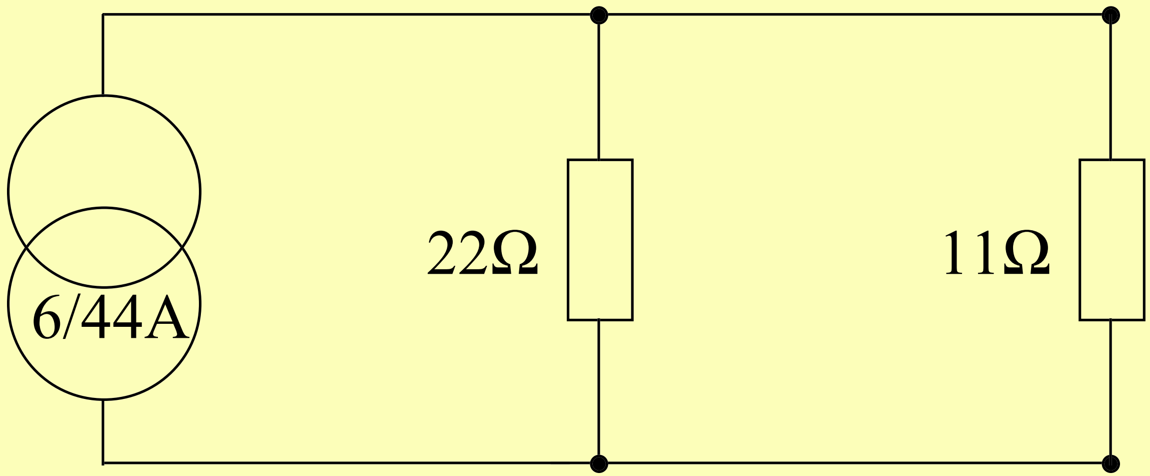
- Re-connect the load to the equivalent circuit.



Part 2:

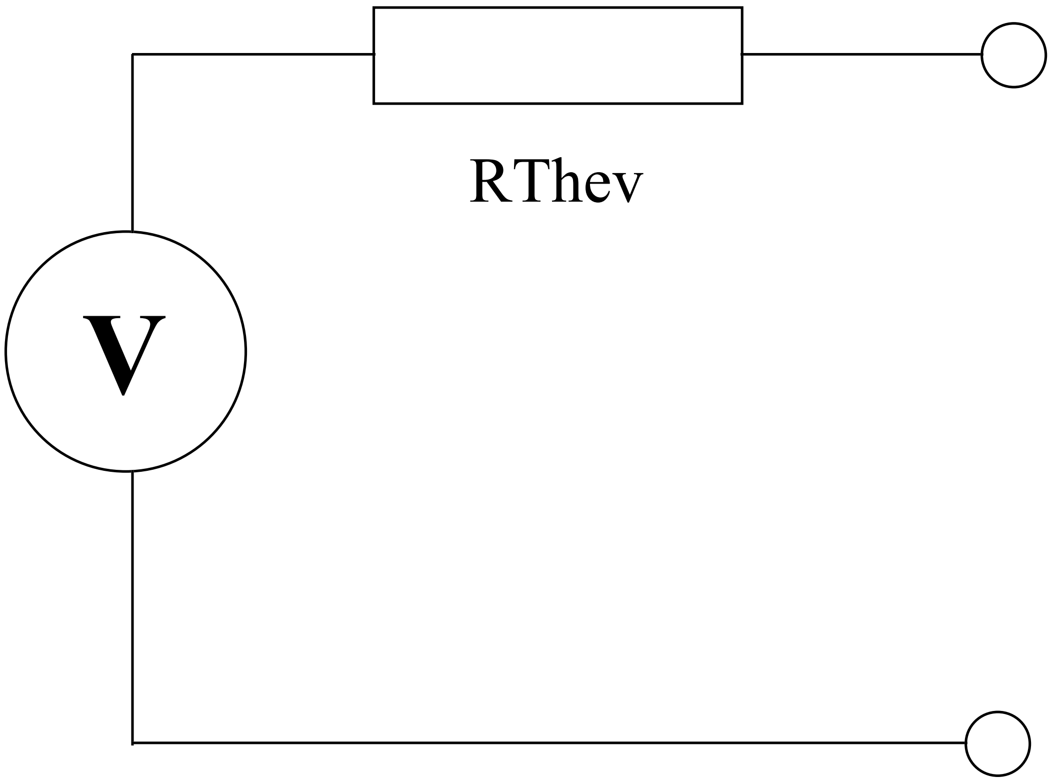
Norton.

- Rcct = 22!11 = 22*11/(22+11) = 242/33Ω
- Vcct = I*R = 6/44*242/33=1 Volts
- Current through RL = V/RL = 1/11 = 0.09 Amps



Thevenin

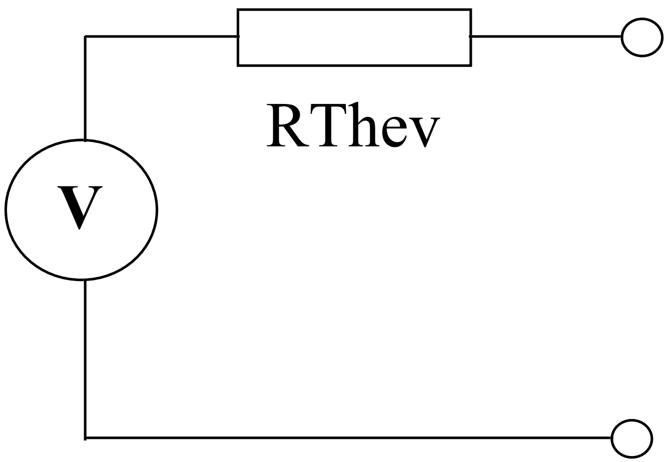
Thevenin.



The Thevenin equivalent Circuit.

Thevenin.

Question: Why does a car battery become less effective on a very cold day ?



Answer:

The internal resistance of the battery becomes higher due to low temperature.

Starting Solutions:

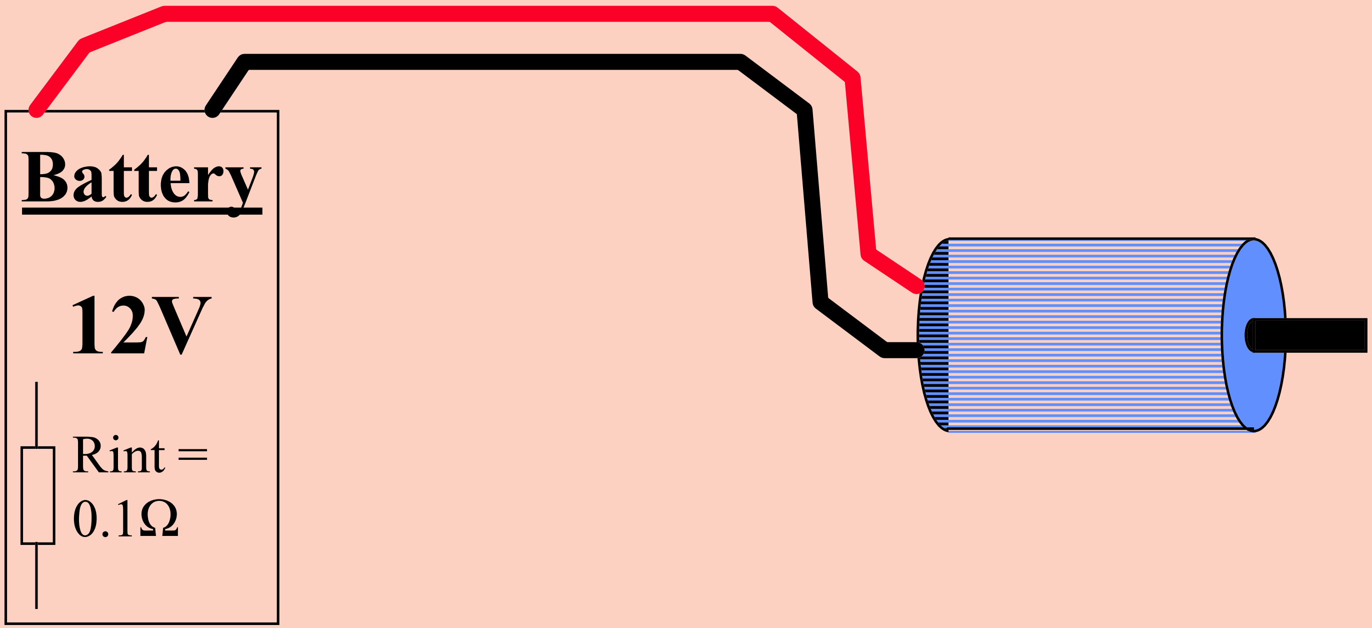
Add Charge or or Warm battery.

The Thevenin equivalent Circuit or a Car battery.

Example:-

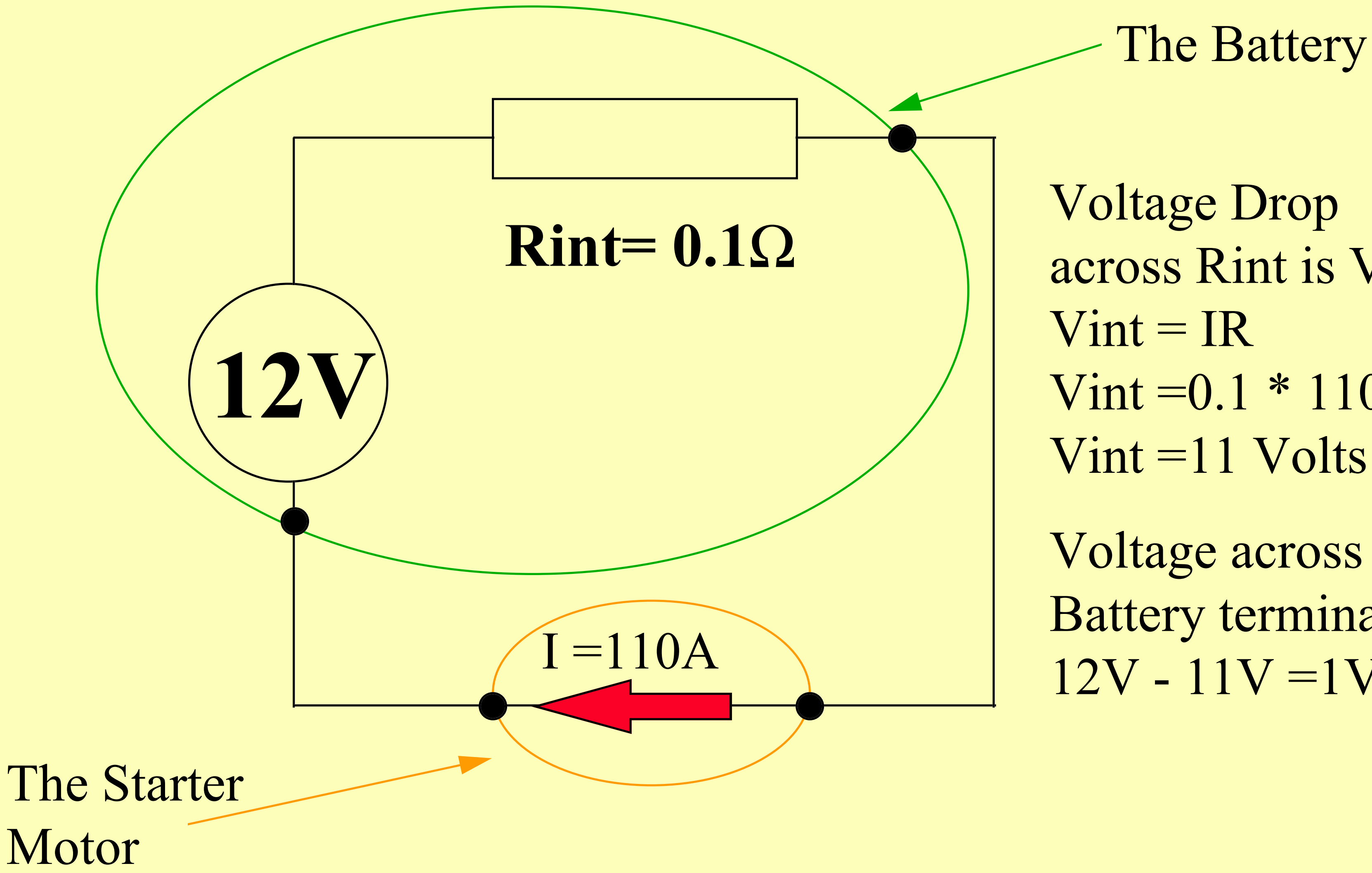
Thevenin.

- The starter motor needs 110Amps to turn the engine. What voltage will appear across the Battery terminals.



Thevenin.

Example:-



Voltage Drop across Rint is Vint.

Vint = IR

Vint =0.1 * 110

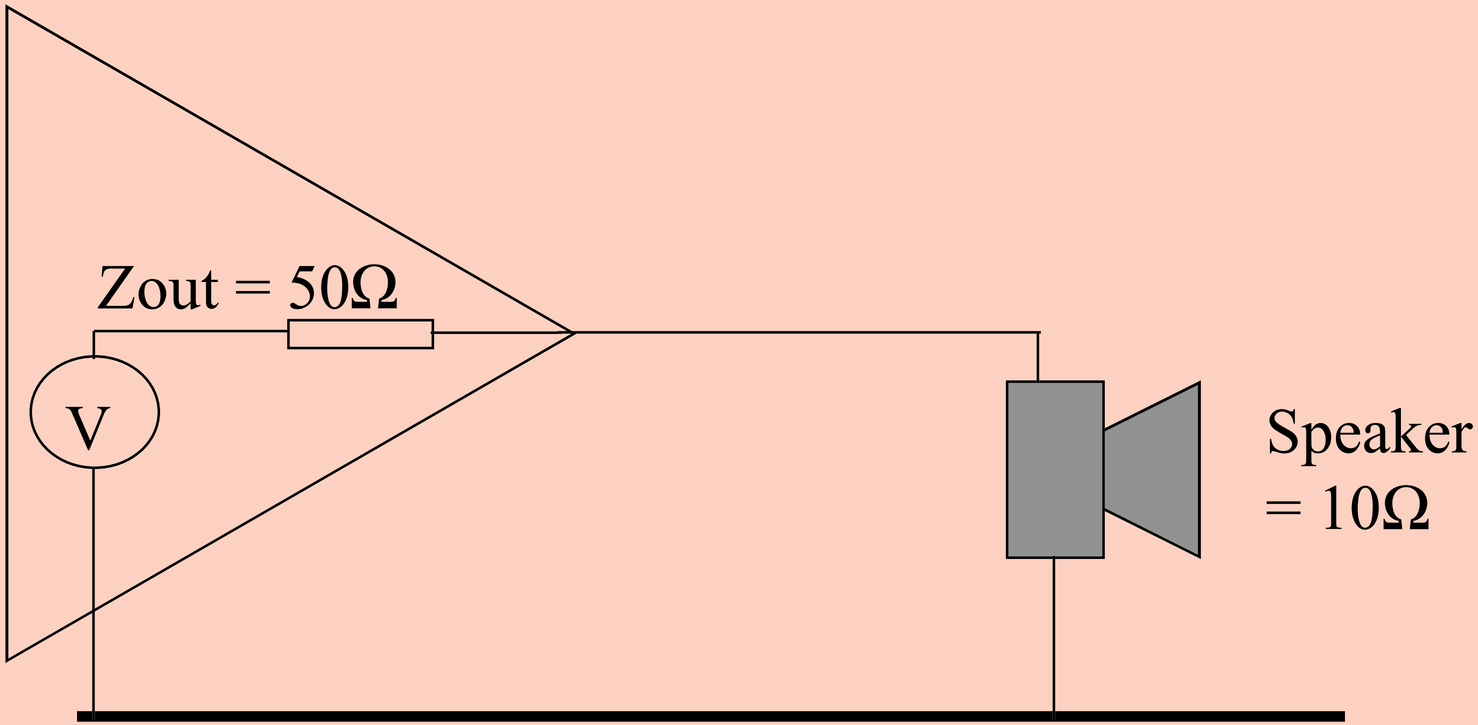
Vint =11 Volts

Voltage across the Battery terminals = 12V - 11V =1V

Application of the Thevenin equivalent Circuit.

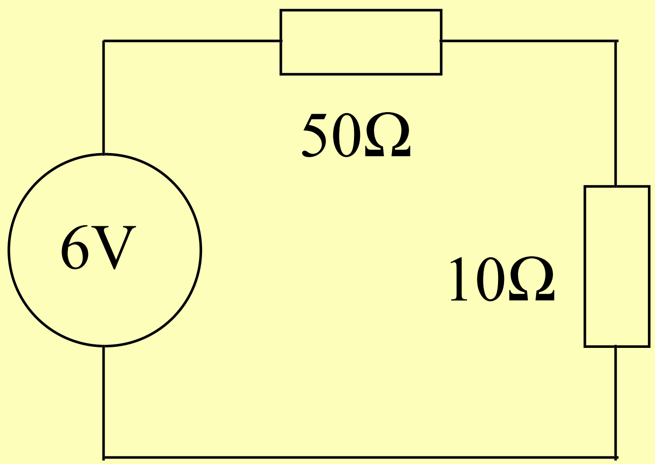
Thevenin.

- The Amplifier generates a 6 volt signal and it is connected to a 10Ω speaker. How much power is developed by the speaker.



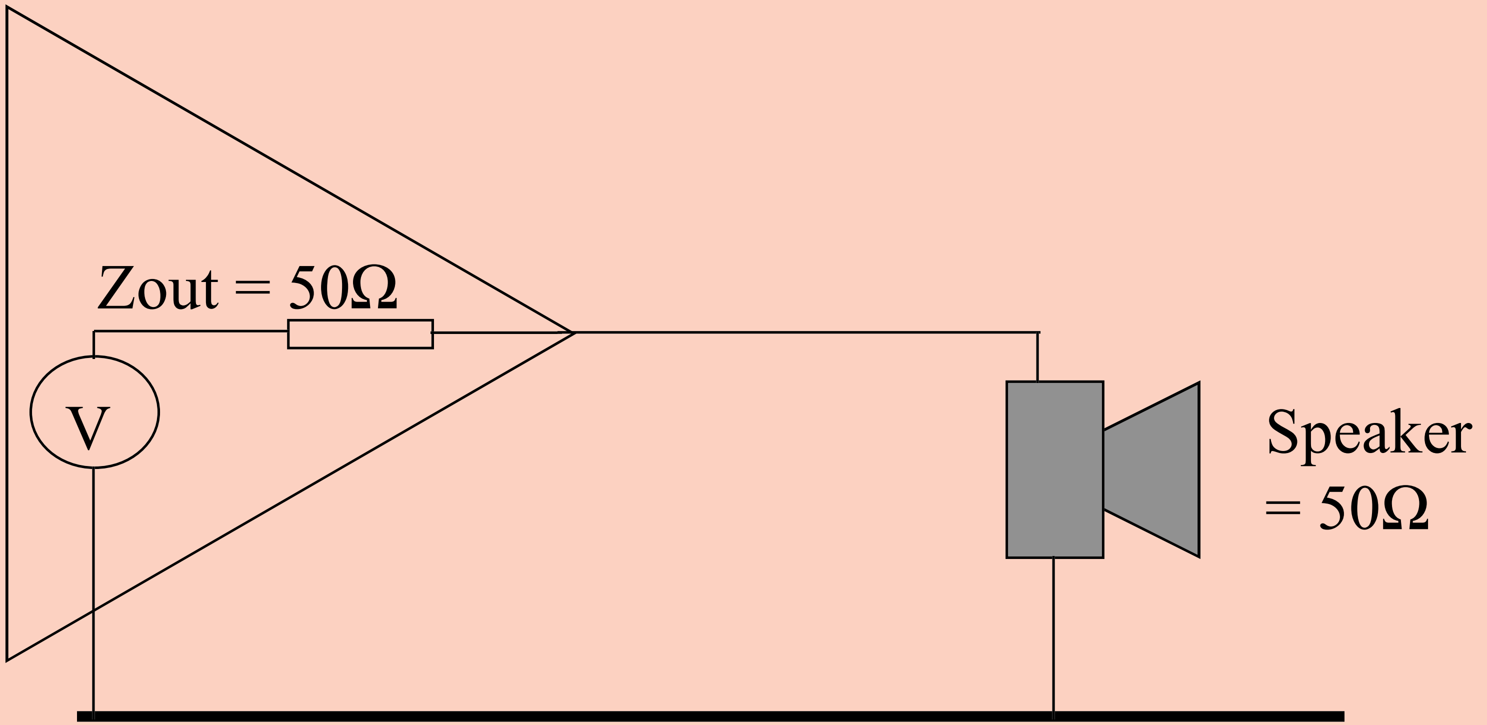
Thevenin.

- Total circuit resistance = 50Ω + 10Ω = 60Ω
- Current in circuit I = V/R = 6/60 =0.1Amps
- Power in speaker = I^2R = (0.1 * 0.1)A * 10Ω = 0.1Watts or 100mW



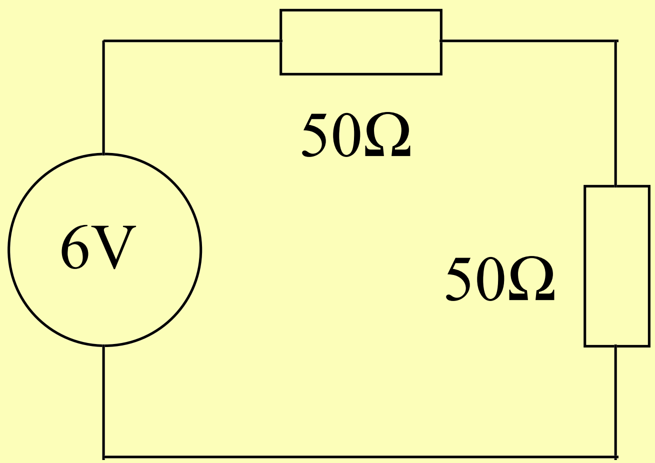
Thevenin.

- The Amplifier generates a 6 volt signal and it is connected to a 50Ω speaker. How much power is developed by the speaker.



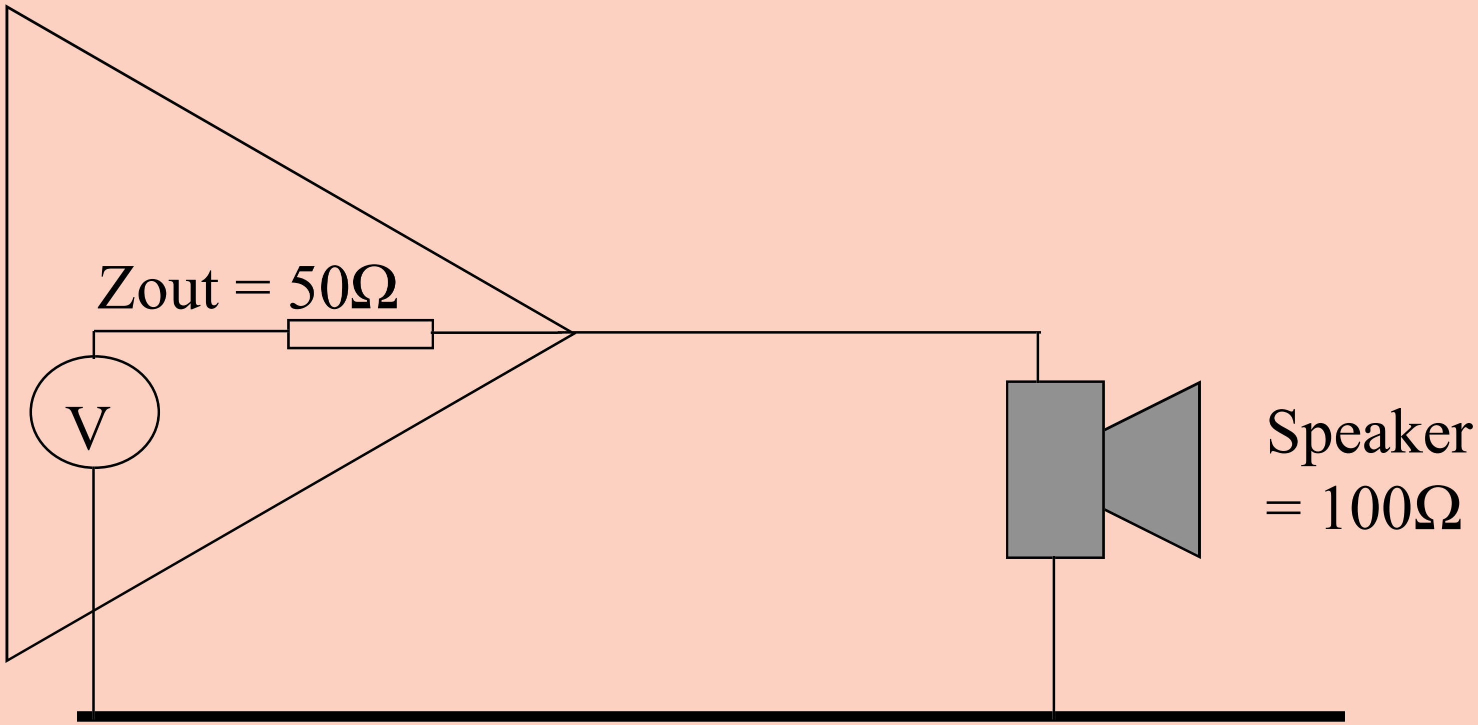
Thevenin.

- Total circuit resistance = 50Ω + 50Ω = 100Ω
- Current in circuit I = V/R = 6/100 =0.06Amps
- Power in speaker = I^2R = (0.06 * 0.06)A * 50Ω = 0.18Watts or 180mW



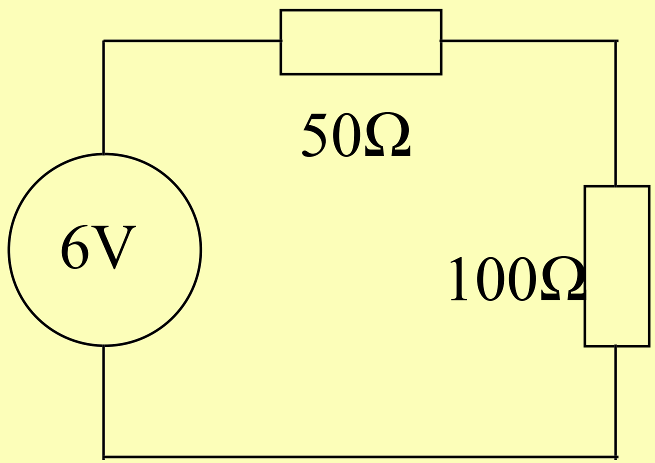
Thevenin.

- The Amplifier generates a 6 volt signal and it is connected to a 100Ω speaker. How much power is developed by the speaker.



Thevenin.

- Total circuit resistance = 50Ω + 100Ω = 150Ω
- Current in circuit I = V/R = 6/150 =0.04Amps
- Power in speaker = I^2R = (0.04 * 0.04)A * 100Ω = 0.16Watts or 160mW



Thevenin.

What have you Observed from last 3 sets of calculations?

<u>Thevenin.</u>

Source Impedance **Less than** Sink Impedance.

- Source Impedance = **50Ω** , Sink Impedance = **10Ω**
- Output power Power in speaker = **<u>100mW</u>**.

Source Impedance **Same as** Sink Impedance.

- Source Impedance = **50Ω** , Sink Impedance = **50Ω**
- Output power Power in speaker = **<u>180mW</u>**.

Source Impedance **More than** Sink Impedance.

- Source Impedance = **50Ω** , Sink Impedance = **100Ω**
- Output power Power in speaker = **<u>160mW</u>**.

Thevenin.

Maximum Power Transfer occurs when Output Impedance matches Input Impedance

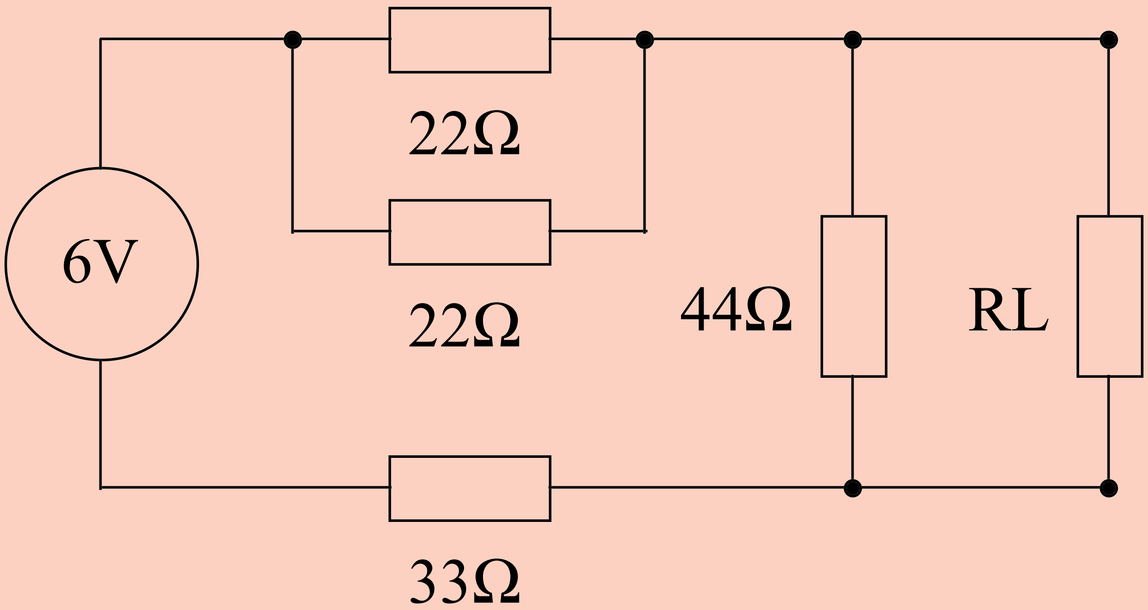
Thevenin.

- The Thevenin Process:
- Remove the load from the circuit you want to find its Thevenin equivalent (**Terminals Open Circuit**).
- Determine the Voltage across the terminal points where the load was connected (VThev).
- Determine the Resistance looking into the terminal points where the load was connected (RThev).
  (Replace all voltage sources with a short circuit)
  (Replace all current sources with an open circuit)
- Redraw circuit using the calculated VThev and RThev to replace the original circuit.

Example:

Thevenin.

- Calculate the Thevenin equivalent for the circuit shown below.
- RL = 11Ω : Calculate the Voltage across RL :-
  - using the Thevenin equivalent circuit.
  - using circuit below.



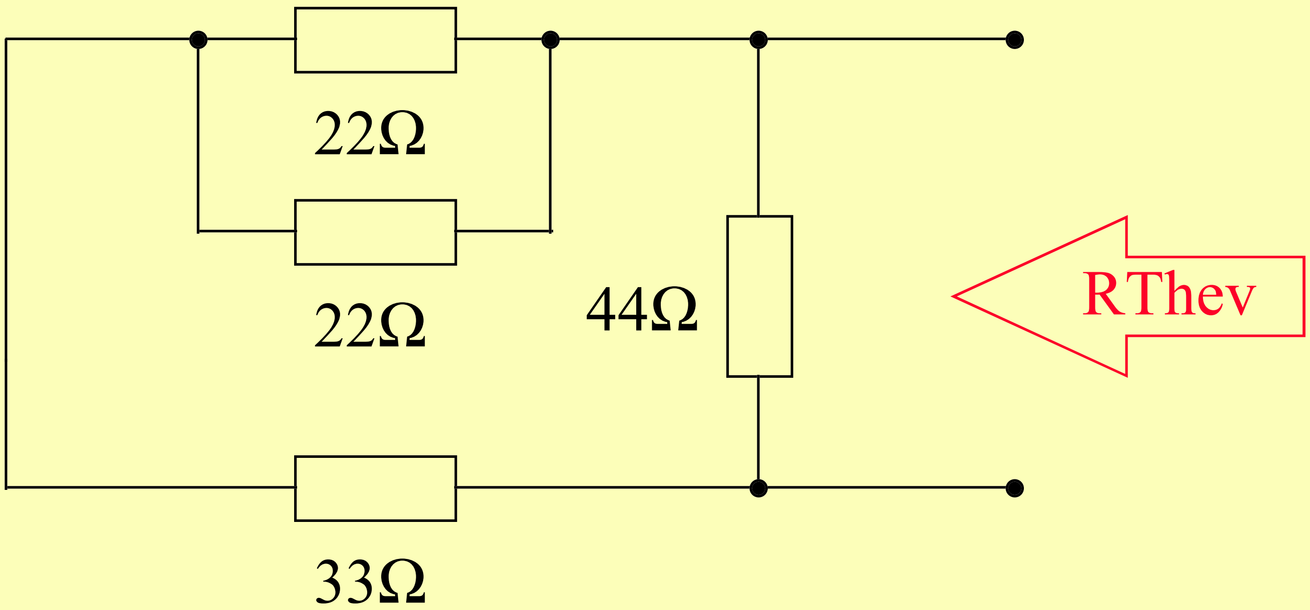
Part 1:

Thevenin.

- Calculate RThev = (22!22 + 33) ! 44
- first part 22!22 = 22*22/(22+22) =11Ω
- second part (22!22 + 33) = (11 +33) = 44Ω
- overall 44!44 = 44*44/(44+44) = 22Ω

! = In Parallel

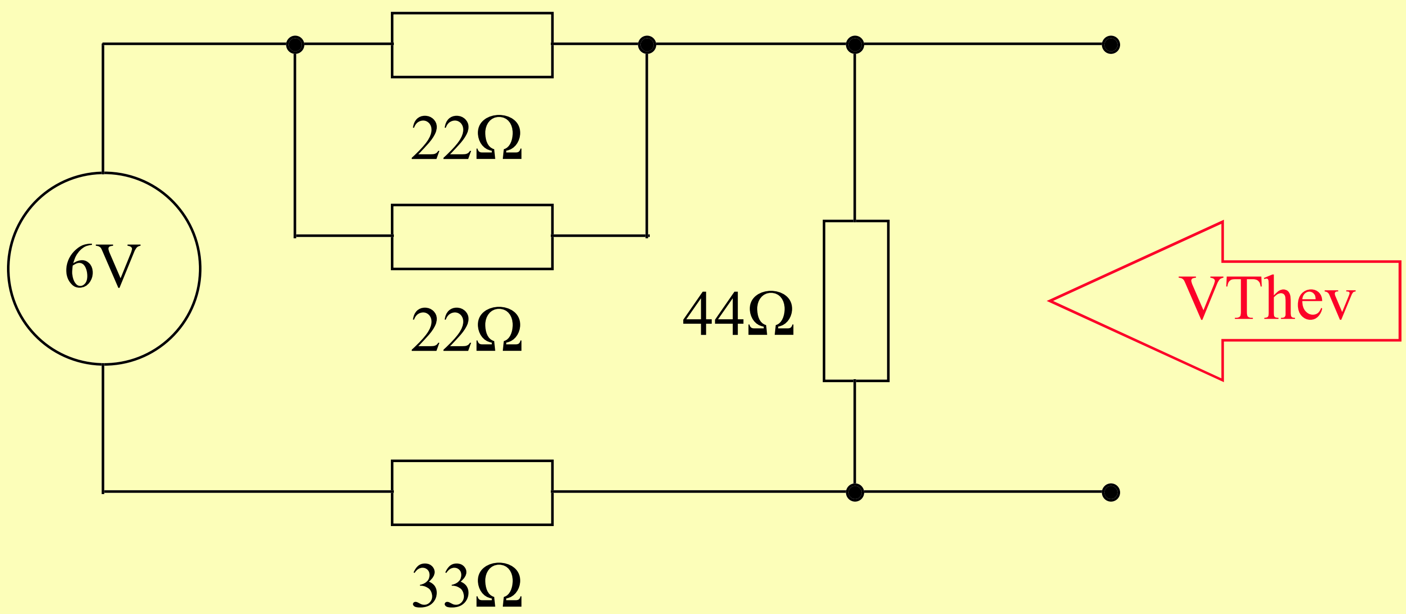
+ = In Series



Part 1:

Thevenin.

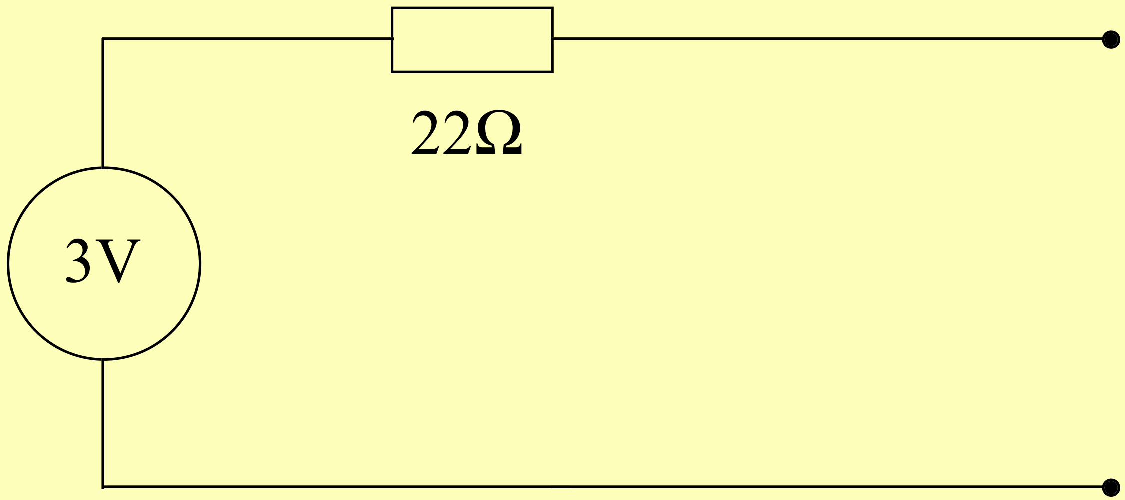
- Calculate Rcct = (22!22+44+33)
- first part 22!22 = 22*22/(22+22)=11Ω
- overall (22!22+44+33)= (11+44+33)= 88Ω
- Circuit Current I = V/R = 6/88
- VThev = I*R = 6/88 * 44 = 3Volts



Part 1:

Thevenin.

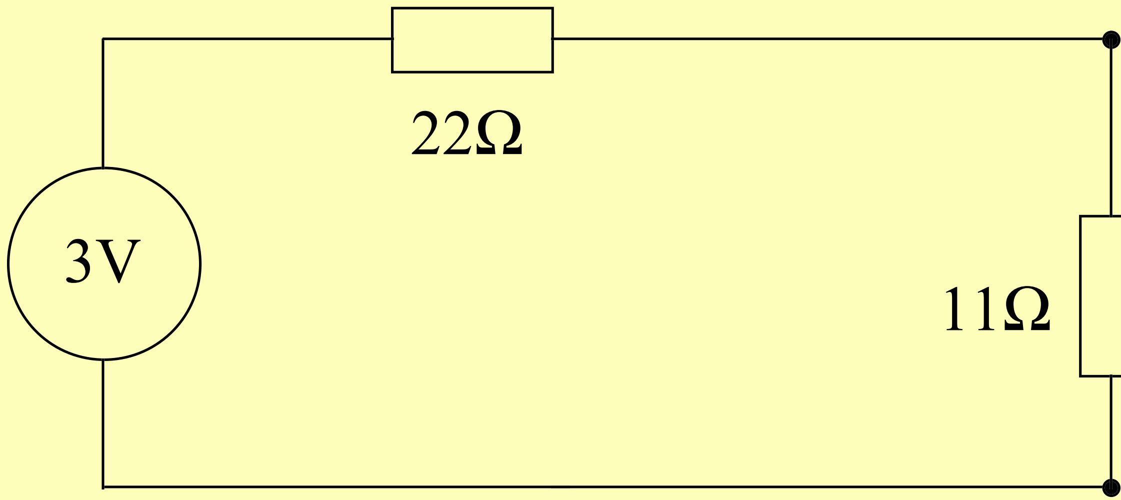
- Equivalent Thevenin Circuit
- RThev = 22Ω
- VThev = 3Volts



Part 2:

Thevenin.

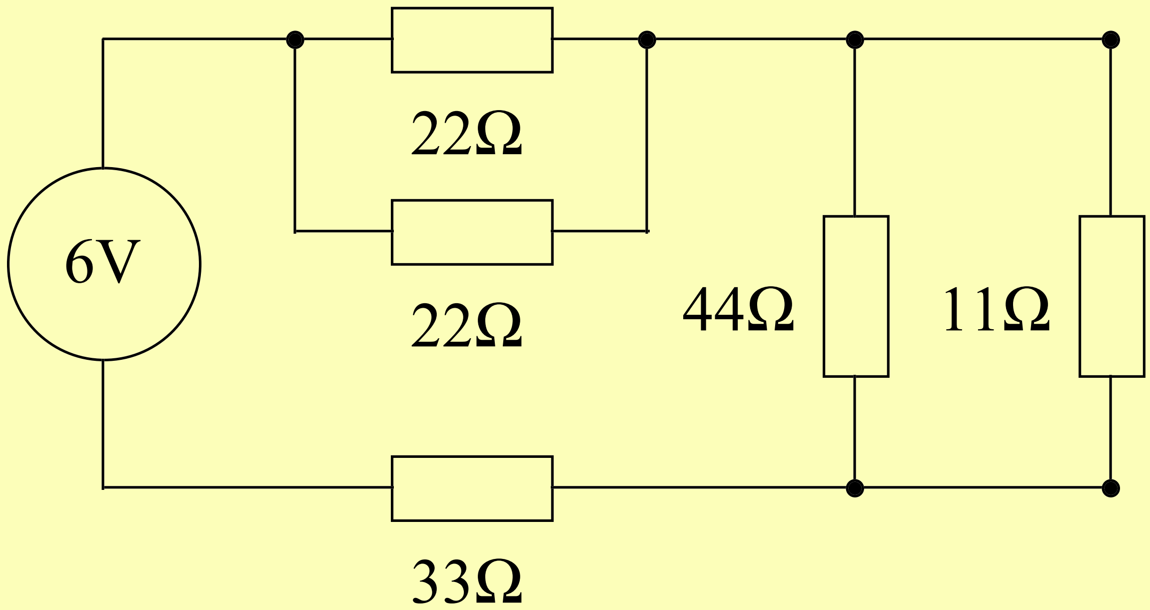
- Rcct = 22+11 = 33Ω
- Icct = V/R = 3/33
- V across RL = I*RL = 3/33*11 = 1 Volt



Part 3:

Thevenin.

- Rcct = (22!22)+(44!11)+33
- Rcct = (22*22/(22+22))+(44*11/(44+11))+33
- Rcct = (11)+(8.8)+33 = 52.8Ω
- Icct = V/R = 6/52.8
- V across RL section = I*R = 6/52.8 * 8.8 = 1 Volt



Norton and Thevenin Conversions

Norton and Thevenin Conversions.

- Convert a Norton Circuit to a Thevenin Circuit:
- As RNort = RThev therefore no conversion needed.
- Calculate VThev from INort Process:
- Calculate voltage across RNort using INort using the calculation VThev = INort * RNort
- Redraw circuit using the newly calculated values to replace the original circuit.

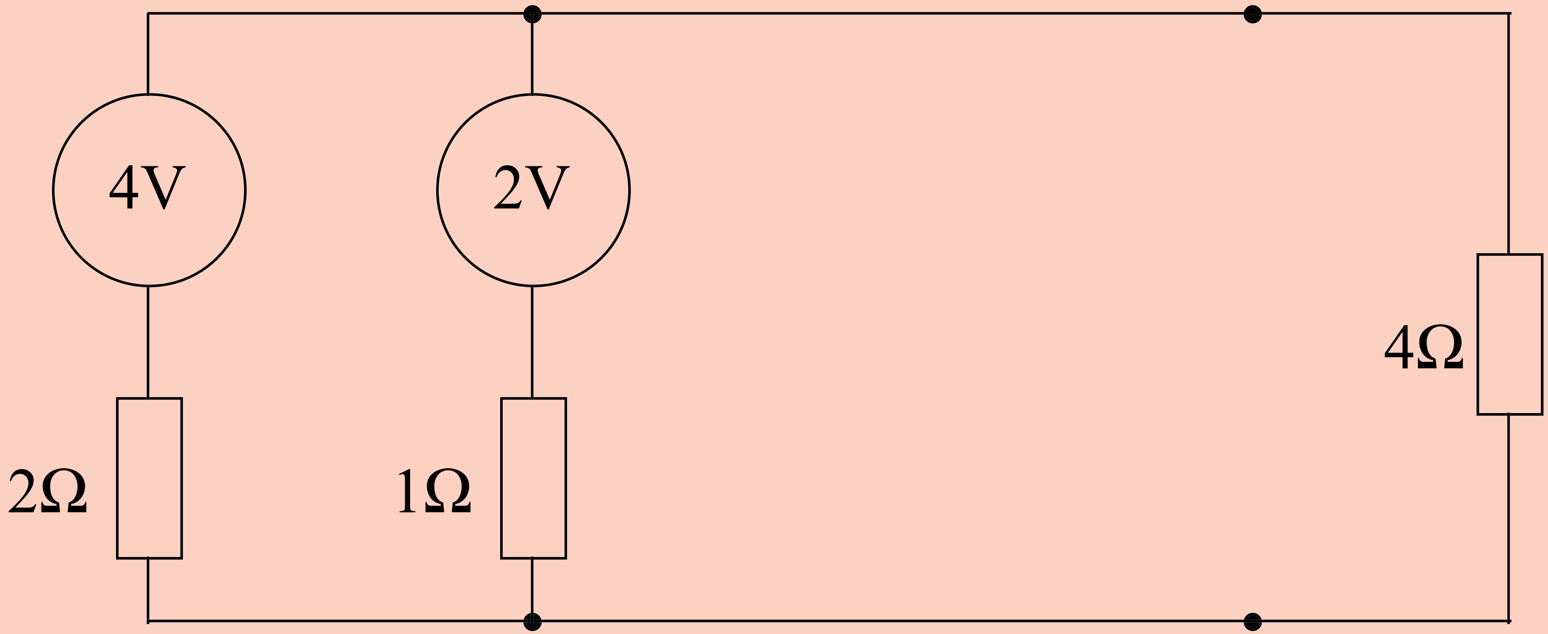
Norton and Thevenin Conversions.

- Convert a Thevenin Circuit to a Norton Circuit:
- As RNort = RThev therefore no conversion needed.
- Calculate INort from VThev Process:
- Short out the terminals of Thevenin circuit
- Calculate current through RThev using VThev using the calculation INort = VThev / RNort
- Redraw circuit using the newly calculated values to replace the original circuit.

Norton and Thevenin Calculations

Norton and Thevenin Calculations.

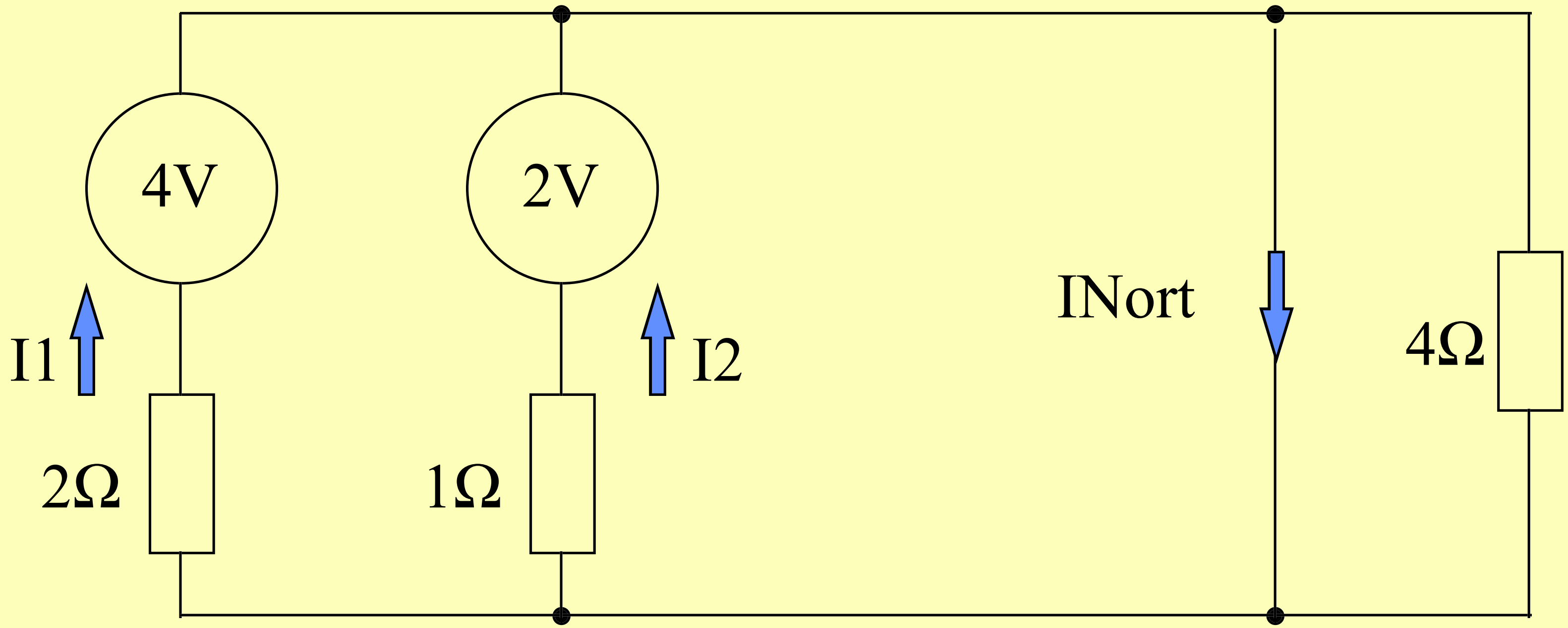
- The circuit shown below shows a 4Ω Resistor supplied by two generators with internal resistance's shown.
  - (a) Use Norton Theorem to determine the value of current in the 4Ω Resistor
  - b) Calculate the internal voltage drop in each generator.



Norton and Thevenin Calculations.

- Step 1. Short out load
- INort = I1 + I2 and I=V/R = 2/1 + 4/2 = 2 + 2 = 4A

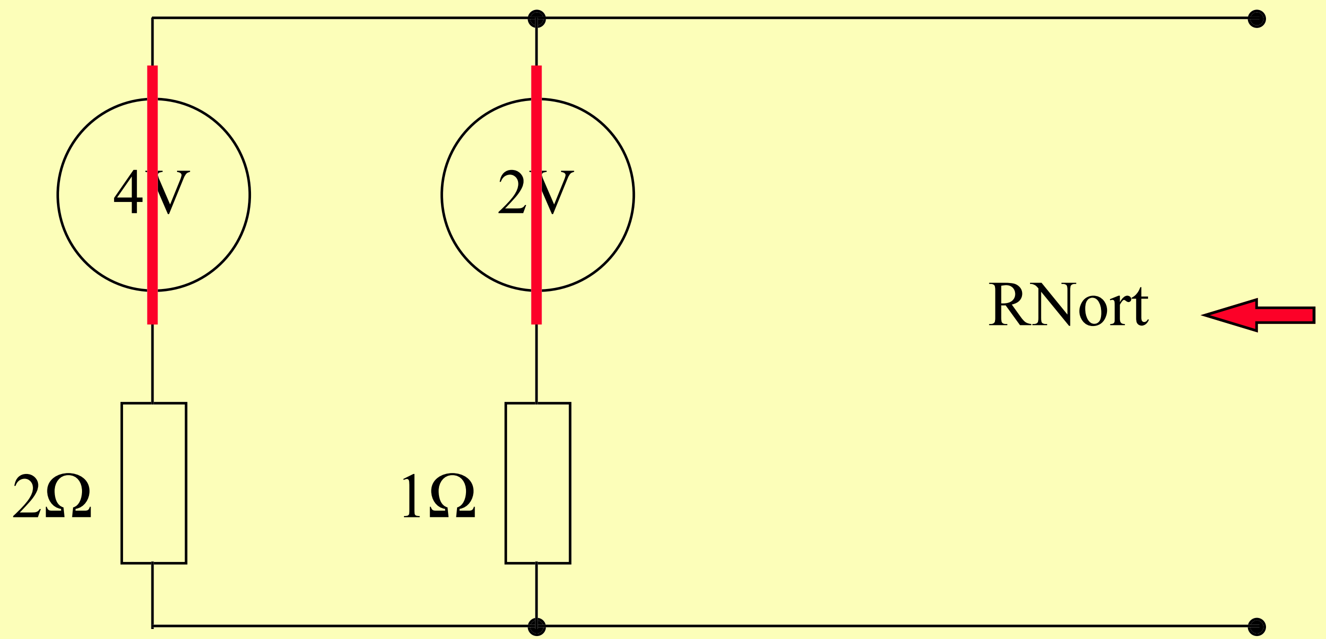
Generator 1



Norton and Thevenin Calculations.

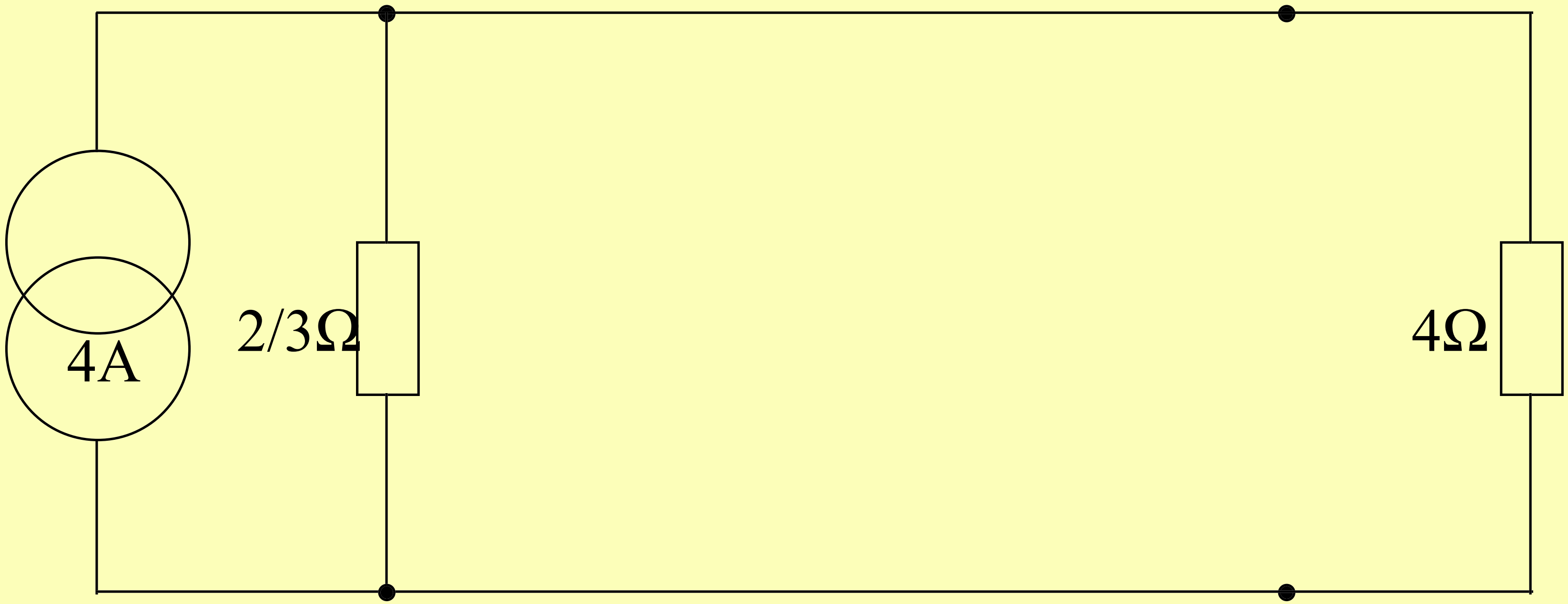
- Step 2. Remove load, Short out Voltages sources, Open Circuit Current sources
- RNort = 2Ω ! 1Ω = (2*1)/(2+1) = 2/3Ω

Generator 1



Norton and Thevenin Calculations.

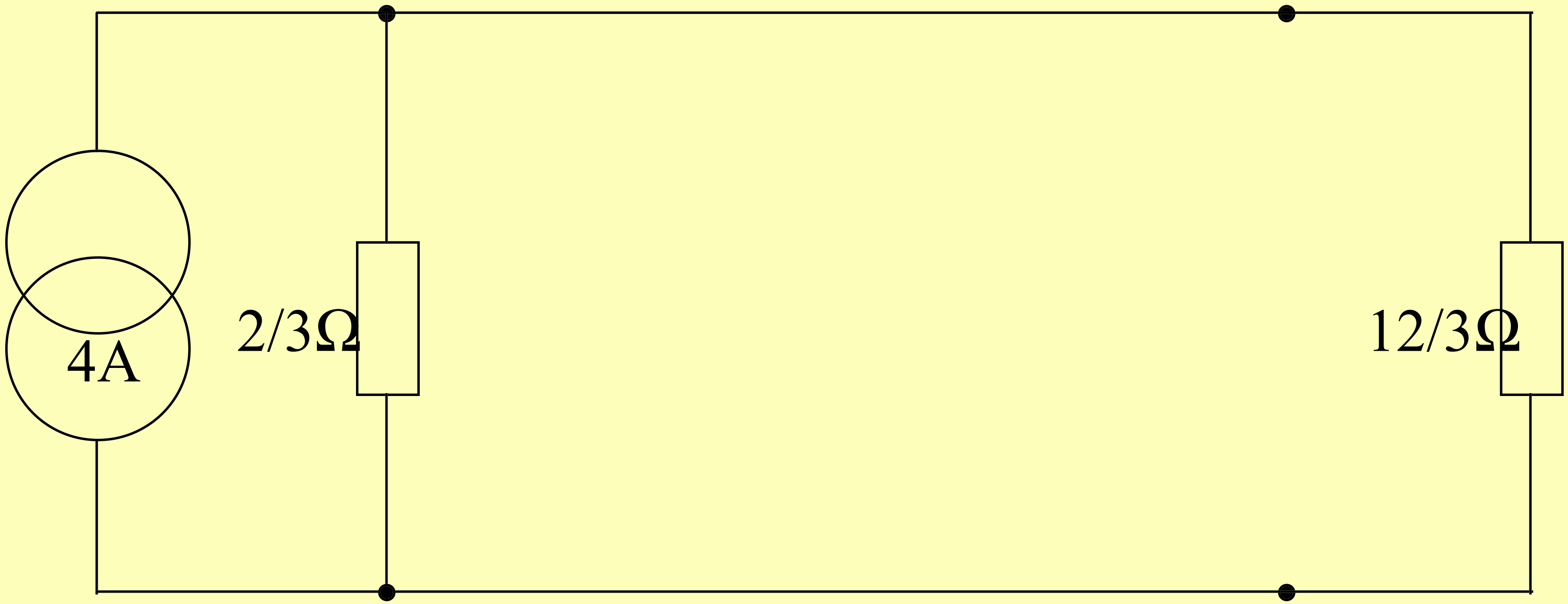
- Step 3. Re-Draw circuit using equivalent Norton Circuit.



Norton and Thevenin Calculations.

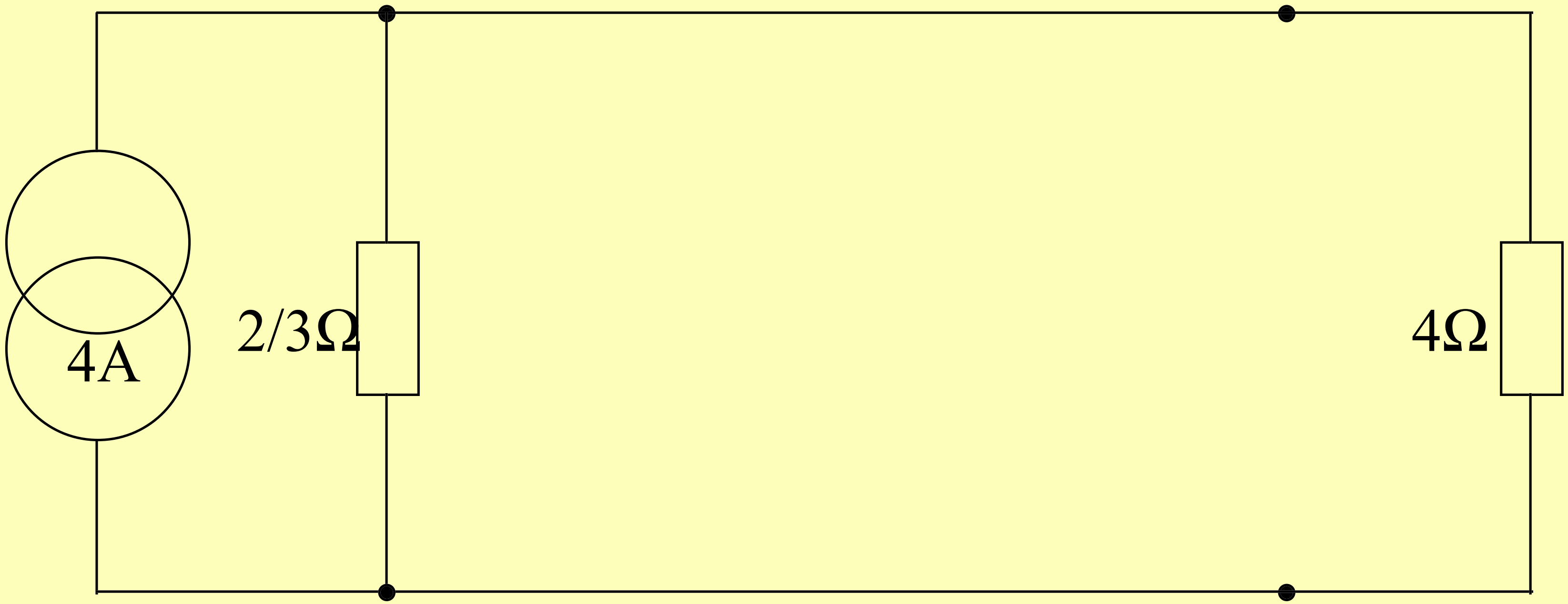
- Step 4. Calculate total circuit resistance.
- Step 4a Convert resistance's into convenient 1/3Ω.
- Rcct = 2/3 * 12/3 / (2/3 + 12/3) = 24/9 / 14/3

  = 8/3 / 14/3 = 8/3 * 3/14 = 8/14Ω.



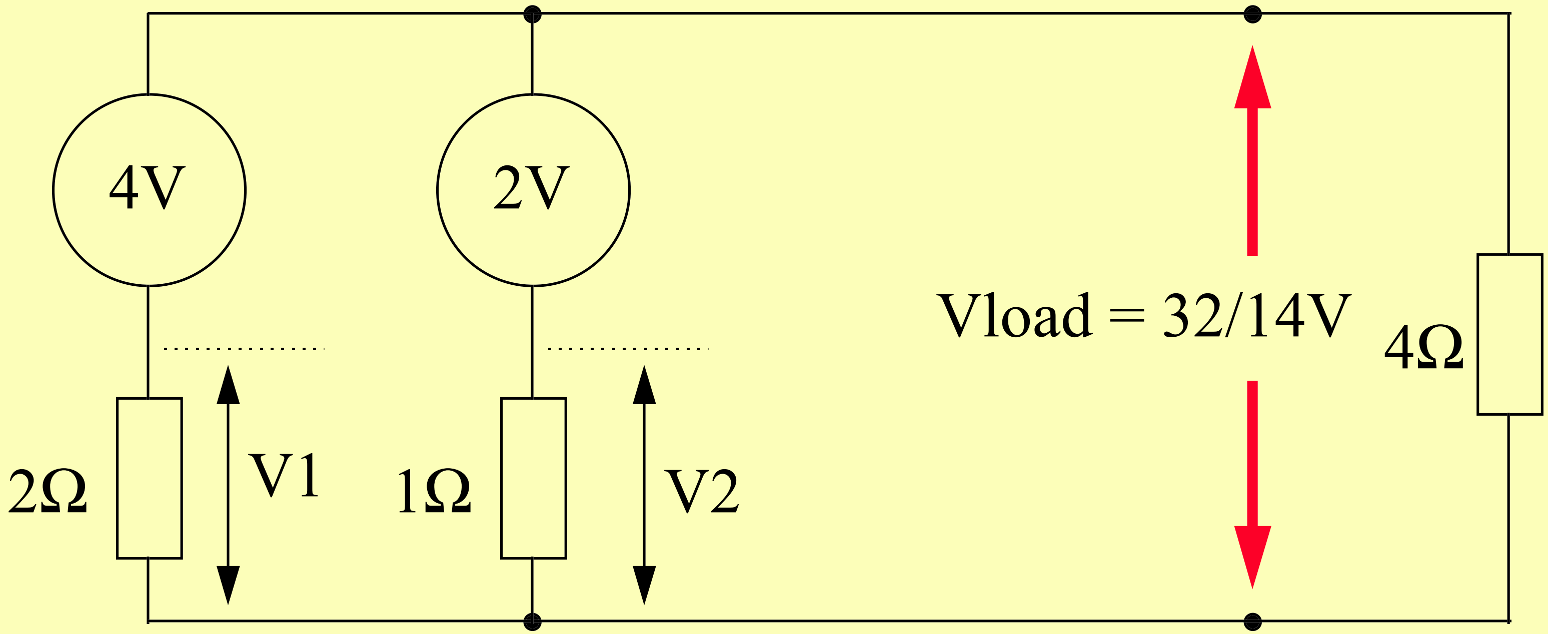
Norton and Thevenin Calculations.

- Step 5. Calculate Voltage across total circuit resistance.
- VLoad = I*Rcct = 4*8/14 = 32/14 Volts
- We could also find current in load
- ILoad = V/R = (32/14) / 4 = 8/14 = 0.57A



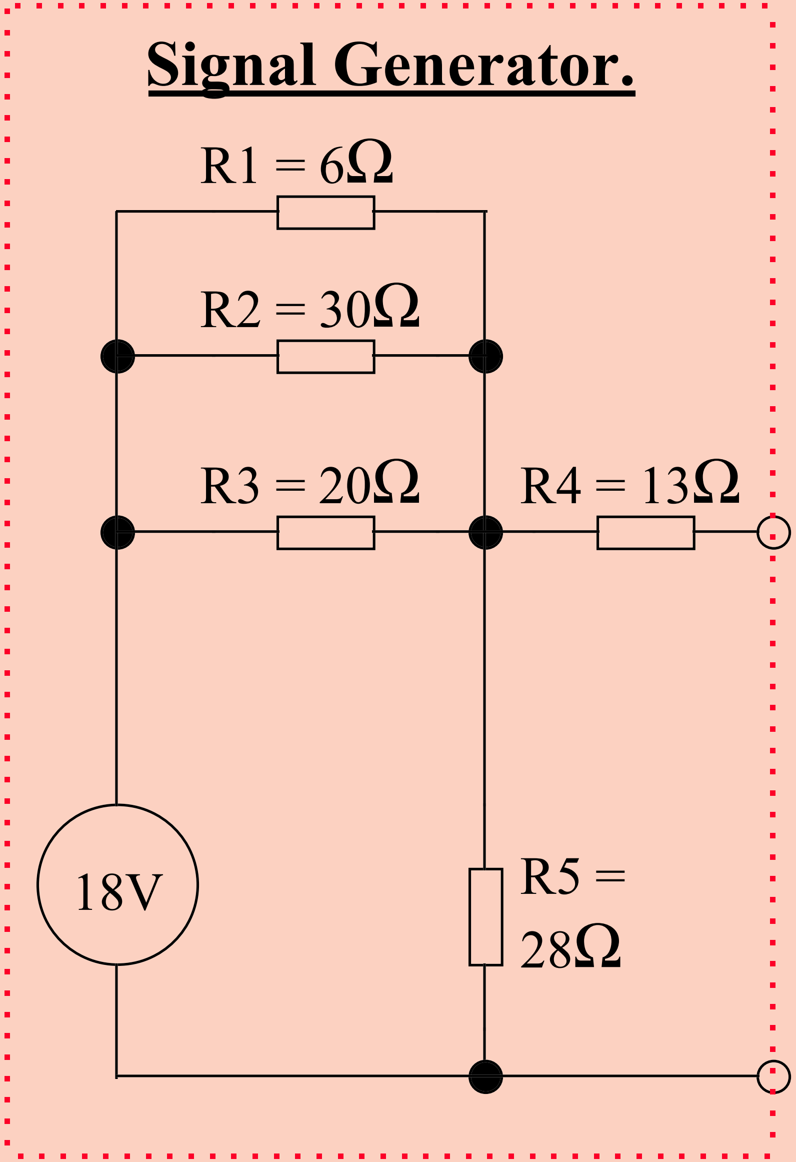
Norton and Thevenin Calculations.

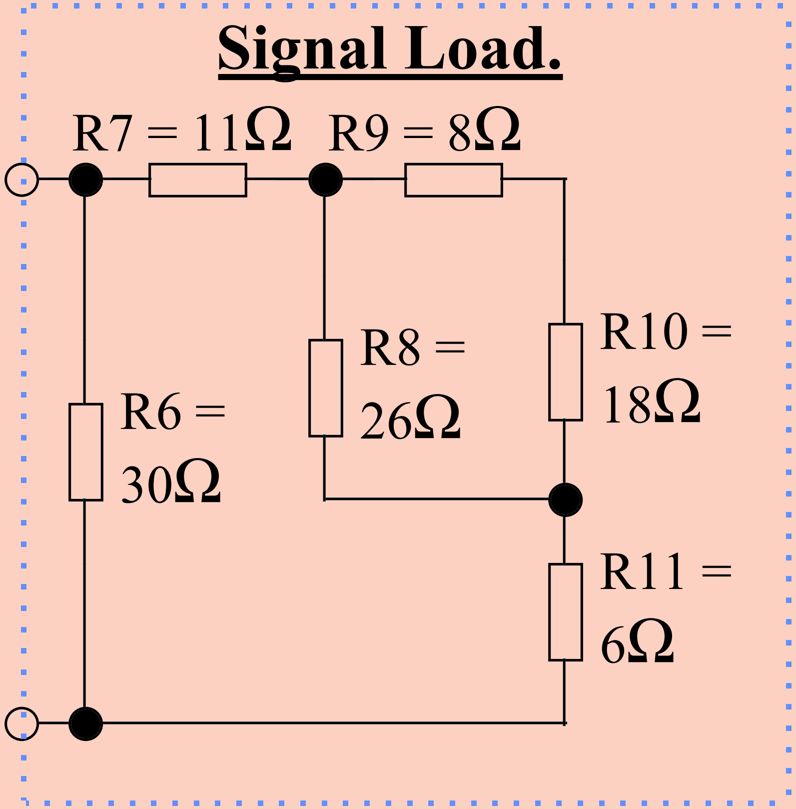
- Step 6. Find voltage drop across each generator.
- V1 = 4Volts - Vload = 4 - 32/14 = 56/14 - 32/14
  = 24/14 = 1.714 Volts
- V2 = 2Volts - Vload = 2 - 32/14 = 28/14 - 32/14
  = -4/14 = -0.286 Volts



Norton and Thevenin Calculations.

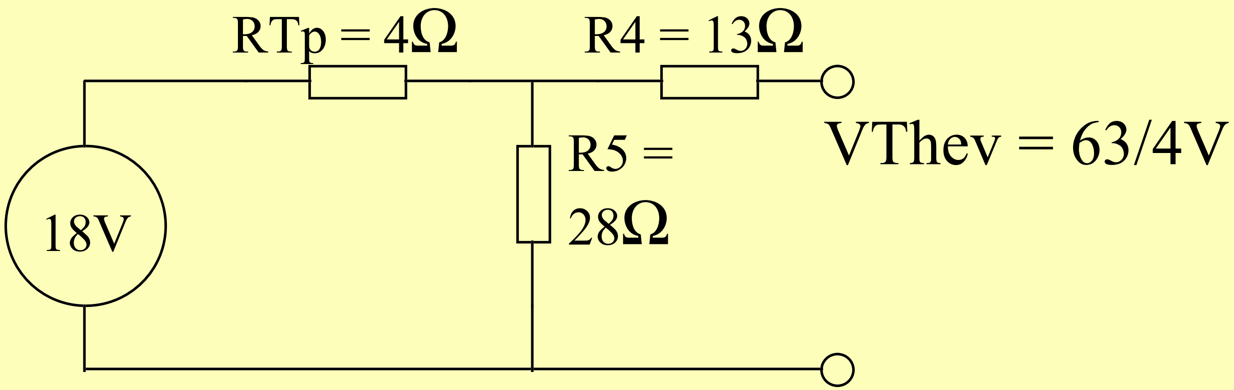
What is the Generator Output voltage with and without the load connected?
Calculate VThev, INort, RNort, RThev.
Draw Equivalent circuits.





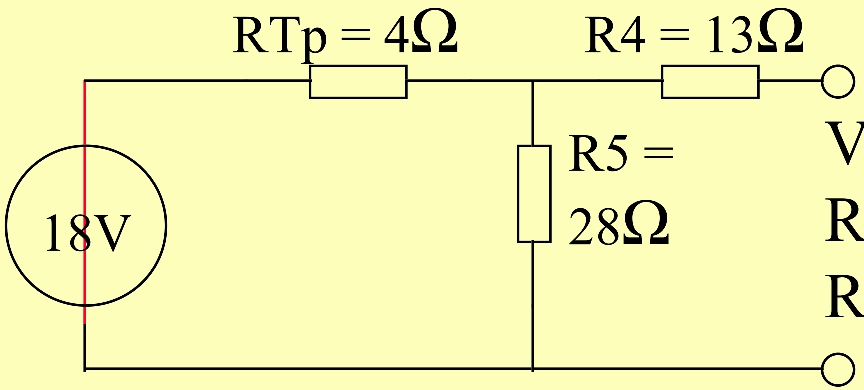
Norton and Thevenin Calculations.

- Calculate Thevenin Voltage
- Step 1. Calculate resistance of R1 ! R2 ! R3.
- 1/RTp = 1/6 + 1/30 + 1/20 (Common denominator 60)
- 1/RTp = (10 + 2 + 3)/60 = 15/60
- Therefore RTp =60/15 = 4 Ω
- Rcct = RTp + R5 = 28 + 4 = 32 Ω
- Icct = V/R = 18/32 Amps
- VThev = Icct * R5 = 18/32 * 28 = 504/32 = 63/4 V



Norton and Thevenin Calculations.

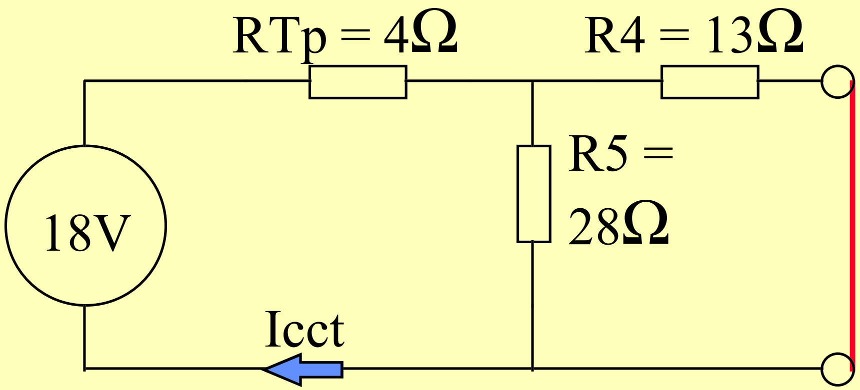
- Calculate Thevenin Resistance / Norton Resistance
- Step 2. Calculate resistance of (RTp ! R5) + R4.
- 1/RTpa = 1/4 + 1/28 (Common denominator 28)
- 1/RTpa= (7 + 1)/28 = 8/28 = 4/14 = 2/7
- Therefore RTpa = 7/2 Ω
- RThev = RTpa + R4 = 7/2 + 13 = (7 + 26)/2 = 33/2 Ω



VThev = 63/4V
RThev = 33/2 Ω
RNort = 33/2 Ω

Norton and Thevenin Calculations.

- Calculate Norton Current
- Step 3a. Calculate resistance of R4 ! R5.
- 1/RTpb = 1/13 + 1/28 (Common denominator 364)
- 1/RTpb = (13 + 28)/364 = 41/364
- Therefore RTpb =364/41Ω = 8.878Ω
- Rcct = RTpb + RTp = 364/41 + 4 = (364 + 164)/41 Ω
- Rcct = 528/41 Ω = 12.878 Ω
- Icct = V/R = 18/(528/41) = (18*41)/528 Amps

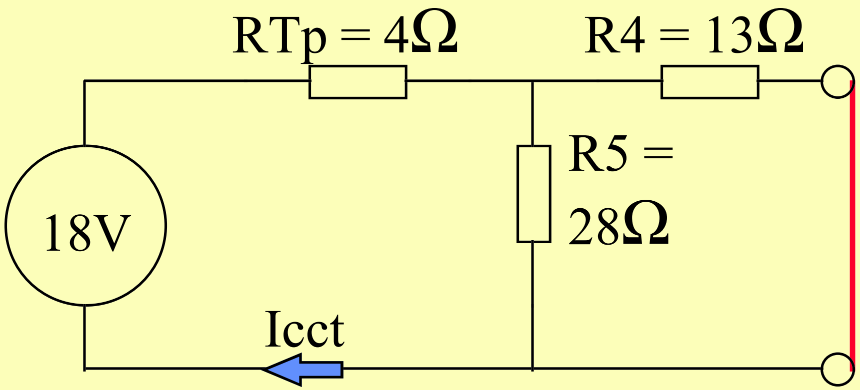


Icct = 738/528 Amps

Icct = 1.398 Amps

Norton and Thevenin Calculations.

- Step 3b. Calculate voltage drop across RTp.
- V RTp =Icct*R = 738/528 * 4 =2952/528 or 5.59 Volts
- 2952/528(÷4) = 738/132(÷2) = 369/66(÷3) = 123/22
- Voltage drop across remainder of the circuit is
  Vsource - VRTp = 18V - 123/22 = (396-123)/22V
- VRTpb = 273/22 or 12.409 Volts
- INort = VRTpb / R4 = (273/22)/13 = 273/(22*13) A
  = 273/286 or 0.9545 Amps

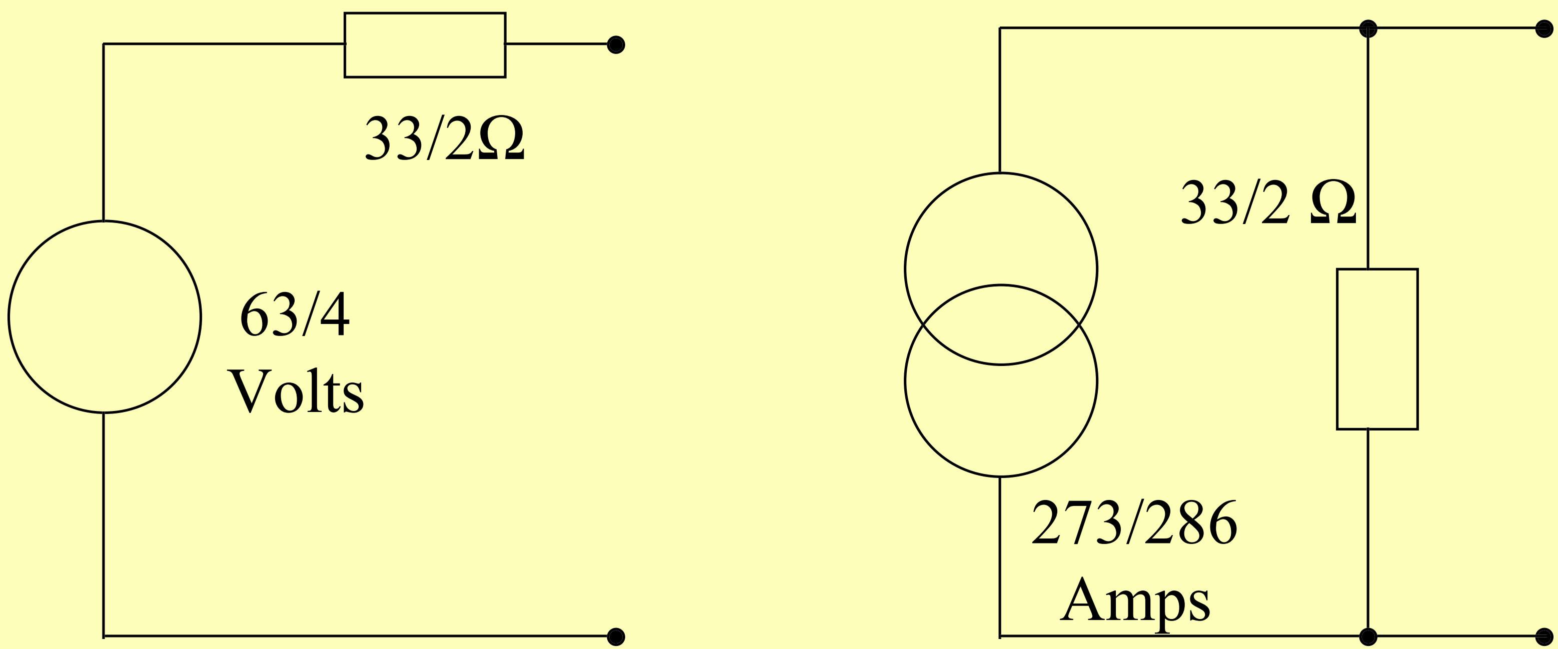


INort = 273/286 Amps

INort = 0.9545 Amps

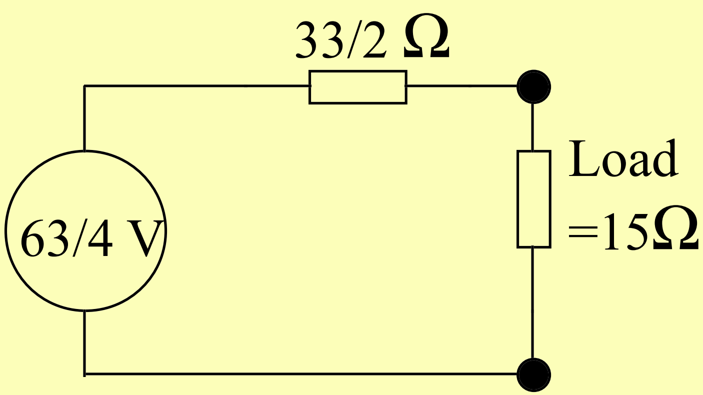
Norton and Thevenin Calculations.

- Step 4a. Re-Draw circuit using equivalent Norton Circuit.
- Step 4b. Re-Draw circuit using equivalent Thevenin Circuit.



Norton and Thevenin Calculations.

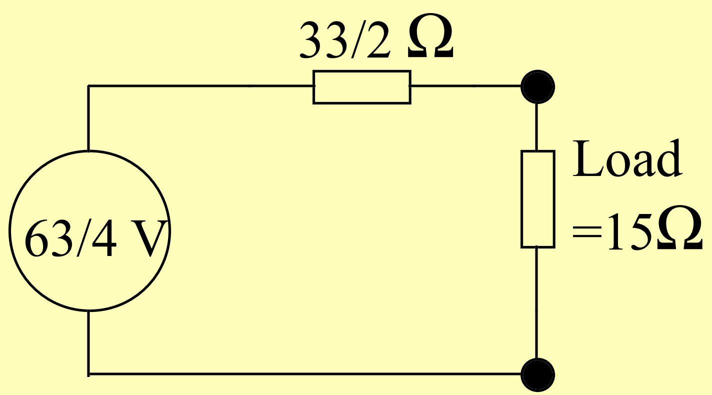
- Calculate The Load Resistance.
- Step 5. Calculate resistance of R9 + R10 = 8+18 = 26 Ω
- In Parallel with R8 = 26 ! 26 = 13 Ω
- In Series with R7 + R11 = 13 + 11 + 6 = 30 Ω
- In Parallel with R6 = 30 ! 30 = 15 Ω
- This gives :-



Norton and Thevenin Calculations.

- Calculate The Total circuit Resistance.
- Step 6. RThev + Load = 33/2+15 = (33+30)/2 = 63/2 Ω
- Circuit current = V/R= (63/4)/(63/2) = (63/4)*(2/63)

  = (63*2)/(63*4) = 2/4 = 1/2 or 0.5 Amps
- Voltage across load = I*R = 1/2 * 15 = 15/2 Volts
- Voltage with no load = 63/4 or 15.75 Volts
- Voltage with load = 15/2 or 7.5 Volts



Norton and Thevenin Calculations.

- Calculate The Total circuit Resistance.
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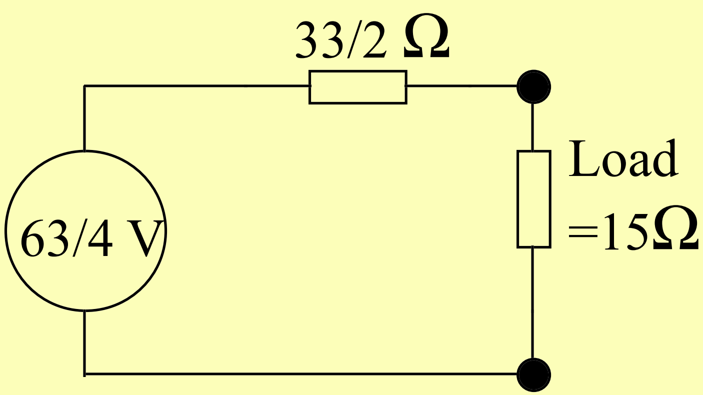
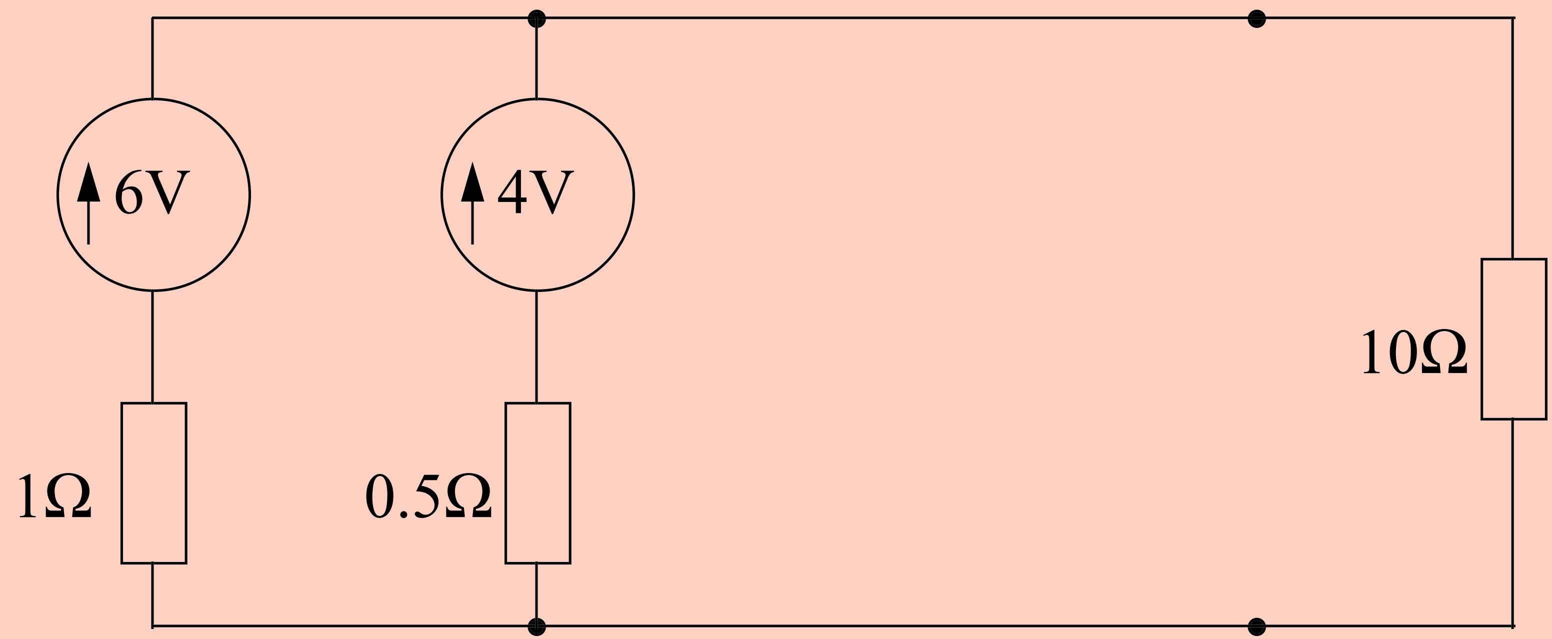
- Circuit current = V/R= (63/4)/(63/2) = (63/4)*(2/63)
  = (63*2)/(63*4) = 2/4 = 1/2 or 0.5 Amps
- Voltage across load = I*R = 1/2 * 15 = 15/2 Volts
- Voltage with no load = 63/4 or 15.75 Volts
- Voltage with load = 15/2 or 7.5 Volts



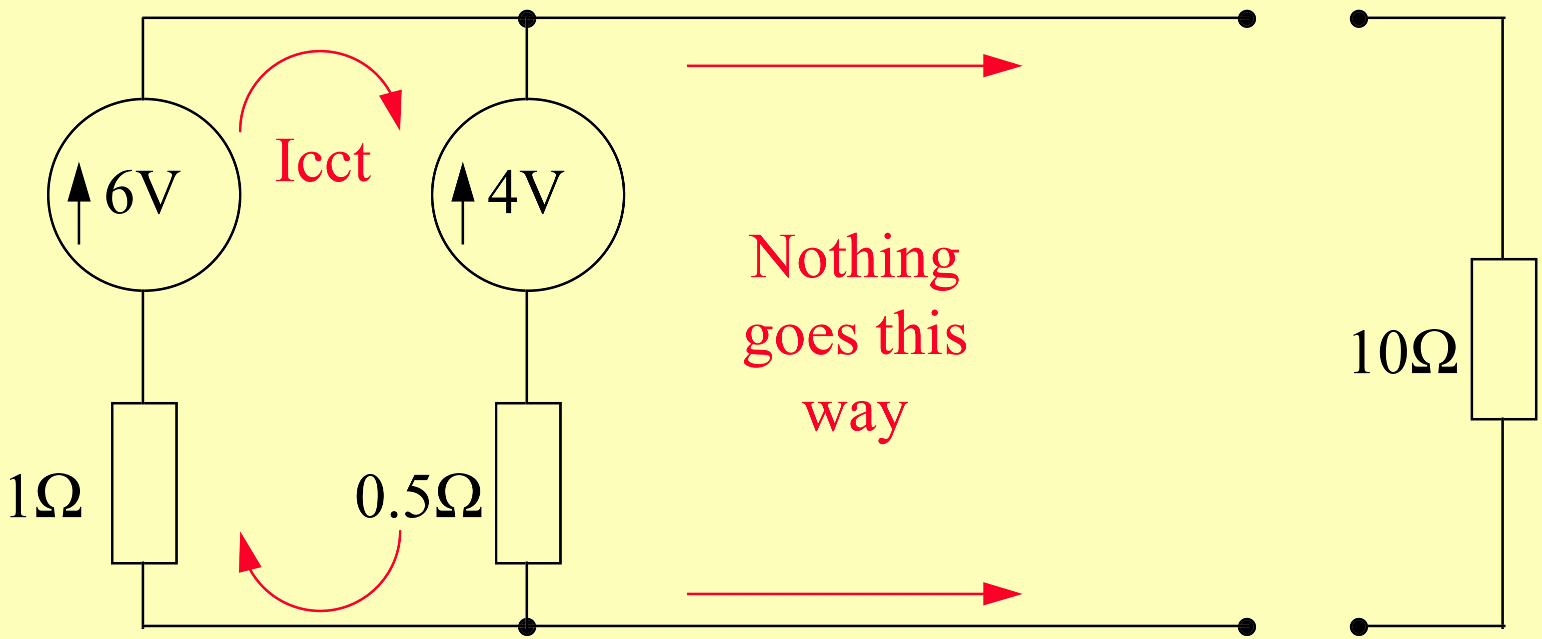
Norton and Thevenin Calculations.

- The circuit shown below shows a 10Ω Resistor supplied by two generators with internal resistance's shown.
  - (a) Use Thevenin Theorem to determine the value of current in the 10Ω Resistor
  - b) Calculate the internal voltage drop in each generator.



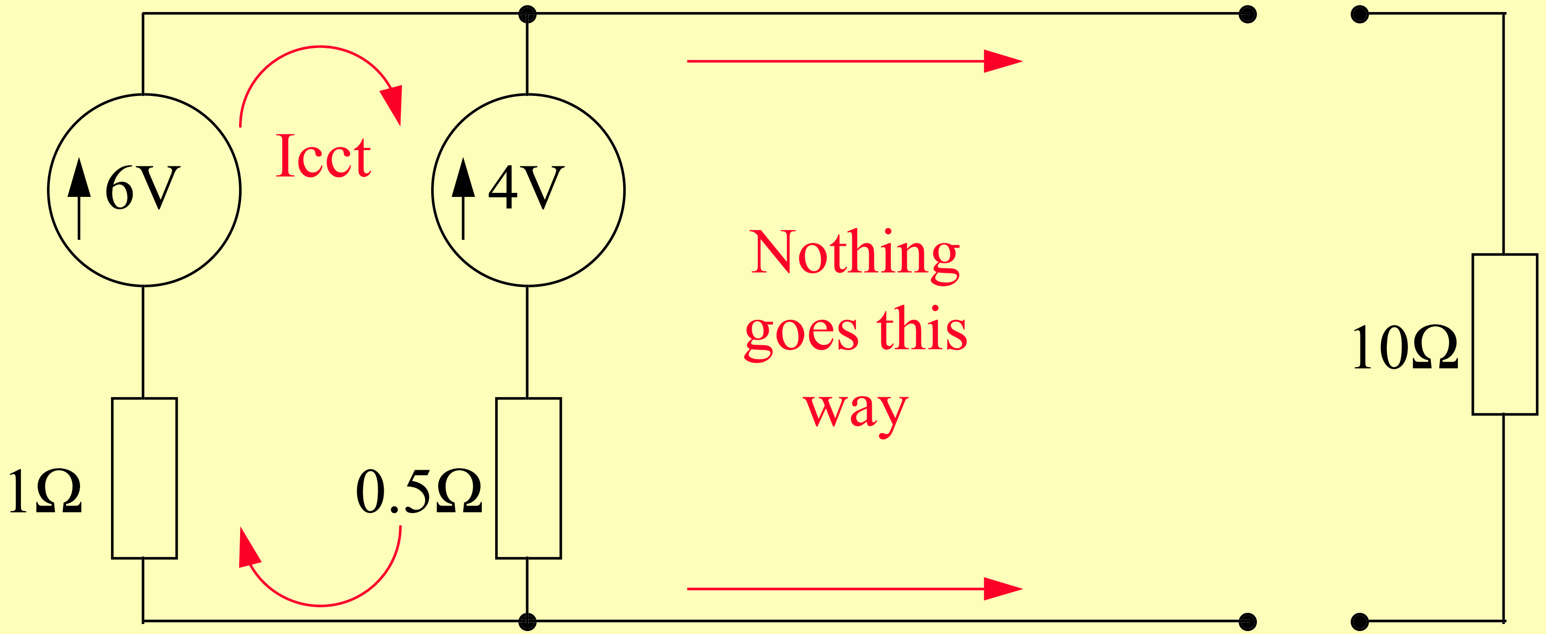
Norton and Thevenin Calculations.

- Step 1. Remove load.
- Make an assumption about current flow around circuit.
- Remember that Kirchhoff tells use that sum of voltage drops plus sum of sources equal zero.



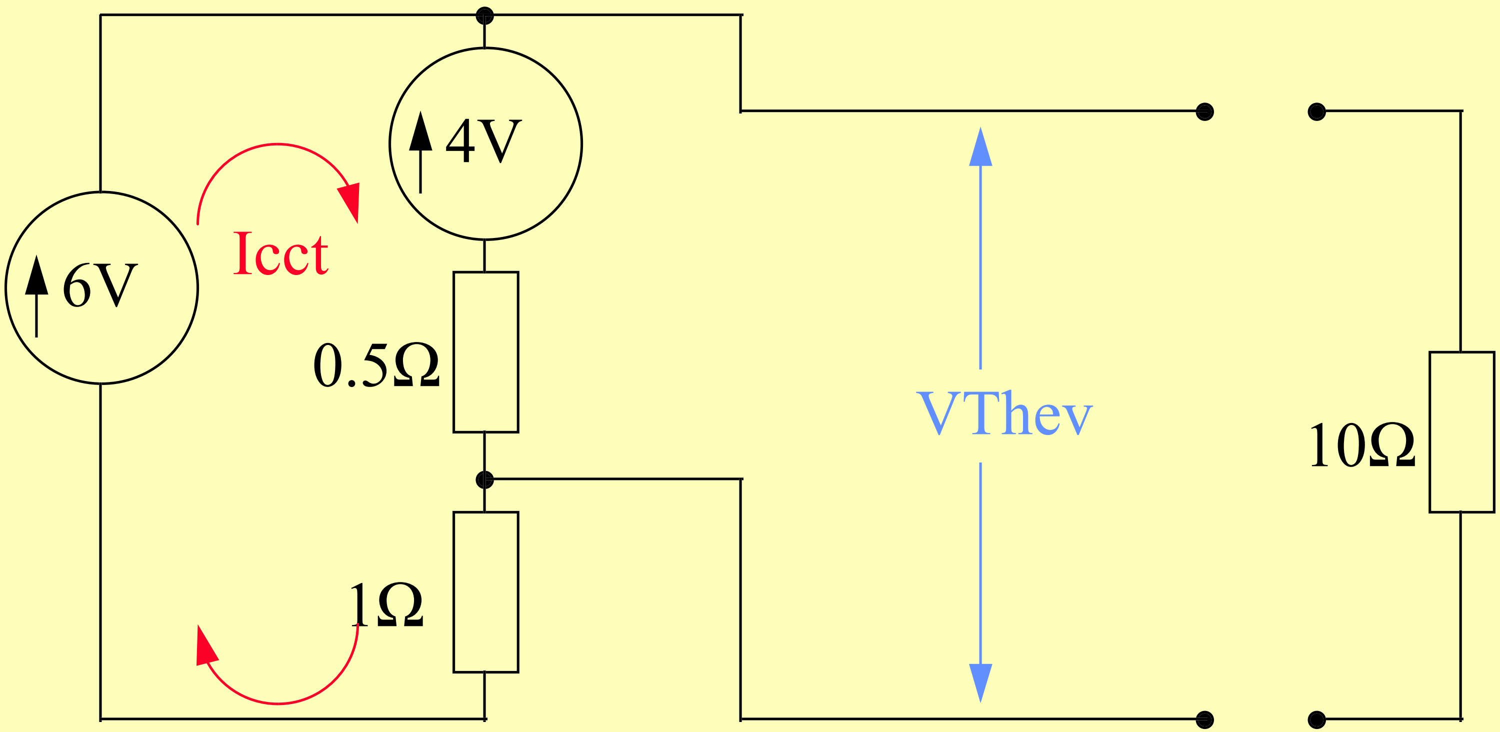
Norton and Thevenin Calculations.

- Step 2. Calculate Current.
- 6V - 4V - 0.5Icct - 1Icct = 0
- 2V -1.5Icct =0 or 2V =1.5Icct
- Therefore Icct = 2/1.5 or 4/3 Amps



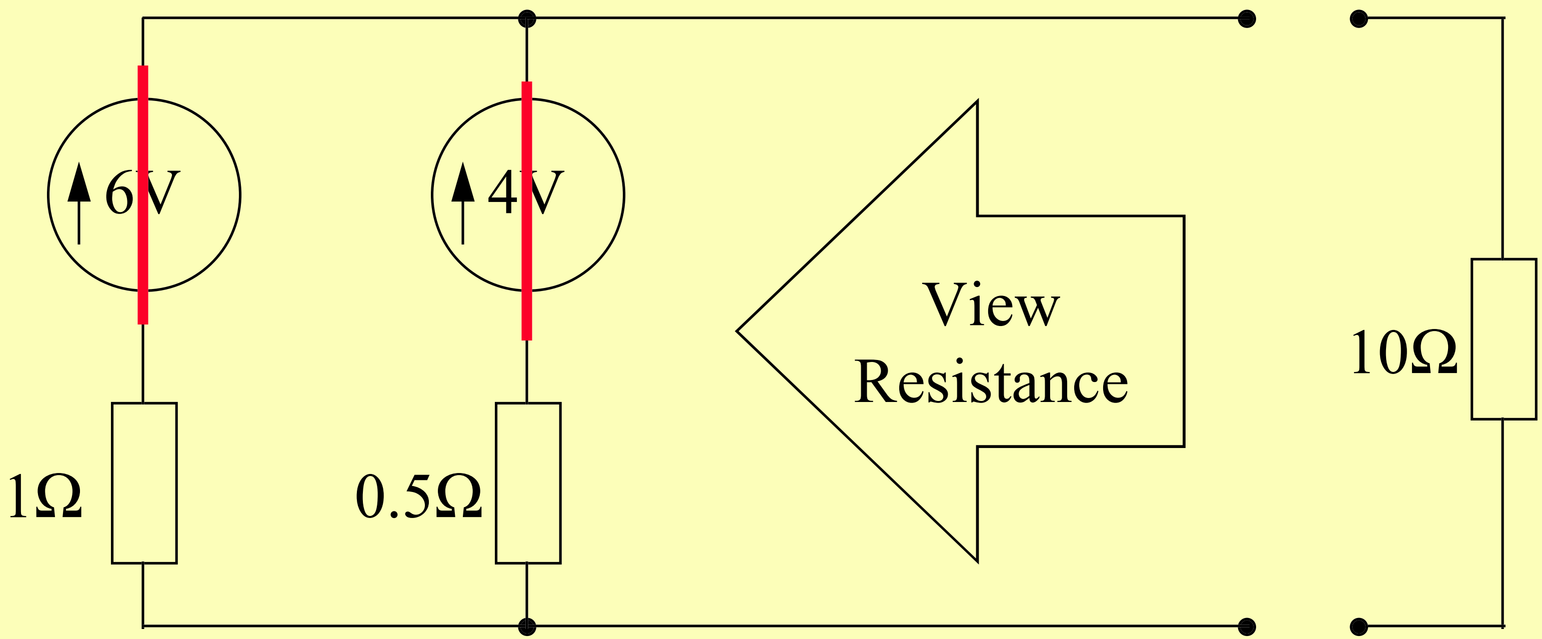
Norton and Thevenin Calculations.

- Step 3. Redraw circuit to show VThev.
- VThev = 4V + (1/2*Icct = 1/2 * 4/3) = 4/1 + 4/6 Volts
- VThev = (24 + 4)/6 = 28/6 = 14/3Volts



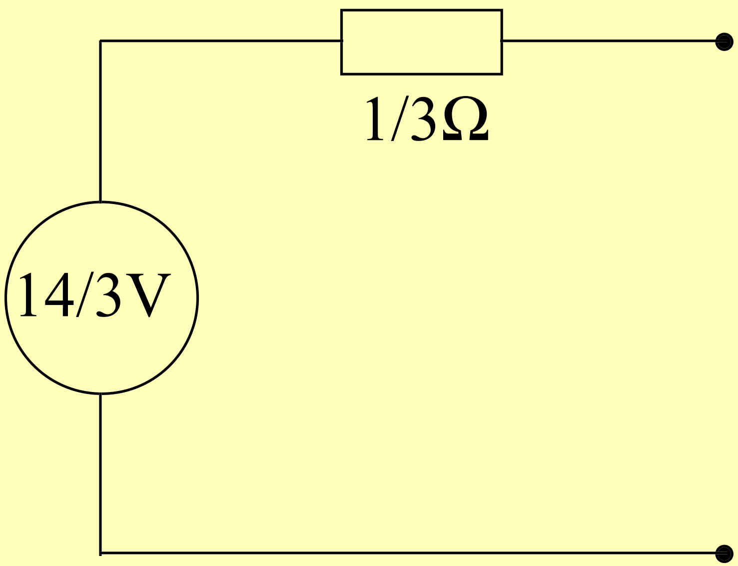
Norton and Thevenin Calculations.

- Step 4. Calculate Thevenin Resistance.
- Short out voltage sources, Open Current Sources.
- For ease use (Produce over Sum calculation method).
- RThev = (1 * 0.5) / 1 + 0.5 = 0.5 / 1.5 = 1/3Ω



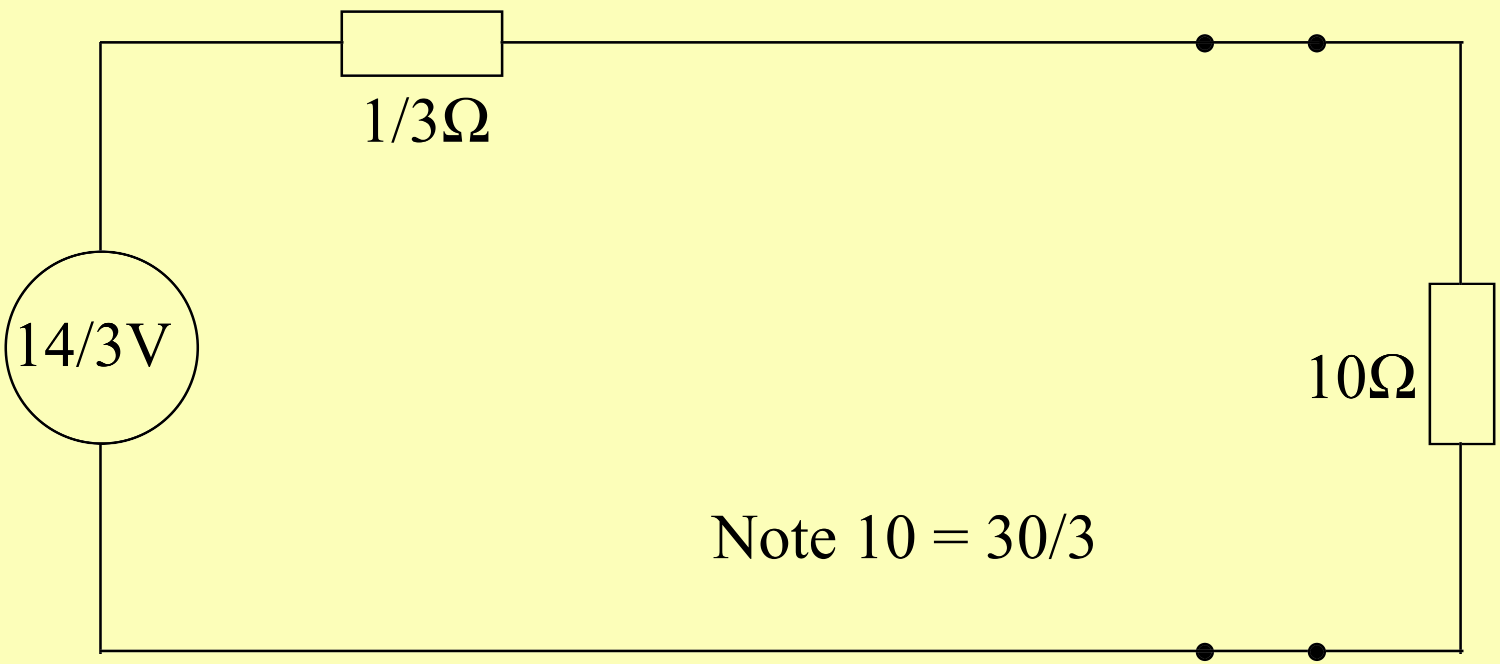
Norton and Thevenin Calculations.

- Step 5. Draw Thevenin equivalent circuit.



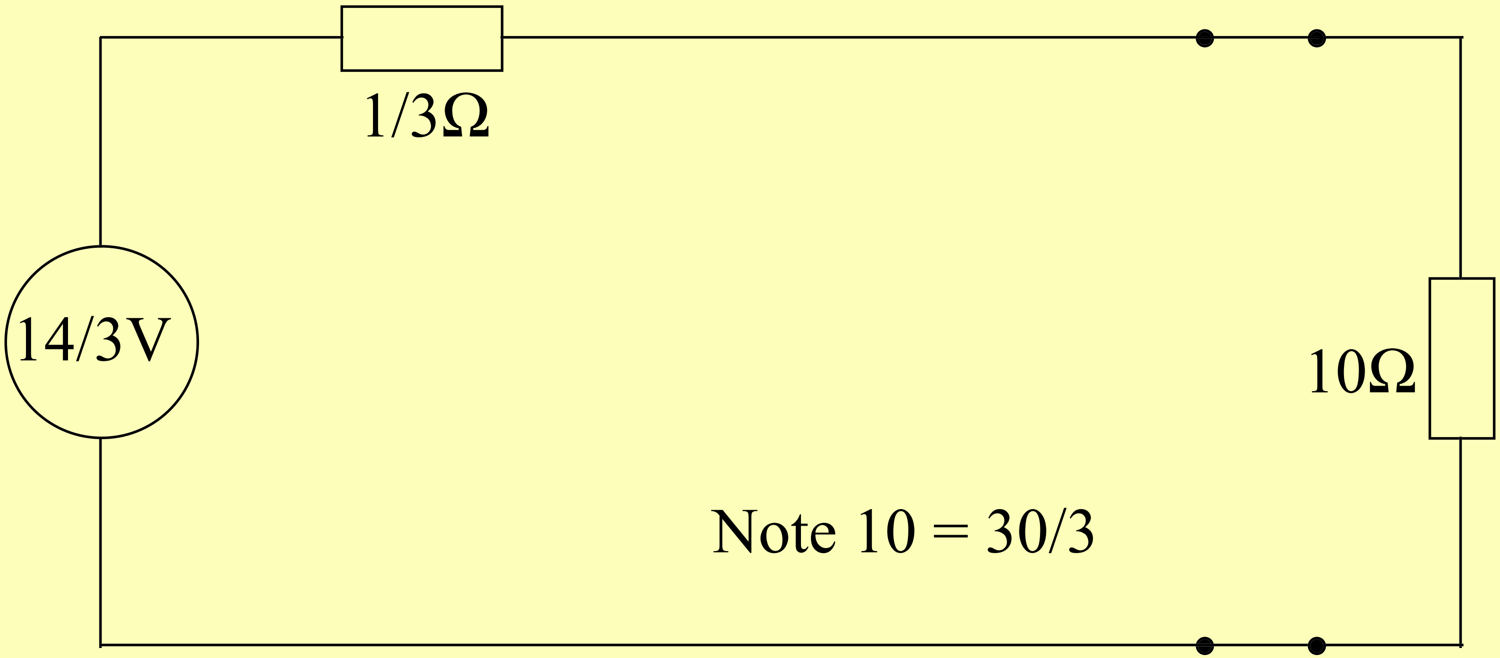
Norton and Thevenin Calculations.

- Step 6. Calculate total circuit resistance.
- Step 6a Convert resistance's into convenient 1/3Ω.
- Rcct = 1/3 + 30/3 = 31/3Ω.



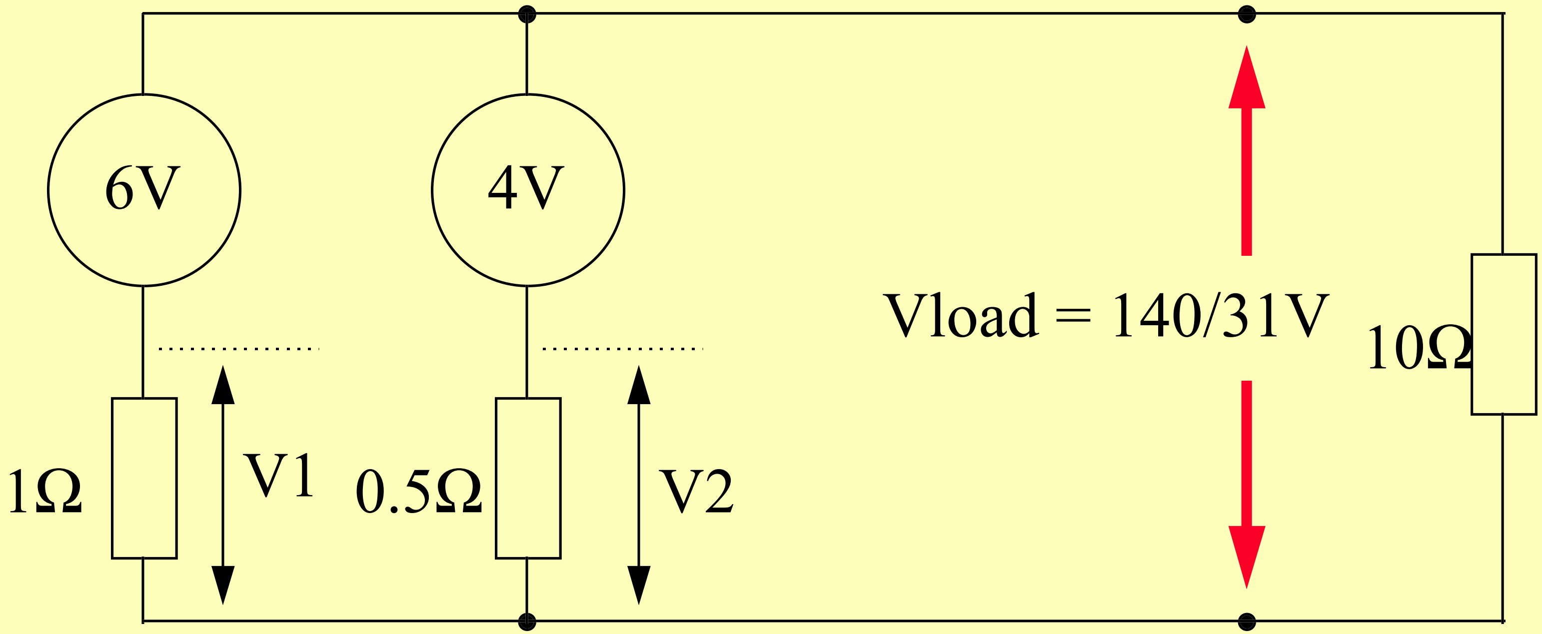
Norton and Thevenin Calculations.

- Step 7. Calculate Current in total circuit resistance.
- ILoad = V / Rcct = (14/3) / (31/3) = (14/3) * (3/31)
  = 14/31 Amps
- We could also find Voltage across load
- VLoad = I*R = (14/31)* 10 = 140/31 = 4.516V



Norton and Thevenin Calculations.

- Step 8. Find voltage drop across each generator.
- V1 = 6Volts - Vload = 6 - 140/31 = 186/31 - 140/31 = 46/31 = 1.484 Volts
- V2 = 4Volts - Vload = 4 - 140/31 = 124/31 - 140/31 = -16/31 = -0.516 Volts



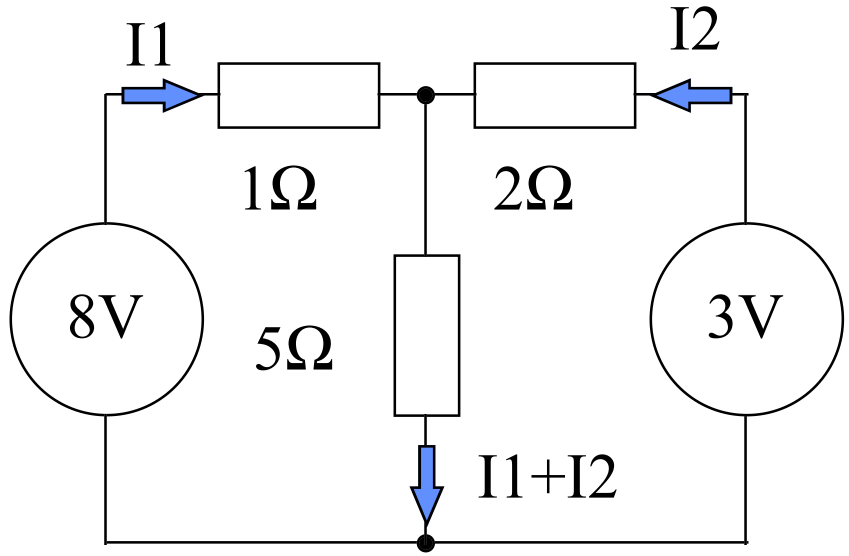
Superposition

Superposition.

- The Superposition Process:
- This process can be used when multiple sources of current or voltage are present in a circuit.
- The process states that in any circuit of linear elements with more that one source of voltage and/or current, the currents flowing are made up of the sum of the currents generated by each source when all other sources are replaced by their characteristic impedance's.

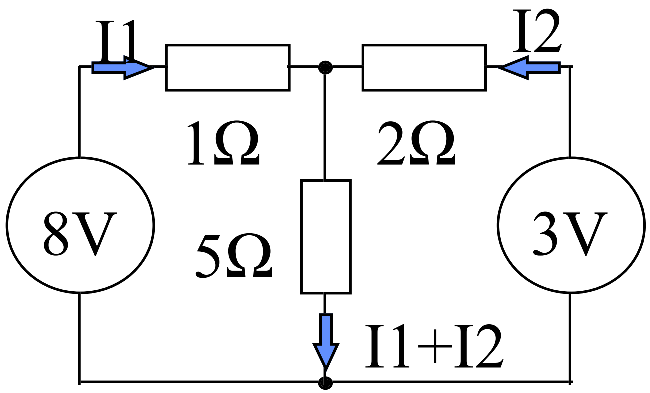
Example: # Superposition.

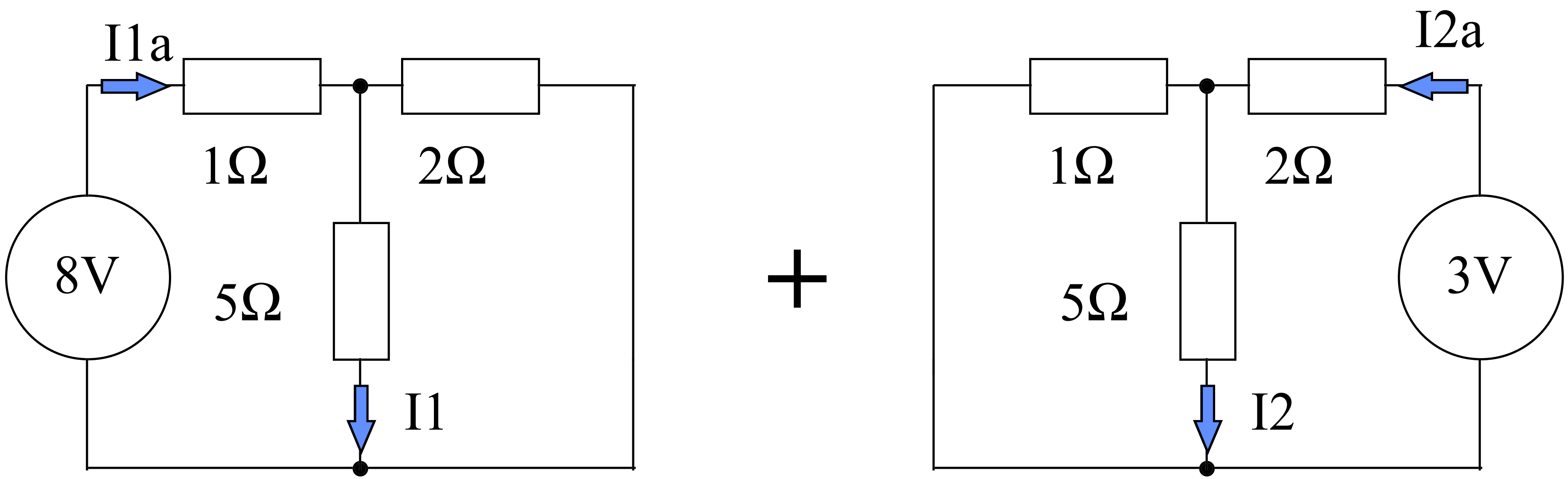
- Let us consider the circuit shown below.



Example: **Superposition.**

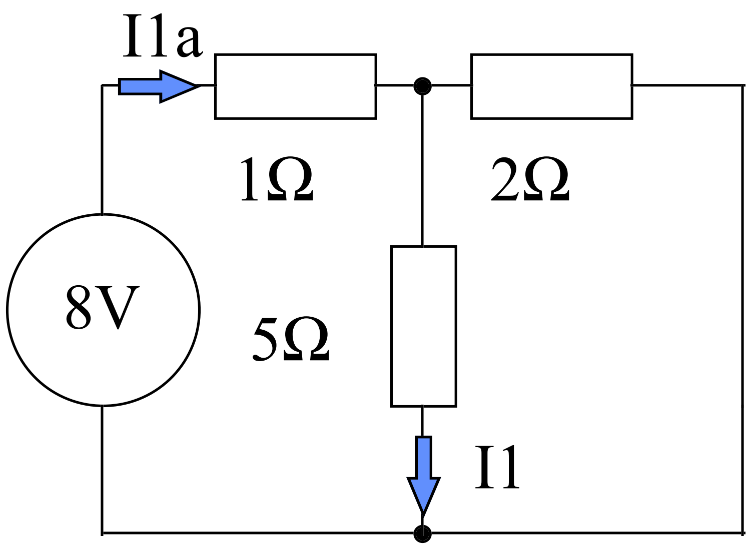
- This circuit can be treated as following two circuit shown below.





Example: # Superposition.

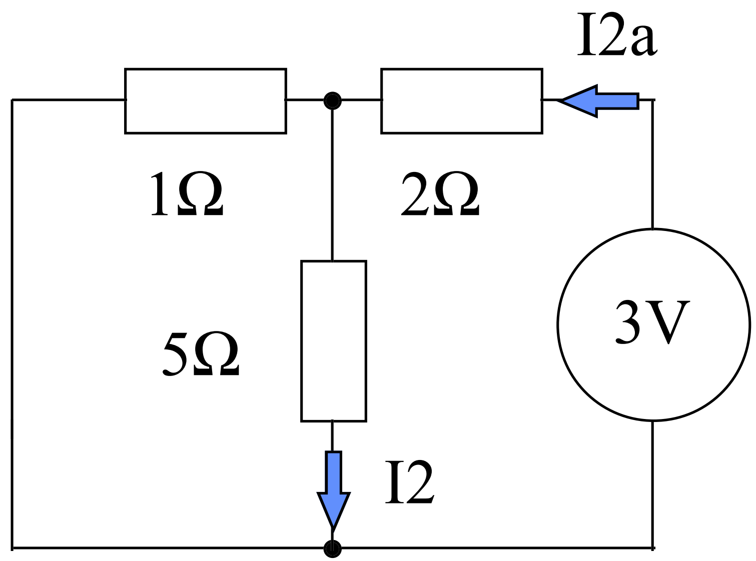
- Rcct = 1+(2!5) = 1+(2*5/(2+5)) = 1 + 10/7 =17/7Ω
- Icct or I1a = V/R = 8/(17/7) = 56/17 Amps
- Voltage across 5Ω = 8V - Icct*1Ω = 8 - 56/17*1
  = 136/17-56/17 = 80/17 = 4.705V (V1)
- I1 = V/R = 80/17/(5) = 16/17 = 0.941 Amps



Example:

Superposition.

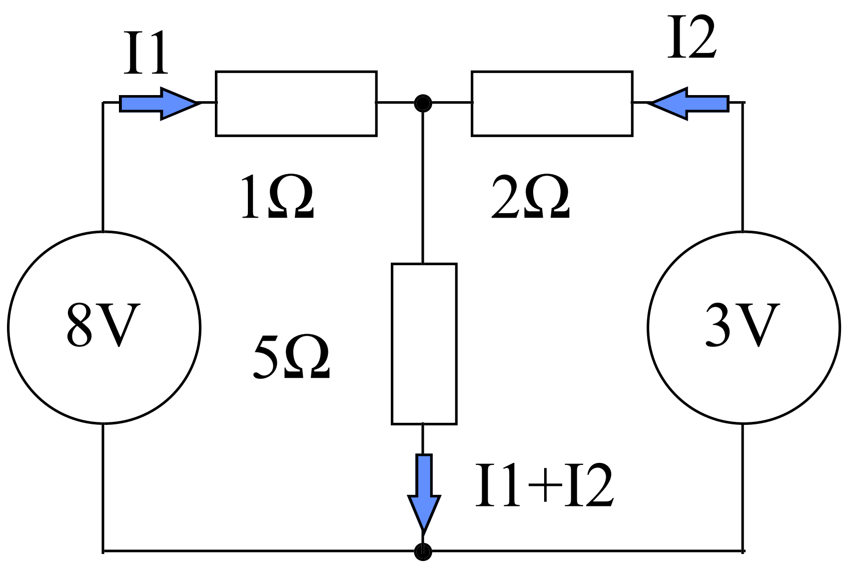
- $R_{cct} = 2+(1!5) = 2+(1*5/(1+5)) = 2 + 5/6 = 17/6\Omega$
- I_{cct} or $I2a = V/R = 3/(17/6) = 18/17$ Amps
- Voltage across $5\Omega = 3V - I_{cct}*2\Omega = 3 - 18/17*2$
  $= 51/17-36/17 = 15/17 = 0.882$Volts (V2)
- $I2 = V/R = (15/17)/(5) = 3/17 = 0.176$ Amps



Example: # Superposition.

- I1 = V/R = 80/17/(5) = 16/17 = 0.941 Amps
- I2 = V/R = 15/17/(5) = 3/17 = 0.176 Amps
- Current in 5Ω resistor = I1+I2 = 16/17+ 3/17 = 19/17A

  or 0.941 + 0.176= 1.117 Amps
- V across resistor = I*R = 19/17*5=95/17 =5.588 Volts

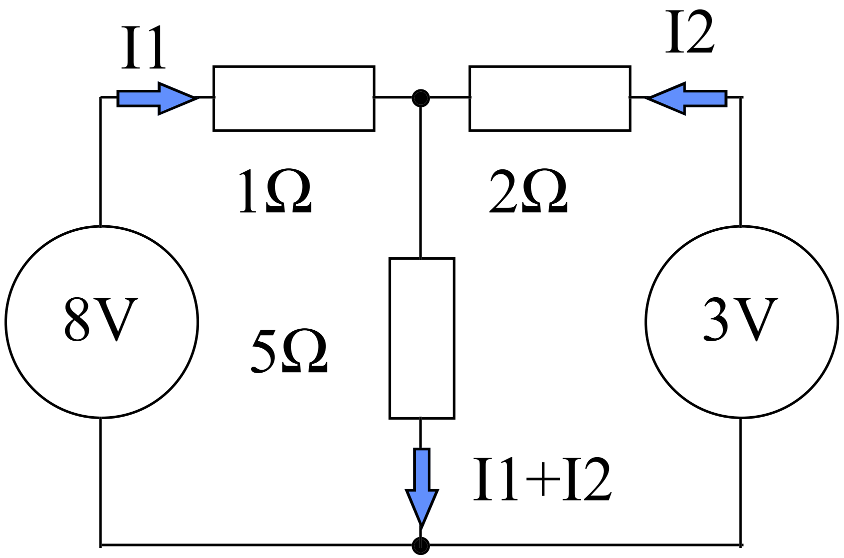


Example: **Superposition.**

- V1 = 80/17 = 4.7V (V1)
- V2 = 15/17 = 0.882Volts (V2)
- V across resistor = V1 + V2 = 80/17 + 15/17

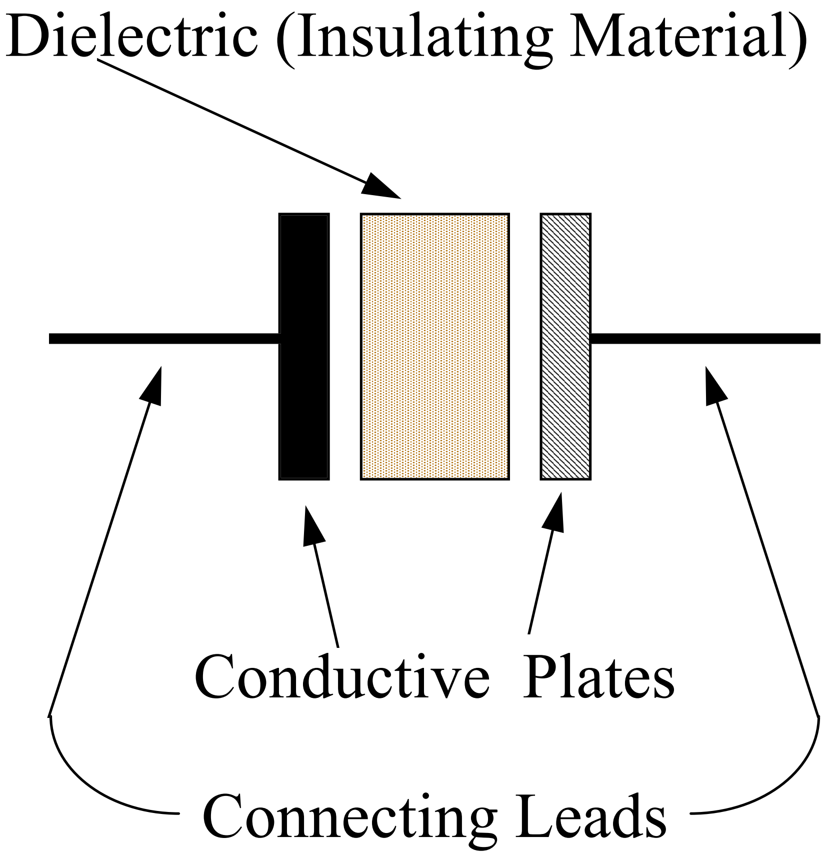
  = 95/17 =5.588 Volts
- Current in 5Ω resistor = V/R = (95/17)/5

  = 95/85A = 1.117 Amps

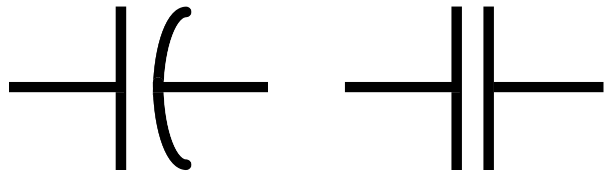


Capacitors

Capacitors.



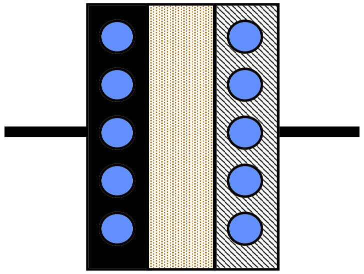
Physical Construction of a Capacitor



Circuit Symbols for
a Capacitor.

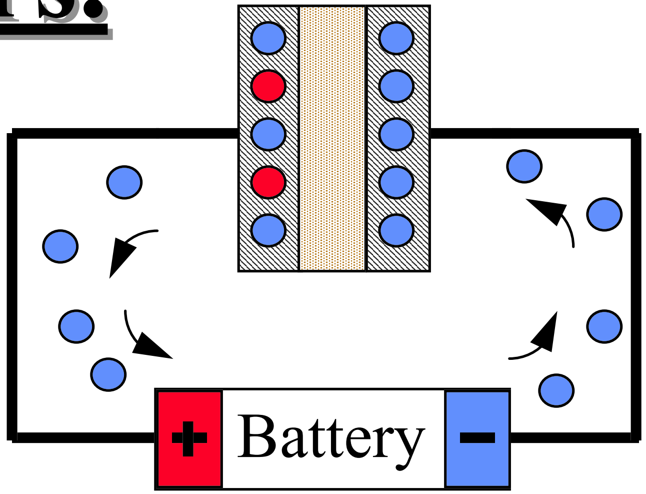
Capacitors.

1



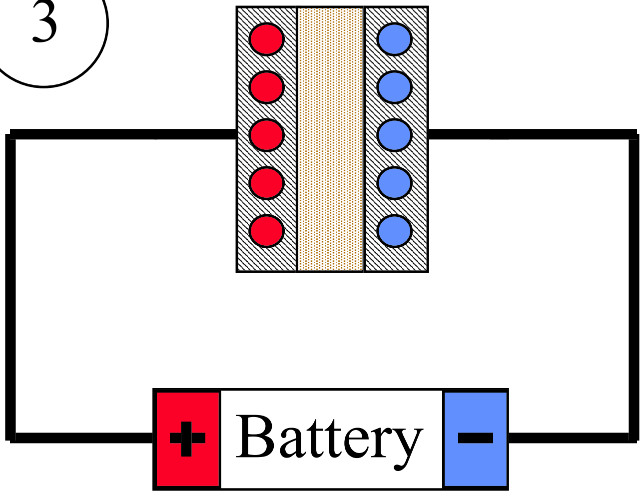
Neutral Uncharged Capacitor

2



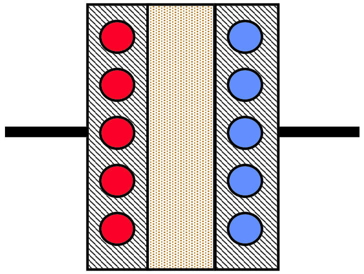
Electron Flowing as
Capacitor is charging

3



Capacitor Fully Charged No
more electrons moving.

4



Capacitor hold charge even
when removed from source.

Capacitors.

- Summary :-
- The amount of Charge that a Capacitor can store across its plates is its Capacitance.
- The Capacitance is a measure of a Capacitors ability to store a charge. The more charge per unit of Voltage that a capacitor can store the greater the Capacitance and is expressed by the formula :-

$$C = \frac{Q}{V}$$

$$or \quad Q = C\,V$$

Where :-

C = The Capacitance in Farads.

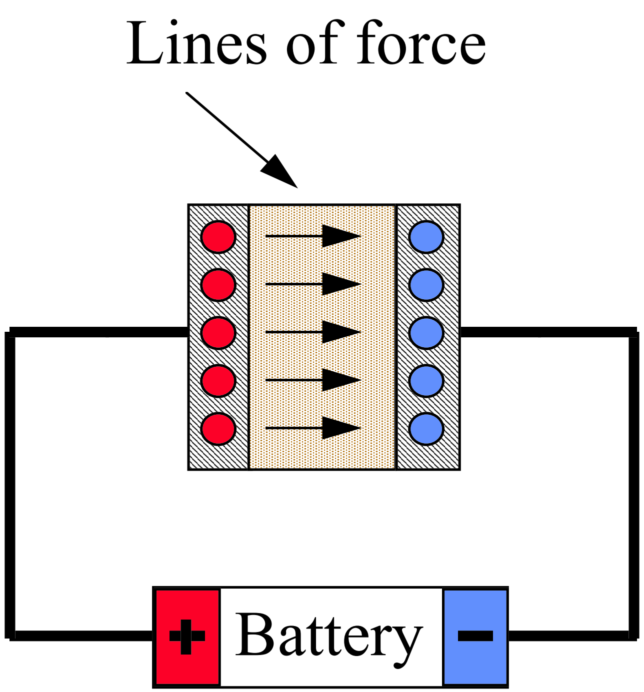
Q = The charge in coloumbs.

V = The voltage

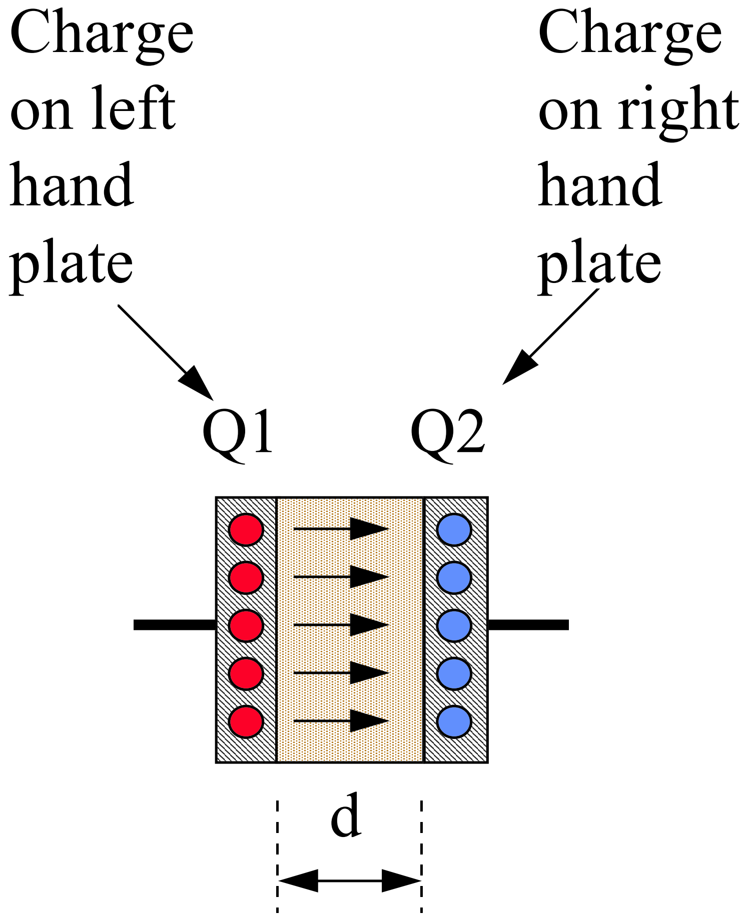
Capacitors.

- The Unit of Capacitance.
- The farad (F) is the basic unit of capacitance and the coulomb (C) is the unit of electrical charge. Remember that One coulomb is the same as One Amp for One second. C = current in Amps * time.
- Definition :-
- One farad is the amount of capacitance when one coulomb of charge is stored with one volt across the plates
- Most capacitors in electronics are measured in (µF) 10^{-6} micro farads or (pF) 10^{-12} pico farads

Capacitors.



The electric field stores the charge in a capacitor.



Coulombs Law

The force $F = k * Q1 * Q2 / d^2$

Capacitors.

- Coulombs Law states :-
- A force exists between two charged bodies that is directly proportional to the product of the two charges and inversely proportional to the square of the distance between the bodies.

$$F = \frac{kQ_1Q_2}{d^2}$$

F = force in newtons.

Q1 & Q2 are the charges in coloumbs.

k = proportionality constant equal to $9*10^9$.

d = distance between charges in metres.

Capacitors.

- Energy stored in a capacitor :-
- The amount of energy stored in the capacitor is directly proportional to the capacitance and from Q=CV. The charge is directly related to the Voltage as well as the capacitance. Therefore the amount of energy stored is also dependent on the square of the voltage across the plates of the capacitor.
- The formula for the energy stored in a capacitor is as follows :-

$$W = \frac{1}{2} CV^2$$

W = energy in joules.

C = capacitance in farads.

V = Voltage in volts.

Capacitors.

- Physical characteristics of a capacitor :-
- **Plate Area** Capacitance is directly proportional to the physical size of the plates as determined by the plate area.
- **Plate Separation** Capacitance is inversely proportional to the distance between the plates.
- **Dielectric Constant** Capacitance is directly proportional to the dielectric constant (a vacuum = 1).
  - The insulating material between the plates of the capacitor is the dielectric.
  - The measure of a material's ability to establish an electric field is called the dielectric constant or relative permittivity, symbolized by ε_r (the Greek letter epsilon)

Capacitors.

- Calculating the Capacitance of a Capacitor :-
- The Capacitance of a capacitor is directly proportional to the area and inversely proportional to the distance between the plates.
- The Permittivity value $\varepsilon = \varepsilon_0 * \varepsilon r$ (in Farads per metre)
  - where ε_0 = permittivity of a vacuum 8.85 $*10^{-12}$ F/m).
  - and εr = relative permittivity of the material.
- The formula for the capacitance of a capacitor is as follows :-

$$C = \frac{\varepsilon A}{d}$$

A = Area of one of the two equal plates.
d = Distance between plates.
ε = permittivity of the material.
C = capacitance in farads.

Capacitors.

- Formula Summary:-

$$Q = C\,V$$

Where :-

C = The Capacitance in Farads.

Q = The charge in coloumbs.

V = The voltage

$$W = \frac{1}{2} C V^2$$

W = energy in joules.

C = capacitance in farads.

V = Voltage in volts.

$$C = \frac{\varepsilon A}{d}$$

A = Area of one of the two equal plates.
d = Distance between plates.
ε = permittivity of the material.
C = capacitance in farads.

Capacitors.

- Example:-
- A Capacitor has a capacitance of 0.1μF and has 30V p.d. across its conductors.
- What amount of charge is stored?

Capacitors.

- Example:-
- A Capacitor has a capacitance of 0.1μF and has 30V p.d. across its conductors.
- How much energy is stored?
- Solution

$$C = \frac{Q}{V} \quad \text{or} \quad Q = CV$$

Therefore amount of stored charge is

$$Q = 0.1*10^{-6} * 30 = 3\mu C$$

Capacitors.

- Example:-
- A Capacitor has a capacitance of 0.1μF and has 30V p.d. across its conductors.
- How much energy is stored?

Capacitors.

- Example:-
- A Capacitor has a capacitance of 0.1μF and has 30V p.d. across its conductors.
- How much energy is stored?
- Solution

$$W = \frac{1}{2} CV^2$$

Therefore amount of stored energy is

$$W = 0.5 * 0.1*10^{-6} * 30 * 30 = 45\mu J$$

Capacitors.

- Example:-
- A Capacitor consists of two plates 1cm * 0.5cm spaced 0.2mm apart and using a dielectric of permittivity $6*10^{-11}$ F/m
- Find the capacitance value.

Capacitors.

- Example:-
- A Capacitor consists of two plates 1cm * 0.5cm spaced 0.2mm apart and using a dielectric of permittivity $6*10^{-11}$ F/m
- Solution The capacitance value is found from

$$C = \frac{\varepsilon A}{d}$$

- Convert cm values to metres
- $A = (1*10^{-2}) * (0.5*10^{-2}) = 0.5*10^{-4}$ m

$$C = \frac{6*10^{-11} * 0.5*10^{-4}}{0.2*10^{-3}} \text{ Farads}$$

$C = 1.5*10^{-11}$ F or $15*10^{-12}$ F which is 15pF

Capacitors.

- Extended Example:-
- A Capacitor consists of two plates 2cm by 3cm spaced 0.5mm apart and using a dielectric of permittivity $7*10^{-10}$ F/m

- Find the capacitance value.

- If the capacitor has 22V across the conductors.
- Find the amount of stored charge.
- Find the amount of stored energy.

Capacitors.

- Example:-
- A Capacitor consists of two plates 2cm by 3cm spaced 0.5mm apart and using a dielectric of permittivity $7*10^{-10}$ F/m
- Find the capacitance value.
- Convert cm values to metres
- $A = (2*10^{-2}) * (3*10^{-2}) = 6*10^{-4}$ m

$$C = \frac{\varepsilon A}{d}$$

$$C = \frac{7*10^{-10} * 6*10^{-4}}{0.5*10^{-3}} \text{ Farads}$$

$C = 8.4*10^{-10}$ F or $840*10^{-12}$ F which is 840pF

Capacitors.

- Example:-
- A Capacitor consists of two plates 2cm by 3cm spaced 0.5mm apart and using a dielectric of permittivity $7*10^{-10}$ F/m
- The capacitance value. = 840pF V=22V

$$C = \frac{Q}{V} \quad \text{or} \quad Q = CV$$

Therefore amount of stored charge is

$Q = 840*10^{-12} * 22 = 18.48*10^{-9}$ C or 18.48nC

Capacitors.

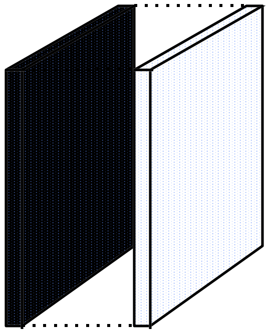
- Example:-
- A Capacitor consists of two plates 2cm by 3cm spaced 0.5mm apart and using a dielectric of permittivity $7*10^{-10}$ F/m
- The capacitance value. = 840pF V=22V

$$W= \frac{1}{2} CV^2$$

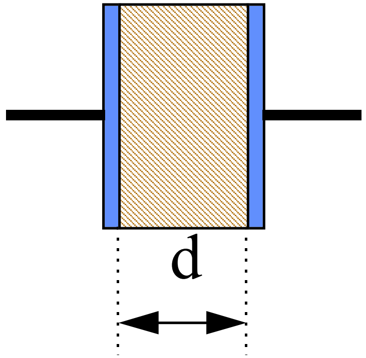
Therefore amount of stored energy is

$$W= 0.5 * 840*10^{-12} * 22 * 22 = 203.28*10\text{-}9\text{J or } 203.28\text{nJ}$$

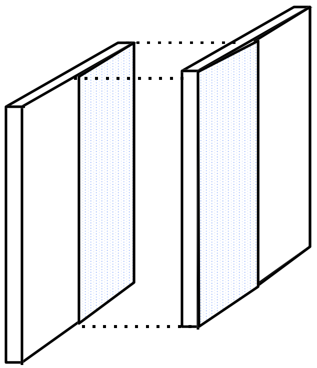
Capacitors.



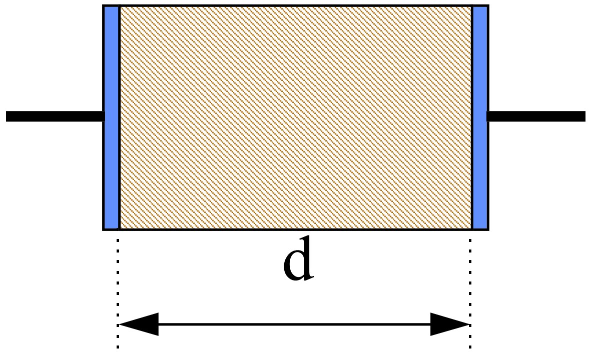
Full plate area
more capacitance



More capacitance



Reduced plate area
less capacitance

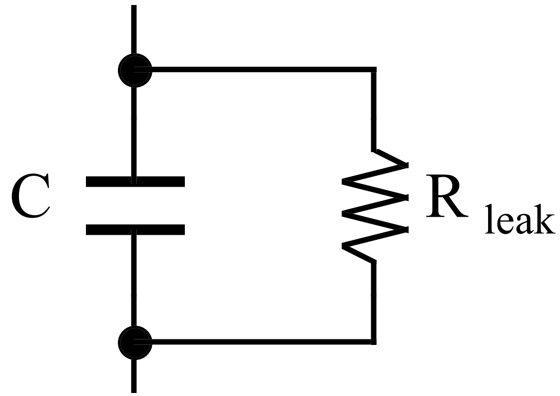


Less capacitance

Capacitors Summary

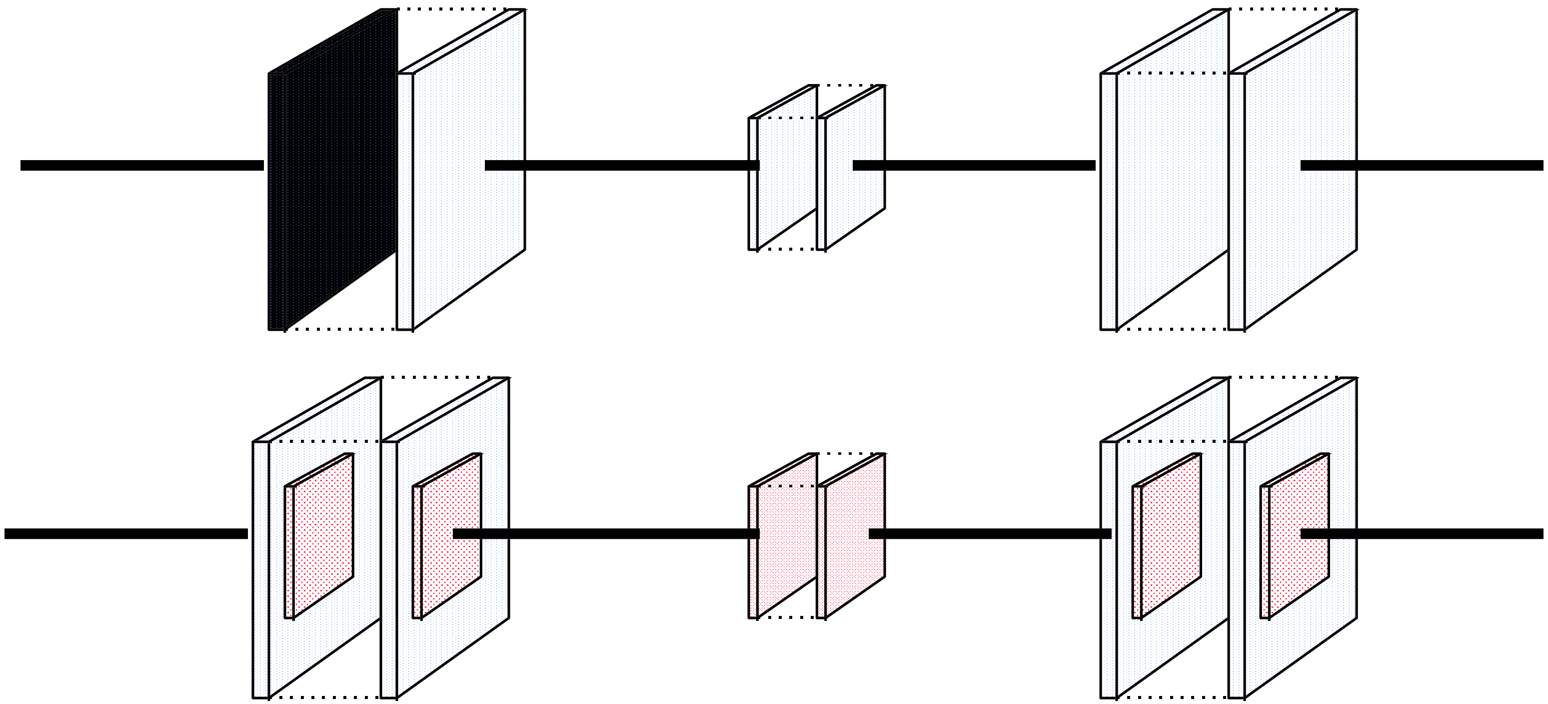
Capacitors.

- **Leakage** in a capacitor :-
- No insulation material is perfect hence the dielectric of any capacitor will conduct some small amount of current. The charge on the capacitor will eventually leak away.
- The equivalent circuit of a non ideal capacitor.



<u>Capacitors in series</u>

Capacitors.

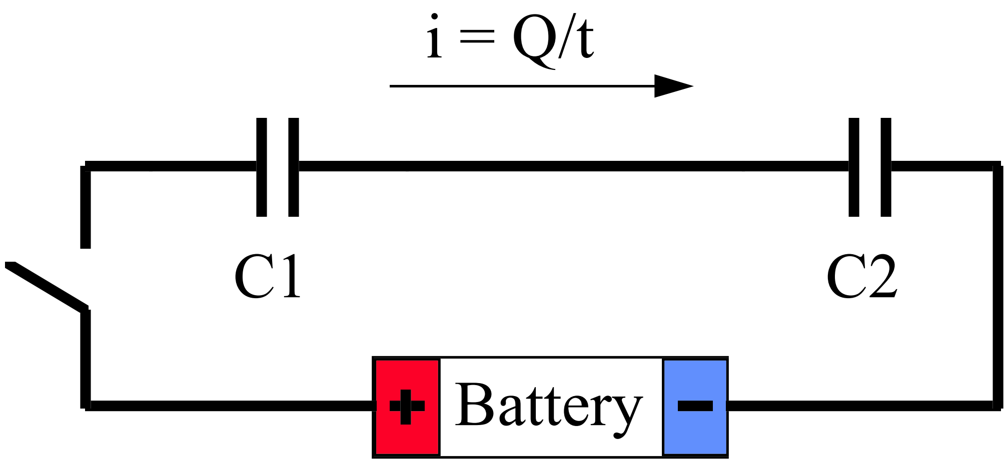


Note: Plate area of all the capacitors becomes effectively the size of the smallest plate and the dielectric distance is the sum of all the widths. Therefore the capacitance of capacitors in series is always smaller than the smallest value.

Capacitors in series

Capacitors.

The Proof



With the switched closed the capacitors charging I = Q/t is same at all points of the circuit.

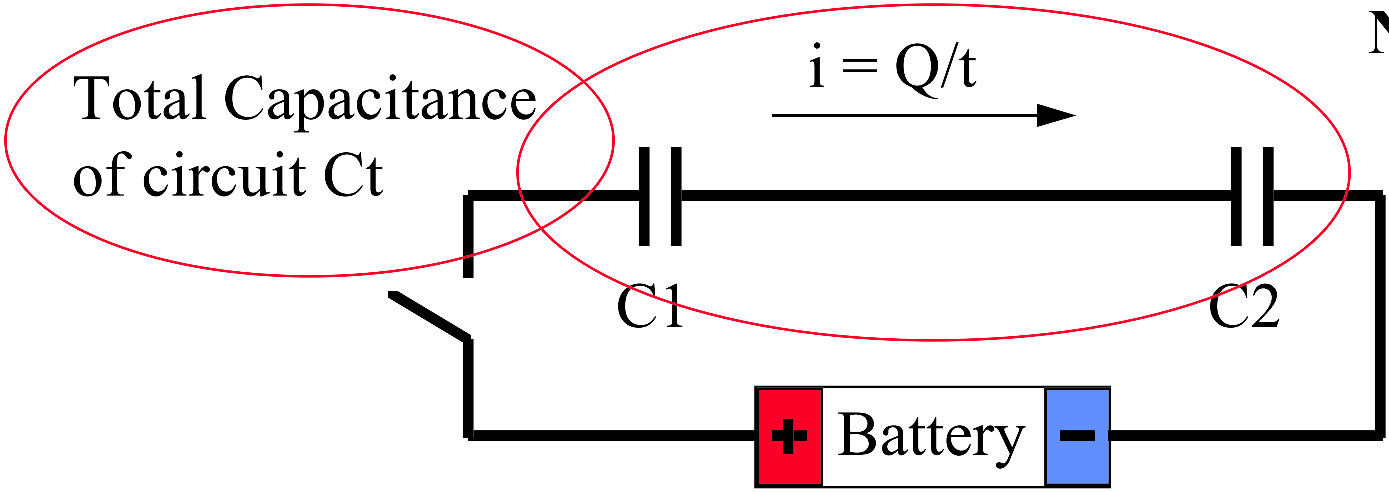
The total charge Qt moved through the circuit equals the charge on C1 and is also equal to the charge on C2. Qt = Q1 = Q2

Capacitors.

Capacitors in series

The Proof

Note: V = Q/C



From Kirchhoff's laws . . . V Battery = $V_{C1} + V_{C2}$

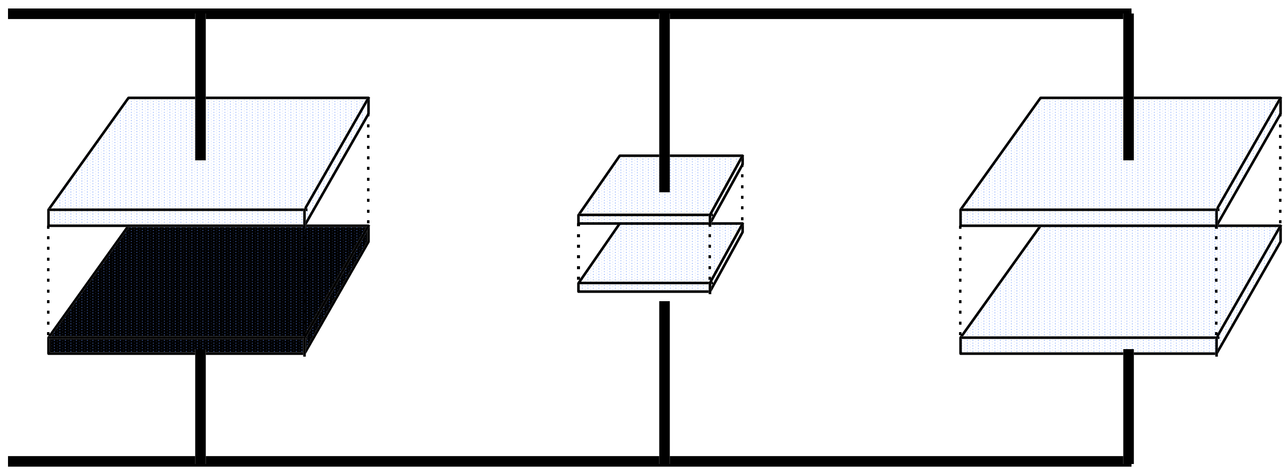
or $V_{Ct} = V_{C1} + V_{C2}$ or $\dfrac{Qt}{Ct} = \dfrac{Q1}{C1} + \dfrac{Q2}{C2}$

However remember that Qt = Q1 = Q2 = say just Q then

$$\frac{Q}{Ct} = \frac{Q}{C1} + \frac{Q}{C2} \quad \text{or} \quad \boxed{\frac{1}{Ct} = \frac{1}{C1} + \frac{1}{C2} \; \ldots\ldots}$$

Capacitors in parallel

Capacitors.

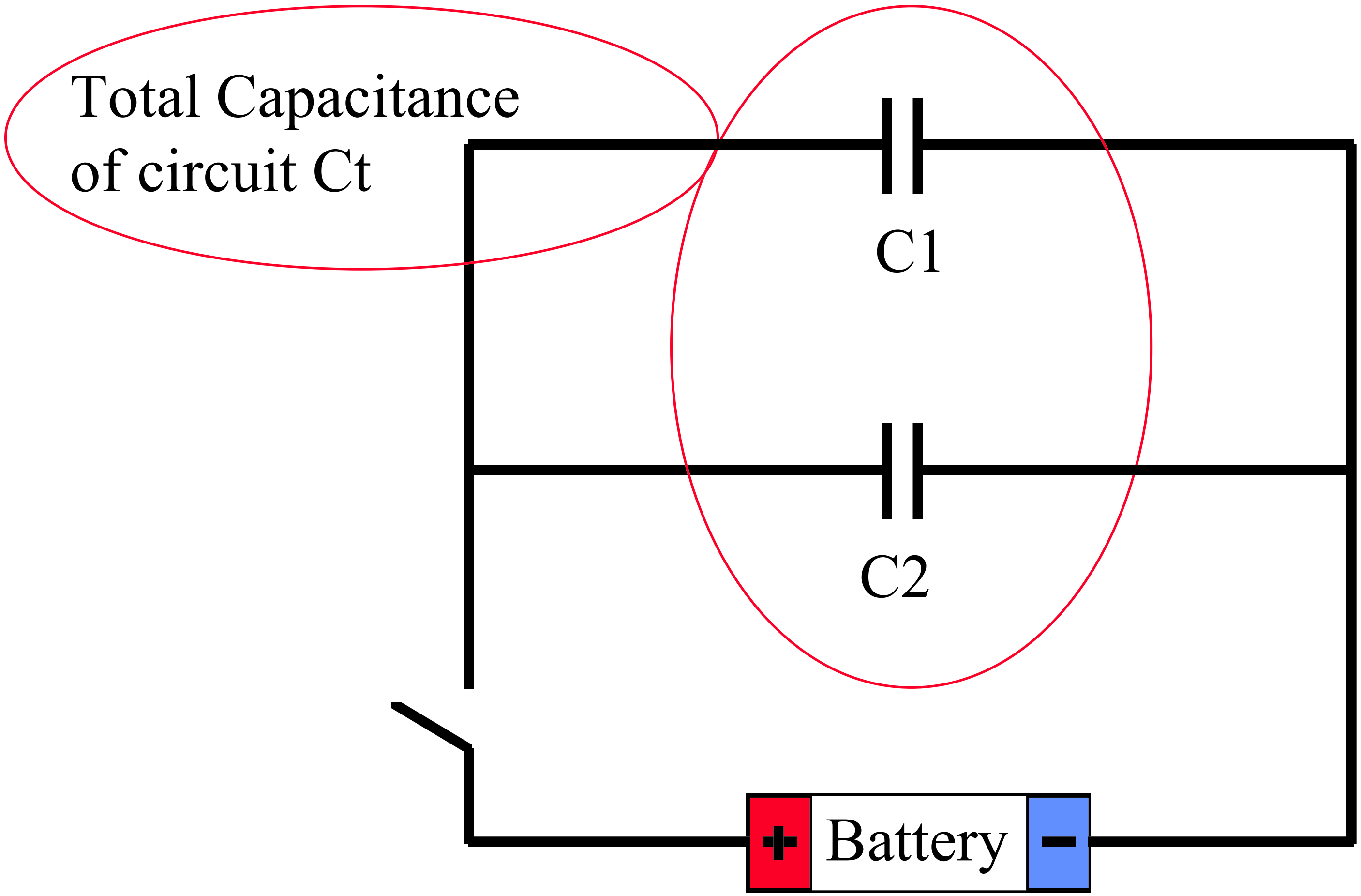


Note: Plate area of all the total capacitance becomes effectively the sum of the sizes of all the plates whilst the dielectric distances remain unchanged. Therefore the capacitance of capacitors in parallel is the sum of their values.

Capacitors in parallel

Capacitors.

The Proof

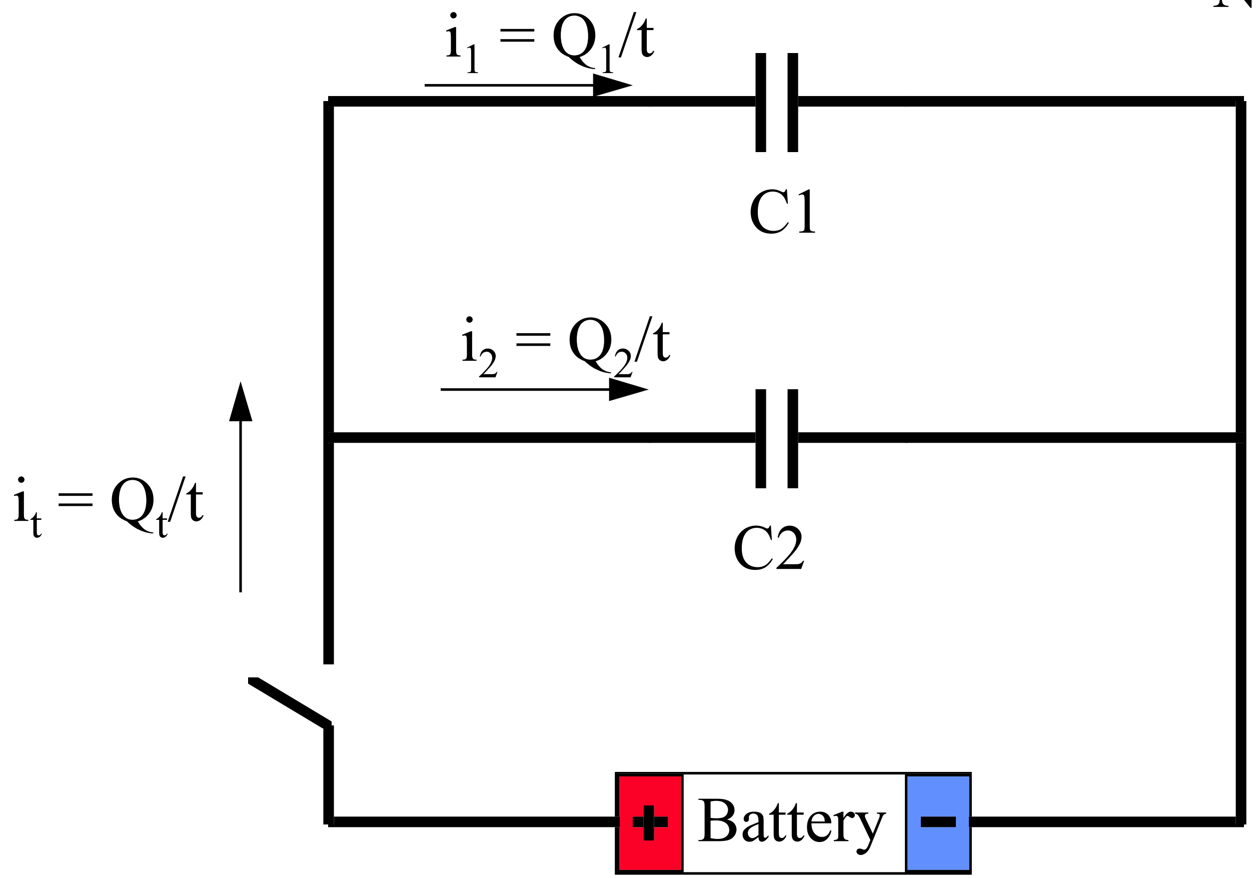


Capacitors in parallel

Capacitors.

The Proof

Note: $Q = C*V$



Note: Using Kirchhoff's laws The charge $Q_t = Q_1 + Q_2$

Capacitors in parallel

Capacitors.

The Proof

So:-

Ct * V Battery = C1 * V Battery + C2 * V Battery

(Ct)* ~~V Battery~~ = (C1 + C2) * ~~V Battery~~

Ct = C1 + C2

The (V Battery) terms can cancel

which gives :-

Ct = C1 + C2

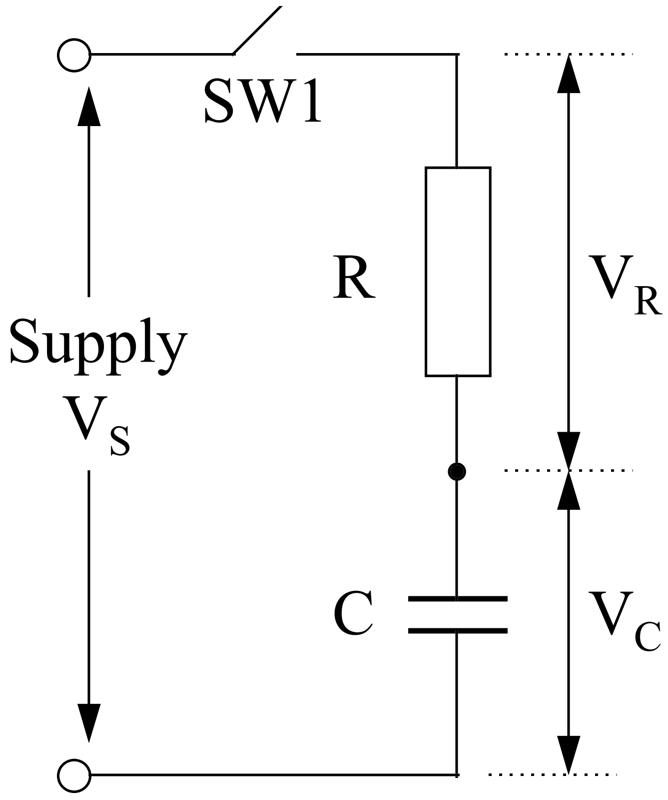
Thinking Exercise

Capacitors.

Initial conditions:

Capacitor C contains no charge.

So what voltage is across it?



Solution:

$Q = CV$

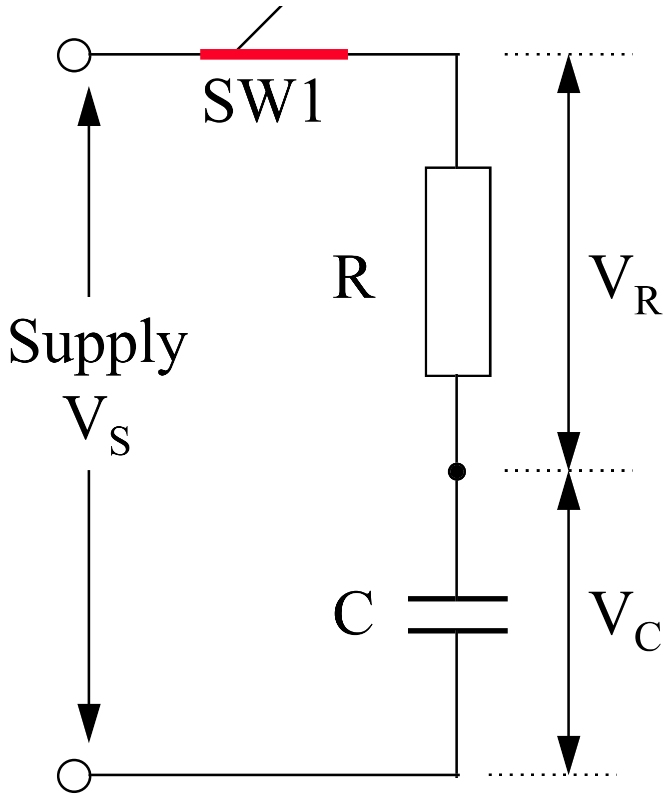
as $Q = 0$ then

$V_C = Q/C$ or $0/C = 0$ Volts

Thinking Exercise

Capacitors.

The instant that SW1 is closed what voltage will be present across V_C and V_R ?



Solution:

$Q = CV$

as $Q = 0$ then

$V_C = Q/C$ or $0/C = 0$ Volts

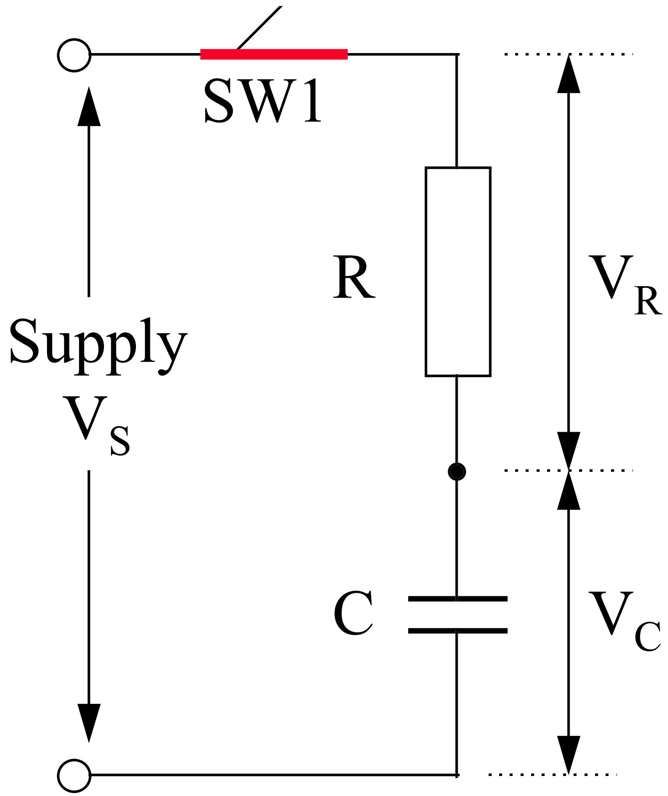
therefore Voltage across V_R is

$V_R = V_S - V_C = V_S - 0 = V_S$

Thinking Exercise

Capacitors.

After SW1 has been closed for a significant time what voltage will be present across V_C and V_R ?



Solution:

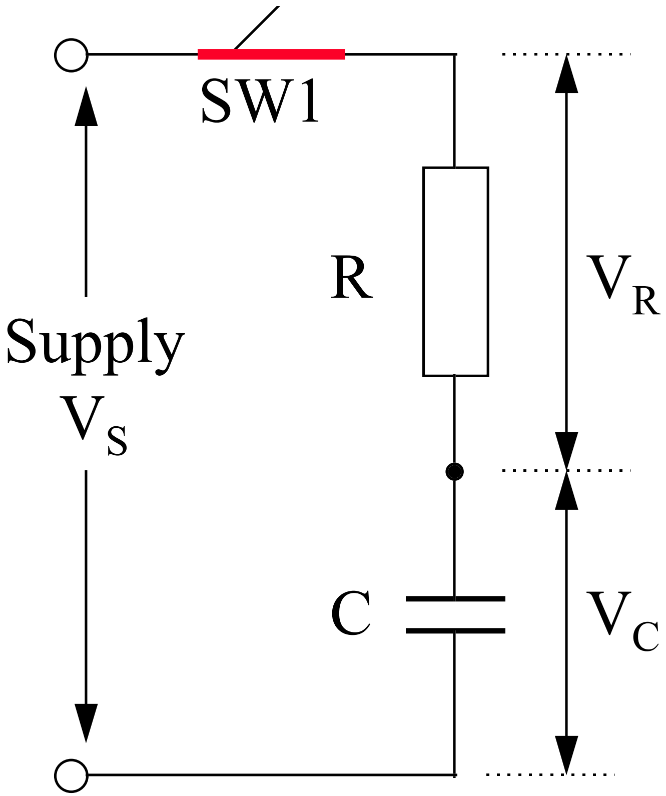
Capacitor becomes full charged so $V_C = V_S$ Volts

therefore Voltage across V_R is $V_R = V_S - V_C = V_S - V_S = 0$

Thinking Exercise

Capacitors.

After SW1 has been closed for a significant time what voltage will be present across V_C and V_R ?



Solution:
Capacitor becomes full charged so $V_C = V_S$ Volts

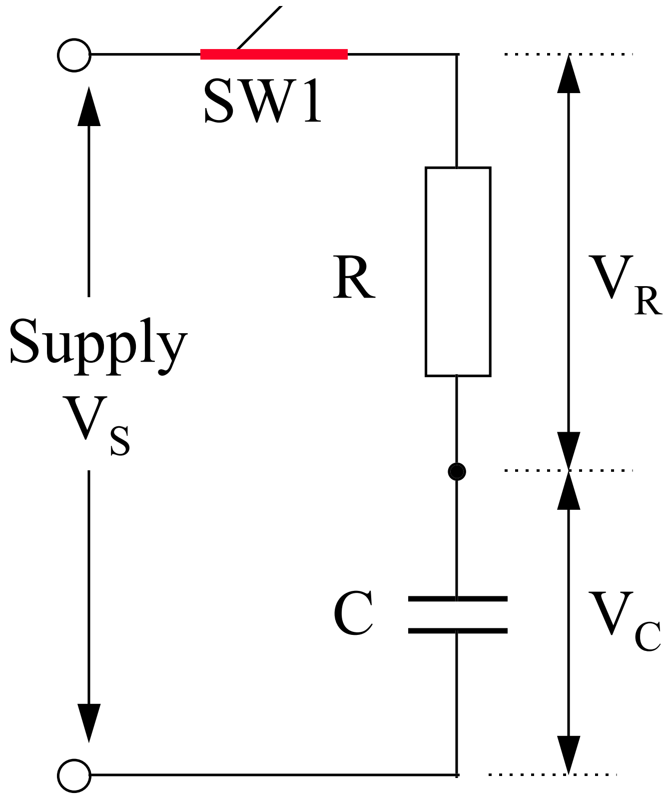
therefore Voltage across V_R is
$V_R = V_S - V_C = V_S - V_S = 0$

Note: As the capacitor charges the voltage across the capacitor rises and the charge rate slows. Therefore the charge rate is non linear. (1 / Exponential form)

Thinking Exercise

Capacitors.

Summary:



At switch on:

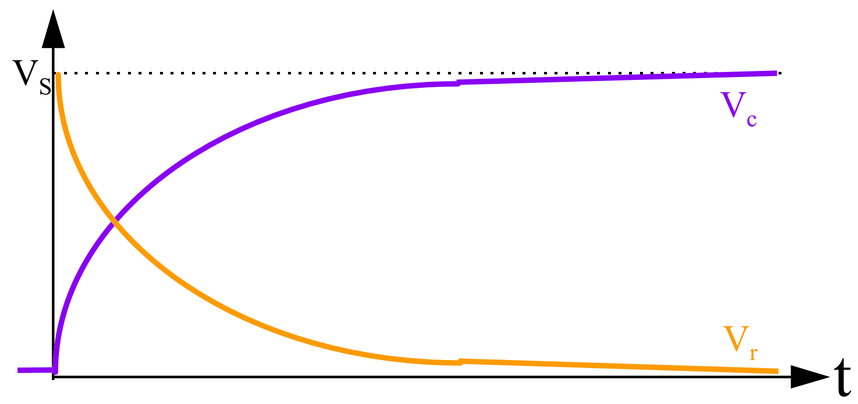
Voltage across Capacitor is minimum

Voltage across Resistor is maximum.

After a long period after switch on:

Voltage across Capacitor is maximum

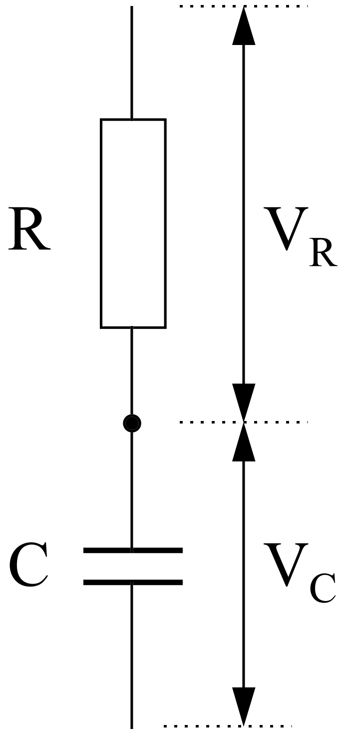
Voltage across Resistor is minimum.



Capacitors.

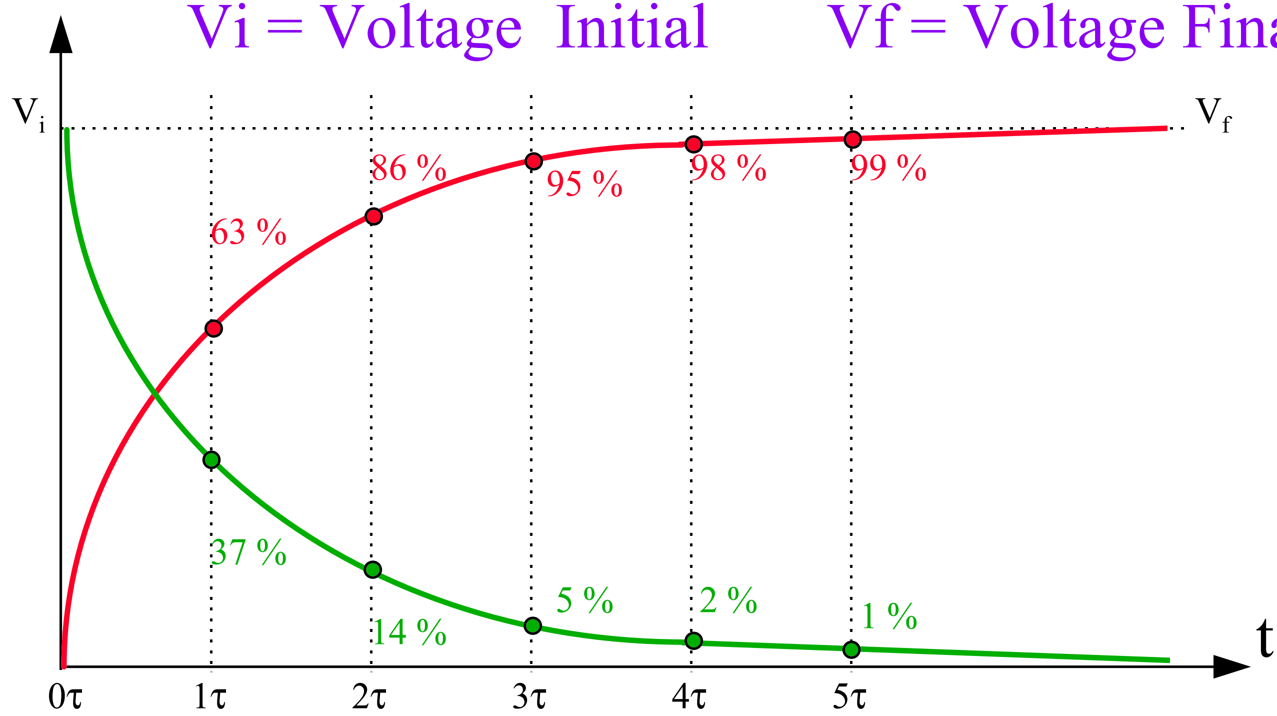
Charging and Discharging cycles.

τ (tau) is the The Time Constant.



τ (tau) in seconds = C in Farads * R in Ohms

Vi = Voltage Initial   Vf = Voltage Final



At **5τ** the Capacitor is assumed to be **Fully** charged or discharged.

General Formula

Capacitors.

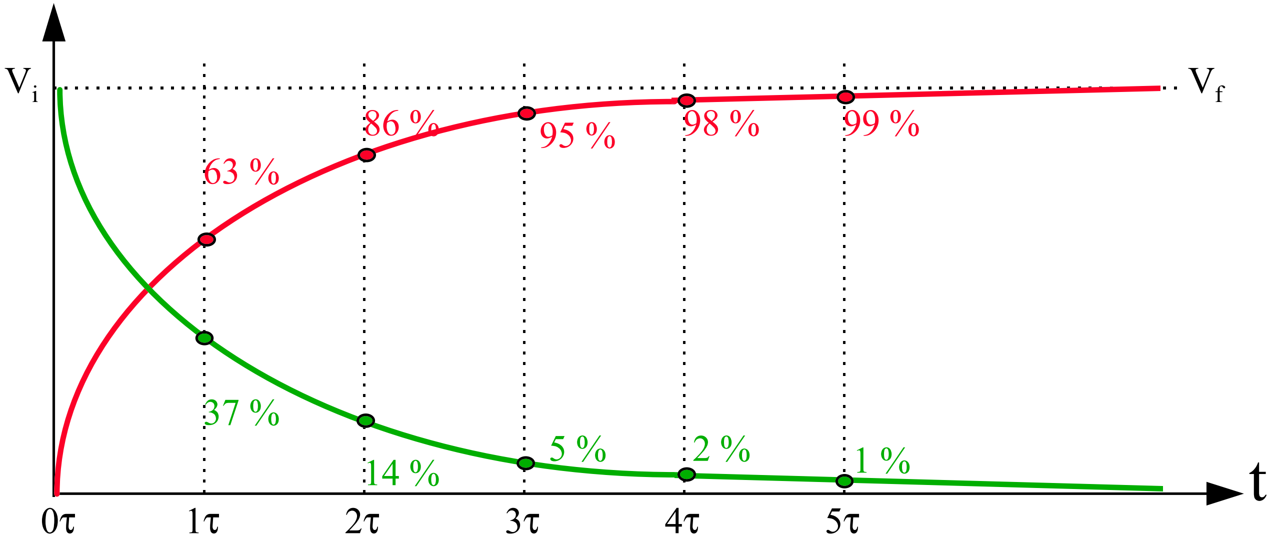
τ (tau) is the
The Time Constant.

$$v = V_f + (V_i - V_f)e^{-t/\tau} \qquad i = I_f + (I_i - I_f)e^{-t/\tau}$$

t = time τ (tau) in seconds = C in Farads * R in Ohms

V_i/ I_i = Voltage/Current Initial V_f / I_f = Voltage/Current Final

v = instantaneous Voltage i = instantaneous Current



At **5τ** the Capacitor is assumed to be **Fully** charged or discharged.
Charging and Discharging cycles.

Capacitors.

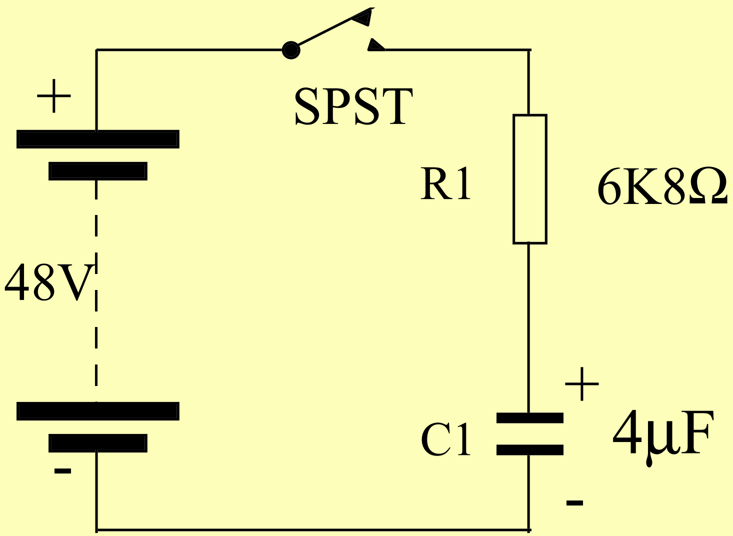
- A 4µF Capacitor is completely discharged. It is connected in series with a 6K8Ω Resistor to a 48V supply through a single pole switch. The switch is closed what voltage will appear across the capacitor after 13.6ms.
  - a) Draw a diagram of the circuit and indicate the polarities of the supply and the capacitor after 13.6ms.
  - b) Determine the voltage across the Capacitor after 13.6ms.
  - c) Calculate how long it will take for the capacitor to be fully charged.

Solution

Capacitors.

- a) Draw a diagram of the circuit and indicate the polarities of the supply and the capacitor after 13.6ms.

SPST
Single Pole
Single Throw



Solution

Capacitors.

- b) Determine the voltage across the Capacitor 13.6ms after the switch has been closed.
- R = 6K8Ω, C = 4μF,
- V_f = 48 Volts, V_i = 0 Volts
- t = 13.6ms
- Initially Calculate τ (tau)
- $\tau = 4*10^{-6} * 6.8 * 10^{3} = 27.2 * 10^{-3}$
- $\tau = 27.2 * 10^{-3}$ seconds or 27.2ms

Solution

Capacitors.

- $R = 6K8\Omega$, $C = 4\mu F$, $V_f = 48$ Volts, $V_i = 0$ Volts
- $t = 13.6ms$, τ (tau) $= 27.2 * 10^{-3}$ seconds
- Using the formula $v = V_f + (V_i - V_f)e^{-t/\tau}$
- $v = 48 + (0 - 48)e^{-(13.6 * 10^{-3}/27.2 * 10^{-3})}$
- $v = 48 + (0 - 48)e^{-(0.5)}$
- Note: $e^{-(0.5)} = 1/e^{(0.5)}$ or $1/1.64872 = 0.60653$
- $v = 48 + (0 - 48)\ 0.60653 = 48 + (-48 * 0.60653)$
- $v = 48 + (-29.11347) = 48 - 29.11347 = 18.8865$
- Voltage across capacitor will be 18.8865 Volts

Solution

Capacitors.

- c) Calculate how long it will take for the capacitor to be fully charged.
- R = 6K8Ω, C = 4μF, V_f = 48 Volts, V_i = 0 Volts
- t = 13.6ms, τ (tau) = 27.2 * 10^{-3} seconds
- A capacitor is assumed to be fully charged after 5τ.
- 5τ = 5 * (27.2 * 10^{-3} seconds) = 136 * 10^{-3}
- Time required for capacitor to be fully charged will be 136 milli seconds.

Capacitors.

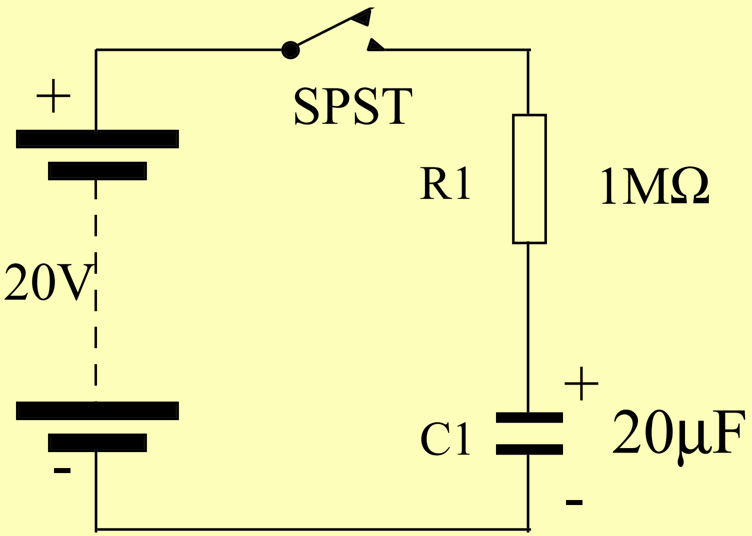
- A 20μF Capacitor is completely discharged. It is connected in series with a 1MΩ Resistor to a 20V supply through a single pole switch. The switch is closed and the capacitor becomes fully charged.
  - a) Draw a diagram of the circuit and indicate the polarities of the supply and the capacitor when it is fully charged.
  - b) Determine the final charge on the Capacitor.
  - c) Calculate the energy stored in the capacitor when it is fully charged.
  - d) Calculate the value of the current immediately after the switch is closed.

Solution

Capacitors.

- a) Draw a diagram of the circuit and indicate the polarities of the supply and the capacitor when it is fully charged.

SPST
Single Pole
Single Throw



Solution

Capacitors.

- b) Determine the final charge on the Capacitor.
- Charge $Q = CV$ C= 20μF, V= 20 Volts
- Therefore Charge = $20*10^{-6} * 20 = 400\mu C$

Next Calculation.

- c) Calculate the energy stored in the capacitor when it is fully charged.
- Energy $W = ½CV^2 = 0.5* 20*10^{-6} * 20^2 = 4mJ$

Solution

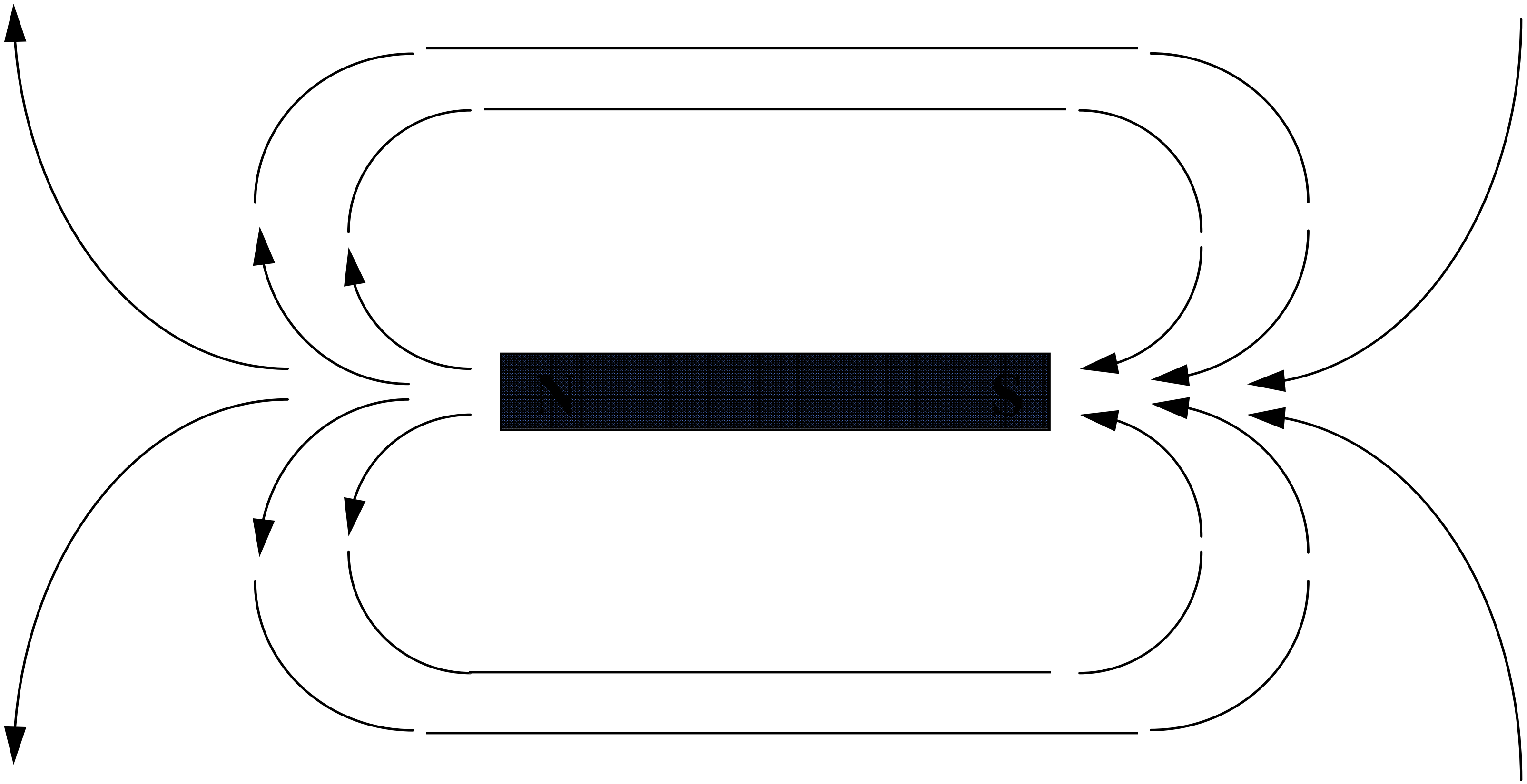
Capacitors.

- d) Calculate the value of the current immediately after the switch is closed.
- Voltage across Capacitor = 0 Volts
- Voltage across Resistor = VSupply - 0 = 20Volts
- Therefore as Resistor is totally responsible for limiting the current then I = V/R

  $= 20V/1M\Omega = 20/10^6$ Amps
- Current = 20μA

Magnetism.

Magnetism.

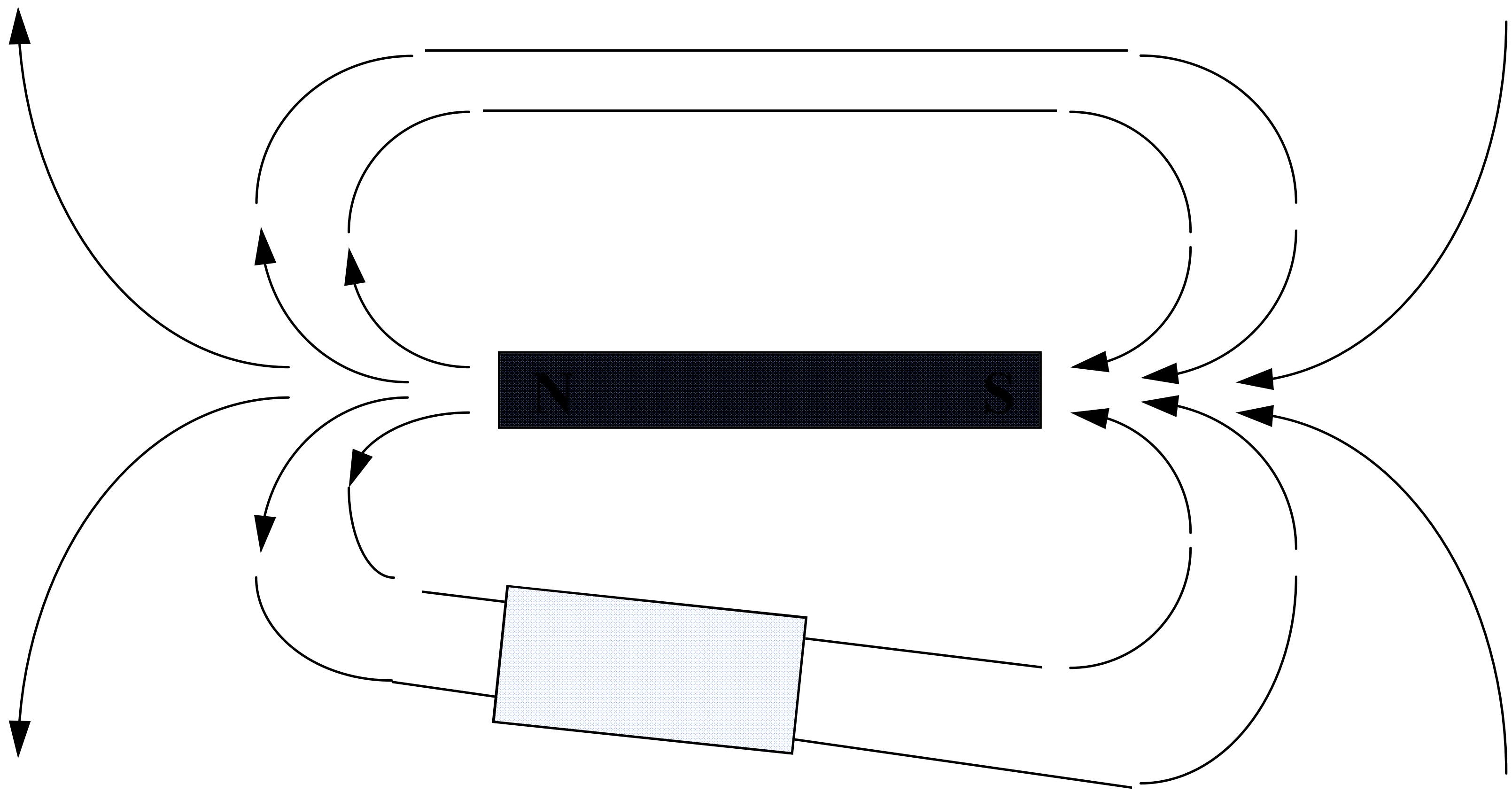


Lines of Flux around a Magnet

Magnetism.

- Terms and Concepts :-
- Magnetic Flux ϕ (phi) measured in Webers Wb
  - 1Wb = 10^8 lines of Flux
  - or 1μWb = 100 lines of Flux **(more common Unit)**

Magnetism.

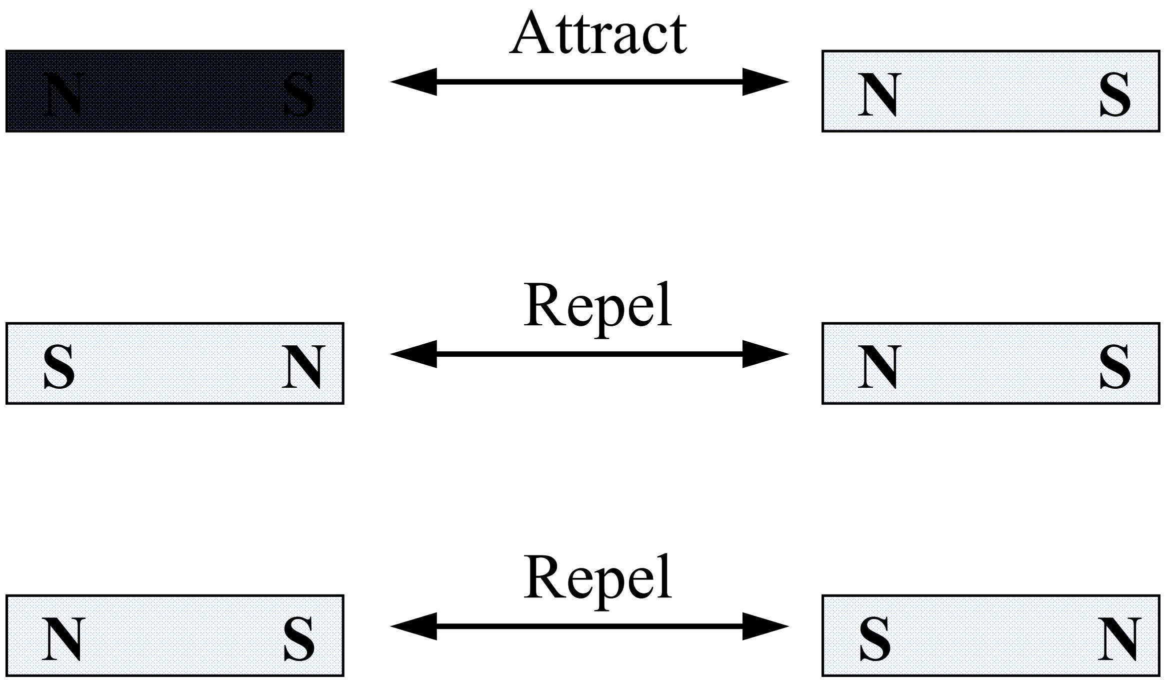


Lines of Flux around a Magnet Distorted by Iron Bar.

Magnetism.

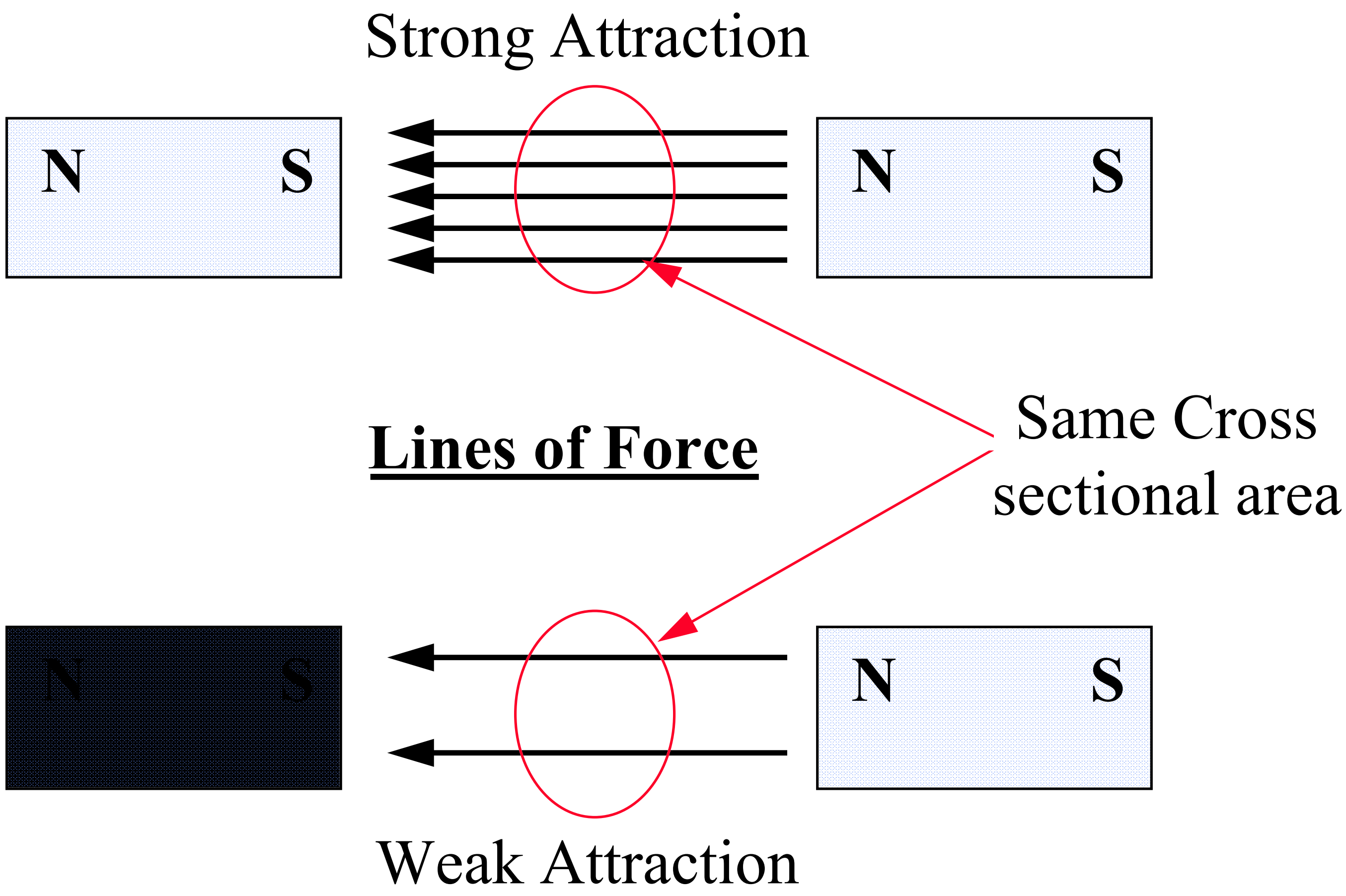
- Terms and Concepts :-
- Magnetic Flux ϕ (phi) measured in Webers Wb
  - 1Wb = 10^8 lines of Flux
  - or 1μWb = 100 lines of Flux **(more common Unit)**
- The line of flux can have their course changed or focused by the use of an Iron former.

Magnetism.



Magnet Attraction and Repulsion

Magnetism.



Magnet Attraction and Line of Force

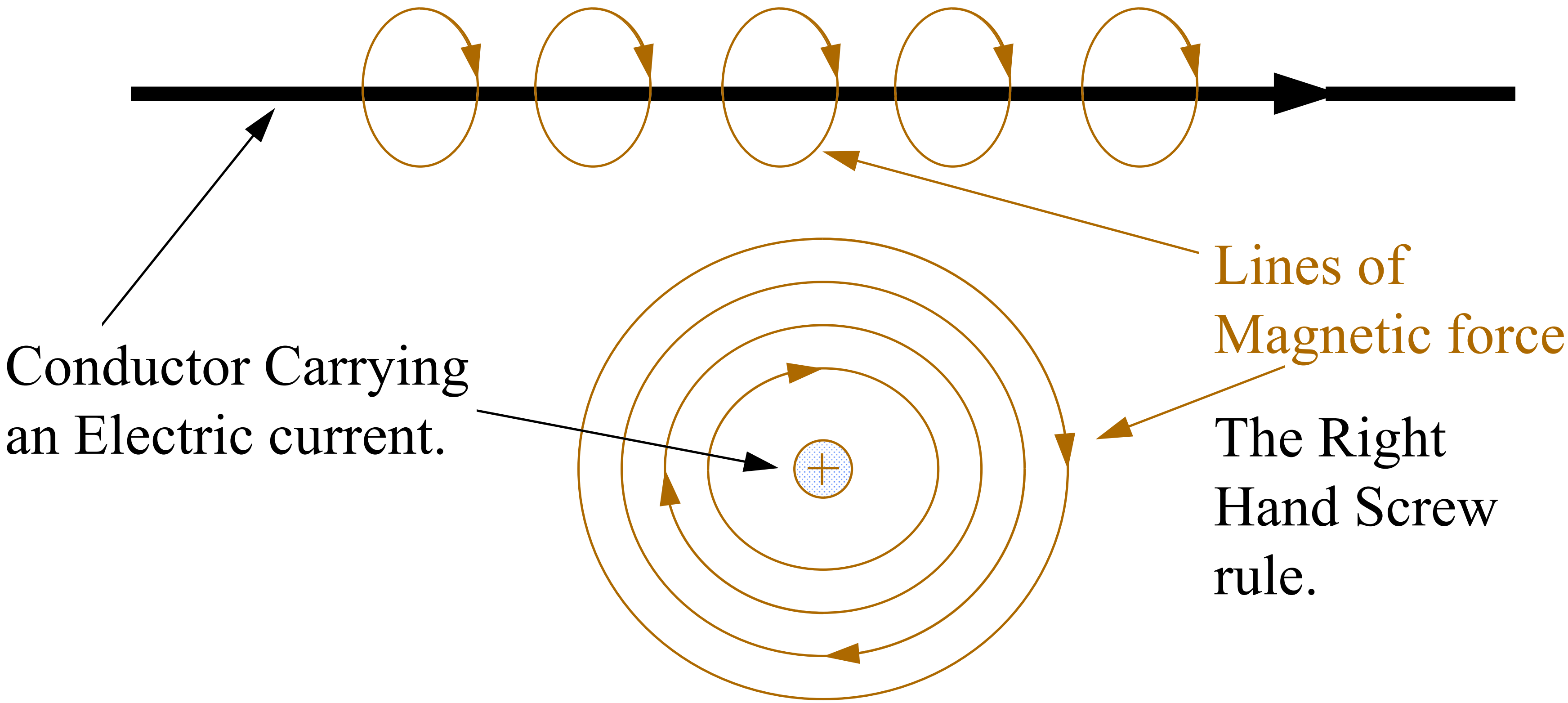
Magnetism.

- Terms and Concepts :-
- Magnetic Flux ϕ (phi) measured in Webers Wb
  - 1Wb = 10^8 lines of Flux
  - or 1μWb = 100 lines of Flux **(more common Unit)**
- The line of flux can have their course changed or focused by the use of an Iron former.
- Flux Density B measured in Wb/m^2 or Tesla (T)

$$\text{Flux Density } \mathbf{B} = \frac{\text{Magnetic Flux } \phi}{\text{Area in Metres}^2 \ \mathbf{A}}$$

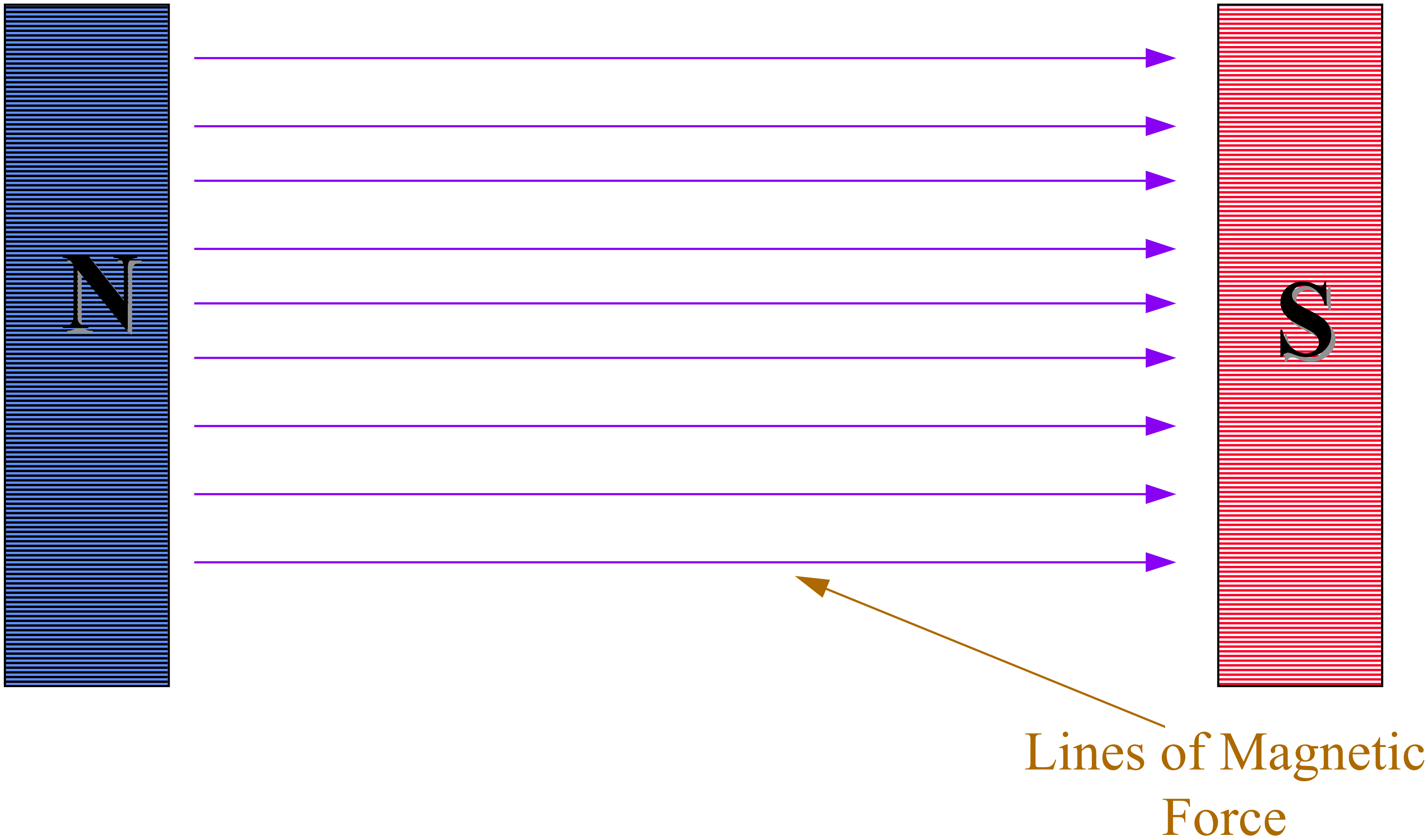
Electromagnetism.

Electromagnetism.



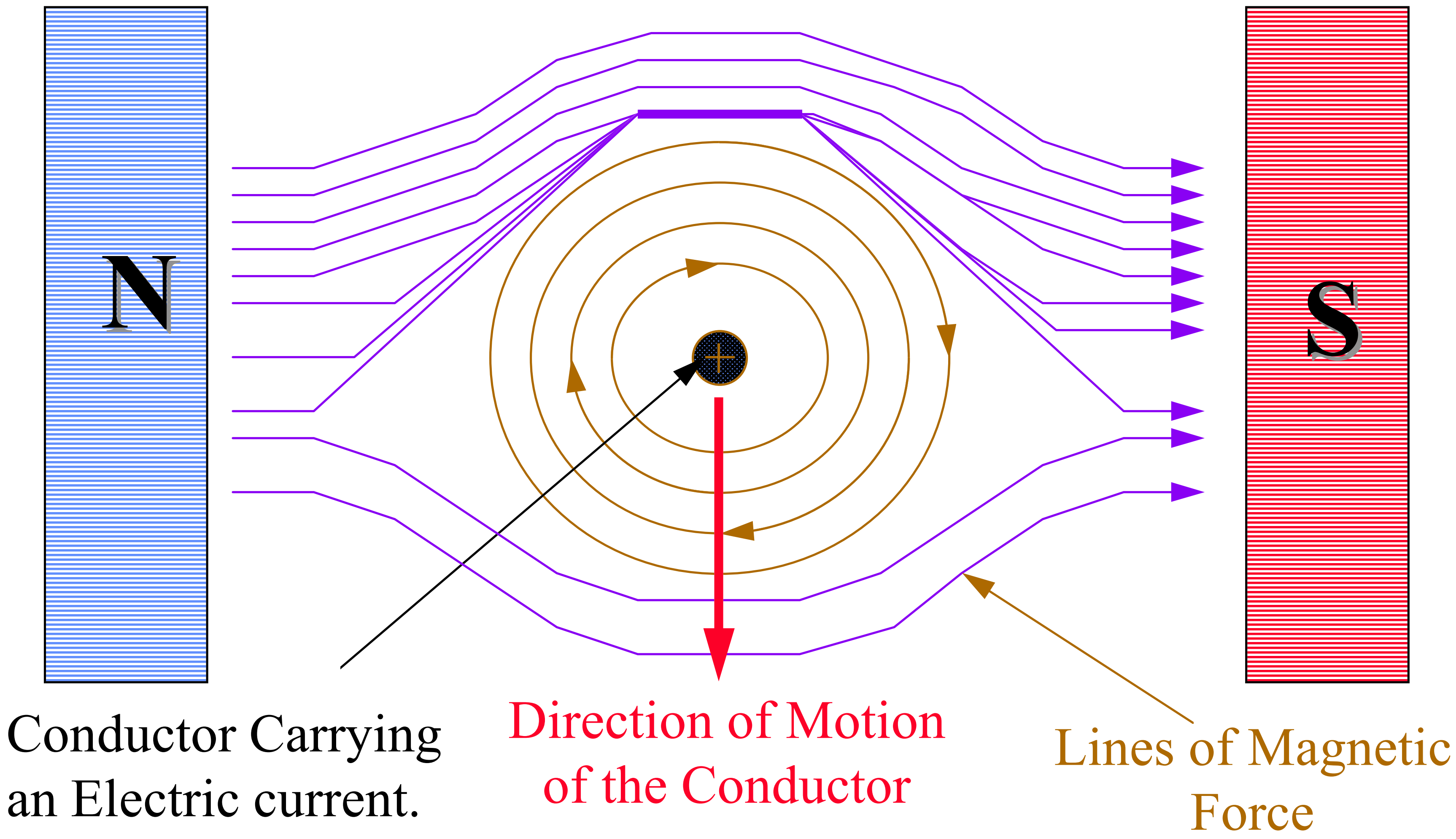
The Magnet effect of current passing through a conductor.

Electromagnetism.



Lines of Magnetic force.

Electromagnetism.



The effect of current passing through a conductor in a magnetic field.

Electromagnetism.

- Terms and Concepts :-
- Force on the current - carrying conductor in Newtons is dependent on :-
  - Flux Density ***B*** measured in Wb/m^2 or Tesla (T)
  - The Strength of the Current ***I*** amperes.
  - The length of the conductor perpendicular to the magnetic field, ***l*** metres, and
  - the directions of the field and the current

When Magnetic field and conductor are at right angles then:-
Force in newtons **F** = Flux Density **B** * Current **I** * Length **l**

When Magnetic field and conductor are at θ^o to each other then:-
Force in newtons **F** = **B * I * l * sin(θ)**

Electromagnetism.

- Example:-
- Calculate the flux density in a piece of iron of circular cross-section, radius 5 cm, if the flux in the iron is 0.5 Wb.
- Calculate

  (a) The Flux density.

Electromagnetism.

- Example:-
- Calculate the flux density in a piece of iron of circular cross-section, radius 5 cm, if the flux in the iron is 0.5 Wb.
- Calculations:-
  - Find the cross sectional area of the iron.

Area of cross section = $\pi * R^2 = \pi * (5*10^{-2})^2 = 78.54*10^{-4}\ m^2$

Electromagnetism.

- Example:-
- Calculate the flux density in a piece of iron of circular cross-section, radius 5 cm, if the flux in the iron is 0.5 Wb.
- Calculations:-
  – Find the flux density.

Area of cross section $A = \pi * R^2 = \pi * (5*10^{-2})^2 = 78.54*10^{-4}\ m^2$

Flux density B = flux ϕ /area $A = 0.5 / 78.54*10^{-4} = 63.66\ Wb/m^2$

Flux density $B = 63.66$ Tesla

Electromagnetism.

- Example:-
- A 1.5 cm length of wire is placed at right angles to a magnetic field of flux density 0.08T. A current of 2 amps flows. What amount of force is exerted between the wire and the flux?
- Calculate

  (a) The force on the wire.

Electromagnetism.

- Example:-
- A 1.5 cm length of wire is placed at right angles to a magnetic field of flux density 0.08T. A current of 2 amps flows. What amount of force is exerted between the wire and the flux?
- Calculate

  (a) The force on the wire.

Force = Flux Density B * Current I $*$ Length of wire in flux L

Force $= 0.08 * 2 * 1.5 * 10^{-2} = 2.4 * 10^{-3}$ Newtons

Electromagnetism.

- Example:-
- A Flux of 1mWb is present in a square section air gap of 2cm by 2cm. A wire carrying 2 Amps is across the middle of the gap.
- Calculate

  (a) The Flux density.

  (b) The force on the wire.

Electromagnetism.

- Example:-
- A Flux of 1mWb is present in a square section air gap of 2cm by 2cm. A wire carrying 2 Amps is across the middle of the gap.
- Identify what we know:-
  - Length $l = 2*10^{-2}$
  - Area = $l*l = l^2 = 2*10^{-2} * 2*10^{-2} = 4*10^{-4}$ m^2
  - Flux $\phi = 10^{-3}$ Wb
  - Current I = 2A

Electromagnetism.

- Example:-
- The calculations:-
  - Length l = $2*10^{-2}$
  - Area A= $4*10^{-4}$ m^2
  - Flux $\phi = 10^{-3}$ Wb
  - Current I = 2A
  - Find Flux Density

$$\textbf{Flux Density B} = \frac{\text{Flux } \phi}{\text{Area where the Flux flows}} \quad Wb/m^2$$

Electromagnetism..

- Example:-
- The calculations:-
  - Length l = $2*10^{-2}$
  - Area A= $4*10^{-4}$ m^2
  - Flux $\phi = 10^{-3}$ Wb
  - Current I = 2A
  - Find Flux Density

$$\textbf{Flux Density B} = \frac{10^{-3}}{4 * 10^{-4}} \quad Wb/m^2$$

Flux Density B = 2.5 Wb/m^2

Electromagnetism.

- Example:-
- The calculations:-
  – Length l = $2*10^{-2}$
  – Current I = 2A
  – Flux Density B = 2.5 **Wb/m^2**
  – Find Force on wire.

Force **F** in Newtons =

Flux Density **B** * Current **I** ∗ Length of wire in flux ***l***

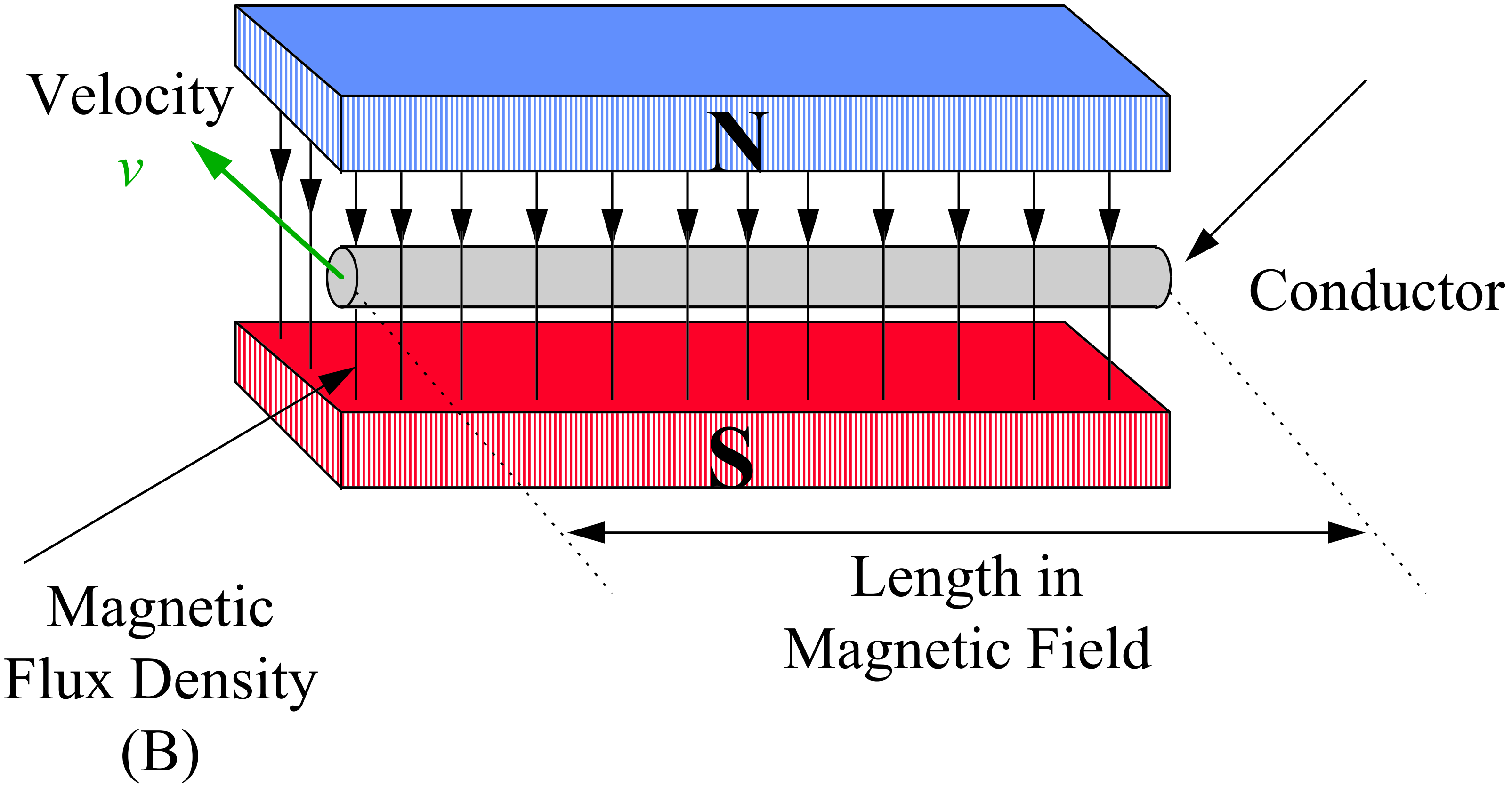
Electromagnetism.

- Example:-
- The calculations:-
  - Length l = $2*10^{-2}$
  - Current I = 2A
  - Flux Density B = 2.5 **Wb/m²**
  - Find Force on wire.

Force in Newtons = 2.5 * 2 * $2*10^{-2}$

Force in Newtons = 0.1 N

Electromagnetism.



Electromagnetic Induction.

Electromagnetism.

- Terms and Concepts :-
- The induced electro motive force e.m.f. in a conductor in Volts is dependent on :-
  - Flux Density ***B*** measured in Wb/m^2 or Tesla (T)
  - The Velocity ***v*** that the conductor moves measured in metres per second.
  - The length of the conductor perpendicular to the magnetic field, ***l*** metres

When conductor moves at right angles Magnetic field and then:-
Induced e.m.f. **E** = Flux Density **B** * Length ***l*** * Velocity ***v***

When Magnetic field and conductor are at θ^o to each other then:-
Induced e.m.f. **E** = **B** * ***l*** * ***v*** * **sin(θ)**

Electromagnetism.

- Example:-
- A conductor 300mm long moves at a uniform speed of 4m/s at right angles to a uniform magnetic field of flux density 1.25T
- Calculate

  The current flowing in the conductor when :-

  (a) The ends are open circuited.

  (b) The ends are terminated to a load of 20Ω .

Electromagnetism..

- Example:-
- The calculations:-
  - Length ***l*** = $300 * 10^{-3}$
  - Velocity ***v*** = 4 metres/second
  - Flux Density B = 1.25Tesla or 1.25**Wb/m²**

Induced e.m.f. E =

Flux Density **B** * Length of wire in flux ***l*** * Velocity *v*

$E = 1.25 * (300 * 10^{-3}) * 4 = 1.5$ volts

Electromagnetism..

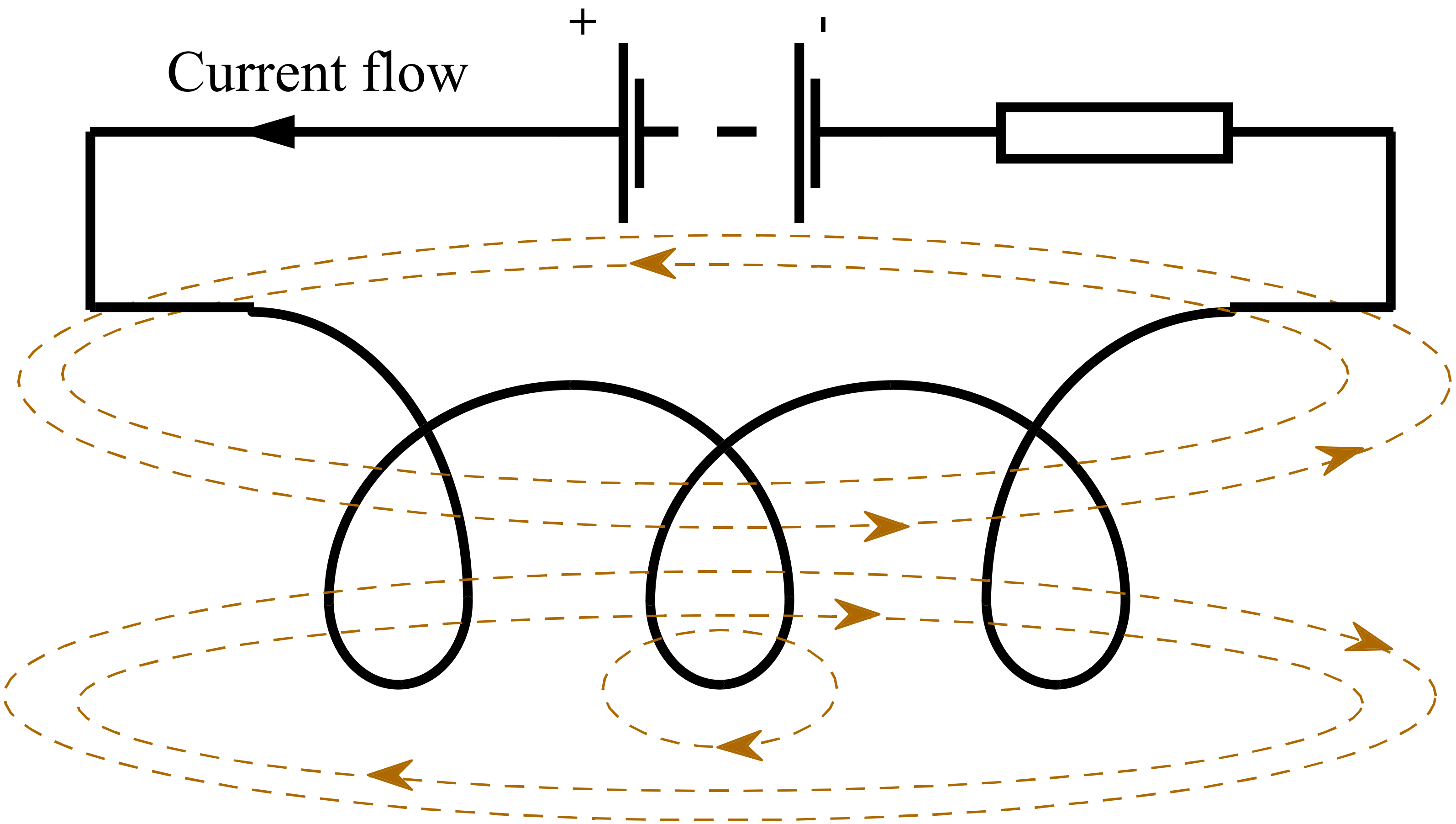
- Example:-
- The calculations:-
  - Length $\boldsymbol{l}$ = $300*10^{-3}$
  - Velocity $\boldsymbol{v}$ = 4 metres/second
  - Flux Density B = 1.25Tesla or 1.25**Wb/m^2**
  - Induced e.m.f E = 1.5 volts

(a) If the ends of the conductor are open circuit no current will flow even though 1.5V has been induced.

(b) From Ohm's law

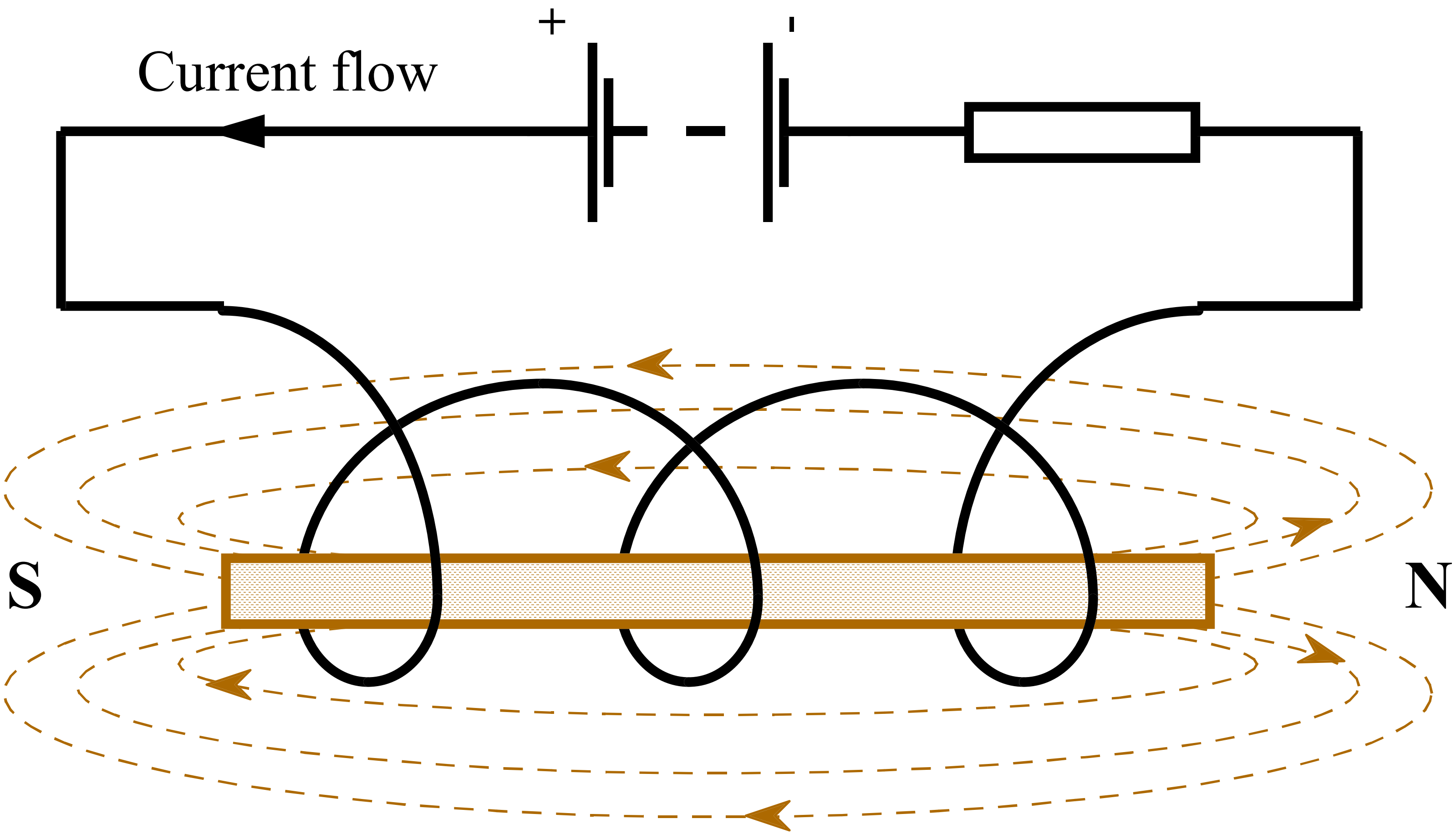
I = V/R = 1.5/20 = 0.075A or 75mA

Electromagnetism.



The Magnet effect of current passing through a coil or Solenoid.

Electromagnetism.



The Magnet effect Intensified due to insertion of an Iron Core.

Electromagnetism.

- You have seen that a current flowing in a wire produces a magnetic field
- The force that produces the magnetic field is the **m**agneto**m**otive **f**orce (**mmf**)
- The unit of **mmf** is the Ampere-turn (**At**) is established on the basis of the current in a single loop(turn) of wire.

mmf = Number of Turns * Current in Amperes

$$Fm = N * I$$

<u>Electromagnetism.</u>

- Terms and Concepts :-
- The Magnetising Force (H) depends on three factors:-
  - The number of turns (N) of the coil of wire
  - The current through the coil.
  - The length of the coil
  - It does **<u>NOT</u>** depend on the type of material.
- Magnetising Force H measured in At/m .
  - At/m = Ampere turns per metre.

$$\text{Magnetising Force } \mathbf{H} = \frac{\text{Magnetomotive Force Fm}}{\text{Length in Metres } \boldsymbol{l}}$$

Electromagnetism.

- Permeability (μ):-
- The ease which a magnetic field can be established in a given material is measured by the **permeability** of the material.
- The higher the permeability, the more easily a magnetic field can be established.
- The symbol of permeability is μ (the Greek letter mu).
- The Permeability value $\mu = \mu_0 * \mu r$ (in Weber per ampere turn metre (Wb/Atm))
  - where μ_0 = permeability of a vacuum.
  - μ_r = relative permeability of the material.
  - $\mu_0 = 4\pi * 10\text{-}7$ Wb/Atm.

Electromagnetism.

- Reluctance ($\Re$):-
- The opposition to the establishment of a magnetic field in a material is called **reluctance** ($\Re$).
- The value of reluctance is directly proportional to the length (***l***) of the magnetic path, and inversely proportional to the permeability (μ) and the cross sectional area (**A**) of the material and is expressed with the following equation:-

$$\Re = \frac{l}{\mu A}$$

A = Area in square metres.
l = Length in metres.
μ = in Wb/Atm.
$\Re$ = Reluctance in Ampere-turn/Weber.

Electromagnetism.

- Example:-
- What is the reluctance of a material that has :-
- A length of 0.05m,
- A cross sectional area of 0.012 m^2,
- and a permeability of 3500 μWb/Atm?

Electromagnetism.

- Example:-
- What is the reluctance of a material that has :-
- A length of 0.05m,
- A cross sectional area of 0.012 m^2,
- and a permeability of 3500 μWb/Atm?

$$\Re = \frac{l}{\mu A} = \frac{0.05}{3500*10^{-6} * 0.012} = 1190 \text{ At/Wb}$$

Concept. # Electromagnetism.

- Ohms law of magnetic circuits :-
- The flux is (ϕ)analogous to current, the mmf (**Fm**) is analogous to voltage, and the reluctance($\Re$) is analogous to resistance.

$$\Re = \frac{Fm}{\phi}$$

$$Fm = \Re * \phi$$

or

$$\phi = \frac{Fm}{\Re}$$

Fm = Magnetomotive force (mmf).
ϕ = in Wb.
$\Re$ = Reluctance in Ampere-turn/Weber.

Electromagnetism.

- Example:-
- There are two amperes through a wire with five turns :-
- What is the mmf?
- What is the reluctance of the circuit if the flux is 250 μWb?

Electromagnetism.

- Example:-
- There are two amperes through a wire with five turns :-
- What is the mmf?
- What is the reluctance of the circuit if the flux is 250 μWb?

Solution

N = 5 and I = 2A

Fm = NI = (5t)*(2A) = 10At

Electromagnetism.

- Example:-
- There are two amperes through a wire with five turns :-
- What is the mmf?
- What is the reluctance of the circuit if the flux is 250 μWb?

$$\Re = \frac{Fm}{\phi}$$

Solution

Fm = 10 and ϕ = 250μWb

$\Re$ = 10At /250 * 10^{-6} = 0.04 * 10^{6} = 4 * 10^{4} At/Wb

Electromagnetism.

Relating units B & H

Where

B = Flux Density.

and

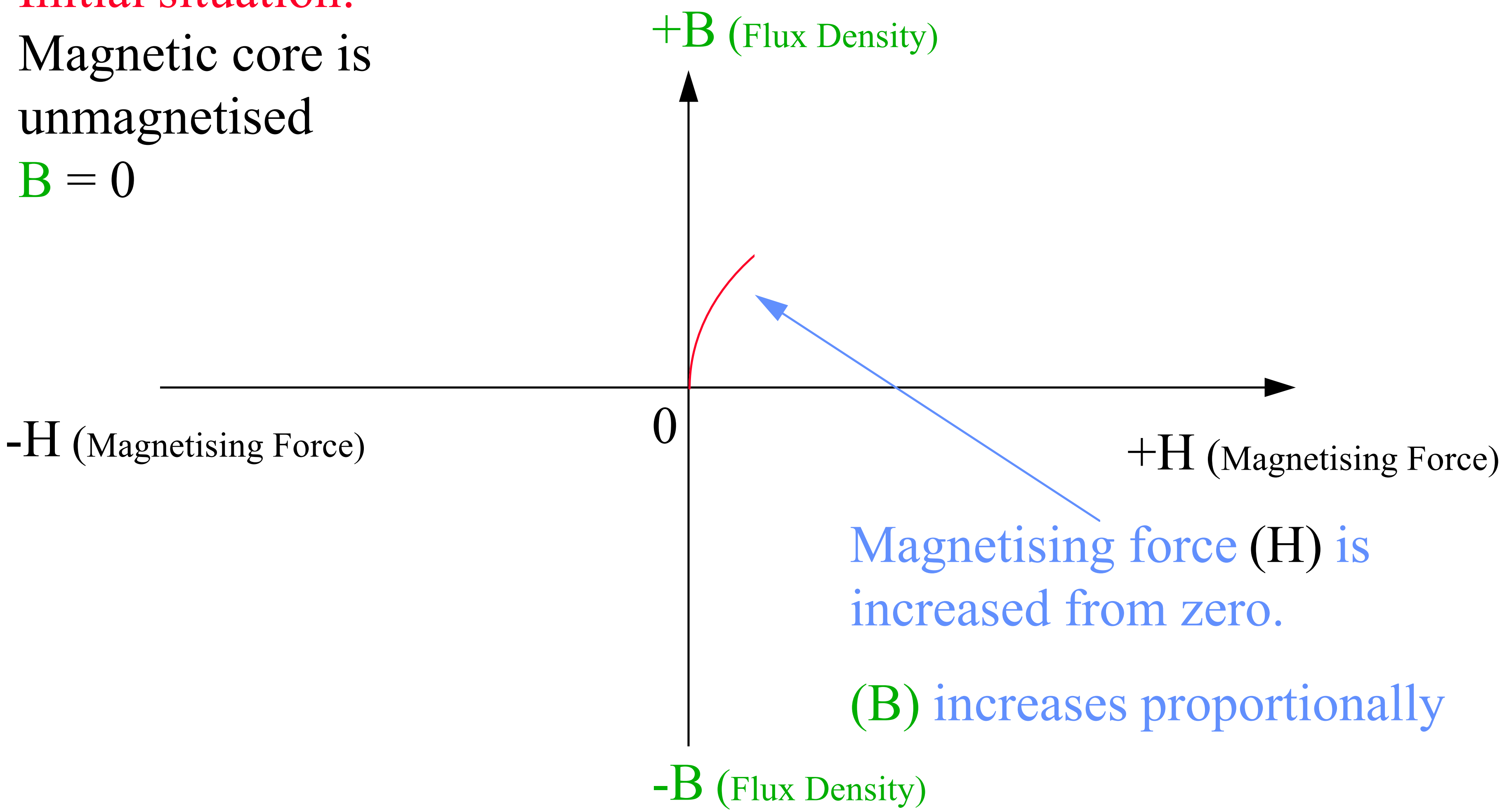
H = Magnetising force.

Electromagnetism.

- **Hysteresis** is a characteristic of a magnetic material where a change in magnetisation lags the application of a magnetising force.
- The magnetising force (H) can readily be increased or decreased by varying the current through the coil of wire.
- The magnetising force (H) can readily be reversed by reversing the voltage polarity across the coil of wire.

Electromagnetism.

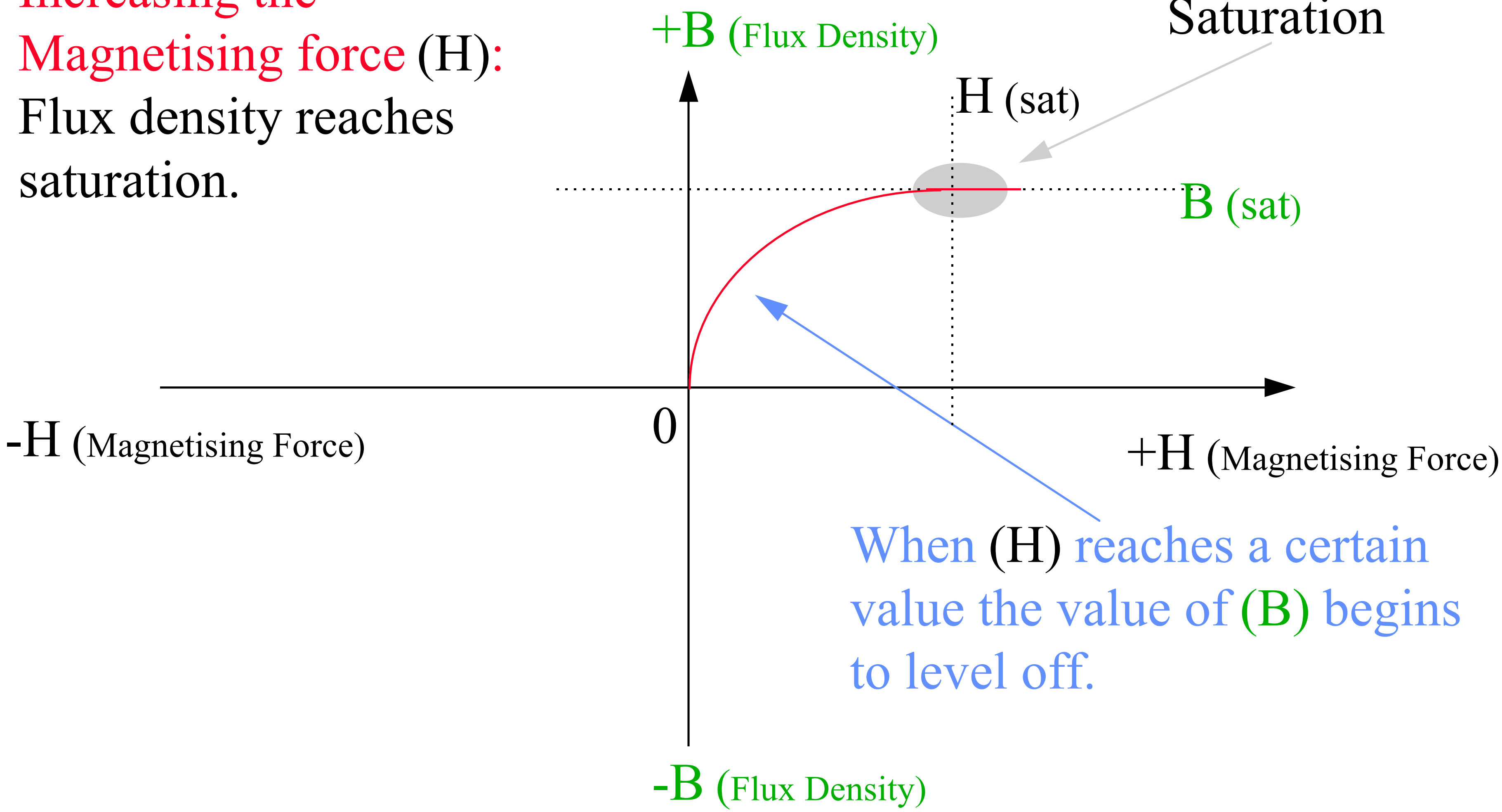
Initial situation:
Magnetic core is unmagnetised
B = 0



The Hysteresis Curve and Retentivity.

Electromagnetism.

Increasing the Magnetising force (H): Flux density reaches saturation.

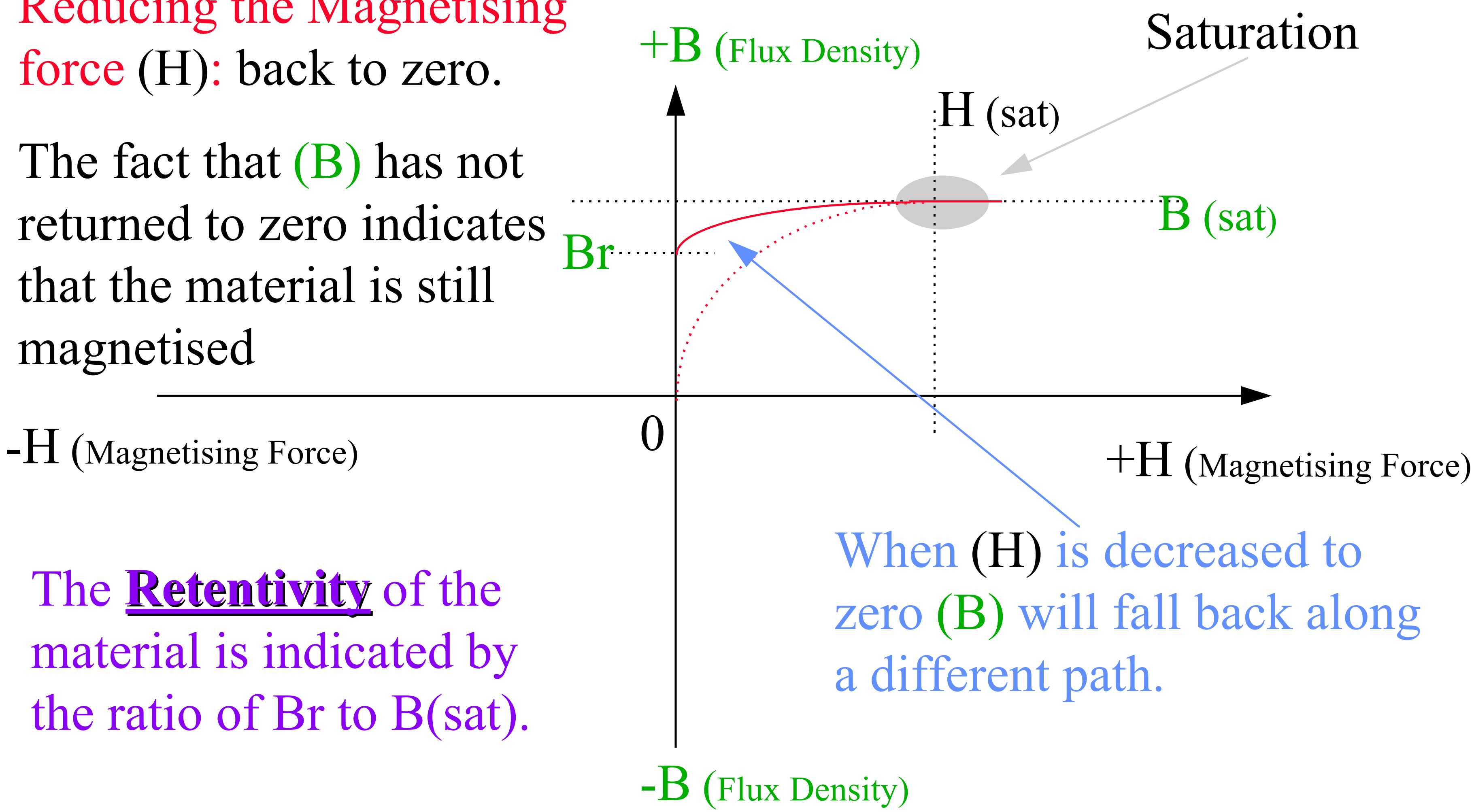


The Hysteresis Curve and Retentivity.

Electromagnetism.

Reducing the Magnetising force (H): back to zero.

The fact that (B) has not returned to zero indicates that the material is still magnetised



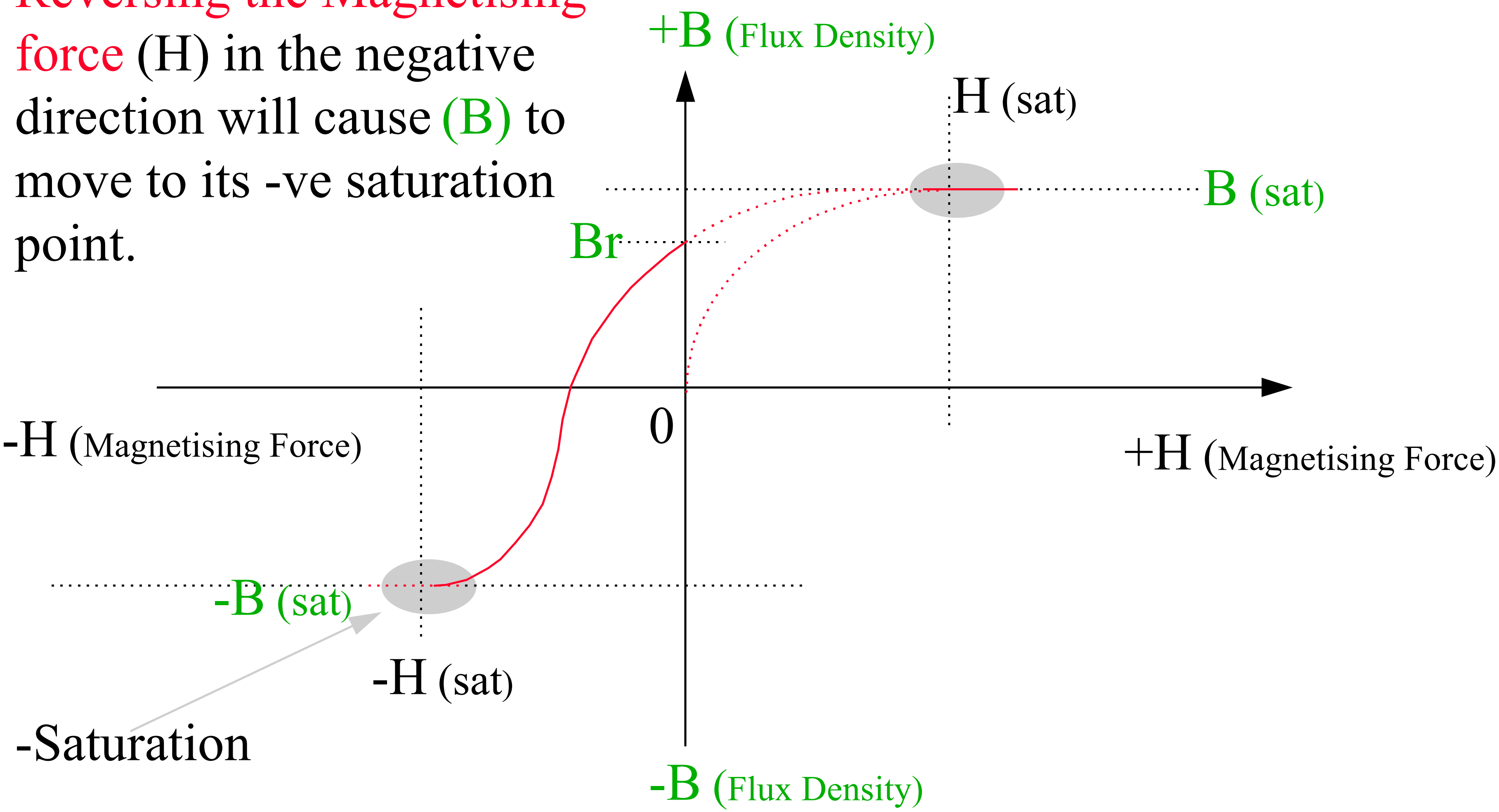
When (H) is decreased to zero (B) will fall back along a different path.

The **Retentivity** of the material is indicated by the ratio of Br to B(sat).

The Hysteresis Curve and Retentivity.

Electromagnetism.

Reversing the Magnetising force (H) in the negative direction will cause (B) to move to its -ve saturation point.

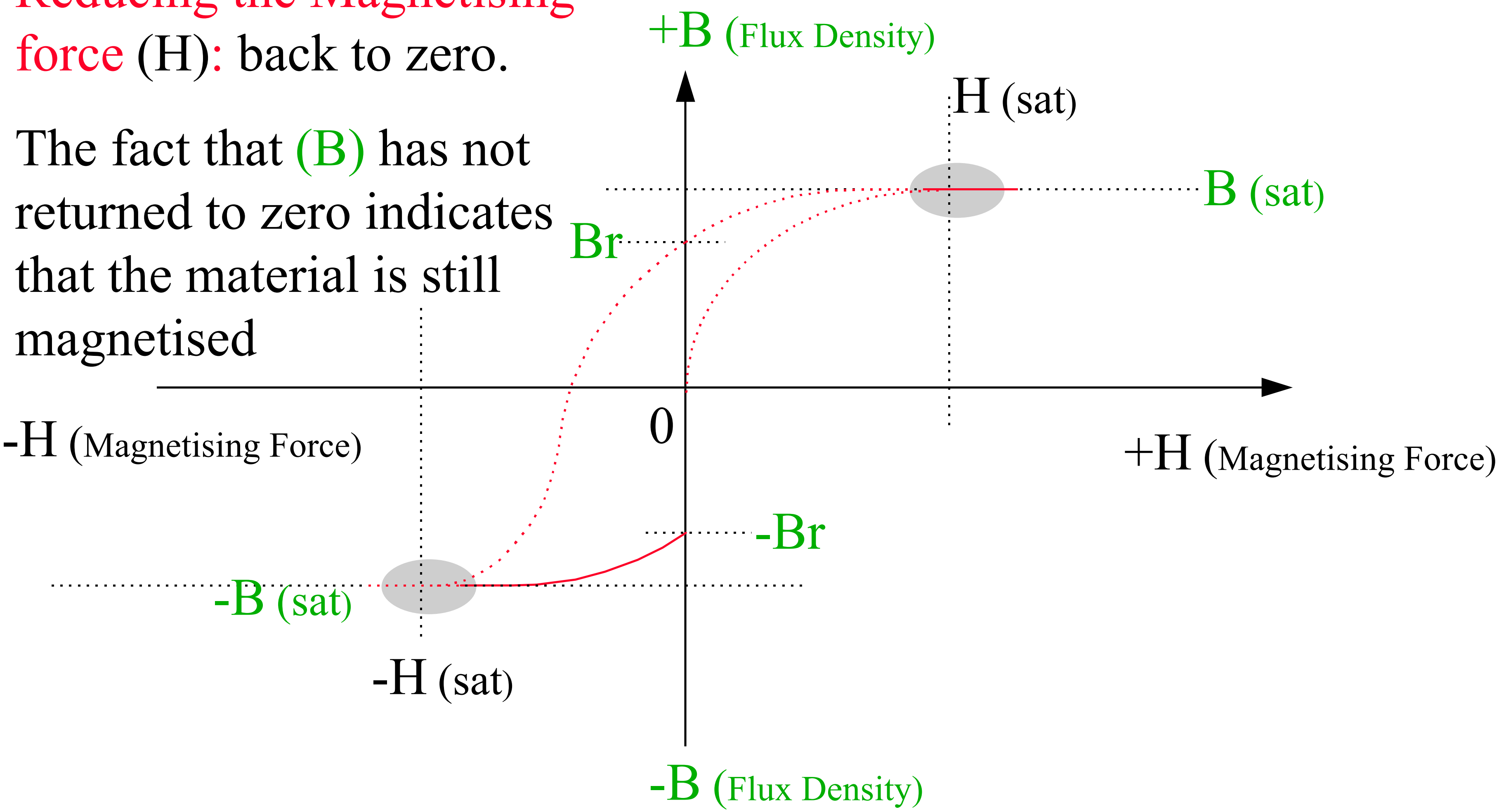


The Hysteresis Curve and Retentivity.

Electromagnetism.

Reducing the Magnetising force (H): back to zero.

The fact that (B) has not returned to zero indicates that the material is still magnetised

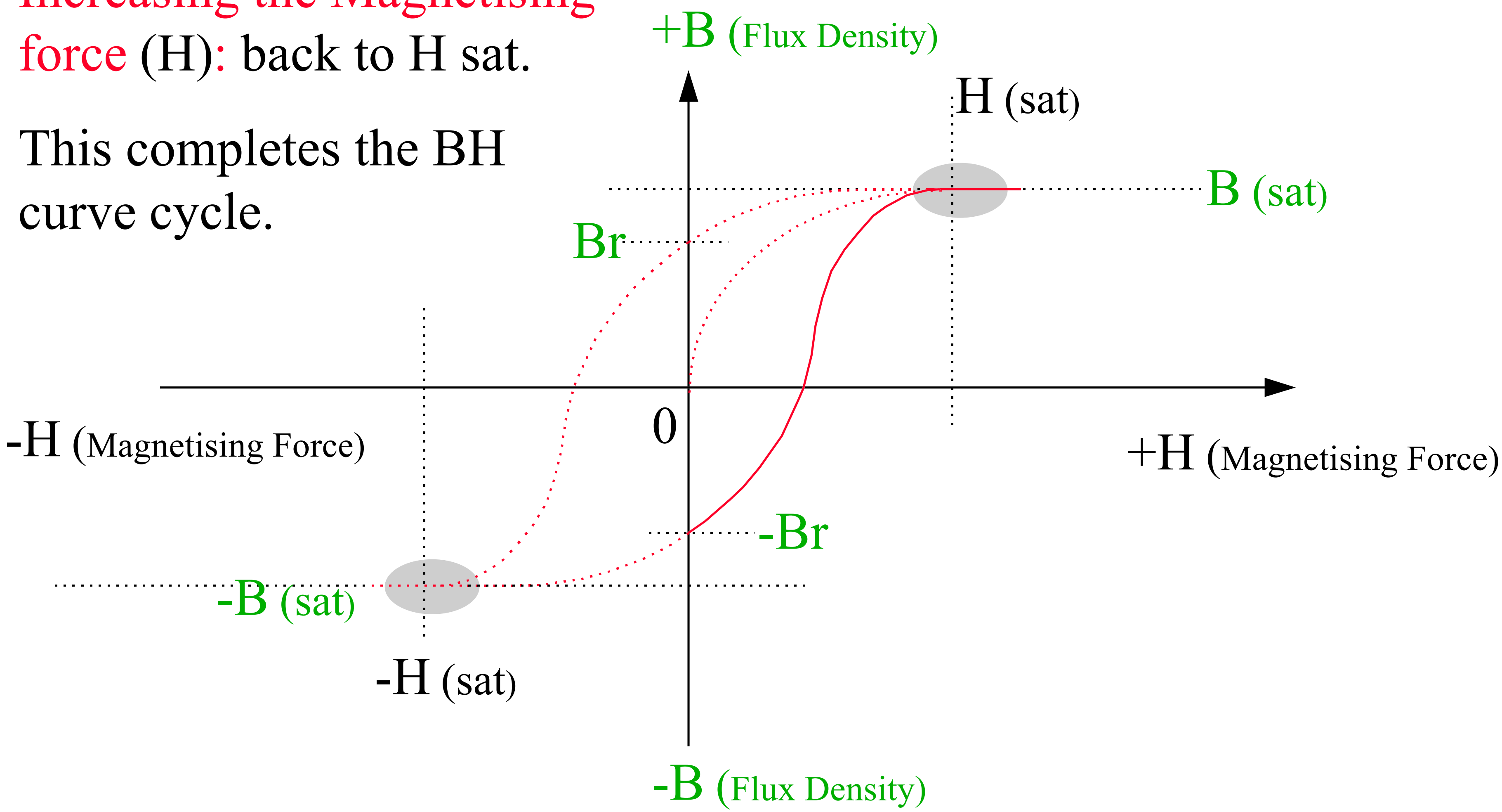


The Hysteresis Curve and Retentivity.

Electromagnetism.

Increasing the Magnetising force (H): back to H sat.

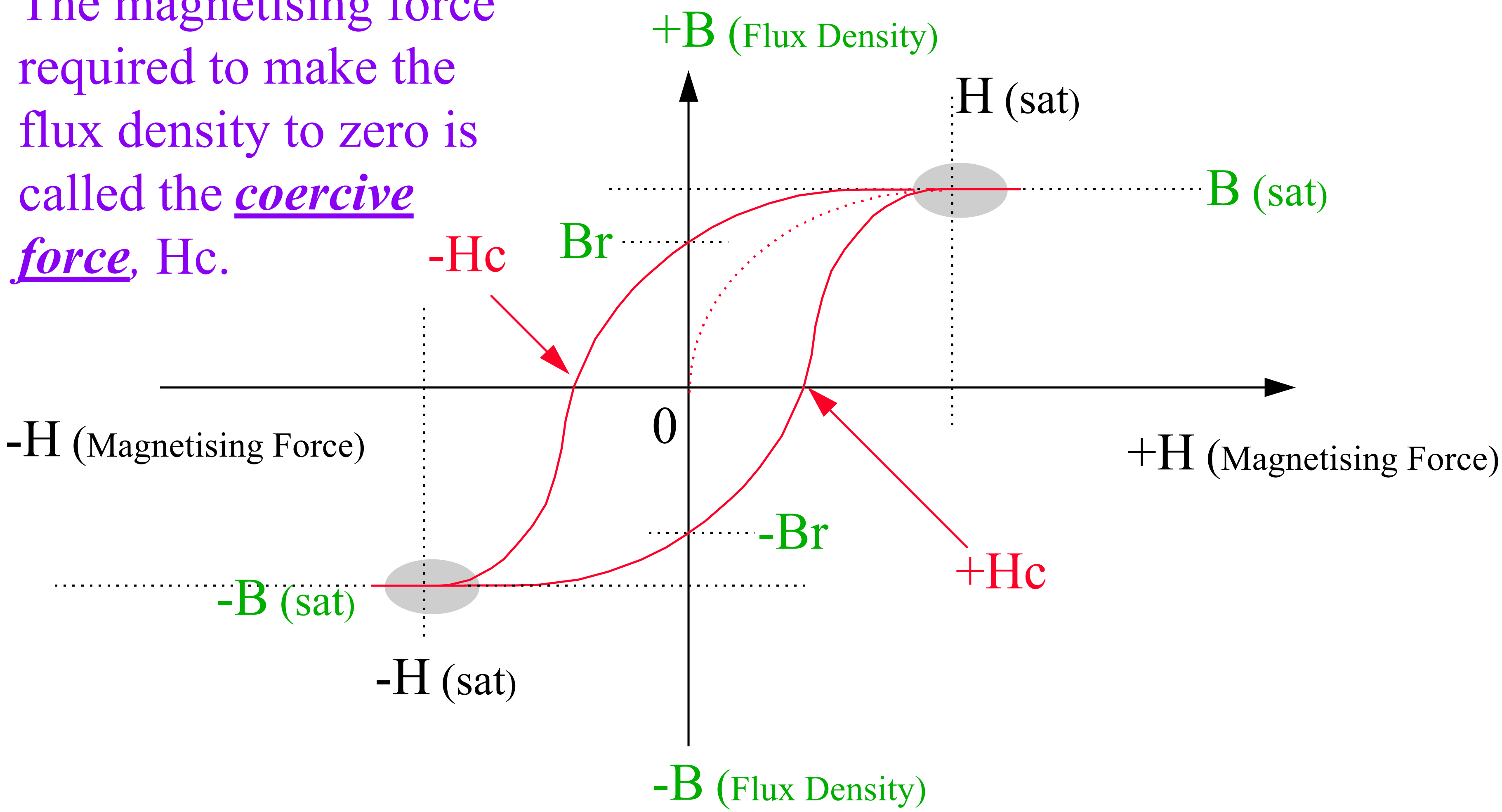
This completes the BH curve cycle.



The Hysteresis Curve and Retentivity.

Electromagnetism.

The magnetising force required to make the flux density to zero is called the ***coercive force***, Hc.



The Hysteresis Curve and Retentivity.

Electromagnetism.

Summary

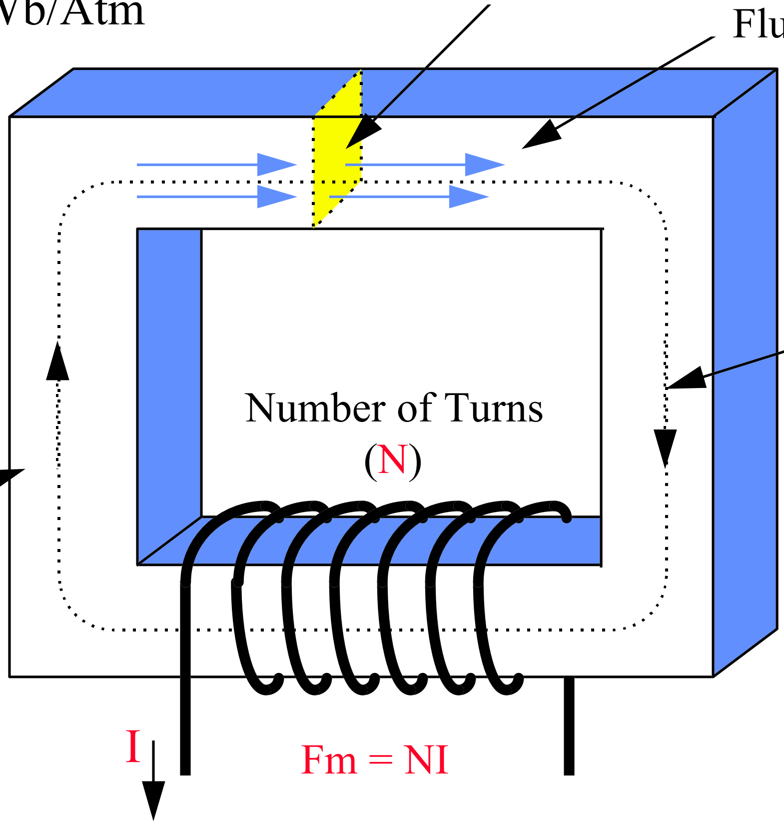
- Material with a Low Retentivity do not retain magnetic fields very well.
- A permanent magnet requires a material with a High Retentivity.
- In AC Motors and Transformers Retentivity is undesirable because the residual magnetic field must be overcome each time the current reverses wasting energy.

Electromagnetism.

$$\mu_0 = 4\pi * 10^{-7} \text{ Wb/Atm}$$

$$\mu = \mu_r * \mu_0$$

$$\Re = \frac{l}{\mu A}$$



$$B = \frac{\phi}{A}$$

$$H = \frac{Fm}{l}$$

$$\phi = \frac{Fm}{\Re}$$

$$\phi * \Re = Fm$$

Electromagnetic Relationships.

Electromagnetism.

$\mu_0 = 4\pi * 10^{-7}$ Wb/Atm

$\mu = \mu_r * \mu_0$

$\Re = \dfrac{l}{\mu A}$

Reluctance of core material ($\Re$)

$\phi = \dfrac{Fm}{\Re}$

$\phi * \Re = Fm$

What we are looking for now is the relationship between B and H

$H = \dfrac{Fm}{l}$

$B = \dfrac{\phi}{A}$

Electromagnetic Relationships.

Electromagnetism.

$\mu_0 = 4\pi * 10^{-7}$ Wb/Atm

$\mu = \mu_r * \mu_0$

$\Re = \dfrac{l}{\mu A}$

Reluctance of core material ($\Re$)

$\phi = \dfrac{Fm}{\Re}$

$\phi * \Re = Fm$

$H = \dfrac{Fm}{l}$

$B = \dfrac{\phi}{A}$

Re-arrange:

To make Cross sectional Area "A" the focus of the equation

Electromagnetic Relationships.

Electromagnetism.

$\mu_0 = 4\pi * 10^{-7}$ Wb/Atm

$\mu = \mu_r * \mu_0$

$A = \dfrac{l}{\mu * \Re}$

$\Re = \dfrac{l}{\mu A}$

Reluctance of core material ($\Re$)

$H = \dfrac{Fm}{l}$

$B = \dfrac{\phi}{A}$

$\phi = \dfrac{Fm}{\Re}$

$\phi * \Re = Fm$

Next re-arrange:

Magnetising Force in terms of Reluctance and Flux density

Electromagnetic Relationships.

Electromagnetism.

$\mu\ \mu_0 = 4\pi * 10^{-7}$ Wb/Atm

$\mu = \mu_r * \mu_0$

$$\Re = \frac{l}{\mu A}$$

$$A = \frac{l}{\mu * \Re}$$

Reluctance of core material ($\Re$)

$$\phi = \frac{Fm}{\Re}$$

$$\phi * \Re = Fm$$

$$H = \frac{\phi * \Re}{l}$$

$$H = \frac{Fm}{l}$$

$$B = \frac{\phi}{A}$$

Next re-arrange so:

Flux density becomes focus of equation

Electromagnetic Relationships.

Electromagnetism.

$\mu_0 = 4\pi * 10^{-7}$ Wb/Atm

$\mu = \mu_r * \mu_0$

$$\Re = \frac{l}{\mu A}$$

$$A = \frac{l}{\mu * \Re}$$

$$H = \frac{\phi * \Re}{l}$$

$$H = \frac{Fm}{l}$$

$$\phi = \frac{H * l}{\Re}$$

$$B = \frac{\phi}{A}$$

Reluctance of core material ($\Re$)

$$\phi = \frac{Fm}{\Re}$$

$\phi * \Re = Fm$

Next substitute these equations:

into this equation

Electromagnetic Relationships.

Electromagnetism.

$\mu_0 = 4\pi * 10^{-7}$ Wb/Atm

$\mu = \mu_r * \mu_0$

$$\Re = \frac{l}{\mu A}$$

$$A = \frac{l}{\mu * \Re}$$

Reluctance of core material ($\Re$)

$$\phi = \frac{Fm}{\Re}$$

$$\phi * \Re = Fm$$

$$H = \frac{Fm}{l}$$

$$H = \frac{\phi * \Re}{l}$$

$$\phi = \frac{H * l}{\Re}$$

$$B = \frac{\phi}{A}$$

$$B = \frac{\frac{H * l}{\Re}}{\frac{l}{\mu * \Re}}$$

Simplifying this equations gives.

Electromagnetic Relationships.

Electromagnetism.

$\mu_0 = 4\pi * 10^{-7}$ Wb/Atm

$\mu = \mu_r * \mu_0$

$$\Re = \frac{l}{\mu A}$$

$$A = \frac{l}{\mu * \Re}$$

Reluctance of core material ($\Re$)

$$\phi = \frac{Fm}{\Re}$$

$\phi * \Re = Fm$

$$H = \frac{Fm}{l}$$

$$H = \frac{\phi * \Re}{l}$$

$$\phi = \frac{H * l}{\Re}$$

$$B = \frac{\phi}{A}$$

$$B = \frac{\dfrac{H * l}{\Re}}{\dfrac{l}{\mu * \Re}} \quad \text{or} \quad \frac{H * l * \mu * \Re}{\Re * l}$$

Electromagnetic Relationships.

Electromagnetism.

$\mu_0 = 4\pi * 10^{-7}$ Wb/Atm

$\mu = \mu_r * \mu_0$

$$\Re = \frac{l}{\mu A}$$

$$A = \frac{l}{\mu * \Re}$$

$$H = \frac{Fm}{l}$$

$$H = \frac{\phi * \Re}{l}$$

$$\phi = \frac{H * l}{\Re}$$

$$B = \frac{\phi}{A}$$

Reluctance of core material ($\Re$)

$$\phi = \frac{Fm}{\Re}$$

$$\phi * \Re = Fm$$

$$B = \frac{\;\frac{H * l}{\Re}\;}{\;\frac{l}{\mu * \Re}\;} \quad \text{or} \quad \frac{H * l * \mu * \Re}{\Re * l}$$

B is proportional to ϕ.
ϕ is proportional to Fm.
H is proportional to Fm.
Therefore
H is proportional to B.

$B = \mu H$

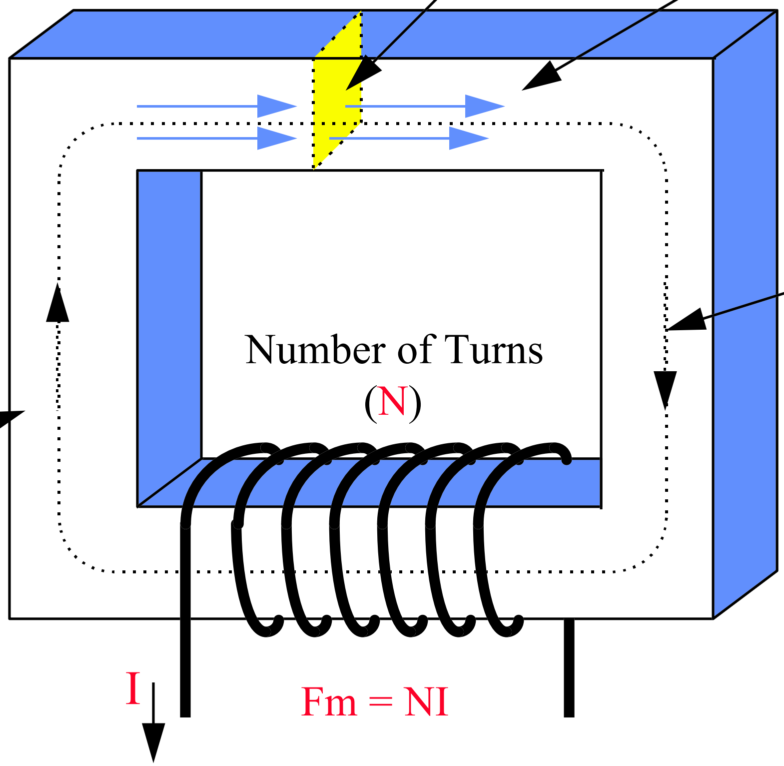
Electromagnetic Relationships.

Electromagnetism.

$\mu_0 = 4\pi * 10^{-7}$ Wb/Atm

$\mu = \mu_r * \mu_0$

$$\Re = \frac{l}{\mu A}$$



$$B = \frac{\phi}{A}$$

$$H = \frac{Fm}{l}$$

$$\phi = \frac{Fm}{\Re}$$

$\phi * \Re = Fm$

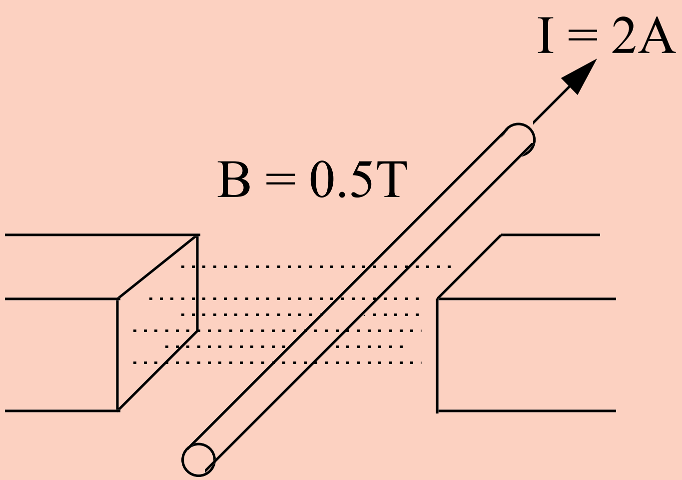
B is proportional to ϕ.
ϕ is proportional to Fm.
H is proportional to Fm.
Therefore
H is proportional to B.

$B = \mu H$

Electromagnetic Relationships.

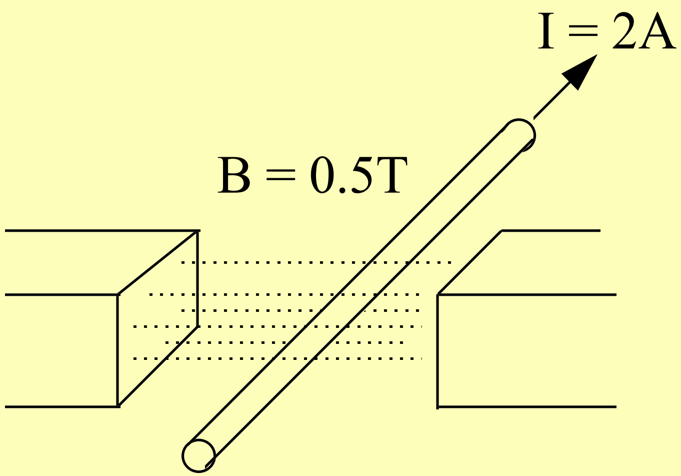
Example # Electromagnetism.

- A straight copper conductor of effective length 120mm rests in a magnetic field of flux density 0.5T as shown in diagram.
- a) Calculate the value of force on the conductor when it carries a steady current of 2A.



Example Electromagnetism.

- Force $F = BI\,l$
- Where :-
- $B = 0.5T$, $I = 2A$, $l = 120mm$
- Force $F = 0.5 * 2 * 120 * 10^{-3} = 0.12$ N



Example

Electromagnetism.

- b) An electromagnet consists of a coil of wire wound over a cylindrical piece of solid steel. Describe the factors which determine the value of magnetic flux density in the steel core.

Example <u>**Electromagnetism.**</u>

- Identifying the control factors
- The initial factors we can recognise are:-
- Flux density in the electromagnet (B).
- The Magnetizing force (H).
- What the electromagnet is made from (μ).
- The relationships between these factors.

Example **<u>Electromagnetism.</u>**

- The Relationship between factors:-

$$B = \mu * H$$

$$\text{or } B = \mu * (N * I) / l$$

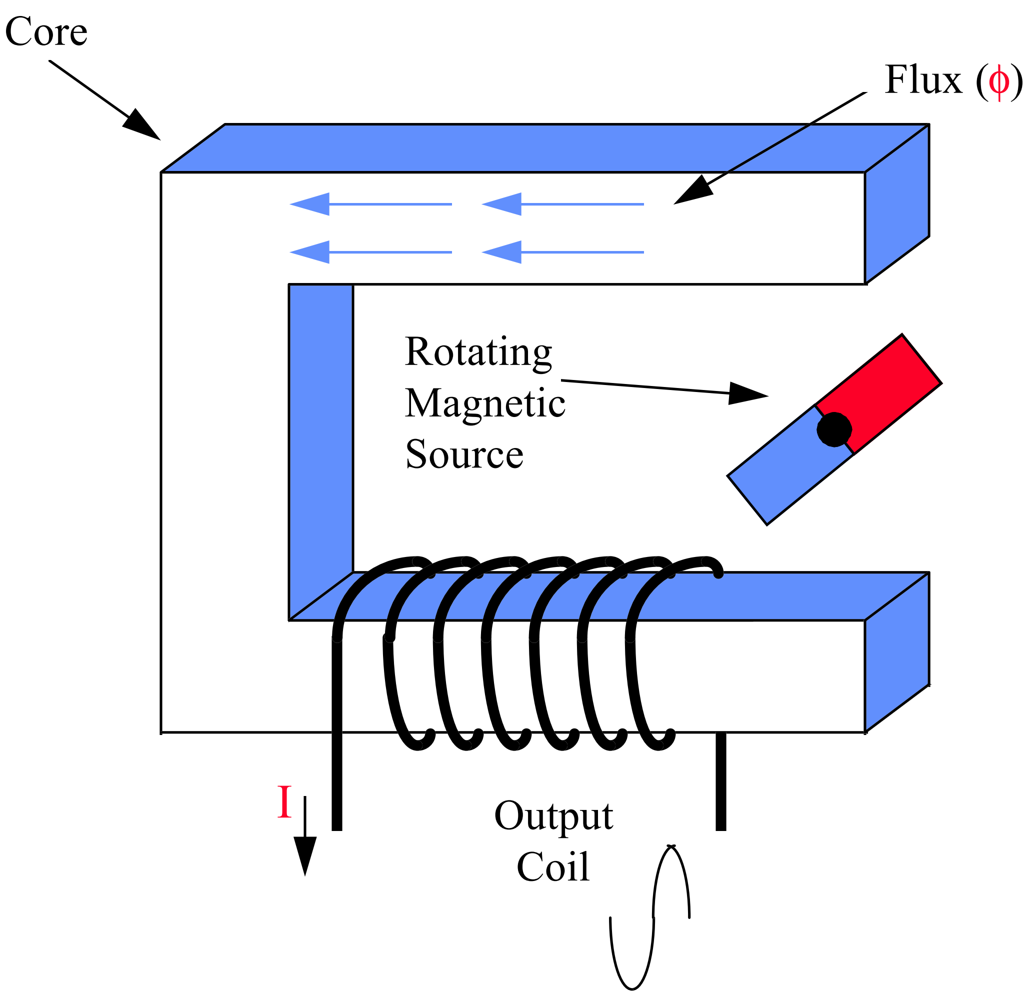
- Where :-
  - B = Flux Density.
  - H = Magnetising Force.
  - μ is the permeability of the material. (or how easy it is to magnetize the material)
  - N = Number of turns on the coil.
  - I = Current flowing in the coil
  - *l* = Length of the coil

Example <u>**Electromagnetism.**</u>

- The type of material used
  - High μ (permeability) (Easier to Magnetise)= More Flux
  - Low μ (permeability) (Harder to Magnetise) = Less Flux
- Number of turn on the coil
  - More turns = More flux
  - Less turns = Less Flux
- Current flowing
  - More current = More Flux
  - Less Current = Less Flux
- The Length of the magnetic circuit
  - Longer path = Less Flux
  - Shorter path = More Flux

Electromagnetism Applications.

Electromagnetism Applications.



The Basic Generator.

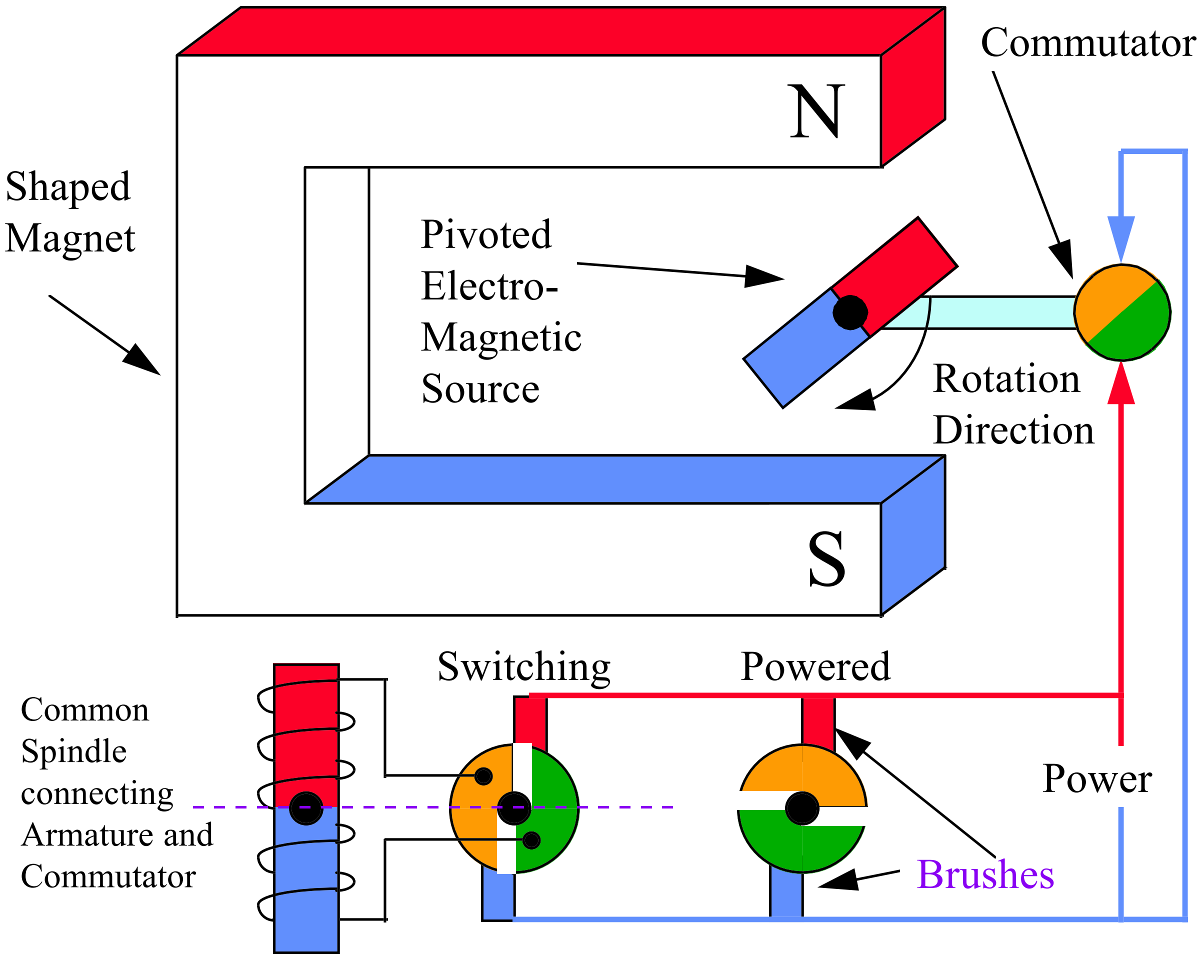
Operation.

(1) The Magnetic Source rotates and this generates a changing magnetic Flux in the Core.
(2) Whilst the Flux is changing in the Core this will cause a Voltage to be produced in the Output Coil.

Electromagnetism Applications.

A rotating electro-magnet is called an Armature.

A Commutator is a connector that can apply power to the Armature.

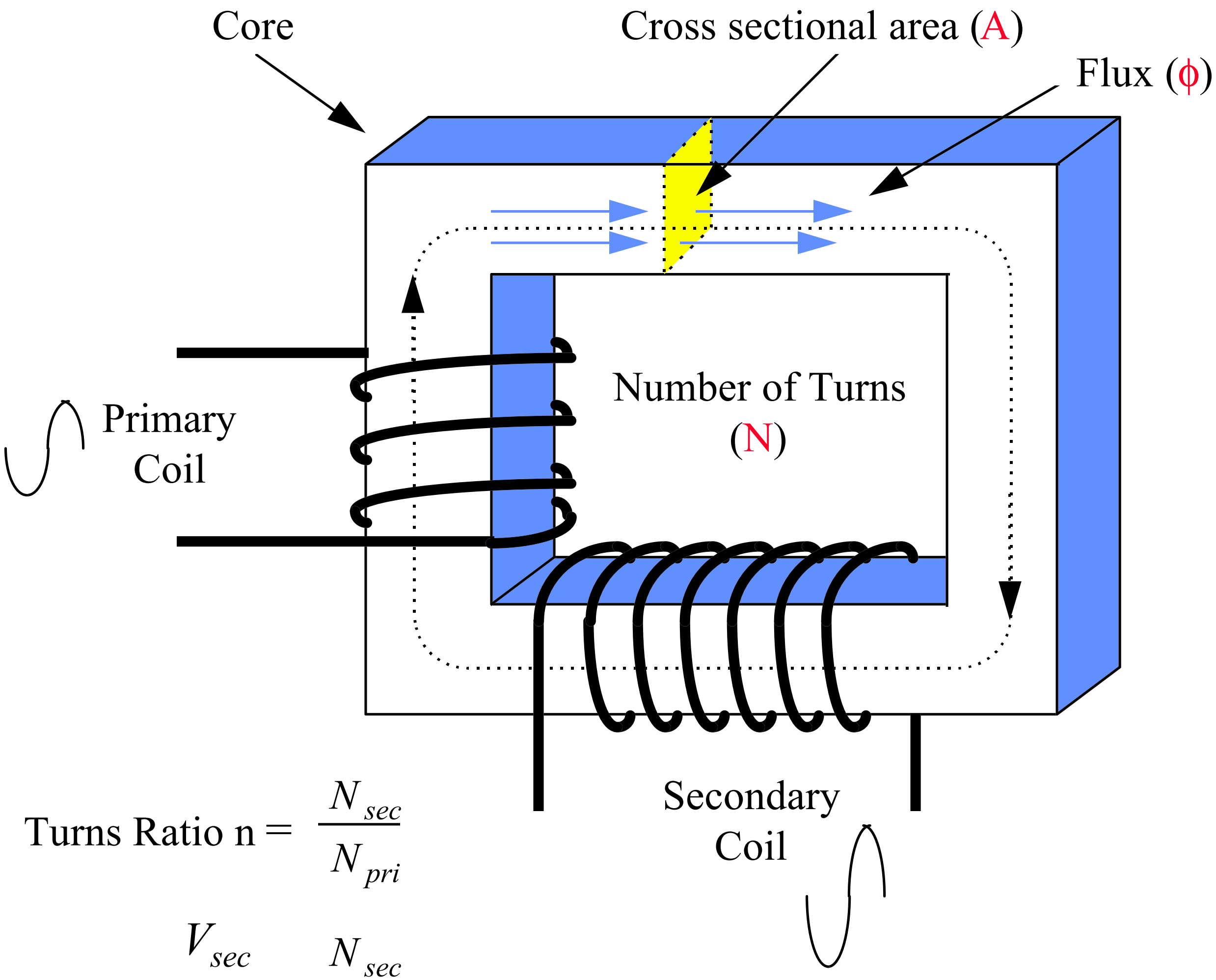


The Basic Electric Motor.

Operation.

(1) Power is applied through the Brushes via Commutator to the Armature.
(2) This causes the Armature to creates a magnetic field.
(3) The Armature will rotate due to the N/S attraction and repulsion of the magnetic forces.
(4) As the N/S poles become aligned the Commutator reverses the current flowing in Armature causing its magnetic field to also reverse.
(5) Armature continues to rotate (Back to (3))

Electromagnetism Applications.



Turns Ratio $n = \frac{N_{sec}}{N_{pri}}$

$$\frac{V_{sec}}{V_{pri}} = \frac{N_{sec}}{N_{pri}}$$

The Basic Transformer.

(1) If a Voltage is applied to the Primary Coil this will cause a Flux to be produced in Core.
(2) Whilst the Flux is changing in the Core this will cause a Voltage to be produced in the Secondary Coil.
(3) The Transformer's operation is therefore dependent on the Input source being an Alternating Current (ac).
(4) The Output Voltage is dependent on the ratio of the number of turns on Input and Output coils.

Transformers

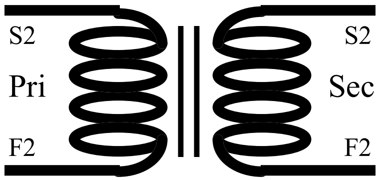
Transformers.

(1) If a Voltage is applied to the Primary Coil this will cause a Flux to be produced in Core.

(2) Whilst the Flux is changing in the Core this will cause a Voltage to be produced in the Secondary Coil.

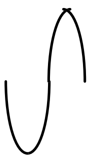
(3) The Transformer's operation is therefore dependent on the Input source being an Alternating Current (ac).

(4) The Output Voltage is dependent on the ratio of the number of turns on Input and Output coils.



Turns Ratio $n = \frac{N_{sec}}{N_{pri}}$

$$\frac{V_{sec}}{V_{pri}} = \frac{N_{sec}}{N_{pri}}$$



The Basic Transformer.

Inductors

Inductors.

- **Inductance** is the name given to the property of a circuit where an e.m.f. induced into the circuit by the change of flux linkages produced by a current change.
- When the e.m.f. is induced in the same circuit in which current changing, the property is called :-

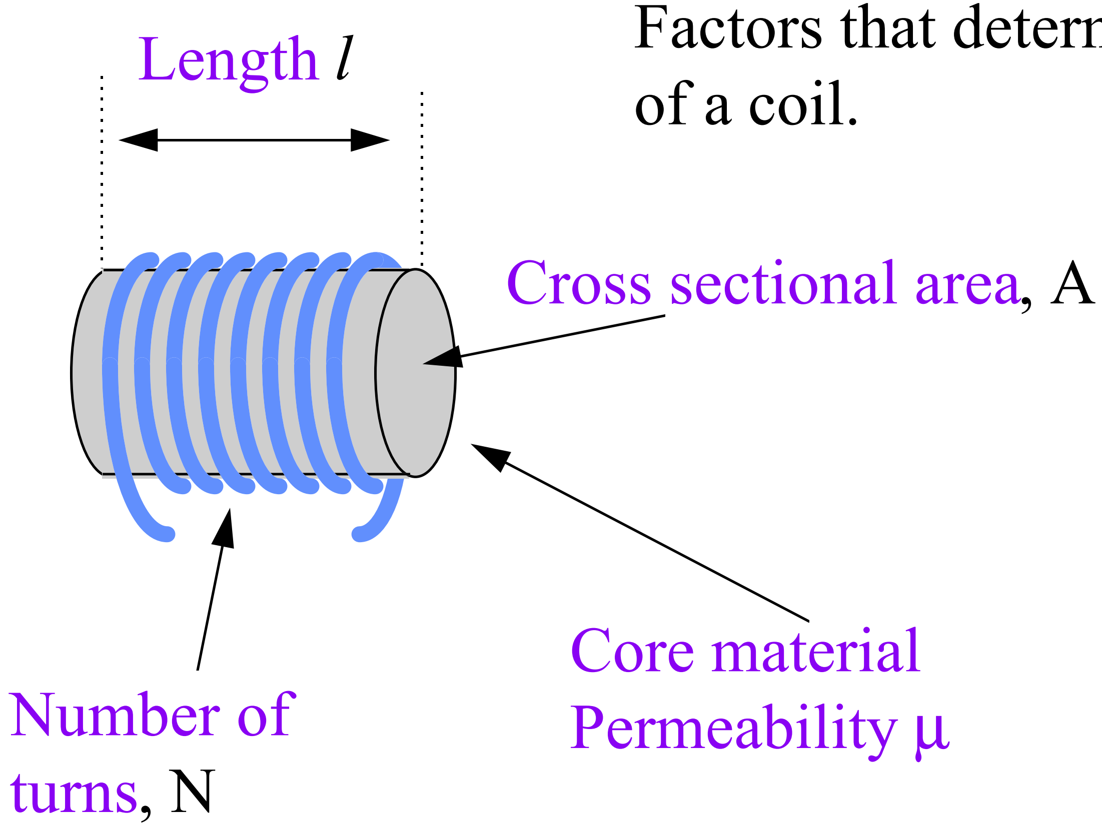
Self Inductance, L.

- When the e.m.f. is induced in a circuit by the change of flux due to current changing in adjacent circuit, the property is called :-

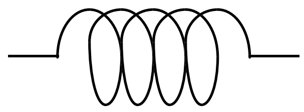
Mutual Inductance, M.

Inductors.

Factors that determine the inductance of a coil.



Physical Construction of an Inductor



Circuit Symbol for an Inductor.

Inductors.

- Calculating the Inductance of a Inductor :-
- The Inductance of an inductor is **directly** proportional to:-
  - the number of turns squared,
  - the permeability of the material,
  - the cross sectional area of the core
  - and **inversely** proportional to the length of the core.
- The formula for the Inductance of a Inductor is as follows :-

$$L = \frac{N^2 \mu A}{l}$$

A = Cross sectional area in metres squared.
l = Core length in metres.
μ = permeability in Henries per metre.
L = Inductance in henries (H).
N = Number of turns.

Inductors.

- The Unit of Inductance is the henry, H.
- Definition :-
- A circuit has an inductance of one henry when an e.m.f. of one volt in induced in it by a current changing at a rate of one ampere per second.
- Most inductors in electronics are measured in (mH) 10^{-3} milli henries.

Inductors.

- The induced e.m.f. in a coil of N turn is:-

$$E = N \frac{\Delta\phi}{\Delta t}$$

Where :-

$\Delta\phi$ = The change in flux in Webers.

Δt = Time taken for flux to change in seconds.

E = The induced e.m.f. in a coil in volts.

N = Number of turns.

- The induced e.m.f. in a coil of Inductance L is:-

$$E = L \frac{\Delta I}{\Delta t}$$

Where :-

ΔI = The change in current in amperes.

Δt = Time taken for current to change in seconds.

E = The induced e.m.f. in a coil in volts.

L = Inductance in henries.

Inductors.

- Example:-
- What is the e.m.f. induced in a coil of 200 turns when there is a change of flux of 25mWb occurs in 50ms :-

Inductors.

- Example:-
- What is the e.m.f. induced in a coil of 200 turns when there is a change of flux of 25mWb occurs in 50ms :-

$$E = N \frac{\Delta\phi}{\Delta t}$$

$$E = 200 * \frac{25 * 10^{-3}}{50 * 10^{-3}} = 100 \text{ Volts}$$

Inductors.

- Example:-
- A flux of 400 μWb passing through a 150 turn coil is reversed in 40ms:-
- Find the average e.m.f. induced.

Inductors.

- Example:-
- A flux of 400 μWb passing through a 150 turn coil is reversed in 40ms:-
- Find the average e.m.f. induced.

Since the flux reverses, the flux changes from +400μWb to -400μWb a total change of 800μWb.

$$E = N \frac{\Delta\phi}{t} = 150 * \frac{800 * 10^{-6}}{40 * 10^{-3}} = 3 \text{ Volts}$$

Inductors.

- Energy stored in a inductor :-
- An inductor stores energy in the magnetic field created by the current. The energy stored in the inductor is directly proportional to the inductance and the square of the current.
- The formula for the energy stored in an inductor is as follows :-

$$W = \frac{1}{2} L I^2$$

W = energy in joules.

L= inductance in henries.

I = Current in amps.

Summary

Inductors.

Inductors in Series

$$Lt = L1 + L2 + L3 \quad \text{... etc...}$$

Inductors in Parallel

$$\frac{1}{Lt} = \frac{1}{L1} + \frac{1}{L2} \quad \text{..........} \quad \text{etc.}$$

or $$Lt = \frac{L1 * L2}{(L1 + L2)}$$ The two Inductor option.

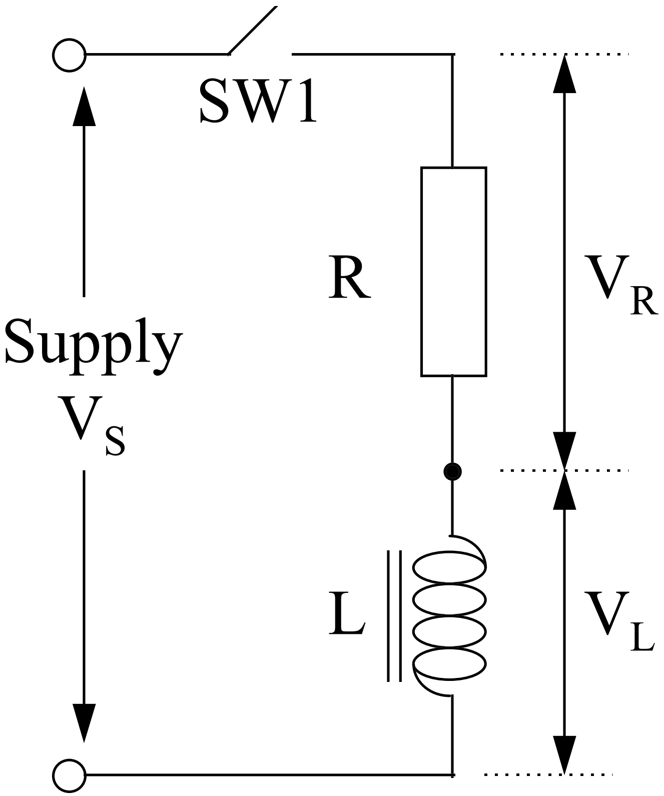
Thinking Exercise

Inductors.

Initial conditions:

Inductor L has no Current flowing through it.

So what voltage is across it?



Solution:

Just looking at the Resistance of the Coil windings.

$V = I * R$

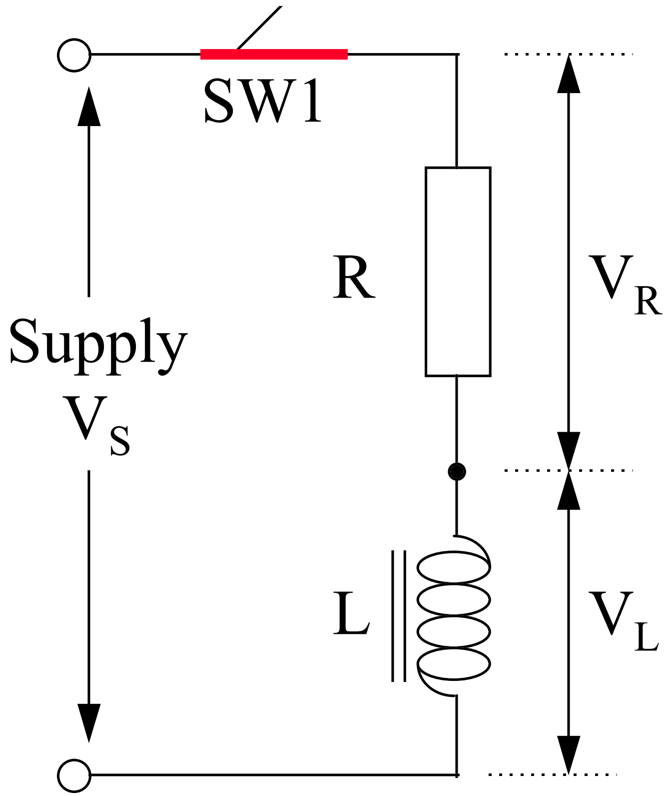
as $I = 0$ then

$V_L = I * R_C$ or $0*R_C = 0$ Volts

Inductors.

Thinking Exercise

The instant that SW1 is closed what voltage will be present across V_L and V_R ?



Solution:
The current will try to change in the coil at a very fast rate in a very short time.

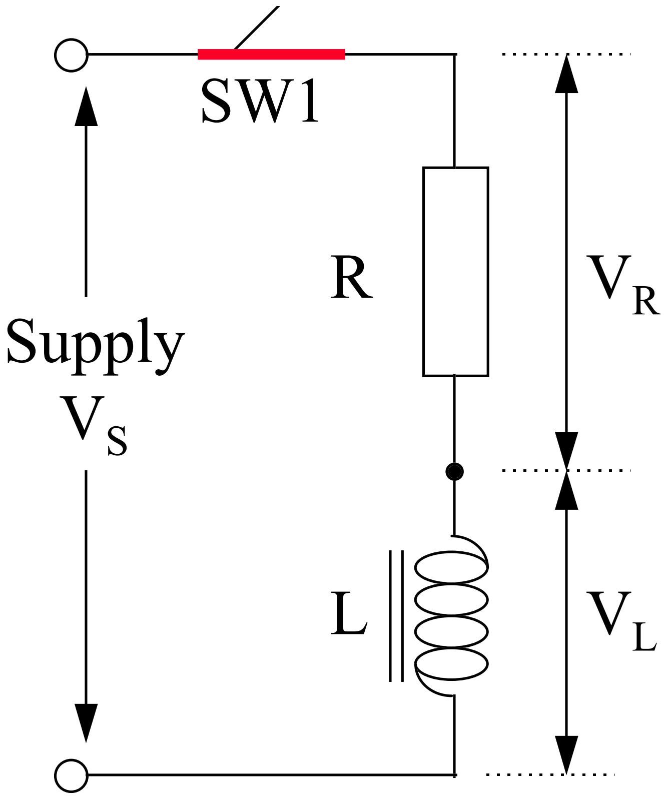
$$V_L = E = L(\Delta I / t) \text{ volts}$$

as ΔI will be large
and t will be small then
V_L will also be large.
By implication if is V_L large the circuit current must be small (0).
$V_L = V_S - V_R$ or
$V_L = V_S-(I*R) = V_S-(0*R)$ Volts
therefore $V_L = V_S$

Inductors.

Thinking Exercise

After SW1 has been closed for a significant time what voltage will be present across V_L and V_R ?



Solution:
The current will cease to change in the coil.

$$V_L = E = L(\Delta I / t) \text{ volts}$$

as ΔI will be 0
and t will be large then
V_L will also be zero.
By implication if is V_L is zero then the circuit current can only be dependent on R.
$V_L = V_S - V_R$ or
$V_L = V_S - V_R = 0$ Volts
$0 = V_S - V_R$ Volts
therefore $V_R = V_S$

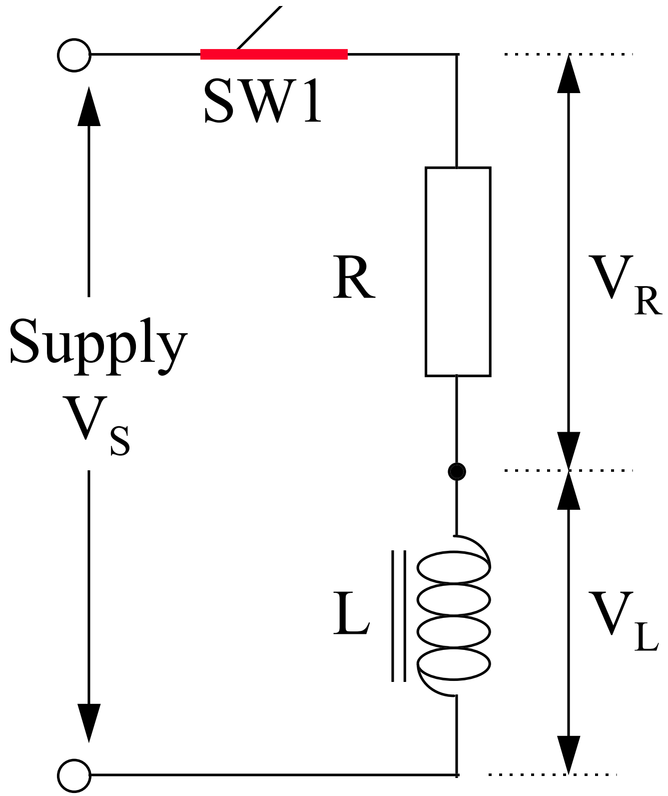
Inductors.

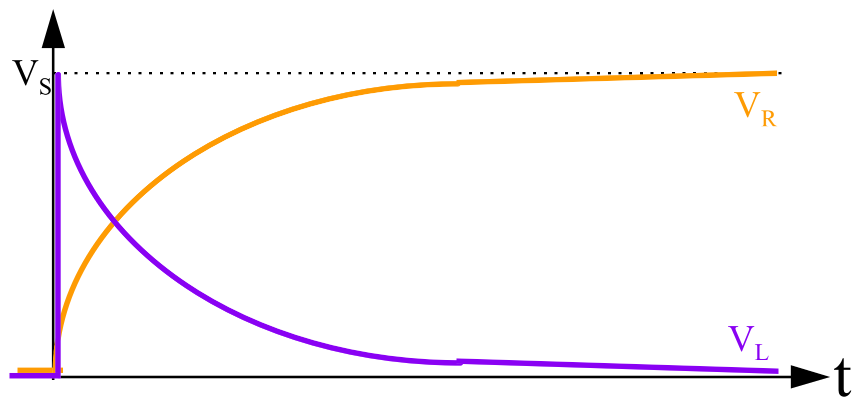
Thinking Exercise

Summary:

At switch on:
Voltage across Inductor is maximum
Voltage across Resistor is minimum.

After a long period after switch on:
Voltage across Inductor is minimum
Voltage across Resistor is maximum.

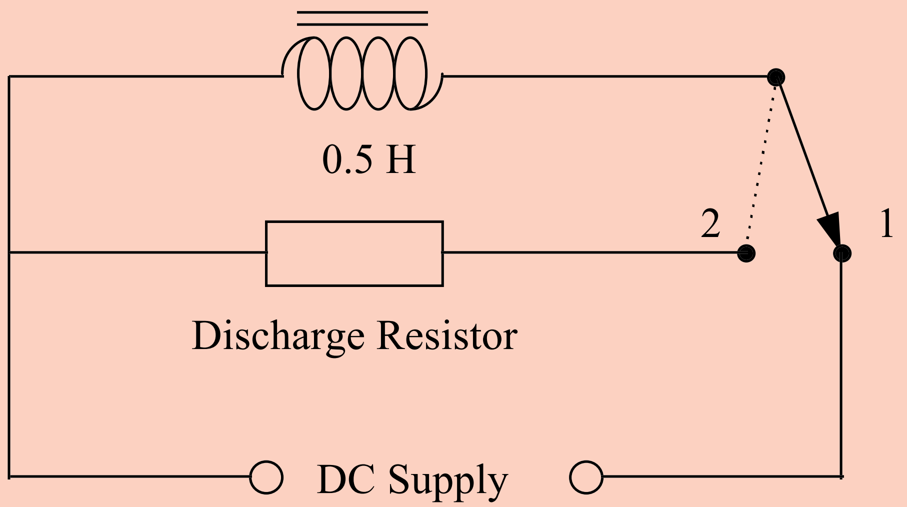




Example

Inductors.

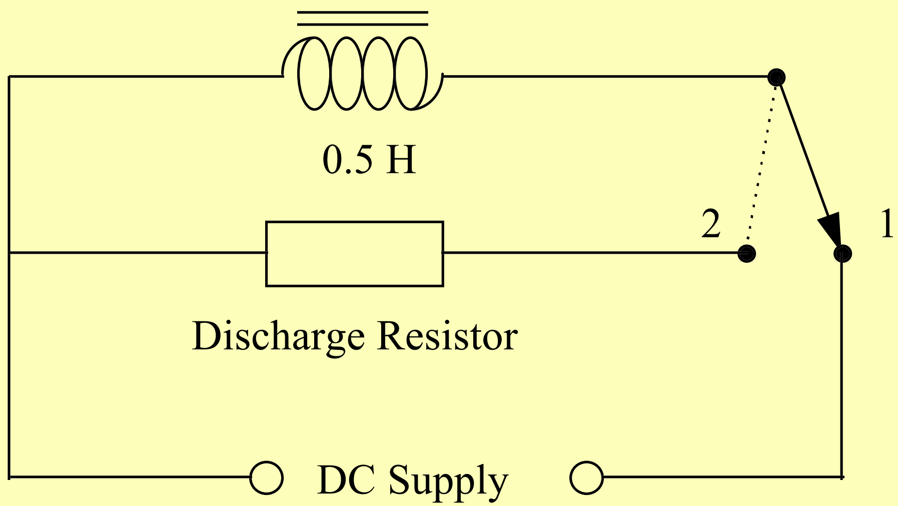
- A coil of negligible resistance is connected as shown in the circuit below. The coil carries a steady current of 5 A.
- a) Calculate the energy stored in the coil.
- b) The switch is moved to position 2. Calculate the average value of emf induced in the coil if the current falls to zero in 0.2 seconds.



Example

Inductors.

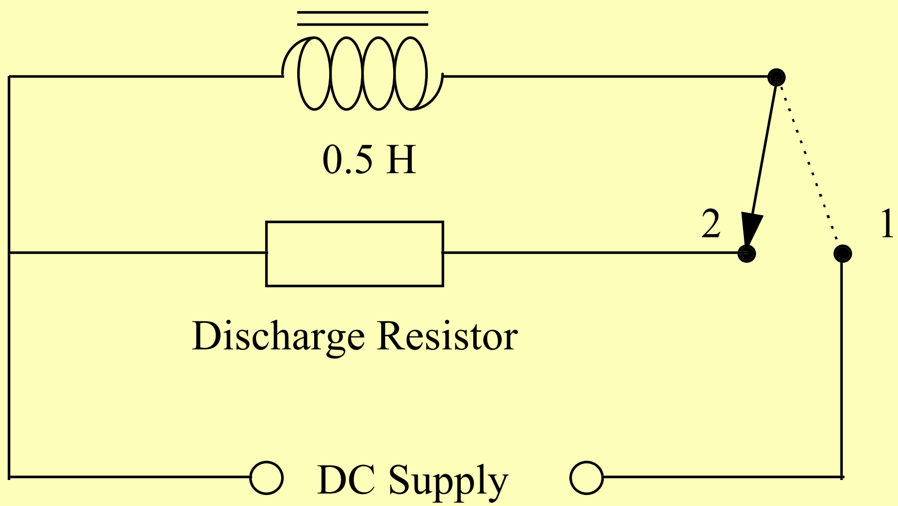
- a) Calculate the energy stored in the coil.
- Energy $W = \frac{1}{2}LI^2 = 0.5 * 0.5 * 5^2 = 6.25J$



Inductors.

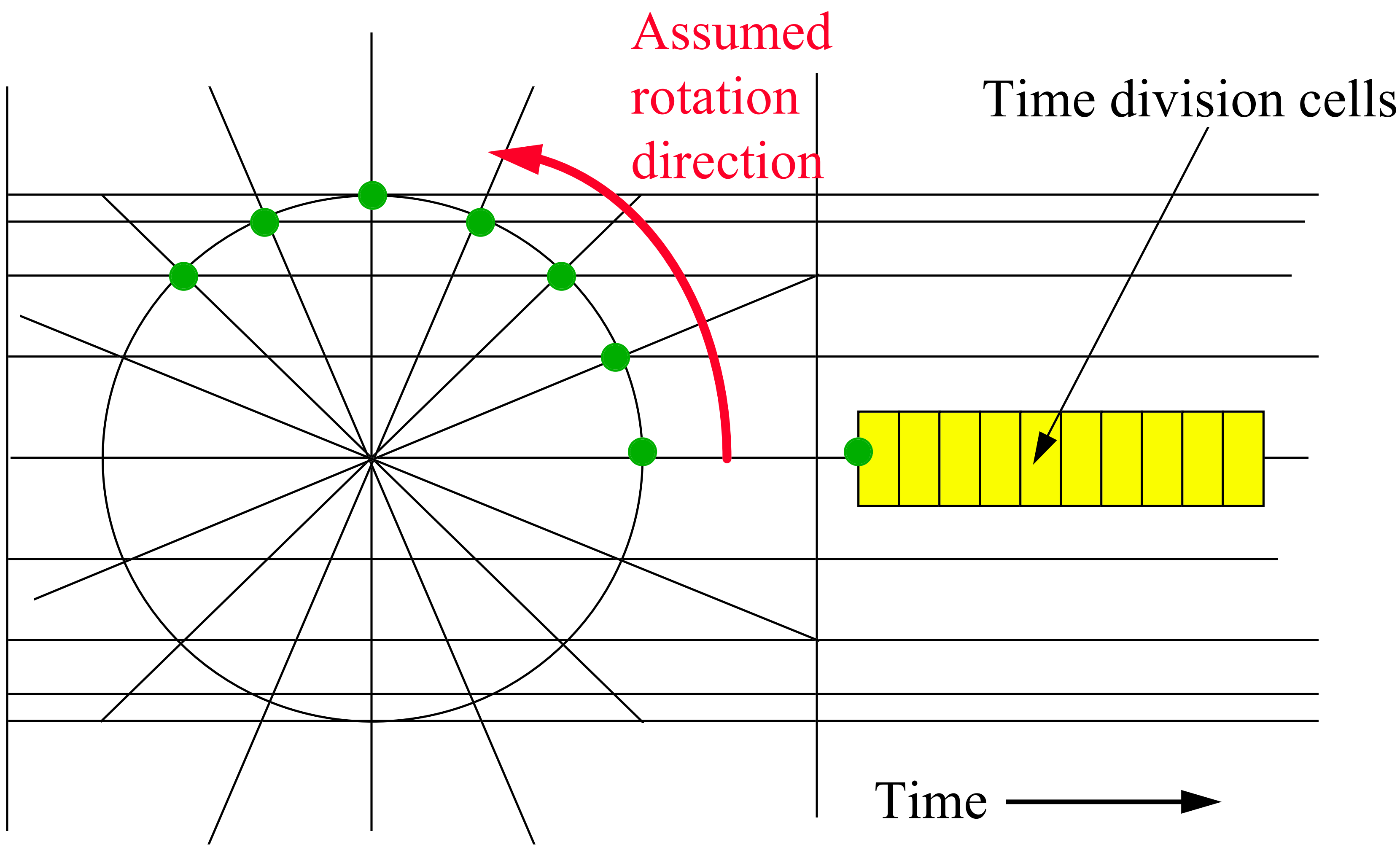
Example

- b) The switch is moved to position 2. Calculate the average value of emf induced in the coil if the current falls to zero in 0.2 seconds.
- $e = L\,\Delta I / \Delta t$ or $e = L\,dI/dt$
- $dt = 0.2$ Seconds, $dI = 5A$, $L = 0.5H$
- $e = 0.5 * (5 / 0.2) = 12.5$ Volts



AC Theory

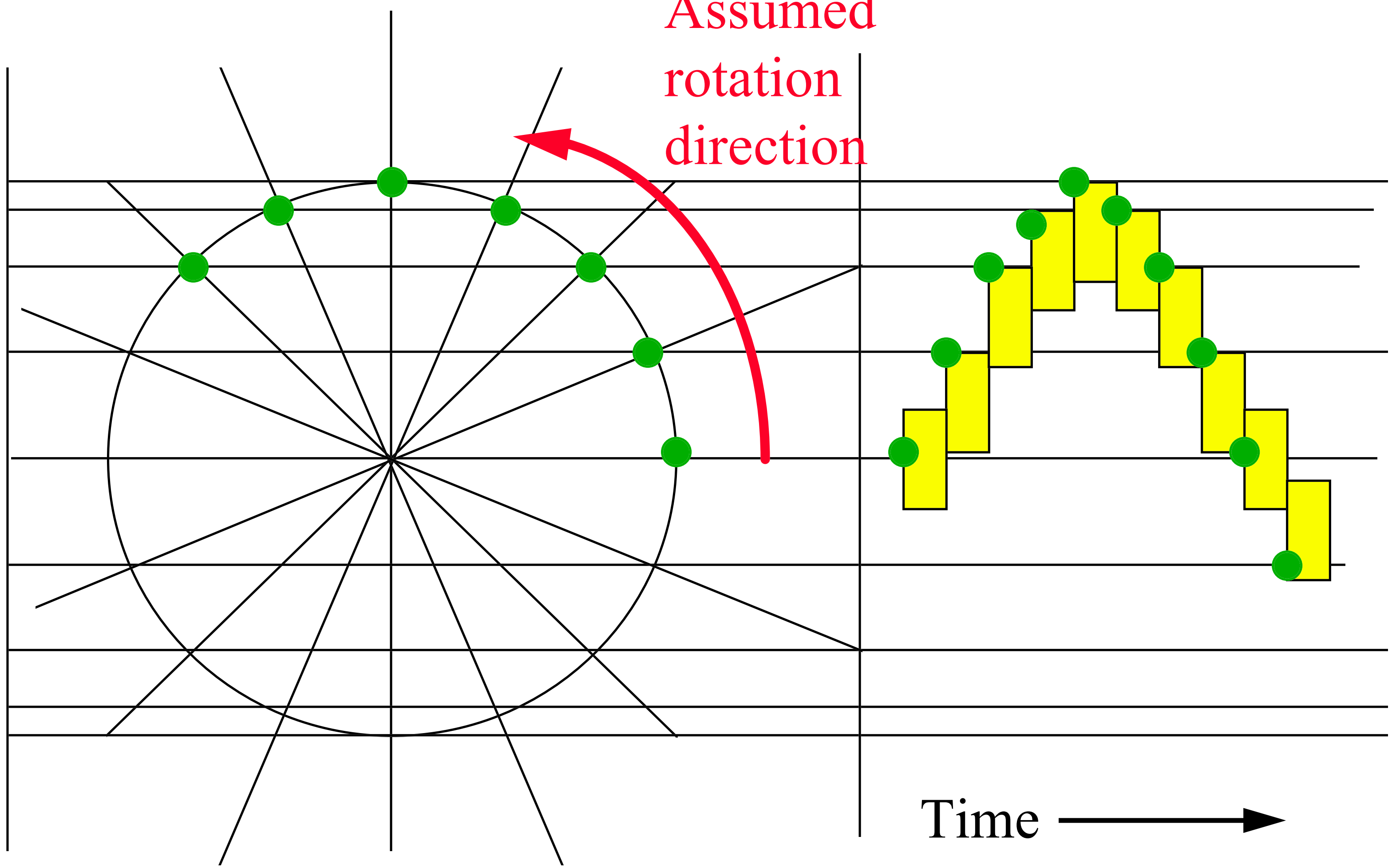
AC Theory.



Rotation at 22.5° Steps

Where the Sine Wave comes from.

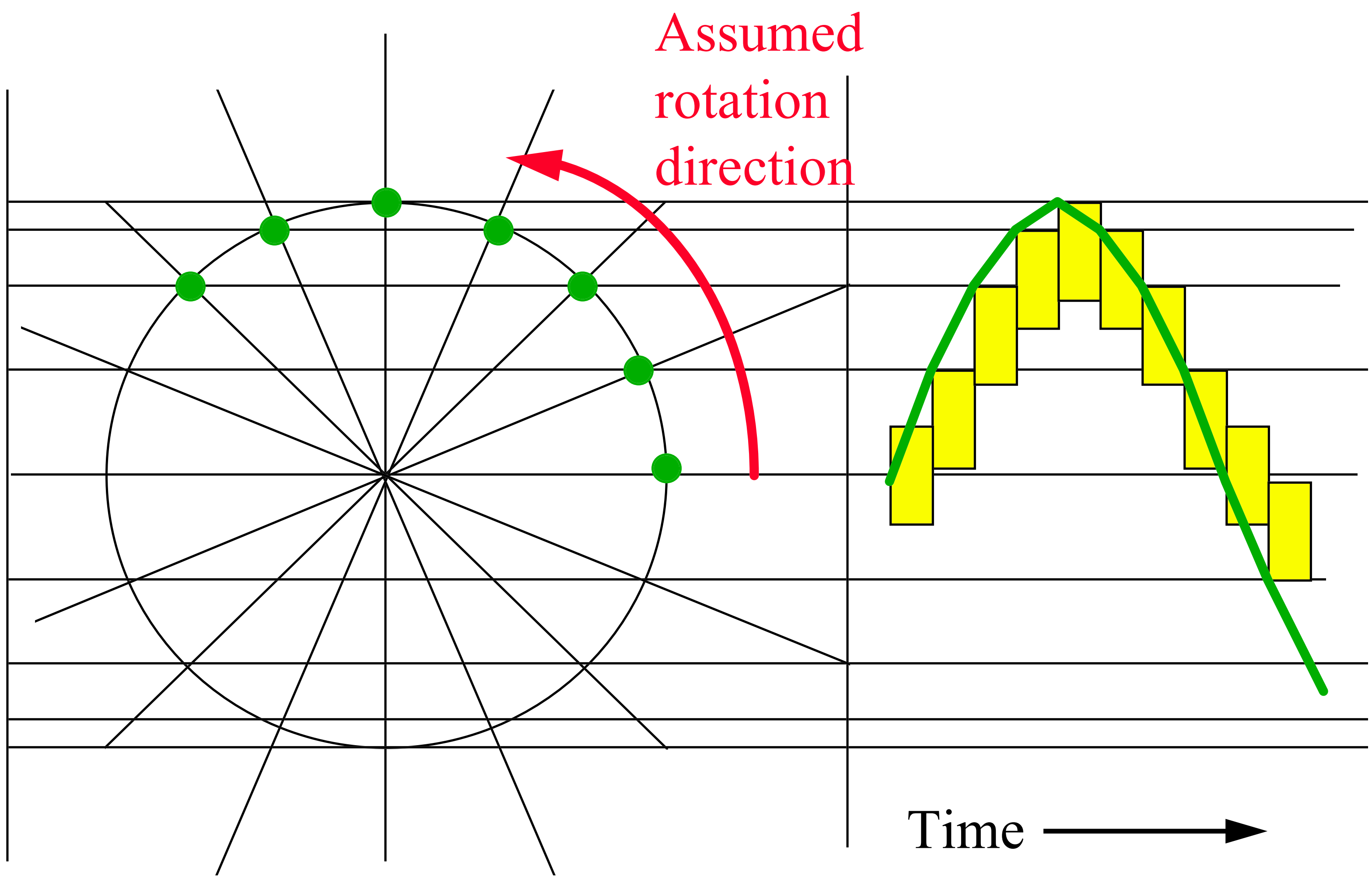
AC Theory.



Rotation at 22.5° Steps

Where the Sine Wave comes from.

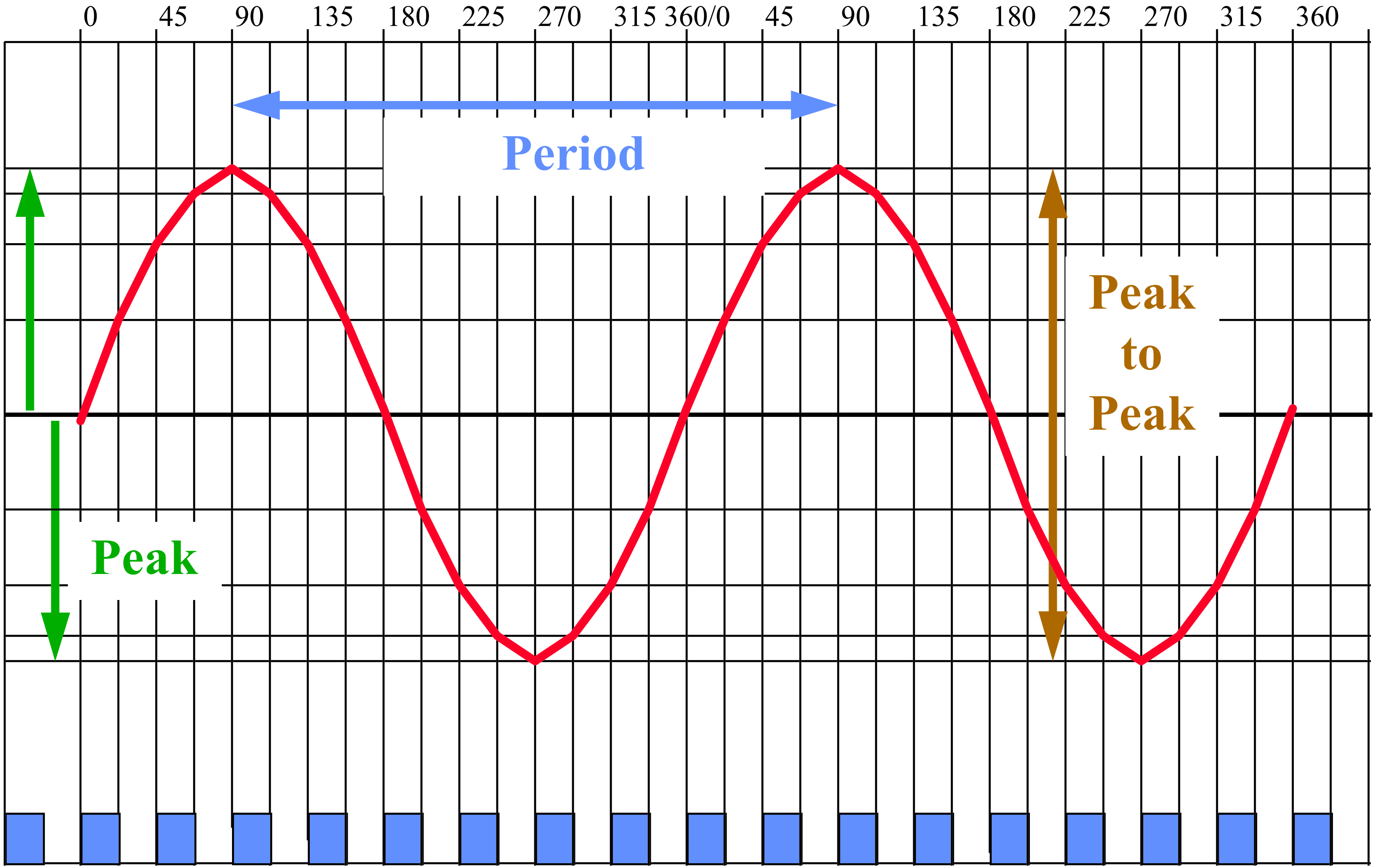
AC Theory.



Rotation at 22.5^o Steps

Where the Sine Wave comes from.

AC Theory.



0
45
90
135
180
225
270
315 360/0
45
90
135
180
225
270
315
360
Period
Peak
Peak
to
Peak

AC Theory.

- Definition 1.
- **Period** is the time taken between two repeated point of a waveform and is measured in seconds.
- **Frequency** is how many times a repeat of a waveform occurs per second and this value is Measured in Hertz (Hz).
- Frequency used to be measured in cycles per second c/s (A cyclic process).

AC Theory.

- Period is the time it takes for one rotation.
- Frequency is how many rotations per unit of time. Measured in Hertz (Hz)
- 1 Hz = 1 Cycle or rotation.
- Therefore the frequency, period relationship is :-

$$\text{Frequency} = \frac{1}{\text{Period}}$$

or

$$\text{Period} = \frac{1}{\text{Frequency}}$$

AC Theory.

- If we know speed we can calculate distance.
- Speed of Light = 186000 miles per second or 299Mms per second (often rounded to 300000Km to ease or speed calculations)
- Therefore the frequency, period , distance relationship is :-

Distance = (Speed of Light) * Period

or

$$\text{Distance} = \frac{\text{Speed of Light}}{\text{Frequency}}$$

AC Theory.

- Example 1
- Frequency = 2GHz , light = 300000000m/s
- Period =
- Distance =

- Example 2
- Frequency = 50Hz , light = 300000000m/s
- Period =
- Distance =

AC Theory.

- Example 1
- Frequency = 2GHz , light = 300000000m/s
- Period = $1/(2*10^9) = .5 * 10^{-9} = 0.5$nSecs
- Distance = $300000000/(2*10^9) = 150*10^{-3} =$ 150mm = 15cm

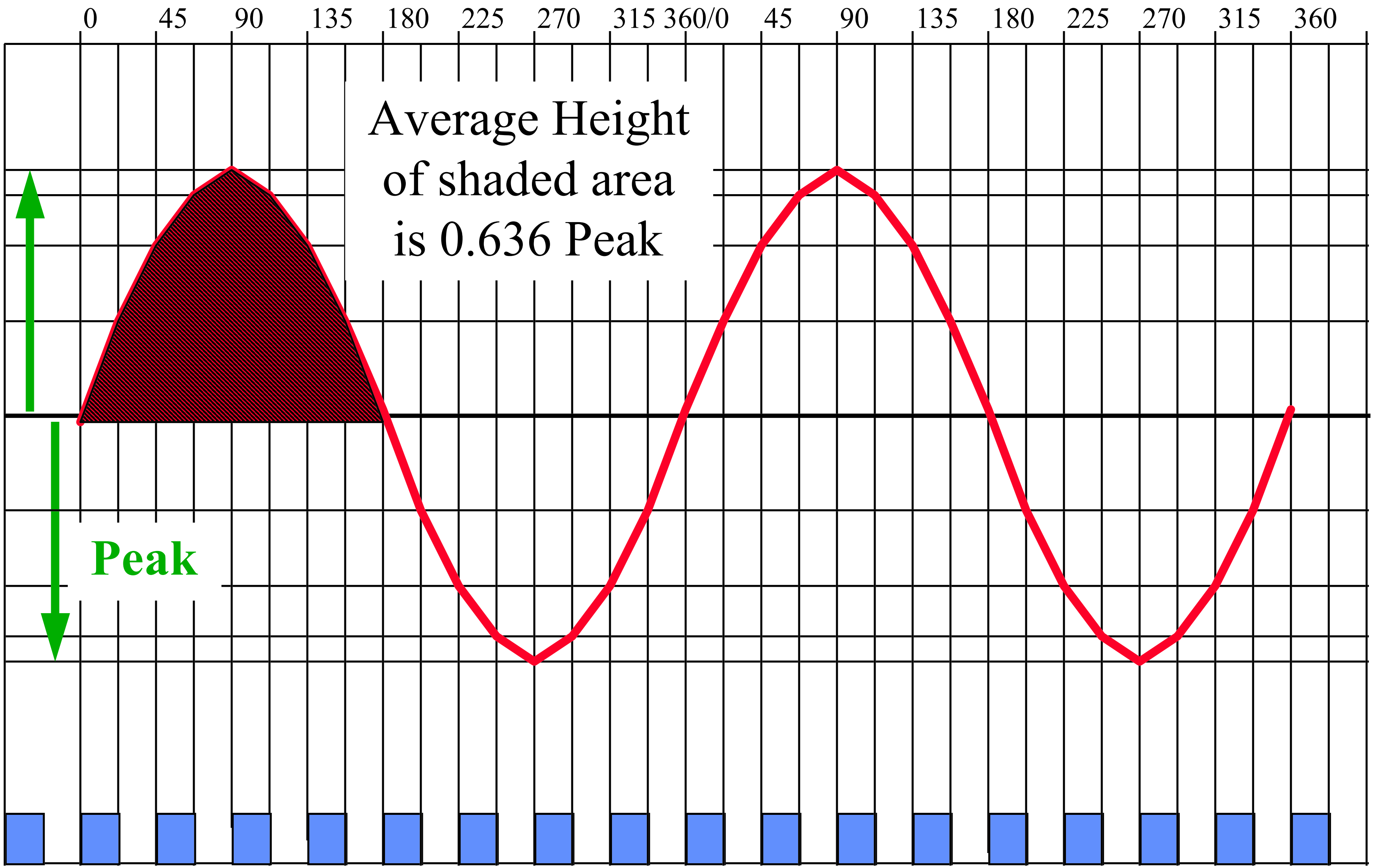
---

- Example 2
- Frequency = 50Hz , light = 300000000m/s
- Period = $1/(50) = 20 * 10^{-3} = 20$mSecs
- Distance = 300000000/(50) = 6000Km

AC Theory.

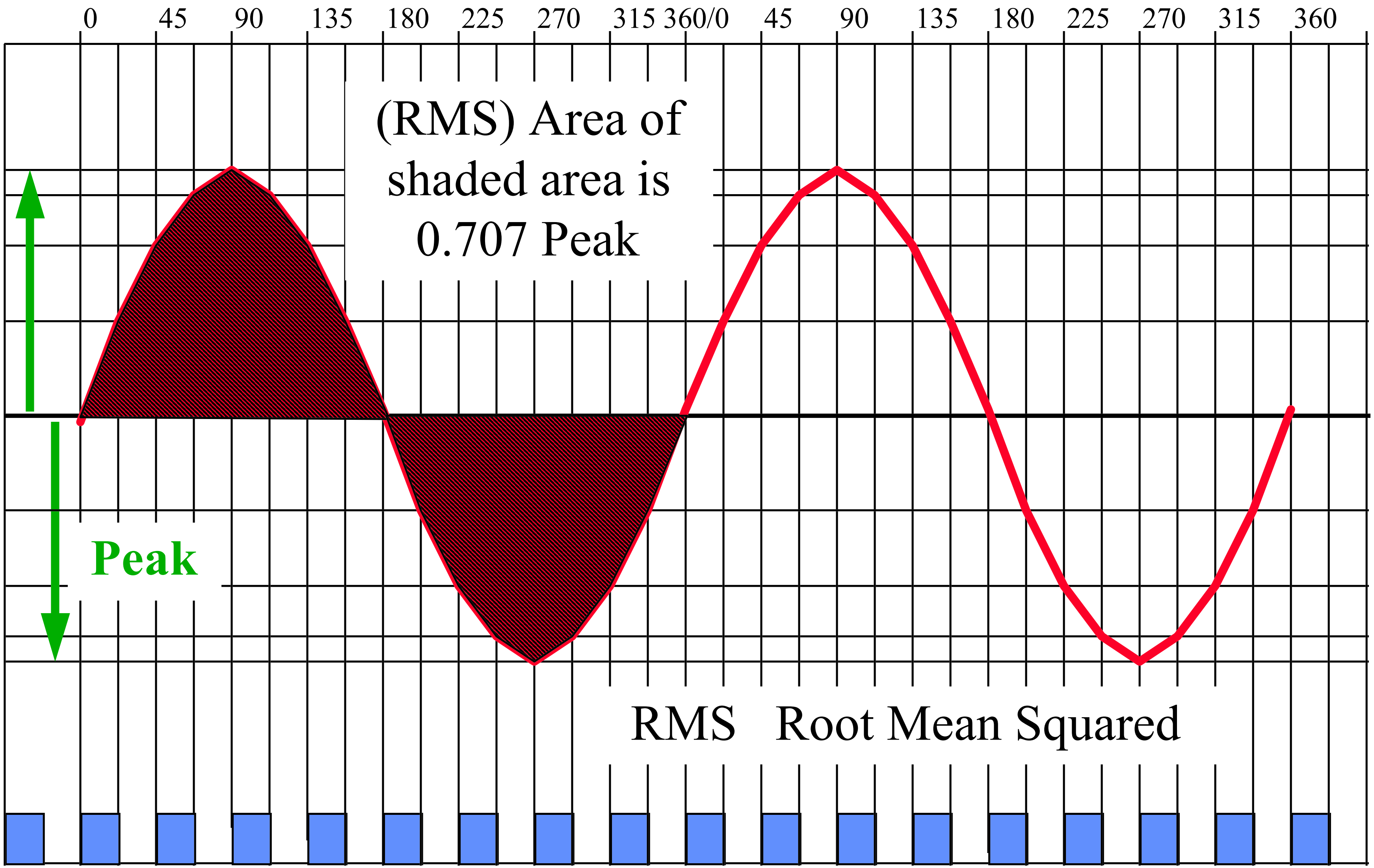
- Implications for modern processors are :-
- The logic in most processors is synchronized by a common clock signal.
- With a 2GHz processor any logic that is say 7.5cms from the clock will be operating 180^{o} out of phase from the master clock.
- This could cause a problem should you need to combine signals from different parts of the circuit. (These phase changes and other delays are a problem known as data skew)

AC Theory.



0
45
90
135
180
225
270
315 360/0
45
90
135
180
225
270
315
360
Average Height of shaded area is 0.636 Peak
Peak

AC Theory.


0
45
90
135
180
225
270
315 360/0
45
90
135
180
225
270
315
360
(RMS) Area of
shaded area is
0.707 Peak
Peak
RMS Root Mean Squared

Summary

AC Theory.

$$\text{Peak value} = \text{RMS value} * \sqrt{2}$$

$$\text{RMS value} = \frac{\text{Peak value}}{\sqrt{2}}$$

$$\text{Peak value} = \frac{\text{Average value}}{0.638}$$

$$\text{Average value} = \text{Peak value} * 0.638$$

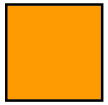
Note

$\sqrt{2} = 1.4142$

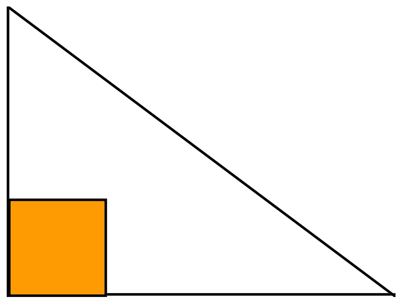
AC Theory.

Basic Math's for AC Theory.

AC Theory.

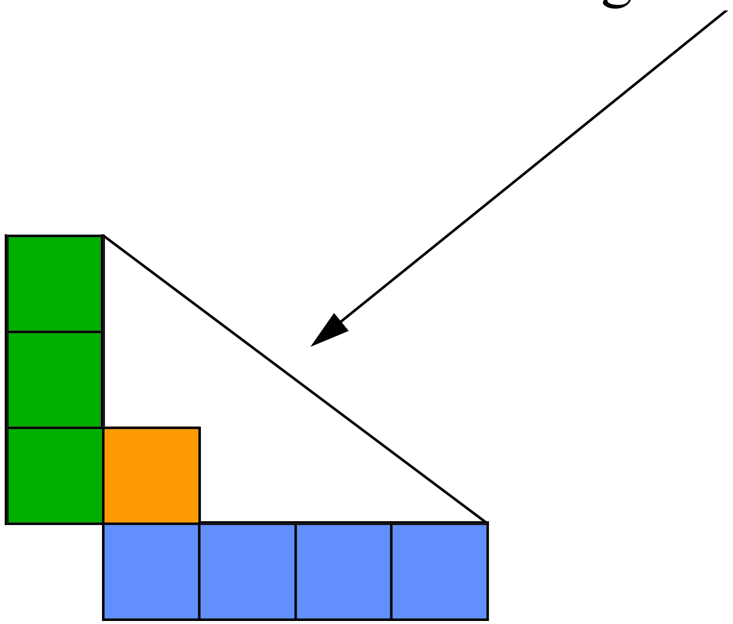
Take a simple square 

Then build a triangle which is 3 unit high and 4 units wide.



AC Theory.

See how many squares will lie along the sloping axis

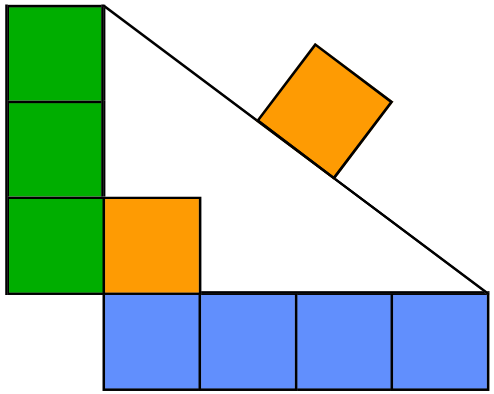


3 Units High

4 Units Wide

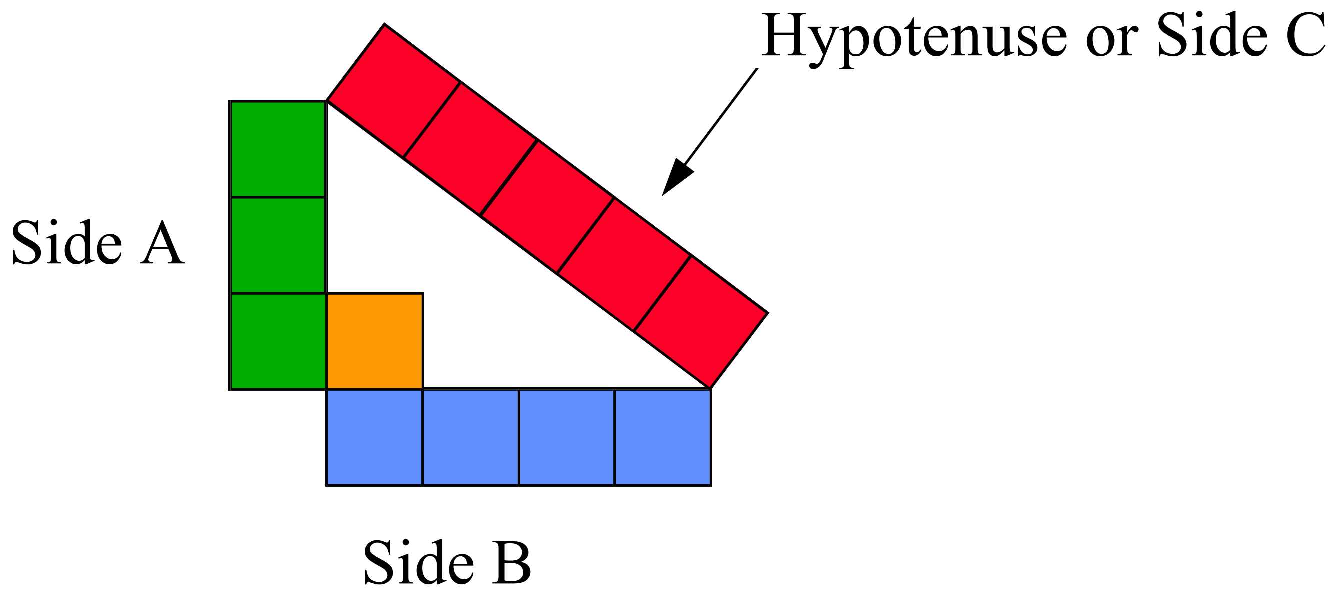
AC Theory.

You should find that 5 square will lie along the slope



AC Theory.

Pythagoras identified that the square on the hypotenuse is equal to the sum of the squares on the other sides

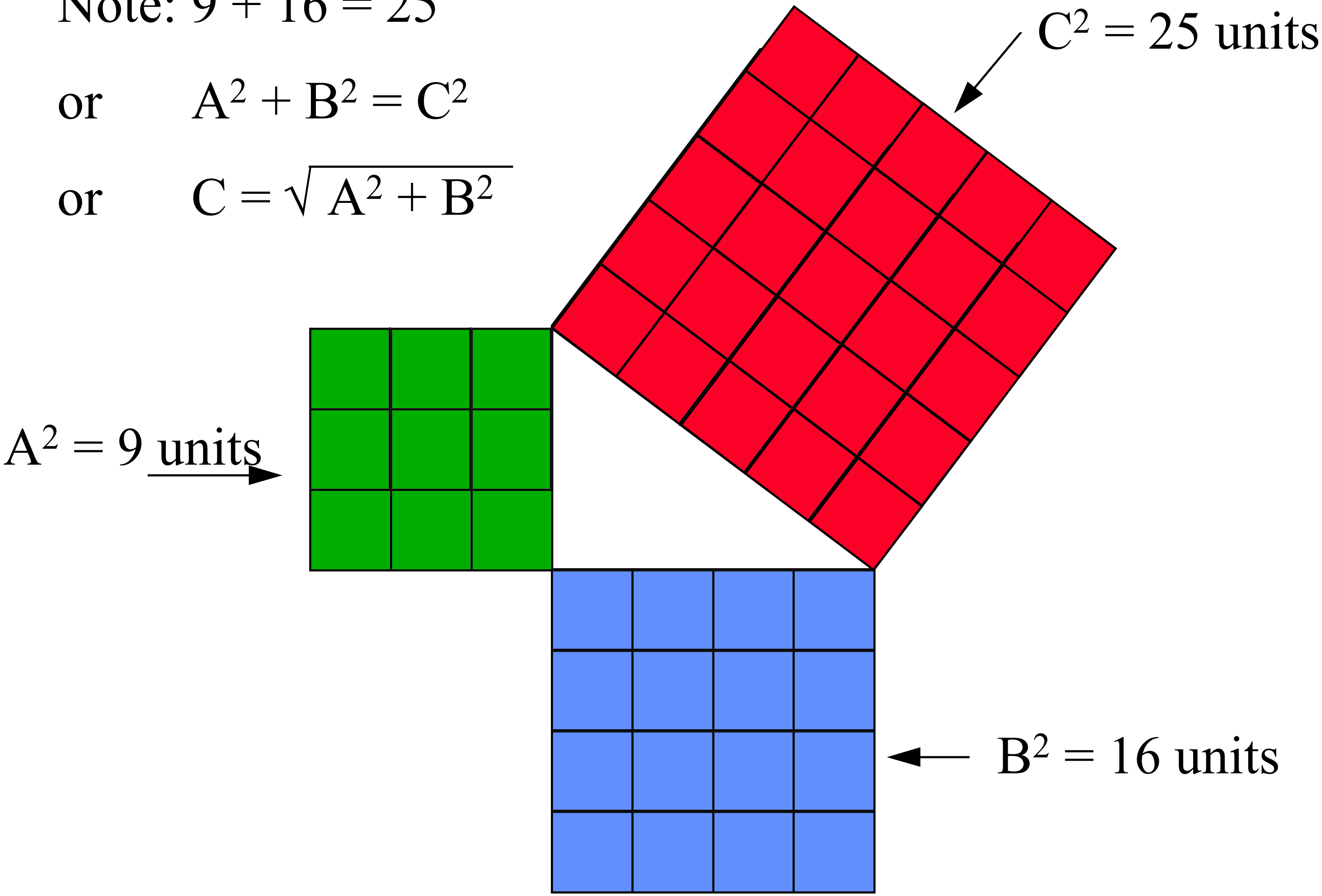


AC Theory.

Note: $9 + 16 = 25$

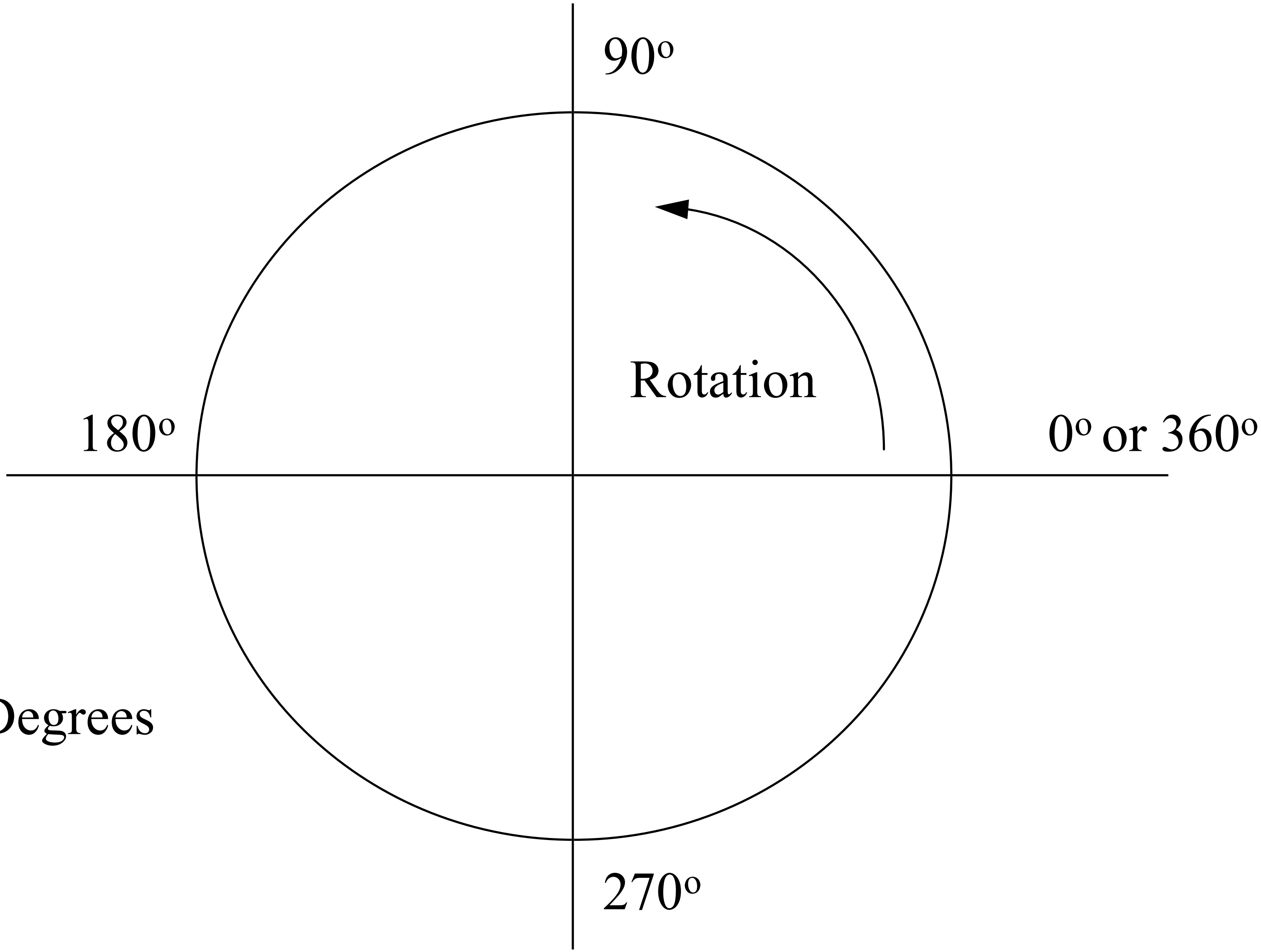
or $A^2 + B^2 = C^2$

or $C = \sqrt{A^2 + B^2}$



Angular Measurement

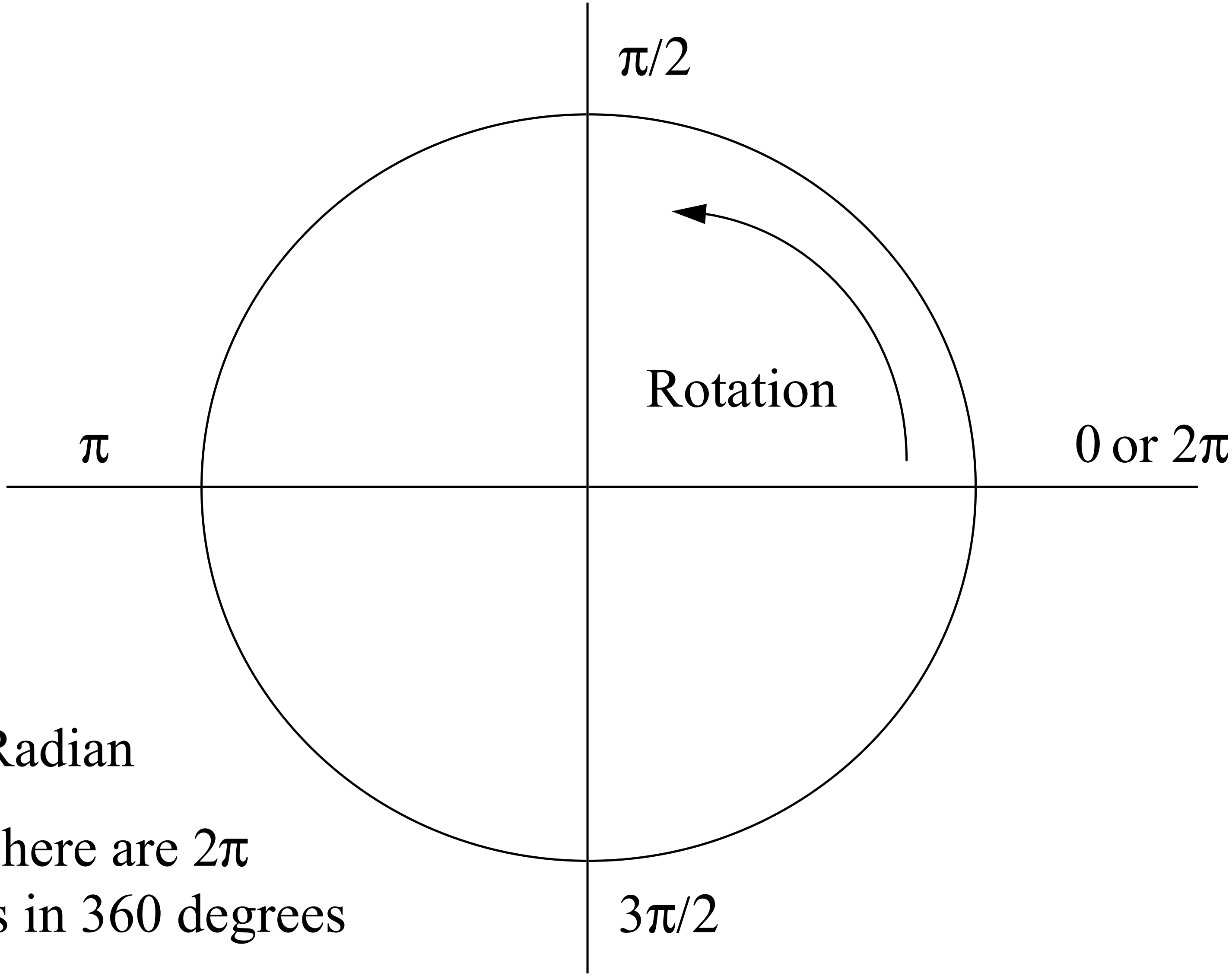
AC Theory.



Using Degrees

Angular Measurement

AC Theory.

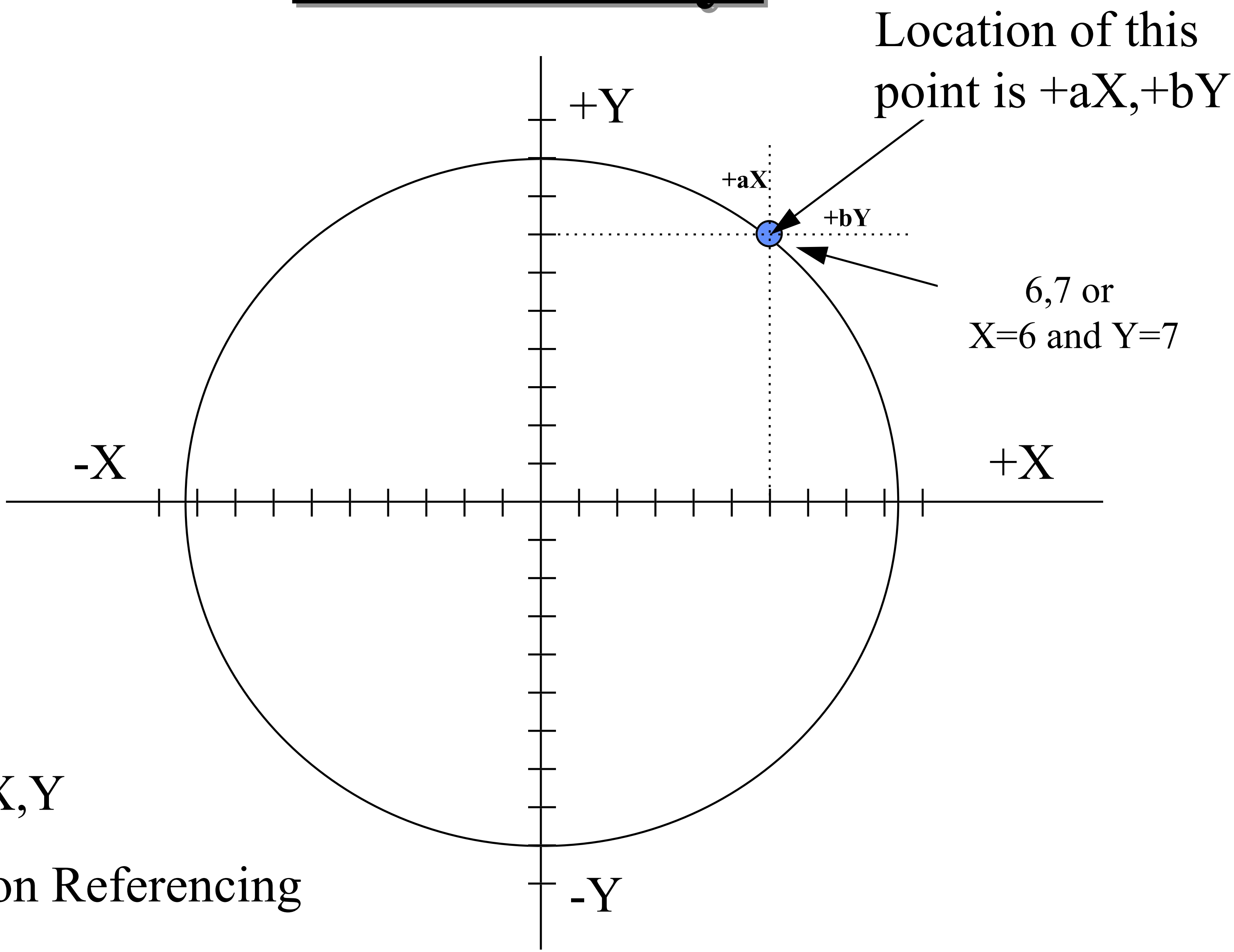


Using Radian

Note: There are 2π Radians in 360 degrees

Coordinates

AC Theory.

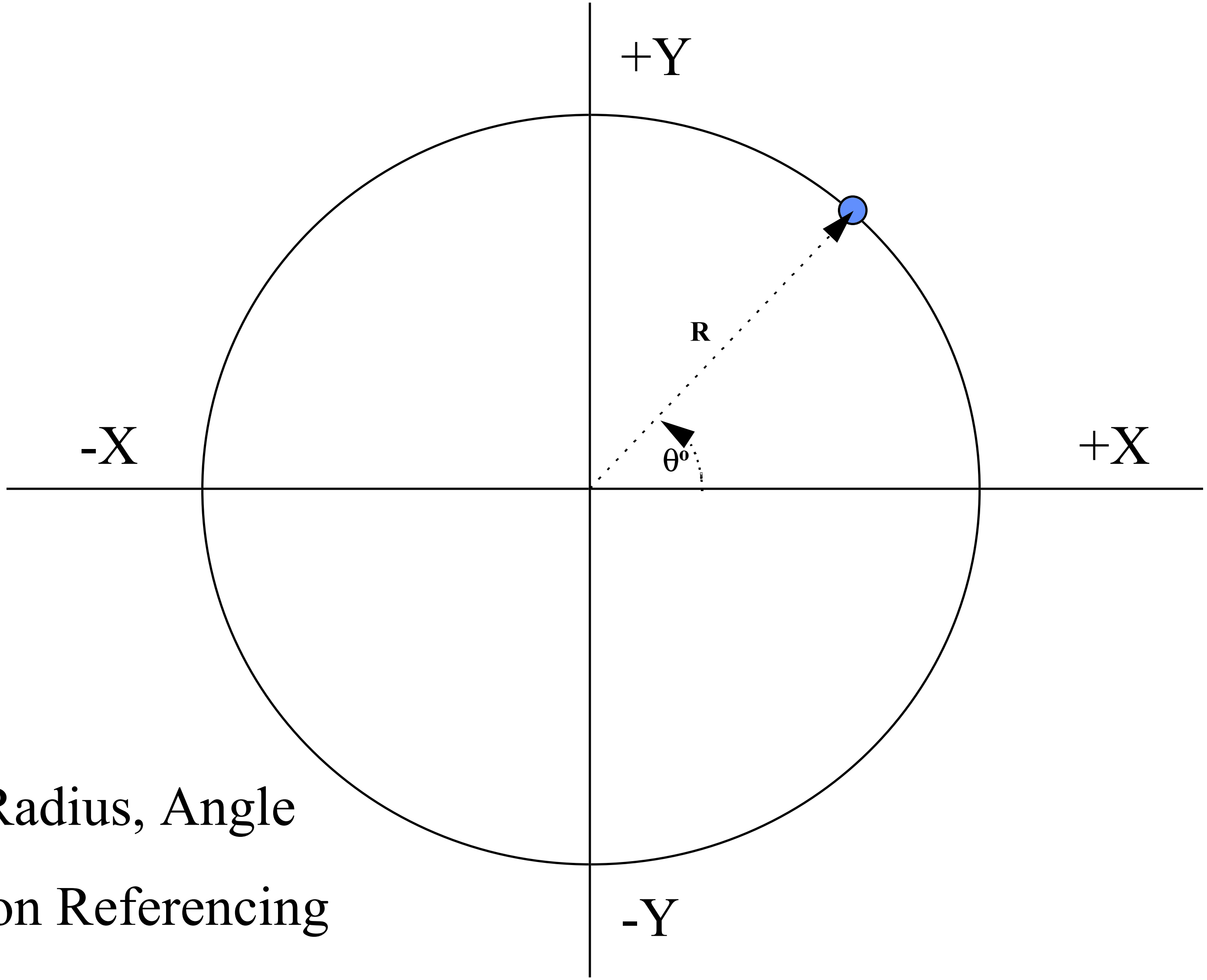


Using X,Y

Location Referencing

Coordinates

AC Theory.

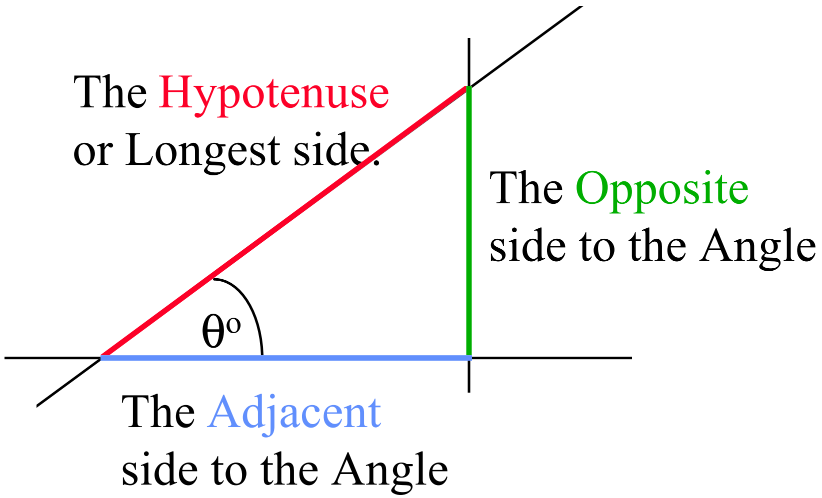


Using Radius, Angle

Location Referencing

Trigonometrical Ratios

AC Theory.



$$\text{Sin } \theta = \frac{\text{Opposite}}{\text{Hypotenuse}}$$

$$\text{Cos } \theta = \frac{\text{Adjacent}}{\text{Hypotenuse}}$$

$$\text{Tan } \theta = \frac{\text{Opposite}}{\text{Adjacent}}$$

These ratios need to be committed to Memory.

AC Theory.

Where do the Ratios come from?

AC Theory.

Where do these ratios come from ?

- pi (π) is the ratio of the circumference of a circle to its diameter. We approximate to 22/7.
- It can be calculated using the following series:-
- PI = 4 - 4/3 + 4/5 - 4/7 + 4/9 - 4/11

AC Theory.

Where do these ratios come from ?

- The number "e" used in logarithms and exponential growth or decay.
- It can be calculated using the following series:-
- e = 1/0! + 1/1! + 1/2! + 1/3! + 1/4!

  where ! indicates factorial.
- Note 0! is a mathematical quirk and = 1
- example 3! = 1 * 2 * 3 ... 4! = 1 * 2 * 3 * 4 etc.

AC Theory.

Where do these ratios come from ?

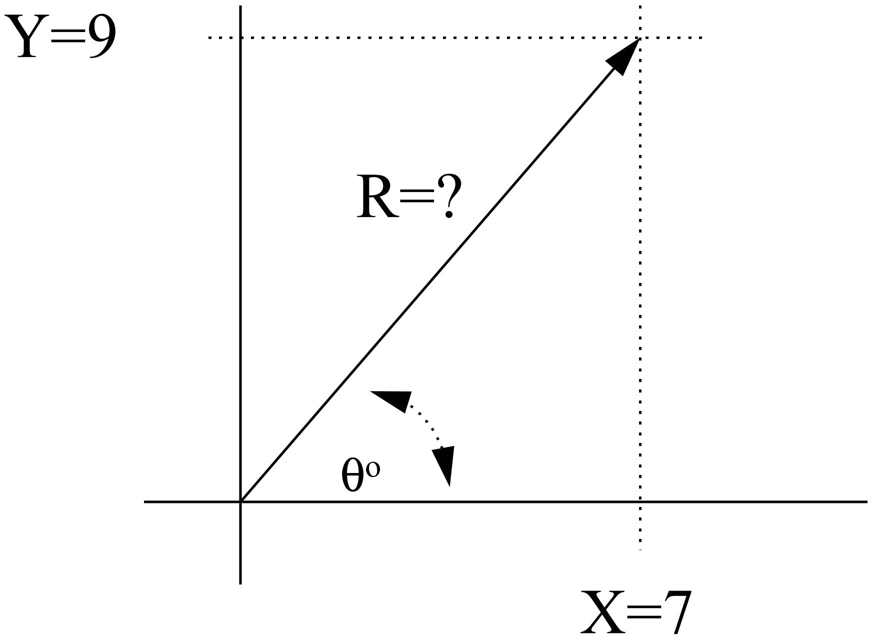
- Sine (x) , Cos (x) and Tan (x)
  where x is in radians
- They can be calculated using the following series or formulae:-
- Sin (x) = x - x^3/3! +x^5/5! -x^7/7! +x^9/9!
- Cos (x) = 1 -x^2/2! +x^4/4! -x^6/6! +x^8/8!
- Tan (x) = Sin (x) / Cos (x)

AC Theory.

Example of usage.

Trigonometrical Ratios Example

AC Theory.



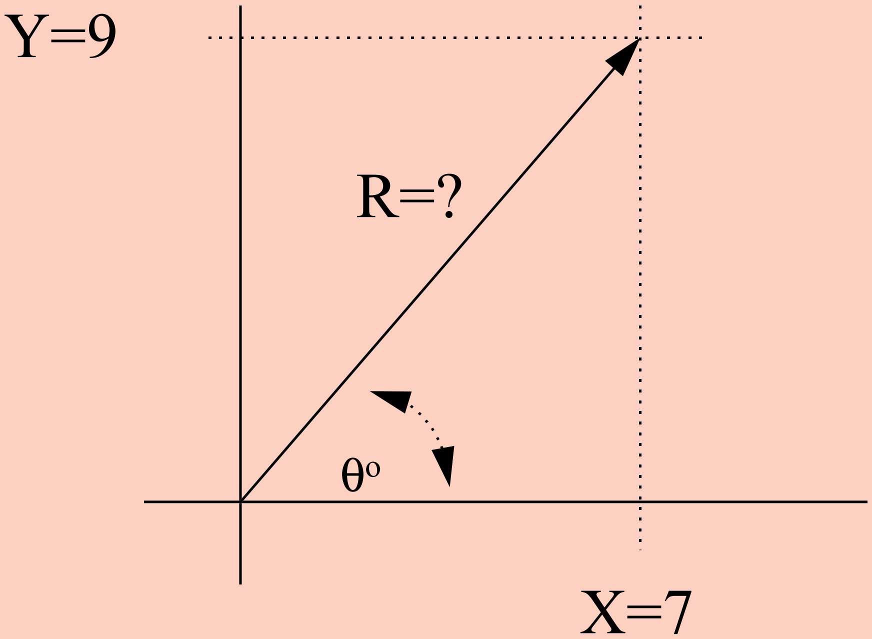
$$\text{Sin}\ \theta = \frac{\text{Opposite}}{\text{Hypotenuse}}$$

$$\text{Cos}\ \theta = \frac{\text{Adjacent}}{\text{Hypotenuse}}$$

$$\text{Tan}\ \theta = \frac{\text{Opposite}}{\text{Adjacent}}$$

Trigonometrical Ratios Example

AC Theory.



Given that:

Y = 9 and

X = 7

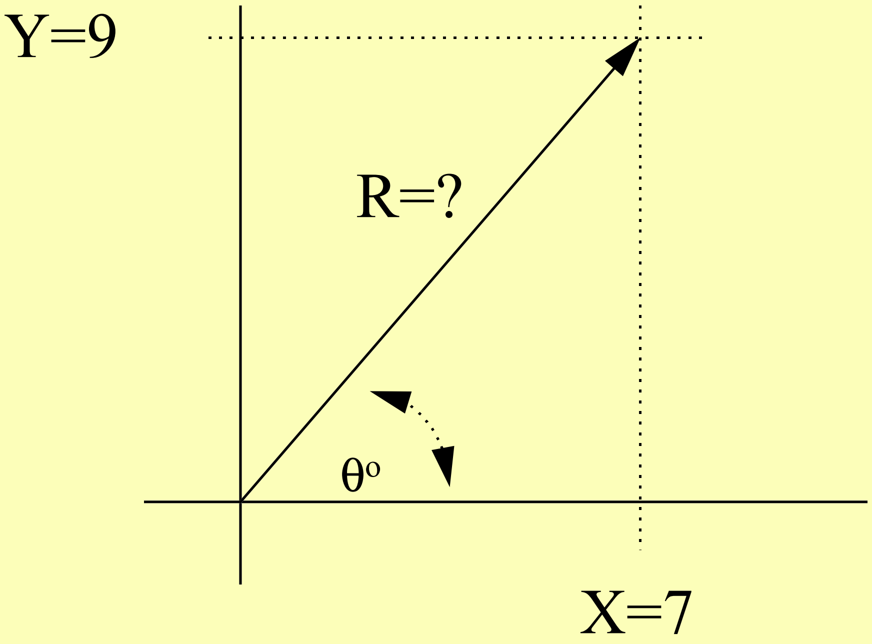
Calculate:

Length of R and

Angle θ

Trigonometrical Ratios Example

AC Theory.



Opposite = Y = 9

Adjacent = X = 7

Using:-

$$\text{Tan}\ \theta = \frac{\text{Opposite}}{\text{Adjacent}}$$

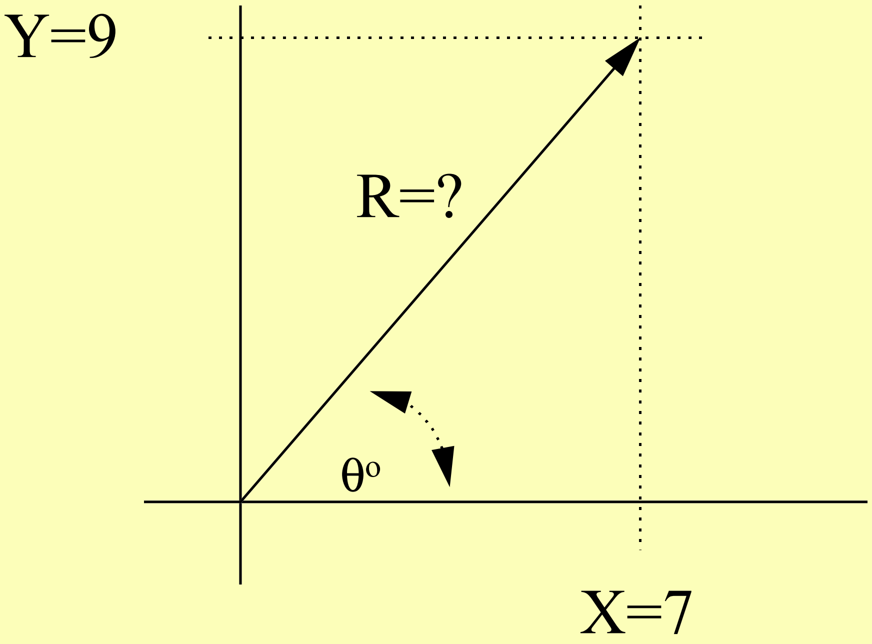
$$\text{Tan}\ \theta = \frac{9}{7} = 1.2857$$

Therefore:

$$\theta = \text{Tan}^{-1}(1.2857) = 52.125^{o}$$

Trigonometrical Ratios Example

AC Theory.



Opposite = Y = 9

Adjacent = X = 7

Using Pythagoras :-

$$C = \sqrt{A^2 + B^2}$$

$$R^2 = X^2 + Y^2$$

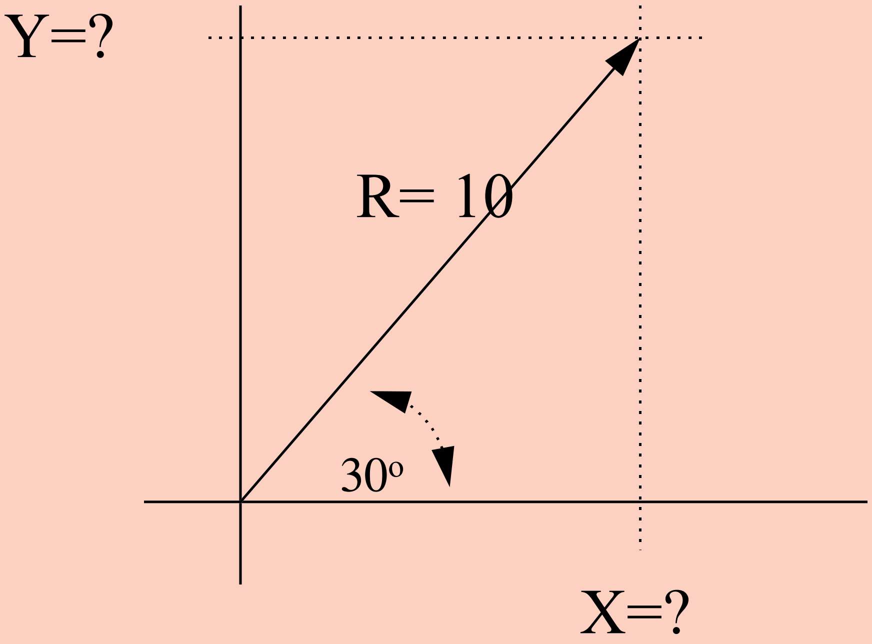
$$R^2 = 7^2 + 9^2 = 49 + 81$$

$$R^2 = 130$$

$$R = \sqrt{130} = 11.4$$

Trigonometrical Ratios Example

AC Theory.



Given that:

Length of R = 10 and

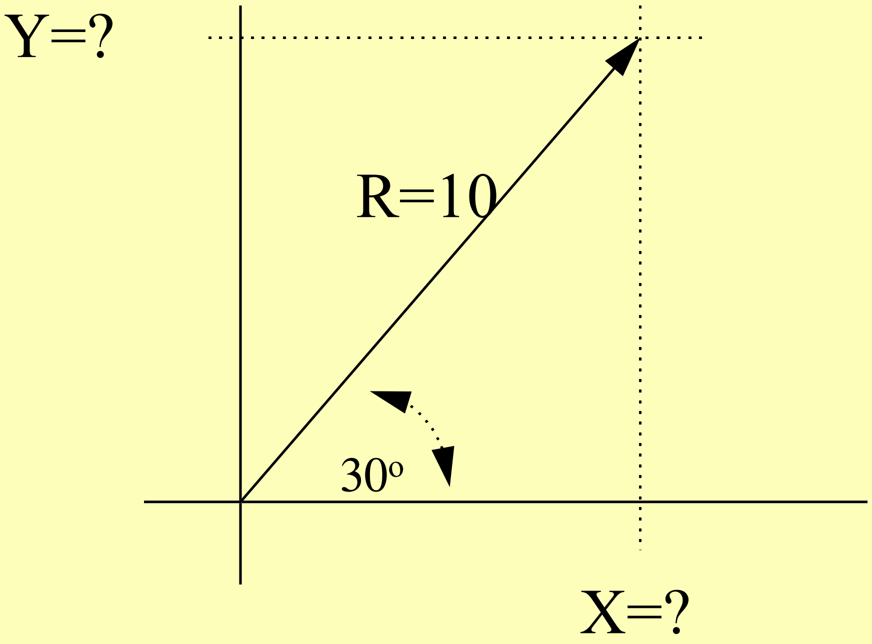
Angle $\theta = 30^o$

Calculate:

X and Y

Trigonometrical Ratios Example

AC Theory.



Angle = 30° = θ

Radius R = 10 = Hypotenuse

Using:-

Sin θ * Hypotenuse = Opposite = Y

Therefore

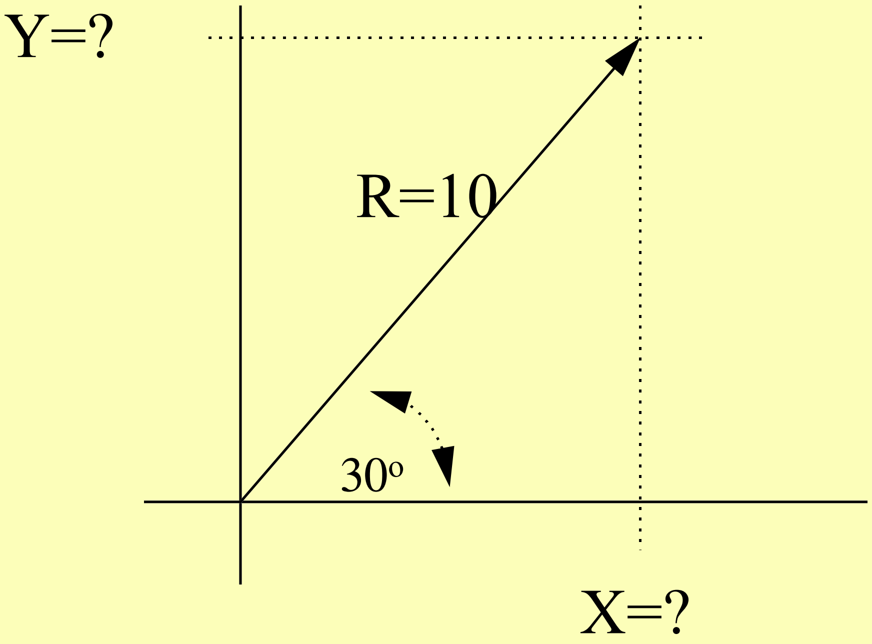
$$0.5 * 10 = Y = 5$$

$$Y = 5$$

$$\sin\theta = \frac{\text{Opposite}}{\text{Hypotenuse}}$$

Trigonometrical Ratios Example

AC Theory.



Angle = 30º = θ

Radius R = 10 = Hypotenuse

Using:-

Cos θ * Hypotenuse = Adjacent = X

Therefore

0.866 * 10 = X = 8.66

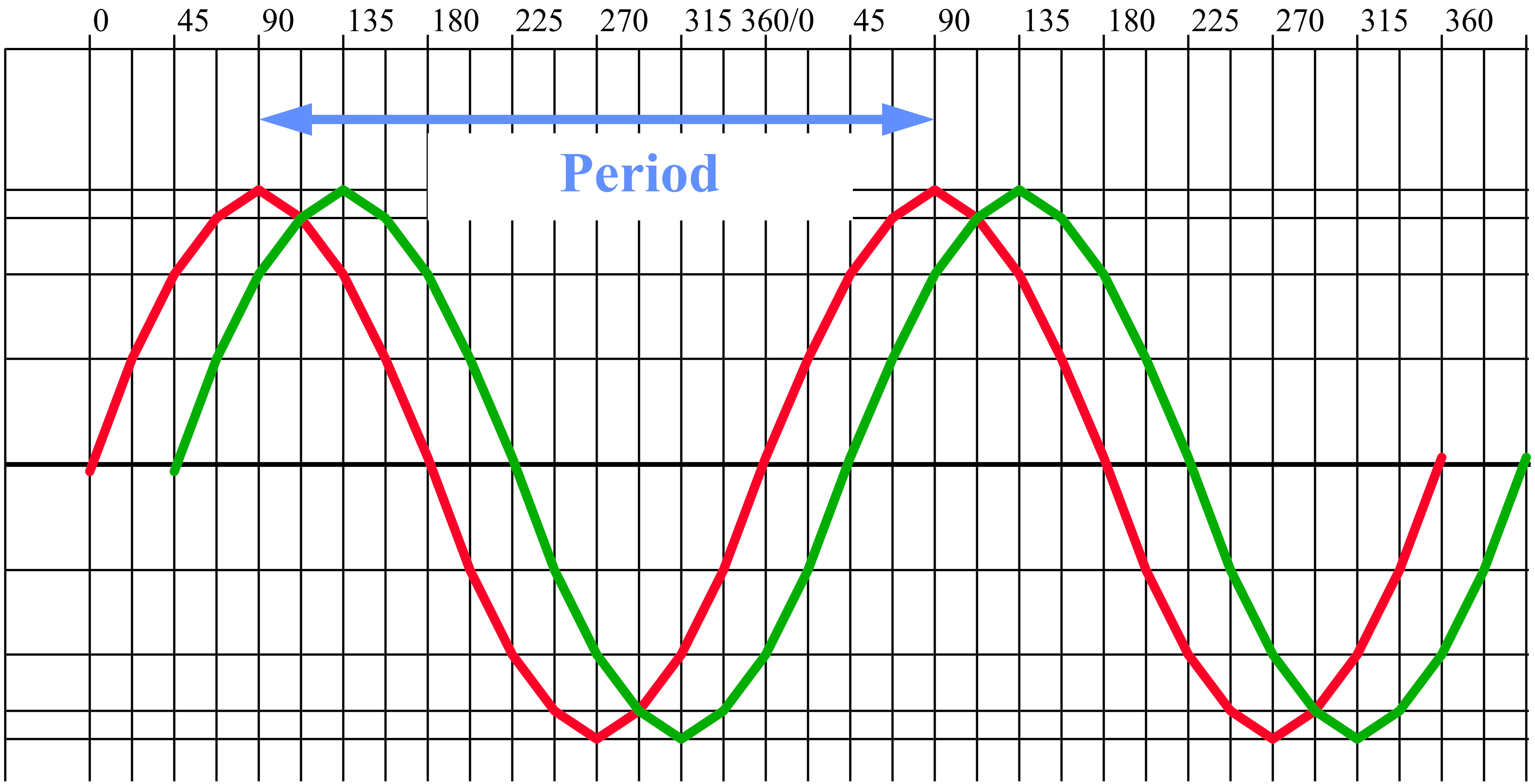
X = 8.66

$$\cos\theta = \frac{\text{Adjacent}}{\text{Hypotenuse}}$$

AC Theory.

Concepts and Terminology.

AC Theory.

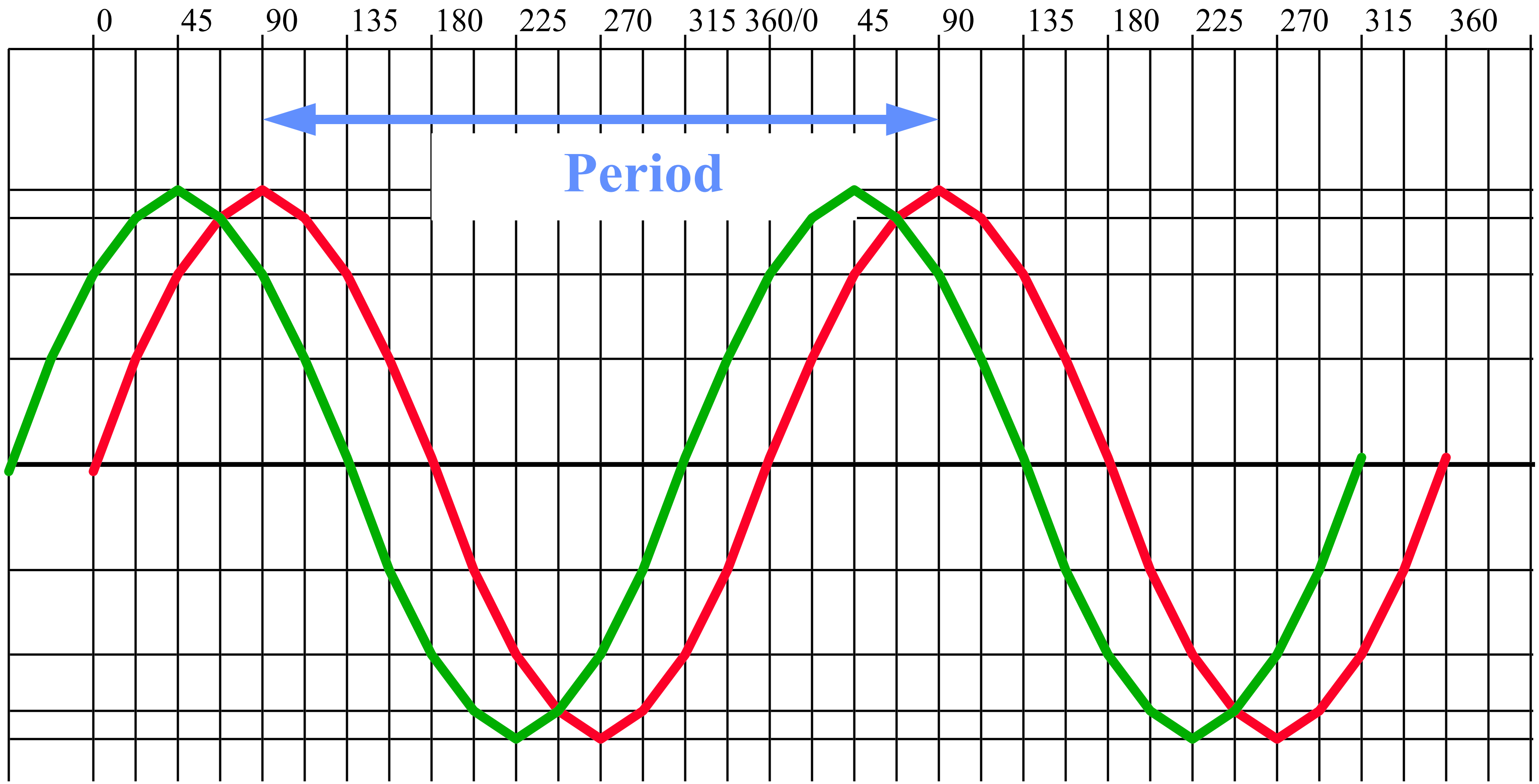


The Green Signal "LAGS" Reference Red Signal by 45^{o}

Signal Phase Difference Measurement

Lag means that it starts after the reference signal.

AC Theory.



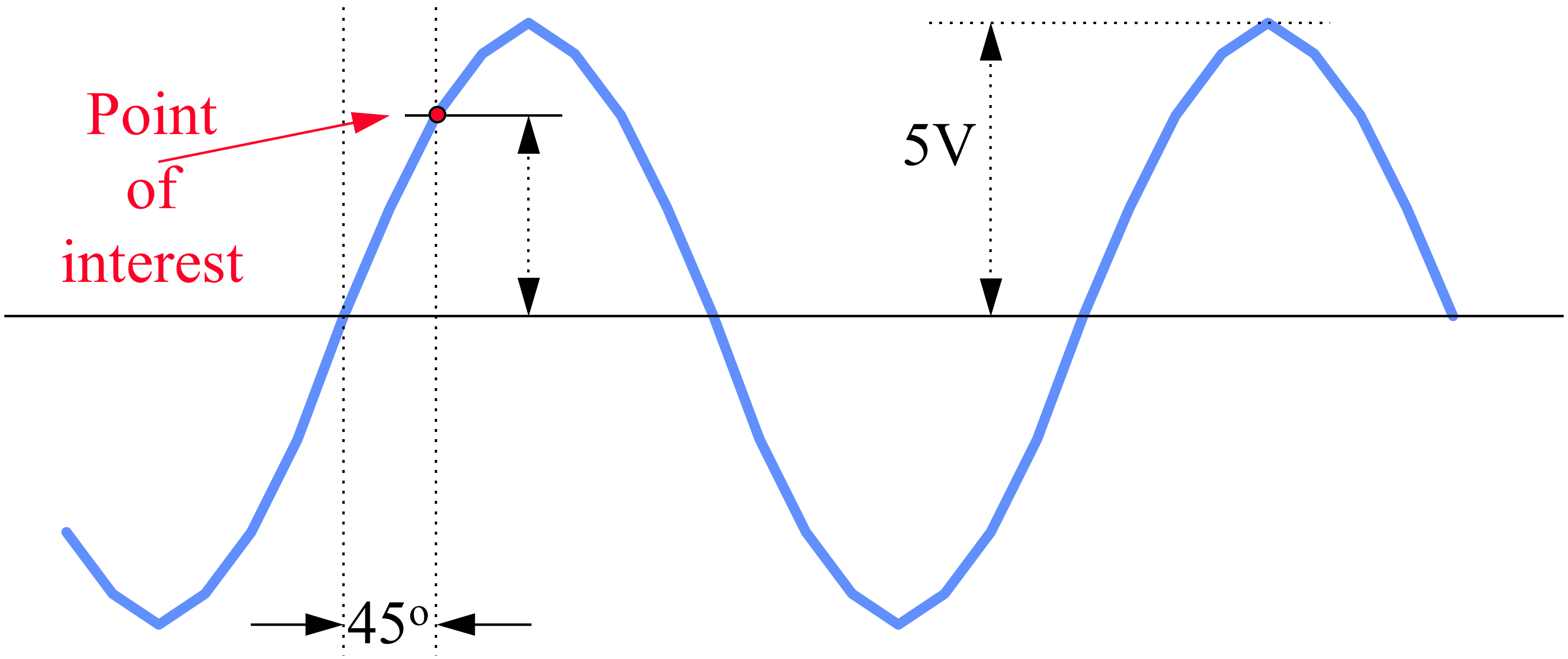
The Green Signal "LEADS" Reference Red Signal by 45º

Signal Phase Difference Measurement

Lead means that it starts before the reference signal.

AC Theory.

Instantaneous Voltages and Current



Amplitude of a sine wave = Vpeak sin (θ Angle ± ϕ phase shift)

Amplitude of a sine wave = 5 sin (45° ± 0°) = 3.53 Volts

AC Theory.

- Example:-
- A sine wave has a peak value of 20 Volts.
- What is the instantaneous value at $+65^{o}$ from the 0^{o} reference ?
- If the signal lags the reference by 5^{o} what would the new instantaneous value at $+65^{o}$ from the 0^{o} reference be?

AC Theory.

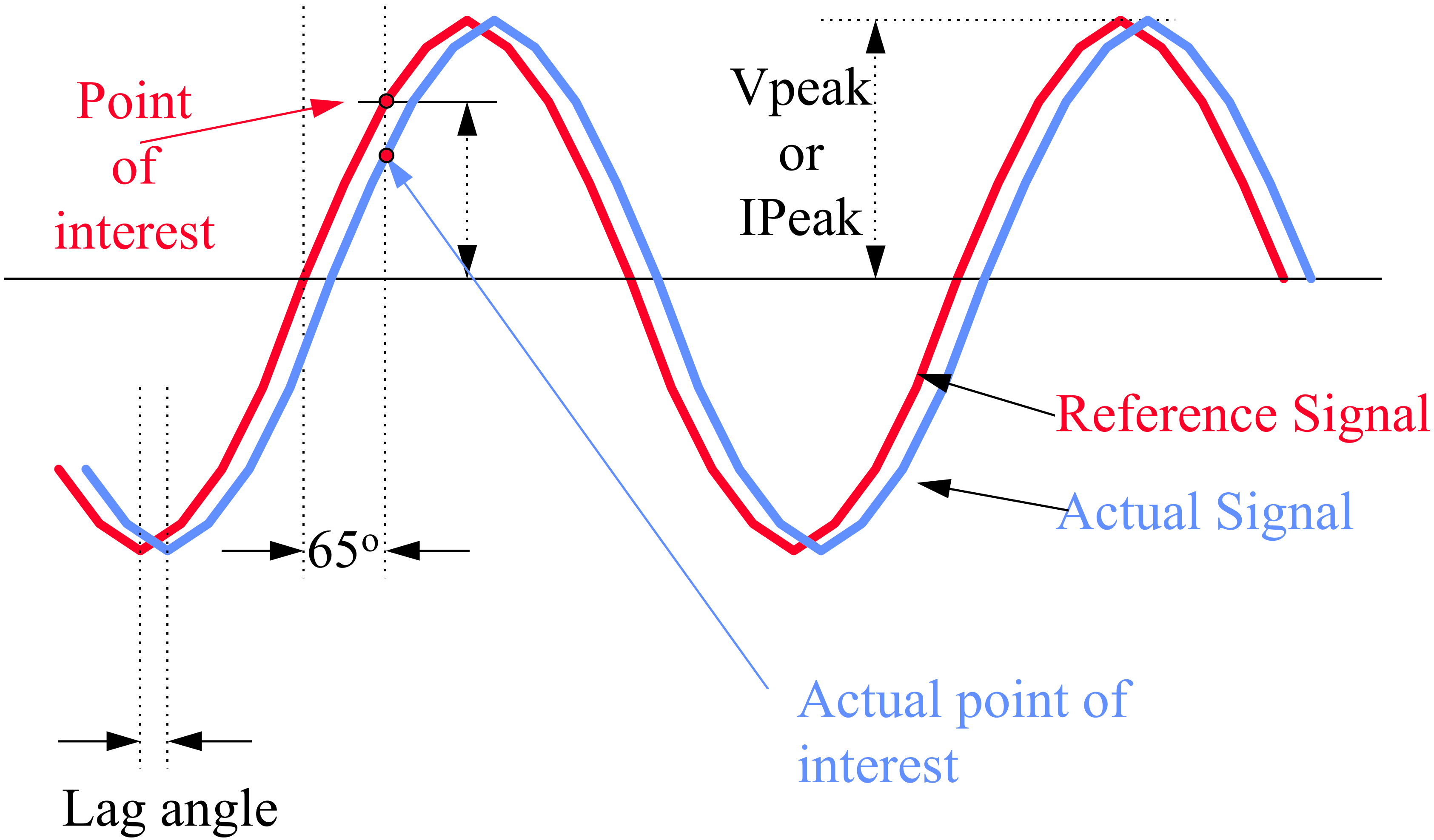
- Example:-
- A sine wave has a peak value of 20 Volts.
- What is the instantaneous value at $+65^o$ from the 0^o reference?
- Solution
- Amplitude of a sine wave

  $= 20 \sin (65^o \pm 0^o)$

  $= 18.126$ Volts

AC Theory.

Instantaneous Voltages and Current



AC Theory.

- Example:-
- A sine wave has a peak value of 20 Volts.
- If the signal lagged the reference by 5^o what would the new instantaneous value at $+65^o$ from the reference be?
- Solution
- Amplitude of a sine wave with 5^o Lag

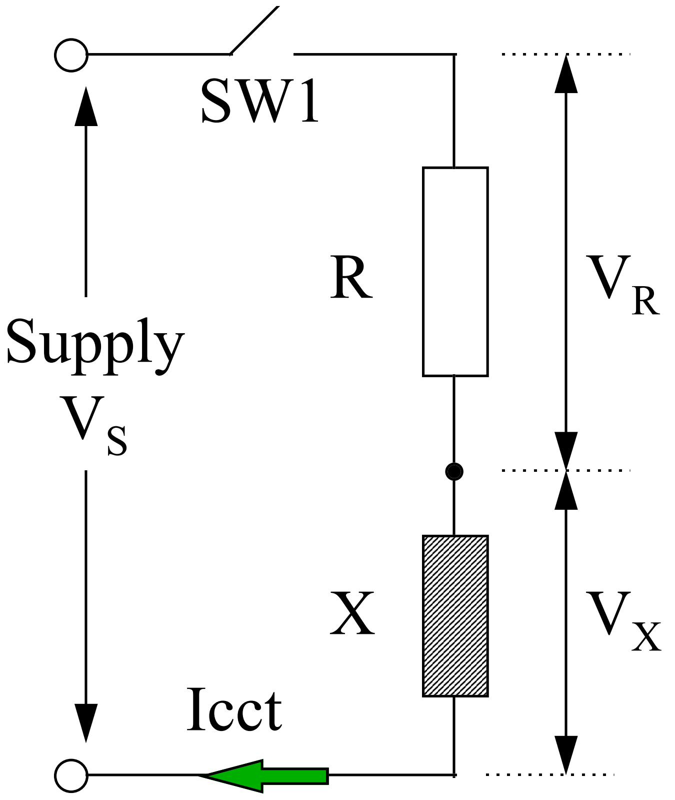
  $= 20 \sin (65^o - 5^o) = \quad 20 \sin (60^o)$

  $= 17.32$ Volts

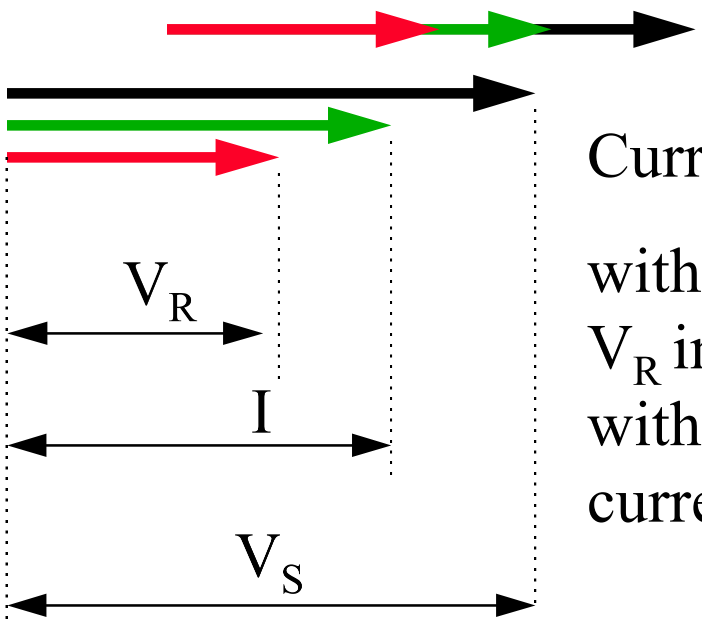
RL or RC Networks

AC Theory.

If we consider this circuit below we can observe that Current flowing through the circuit is common to both R and X.



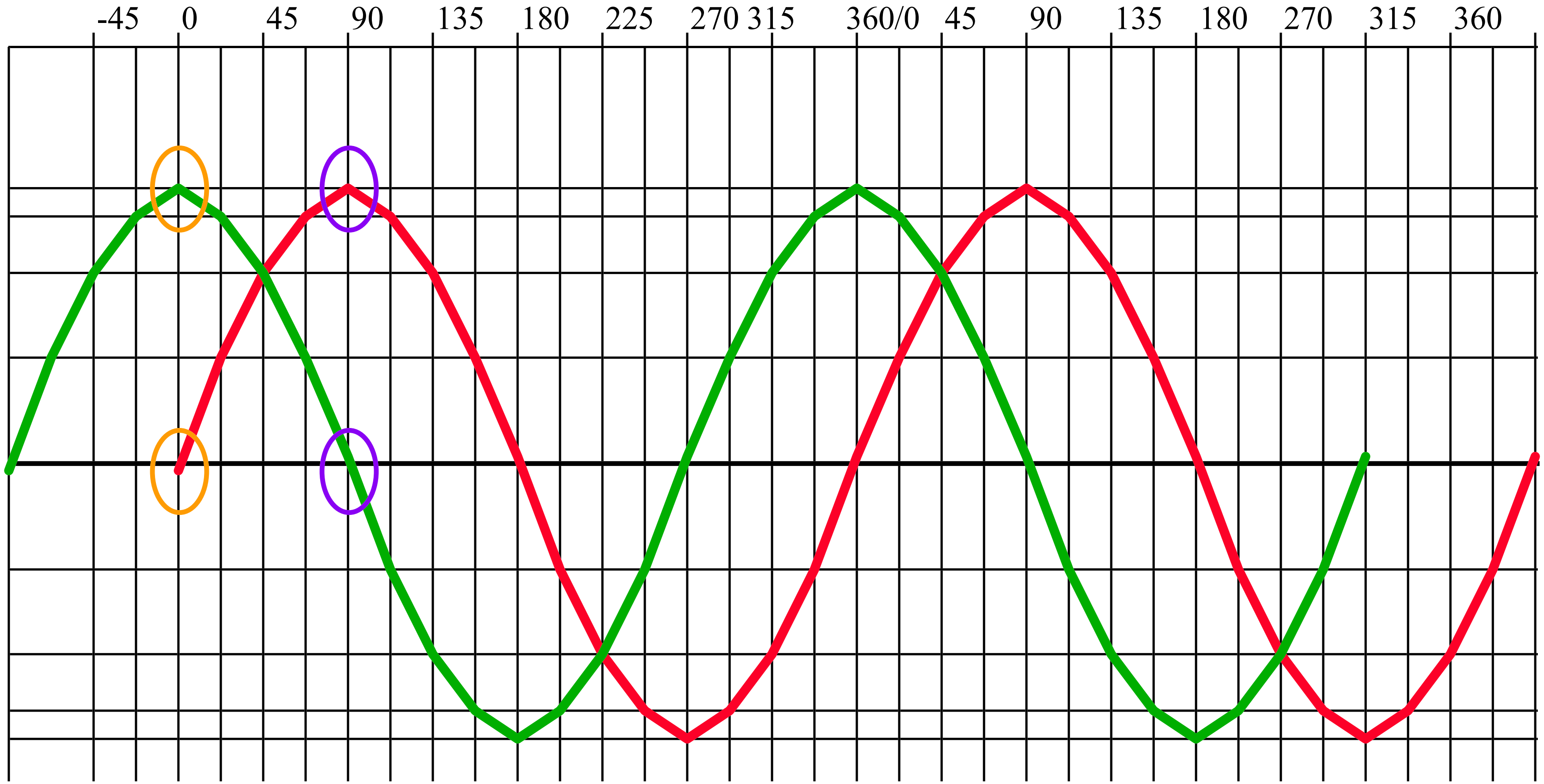
Graphically we can represent these amplitudes on a vector diagram with Current **I** as the reference.



Current I

with V_S and V_R in phase with the current.

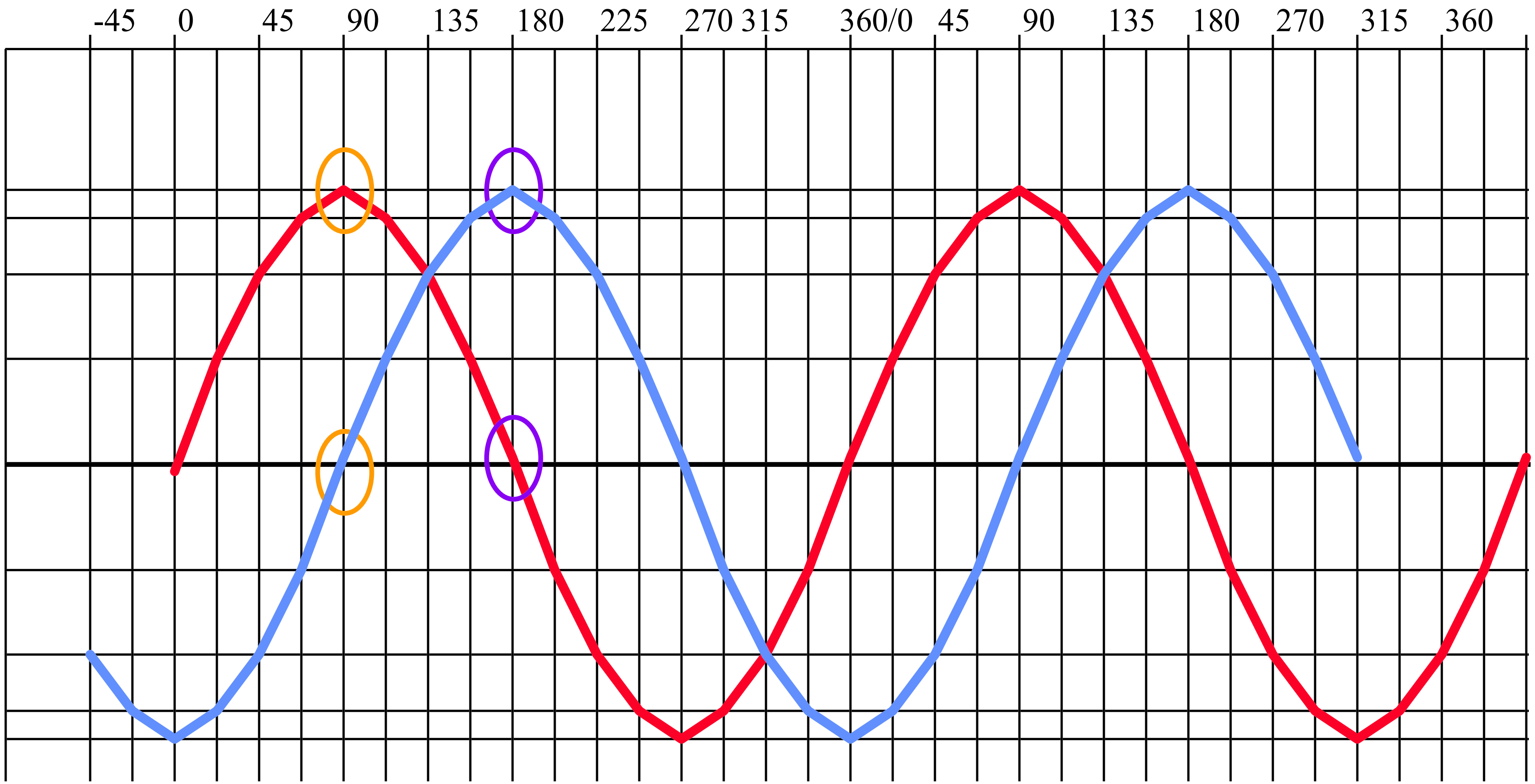
AC Theory.



Remember with the Inductor

Point 1: When the voltage across the Resistor was minimum then the voltage across the Inductor was a maximum. Point 2: When the voltage across the resistor was maximum then the voltage across the Inductor was a minimum.

AC Theory.



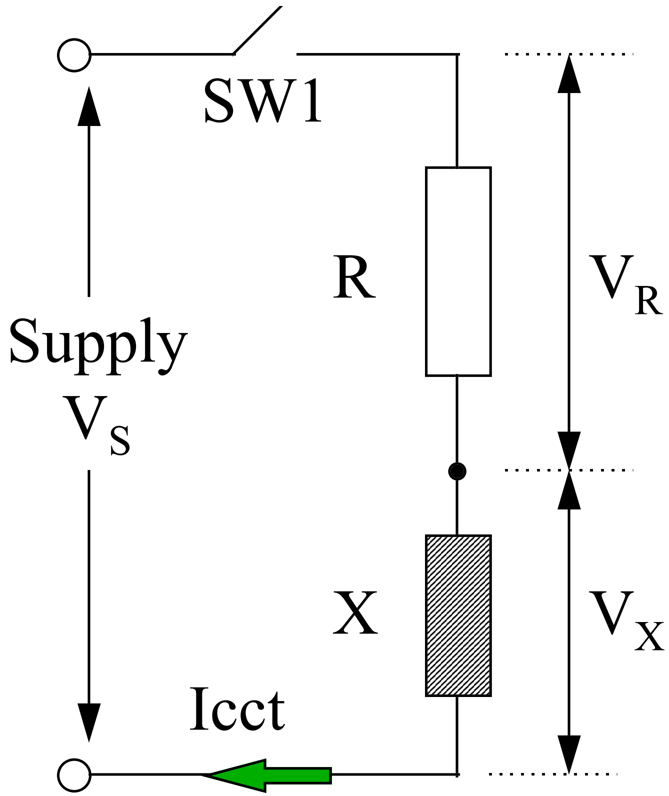
Remember with the Capacitor

Point 1: When the voltage across the Resistor was maximum then the voltage across the Capacitor was a minimum. Point 2: When the voltage across the resistor was minimum then the voltage across the Capacitor was a maximum.

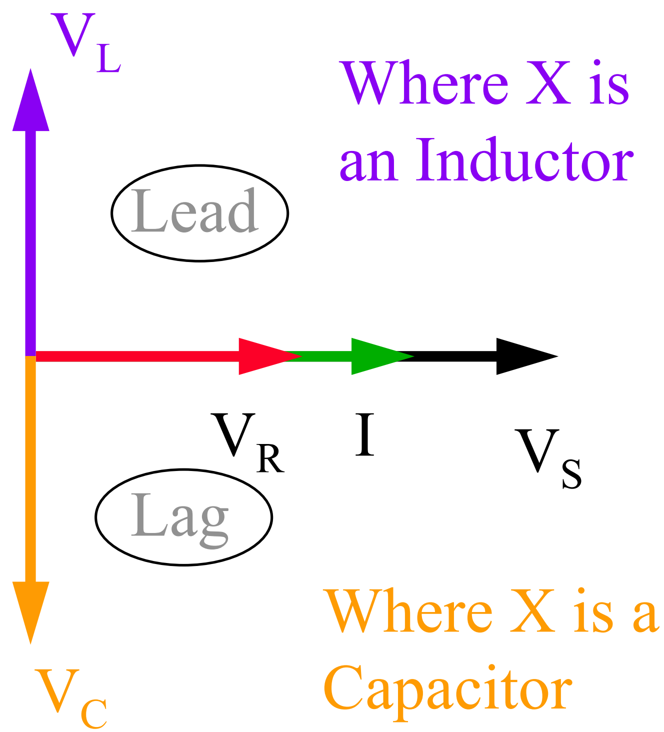
CIVIL

AC Theory.

If we consider this circuit below we can observe that Current flowing through the circuit is common to both R and X.



Graphically we can represent these amplitudes on a vector diagram with Current **I** as the reference.



Example

AC Theory.

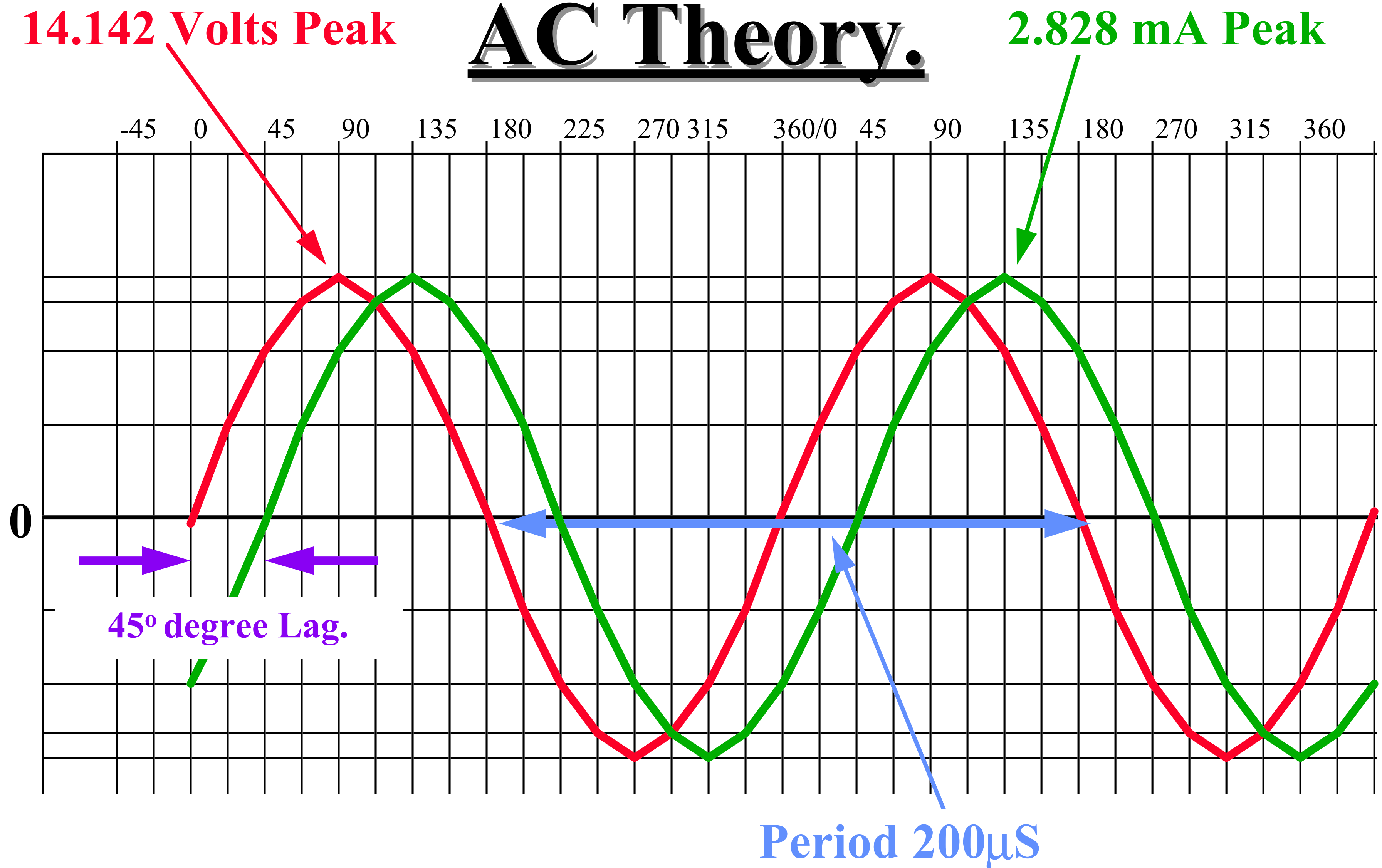
- Sketch a graph to show the following quantities:-
- A sinusoidal voltage of rms value 10V and frequency 5kHz.
- A sinusoidal current of rms value 2mA and frequency 5kHz lagging the voltage by 45^o.
- Use the x-axis for the common time scale and the y-axis for both the voltage and current scales. Show at least two cycles of each waveform.
- Indicate significant values and units on each scale.

Example

AC Theory.

- Step one calculate any appropriate values:-
- 10V rms = therefore Peak Voltage = 1.4142 * 10 = 14.142 Volts.
- 2mA rms = therefore Peak Current = 1.4142 * 2 = 2.8284 mA.
- Period = 1/frequency = 1/5000 = 200μ s

AC Theory.



Signal 1: The voltage waveform

Signal 2: The current waveform lagging the voltage waveform by 45º.

AC Theory.

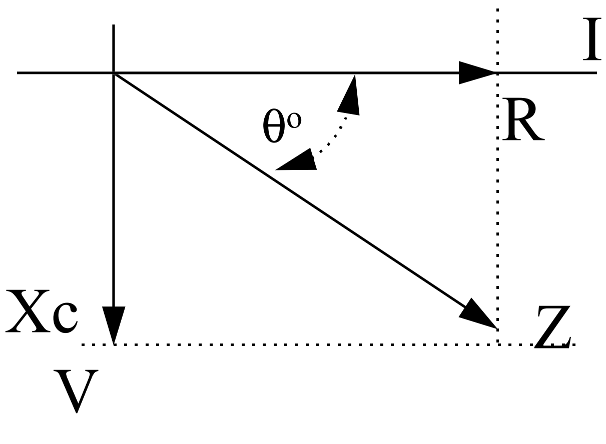
Power in an AC Circuit.

AC Theory.

- Power in AC Circuits:-
- In a purely Resistive AC circuit, all the energy delivered by the source is dissipated in the form of heat by the resistance.
- In a purely (Inductive or Capacitive) circuit, all the energy delivered by the source is stored in the (Inductor or Capacitor) during a portion of the voltage cycle and returned to the source during another portion of the cycle so that there is no net energy conversion to heat.

AC Theory.

- Power in AC Circuits:-
- Apparent power $(P_a) = (I_{tot})^2 * Z$
  - The unit of apparent power is :-
  - The volt-ampere (VA)
- True Power can be expressed $P_{true} = P_a * \text{Cos}\ \theta$



Cos θ = the Power Factor (PF)

$$\text{Power Factor} = \frac{\text{Watts}}{\text{VA}}$$

AC Theory.

- Example:-
- An electrical machine powered by 240Volts mains draws 10Amps from the supply. The Phase angle between voltage and current is 30^o.
- Calculate the true power.

AC Theory.

- Example:-
- An electrical machine powered by 240Volts mains draws 10Amps from the supply. The Phase angle between voltage and current is 30^o.
- Calculate the true power.
  - Power $P = VI \cos \theta$
  - Power $P = 240 * 10 * \cos 30$
  - Power $P = 240 * 10 * 0.87$
  - Power $P = 2088$ Watts

Example

AC Theory.

- The following measurements were taken in an inductive ac circuit.
  - Supply Voltage 250V
  - Supply Current 16A
  - Total real power 2400W
- Calculate the circuit impedance.
- Calculate the circuit power factor.

AC Theory.

- Calculate:-
- Circuit impedance
  - $Z = V/I = 250/16 = 15.625\Omega$
- Calculate:-
- Power Factor
  - (PF) $\cos\phi$ = True Power/Apparent power
  - $\cos\phi = 2400/250*16 = 2400/4000 = 0.6$
- Calculate:-
- Phase angle
  - $\cos\phi = 0.6 = 53.13^{o}$

AC Theory.

Calculating the
Impedance (AC Resistance)
of a Reactive Component
(Capacitor or Inductor)
in an AC Circuit .

AC Theory.

- Impedance of a Capacitor is :-

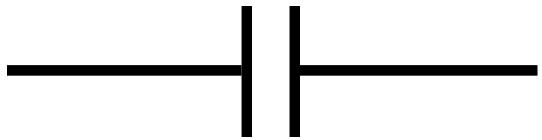
$$Xc = \frac{1}{2\pi FC}$$

Where :-

Xc = Reactance in Ohms.

F = Frequency in Hertz.

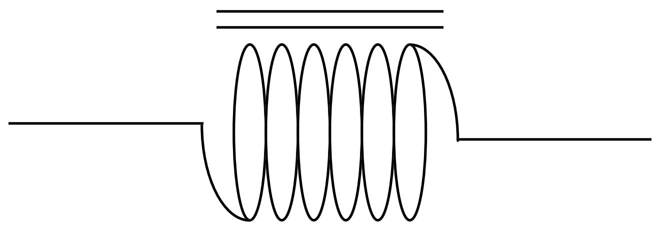
C = Capacitance in Farads.



AC Theory.

- Impedance of a Inductor is :-

$$X_l = 2\pi FL$$



Where :-
X_l = Reactance in Ohms.
F = Frequency in Hertz.
L = Inductance in Henries.

AC Theory.

- Example:-
- What is the impedance of a 10μF Capacitor at a frequency of 1KHz.

Solution

AC Theory.

- What is the impedance of a 10μF Capacitor at a frequency of 1KHz.
- Solution
- $Xc = 1/2\pi FC = 1/(2 * \pi * (1*10^{3)} * (10*10^{-6}))$
- $Xc = 1/(6.283 * 10^{-3}) = 159.15\Omega$

AC Theory.

- Example:-
- What is the impedance of a 10H Inductor at a frequency of 1KHz.

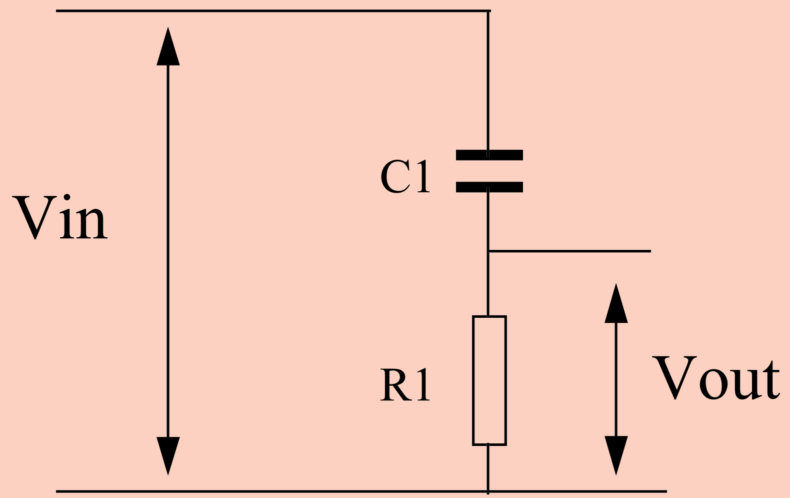
Solution

AC Theory.

- What is the impedance of a 10H Inductor at a frequency of 1KHz.
- Solution
- XL = 2πFL = (2 * π * (1*10$^{3)}$ * (10))
- XL = (6.283 * 10^4) = 62.83KΩ

AC Theory.

- Example:-
- The Capacitor C1 has a value of 1000nF.
- The Resistor R1 has a value of 1000Ω.
- When an input signal of 240Volts at a frequency of 50Hz is applied what voltage will be present on the output terminals Vout.



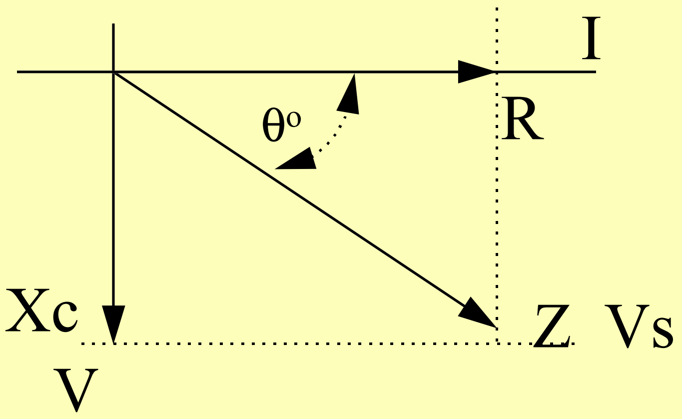
Solution

AC Theory.

- Reactance of Capacitor XC = $1/2\pi FC$

  $= 1/(2 * \pi * 50 * (1*10^{-6}))) = 3183\Omega$
- Circuit Impedance = $\sqrt{R^2+XC^2} = \sqrt{3183^2+1000^2}$

  $= \sqrt{11131489} = 3336\Omega$
- Phase angle Tan $\theta = 3182/1000 = 3.182$
- Therefore $\theta = 72.55^o$
- Voltage out = Vs*Sin θ = 240*Sin θ = 228.9 Volts



AC Theory.

Power Factor Correction

in AC Circuits.

AC Theory.

- Why Power correction in AC Circuits ? :-
- In a purely Resistive AC circuit, all the energy delivered by the source is dissipated in the form of heat/energy by the Load.
- If the Load is (Inductive or Capacitive) it will not use all the raw power effectively.
  - It will need conductors to be thicker because of the higher current requirements.
  - It will need the insulation to be thicker because of the higher voltage requirements.
- It could reduce costs to the consumer if the power factor is corrected.

AC Theory.

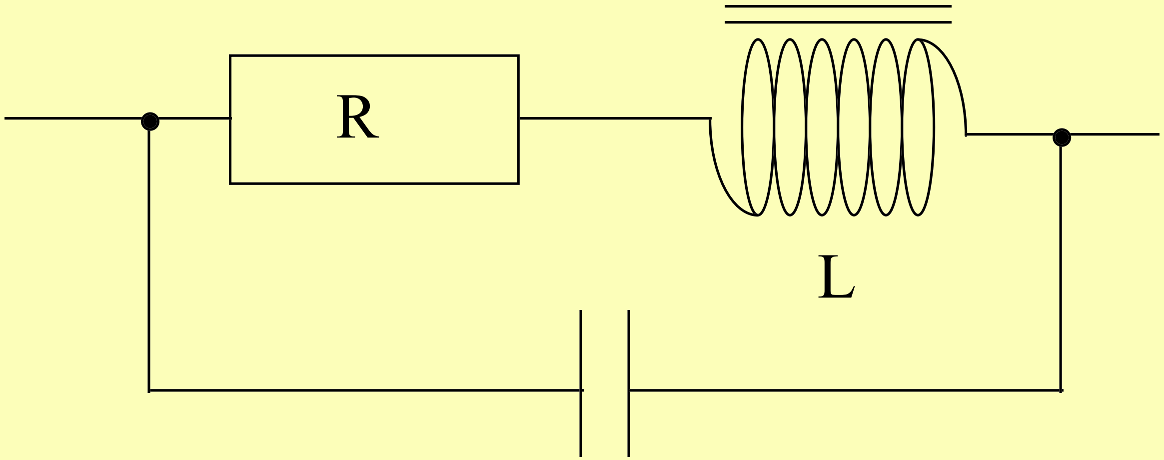
- Some advantages of Power Factor correction are:-
- Lower voltages ∴ Thinner insulation.
- Lowers current ∴ Thinner conductors.
- Less losses in transmission system / grid.
- Less power regulation needed at the generator station.
- Less power generated at the generator station.
- Reduces costs on industrial tariffs.
- Leading capacitor current cancels lagging current of load.
- Connect Capacitor of appropriate value in parallel.
- Reduces current from supply for inductive load.
- Reduces overall kVA.

AC Theory.

- How do we correct the Power Factor ? :-
- If the load is (Inductive) then we add a (Capacitor) to restore the Power Factor (Cos θ) back to 1.
- If the load is (Capacitive) then we add an (Inductor) to restore the Power Factor back to 1.
- If we are dealing with a series circuit then we could add a Capacitor in series which had the same reactance value as the circuit Inductance.
- The Inductance would cause the current to LAG, the Capacitance would cause the current to LEAD and the overall effect would give a circuit that appears to be purely Resistive.

AC Theory.

- Basic circuit diagram with one method of Power factor correction.



Capacitor
Used to correct power factor

AC Theory.

- A 50μF capacitor is connected in series with a 2K7Ω resistor across a 100V, 50Hz supply calculate.
- The phase angle between voltage and current.
- The Voltage across the capacitor.
- What value of inductance would give the same phase angle?

Solution

AC Theory.

- Phase angle may be obtained from tan θ = Xc/R
- Reactance of Capacitor XC = 1/2πFC

  = 1/(2 * π * 50 * (10*10$^{-6)}$)) = 318.3Ω
- Phase angle tan θ = 318/2700 = 0.1179 = 6.72^{o}
- Circuit Impedance = $\sqrt{}$ R^2+XC^2 = $\sqrt{}$ 318.3^2+2K7^2

  = $\sqrt{}$7391314.89 = 2718.69Ω
- Circuit Current V/X = 100/2718.7 = 36.78mA
- Capacitor voltage = Xc*I = 318.3*36.78*10-3

  = 11.71 Volts.
- Inductive reactance = 2πFL = Xc = 318.3
- L = 318.3/ 2 * π * 50 = 1 Henry

AC Theory.

- Part 1
- A circuit with a 230V, 50Hz supply has a 50μ F capacitor and 200Ω Resistor in series.
- Calculate reactance of the capacitor.
- Calculate the circuit impedance.
- Part 2
- A series ac circuit has a coil of negligible resistance in series with a resistor. The Voltages measured as follows:-
- Across the coil 160V , Across the resistor 120v
- Draw the phasor diagram of these voltages.
- Determine the supply voltage.

Solution

AC Theory.

- Part 1.
- Reactance of Capacitor XC = $1/2\pi FC$

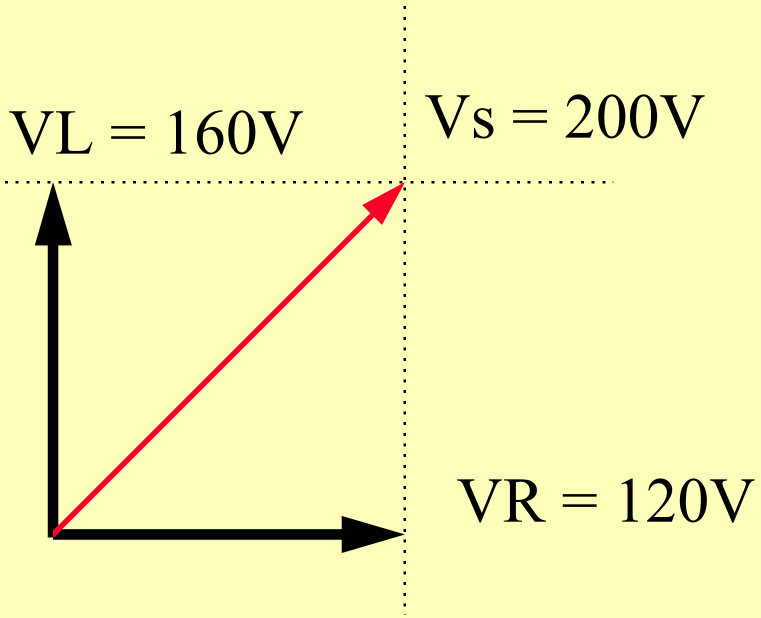
  $= 1/(2 * \pi * 50 * (50*10^{-6)})) = 63.66\Omega$
- Circuit Impedance = $\sqrt{R^2+XC^2} = \sqrt{63.66^2+200^2}$

  $= \sqrt{44052.8} = 209.88\Omega$

Solution

AC Theory.

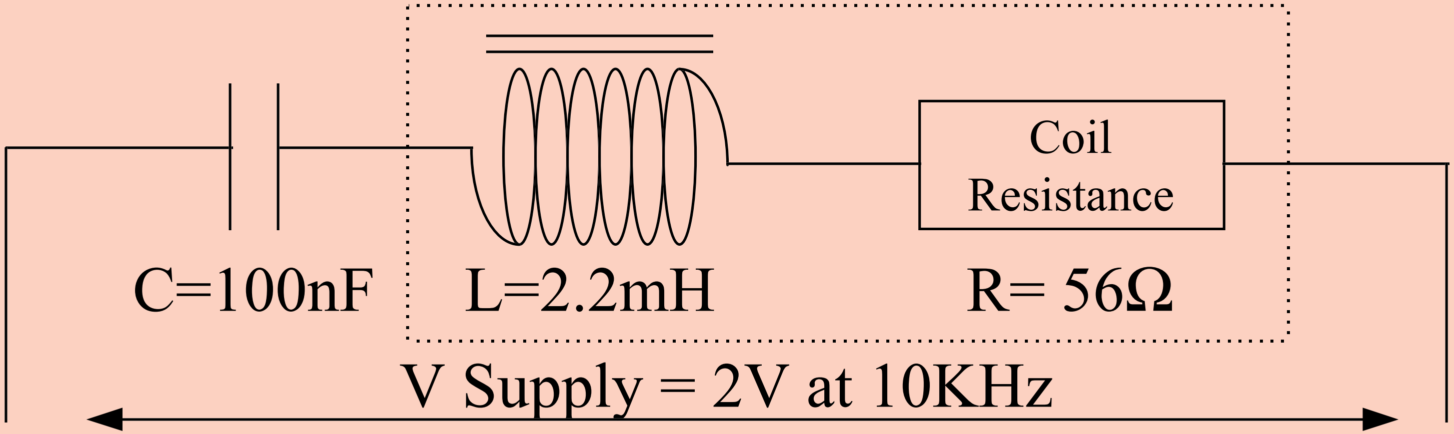
- Part 2.
- $Vs = \sqrt{(VL)^2 + (VR)^2}$
- $Vs = \sqrt{(160)^2 + (120)^2}$
- $Vs = \sqrt{25600 + 14400}$
- $Vs = \sqrt{40000}$
- $Vs = 200$



RLC Networks

AC Theory.

- Given the following circuit.
- Calculate the circuit impedance.
- Calculate current flowing in the circuit .
- Calculate and the phase difference between the supply voltage and current.
- Calculate the voltage across the Capacitor
- Calculate the voltage across the Inductor.
- Draw the phasor diagram of these voltages.



AC Theory.

- XC = 1/(2 πfC) Where C=100nF and f=10KHz
- XC = 1(2*π*10000*100*10^{-9}) = 159.15Ω
- XL = 2πfL Where L=2.2mH and f=10KHz
- XL = 2πfL = 2*π*(1000)*(2.2*10-3) = 138.23Ω
- Since XC is greater than XL the circuit is capacitive. ∴ Circuit reactance =
- XC - XL = 159.15 - 138.23 = 20.92Ω
- Circuit impedance $Z = \sqrt{}[R^2 + (XL^2 - XC^2]$
  $Z = \sqrt{}(56)^2 + (-20.92)^2] = 59.78\Omega$
- Current I = Icct = V/Z = 2/59.78 = 33.46mA
- Phase angle φ = arctan(XL - XC)/R)
- Phase angle φ =arctan -20.92/56 = -20.48°

AC Theory.

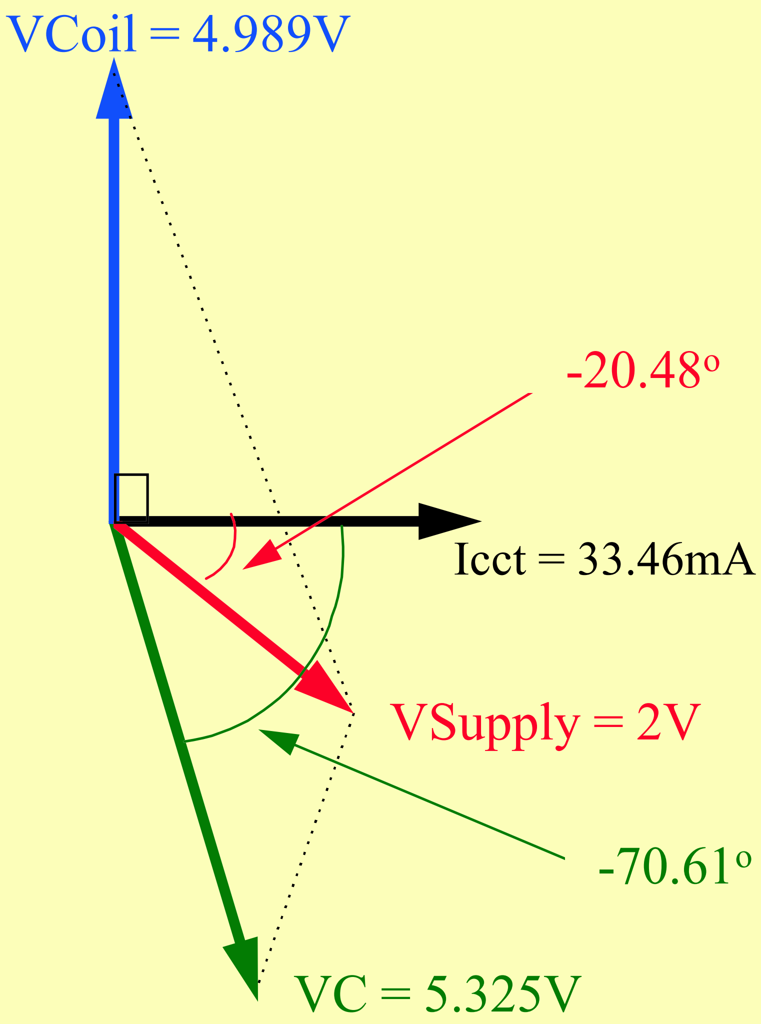
- Impedance of coil (Assume R = Coil Resistance)
- Zcoil = $\sqrt{(R^2 + XL^2)} = \sqrt{[(56)^2 + (138.23)^2]}$
- Zcoil = 149.14Ω
- Voltage across coil Vcoil = Icct * Zcoil
- Vcoil = (0.03346)*(149.14) = 4.989V
- Coil ϕ = arctan (XL / R) = 90^o (Circuit Capacitive)

- Voltage across capacitor VC
- VC = I * XC = (0.03346)*159.15) = 5.325V
- Phase angle of the Capacitor = Cap ϕ
- Cap ϕ = arctan (-XC / R)
- Cap ϕ = arctan(-159.15 /56) = -70.61^o

AC Theory.

CIVIL

- Phasor Diagram

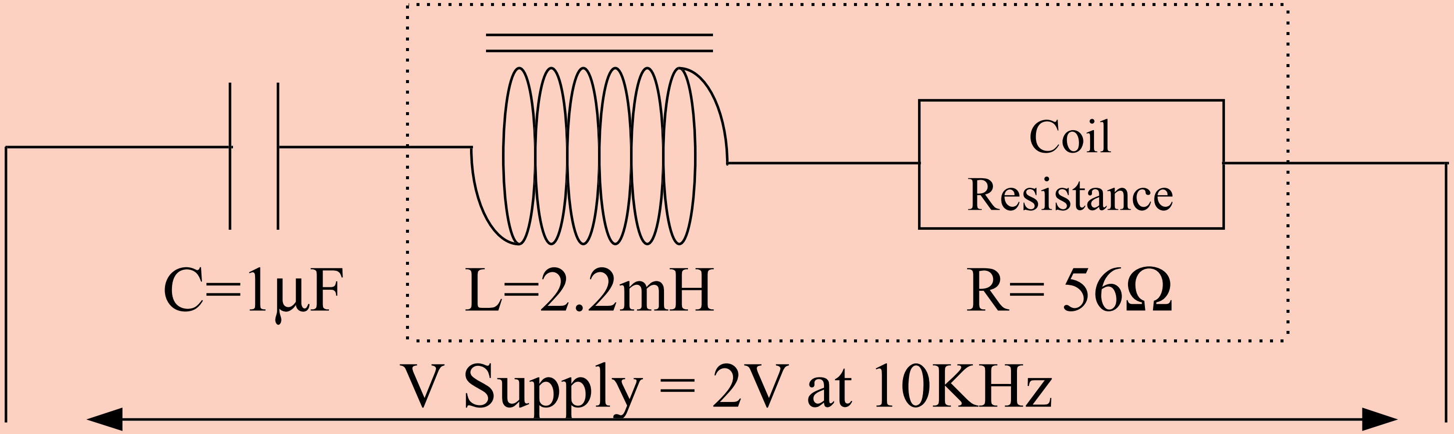


Note:

The supply voltage V is the phasor sum of VCoil and VC

AC Theory.

- Given the following circuit.
- Calculate the circuit impedance.
- Calculate current flowing in the circuit .
- Calculate and the phase difference between the supply voltage and current.
- Calculate the voltage across the Capacitor
- Calculate the voltage across the Inductor.
- Draw the phasor diagram of these voltages.



AC Theory.

- XC = 1/(2 πfC) Where C=100nF and f=10KHz
- XC = 1(2*π*10000*1*10^{-6}) = 15.915Ω
- XL = 2πfL Where L=2.2mH and f=10KHz
- XL = 2πfL = 2*π*(1000)*(2.2*10-3) = 138.23Ω
- Since XL is greater than XC the circuit is Inductive. ∴ Circuit reactance =
- XL - XC = 138.23 - 15.92 = 122.31Ω
- Circuit impedance $Z = \sqrt{[R^2 + (XL^2 - XC^2]}$

  $Z = \sqrt{(56)^2 + (122.31)^2]} = 134.52\Omega$
- Current I = Icct = V/Z = 2/134.52 = 14.87mA
- Phase angle ϕ = arctan(XL - XC)/R)
- Phase angle ϕ =arctan 122.31/56 = 65.4^o

AC Theory.

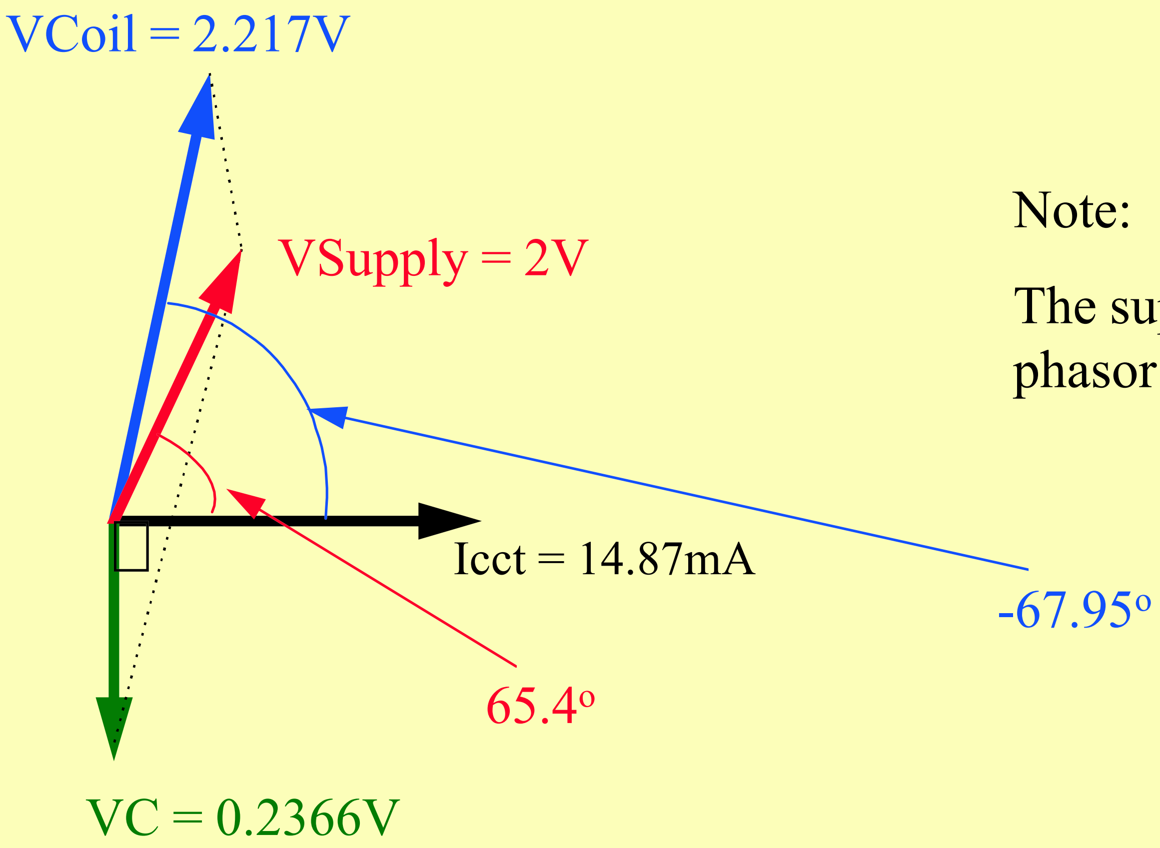
- Impedance of coil (Assume R = Coil Resistance)
- Zcoil = $\sqrt{}$ $(R^2 + XL^2)$ = $\sqrt{}[(56)^2 + (138.23)^2]$
- Zcoil = 149.14Ω
- Voltage across coil Vcoil = Icct * Zcoil
- Vcoil = (0.01487)*(149.14) = 2.217V
- Coil ϕ = arctan(138.23 / 56) = 67.95^o

- Voltage across capacitor VC
- VC = I * XC = (0.01487)*15.915) = 0.2366V
- Phase angle of the Capacitor = Cap ϕ
- Cap ϕ = arctan (-XC / R) = -90^o (Circuit Inductive)

AC Theory.

CIVIL

- Phasor Diagram



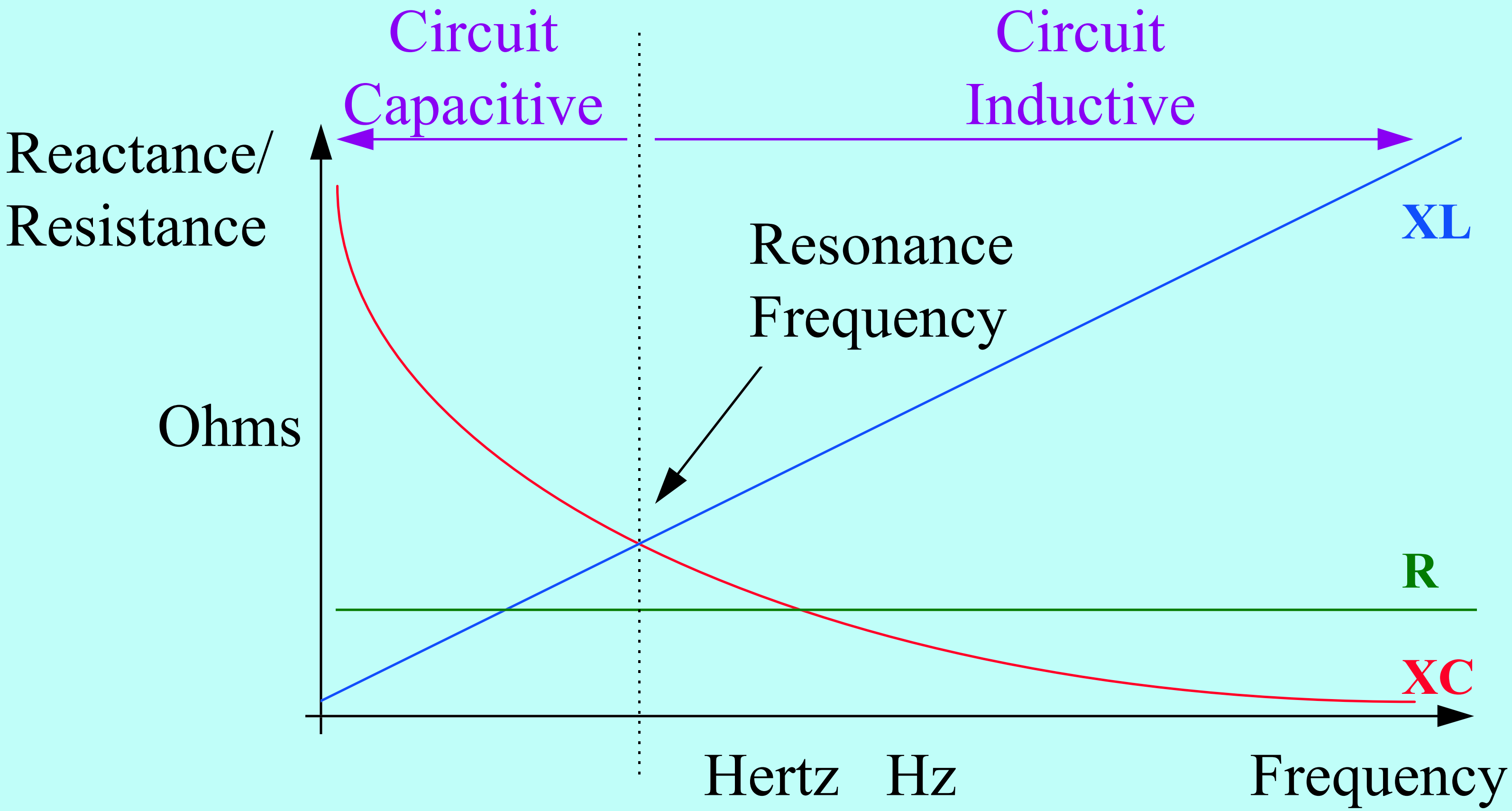
Note:

The supply voltage V is the phasor sum of VCoil and VC

Resonant Networks

AC Theory.

- Relationship between R, L and C to Frequency.
- Note: at a frequency XL = XC (Resonance)



AC Theory.

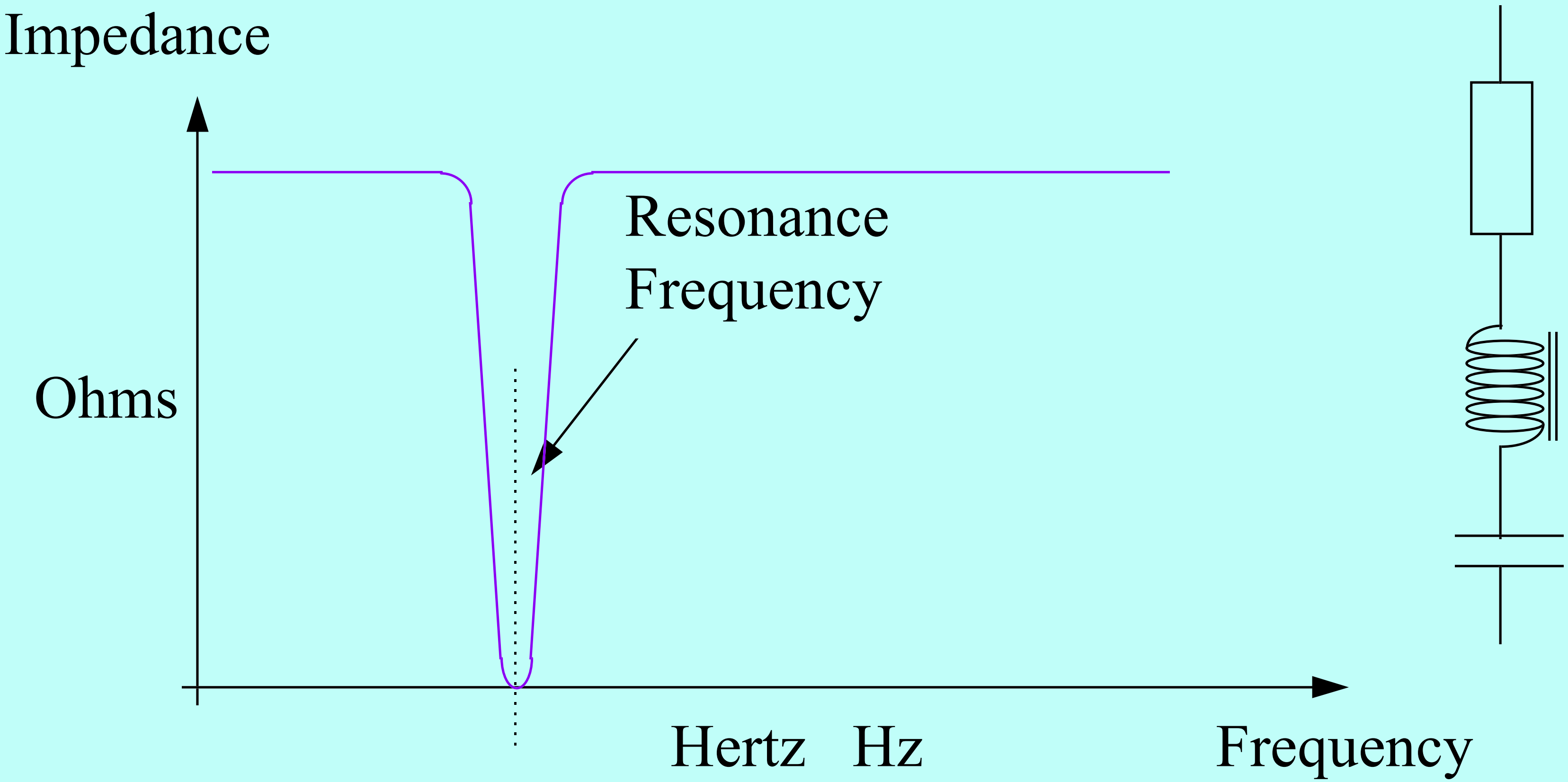
- RLC circuits.
- At resonance both XL and XC are equal therefore we can calculate the resonant frequency from the component values :-
- Resonant frequency F_0 can be calculated from
- $XC = 1/2\pi FC = XL = 2\pi FL$ or
- $(2\pi F)(2\pi F) = 1/LC = (2\pi)^2 * F^2$
- $F^2 = 1 /(2\pi)^2 * LC$
- $F = \sqrt{1} / \sqrt{(2\pi)^2} * \sqrt{LC} = 1 / 2\pi\sqrt{LC}$
- Resonant Frequency = $F_0 = 1 / 2\pi\sqrt{LC}$

AC Theory.

- RLC circuits.
- At resonance both XL and XC are equal and opposite therefore depending on the circuit configuration the reactances will either cancel or re-enforce each other.
- Series resonant circuits appear as Low Impedance.
- Parallel circuits appear as High Impedance.
- A Parallel resonant circuit present an impedance greater than that of either XC or XL and is called the Dynamic Impedance Z_0 .
- Z_0 Dynamic impedance is calculated by $Z_0 = L/RC$ where R is the DC resistance of the inductor.

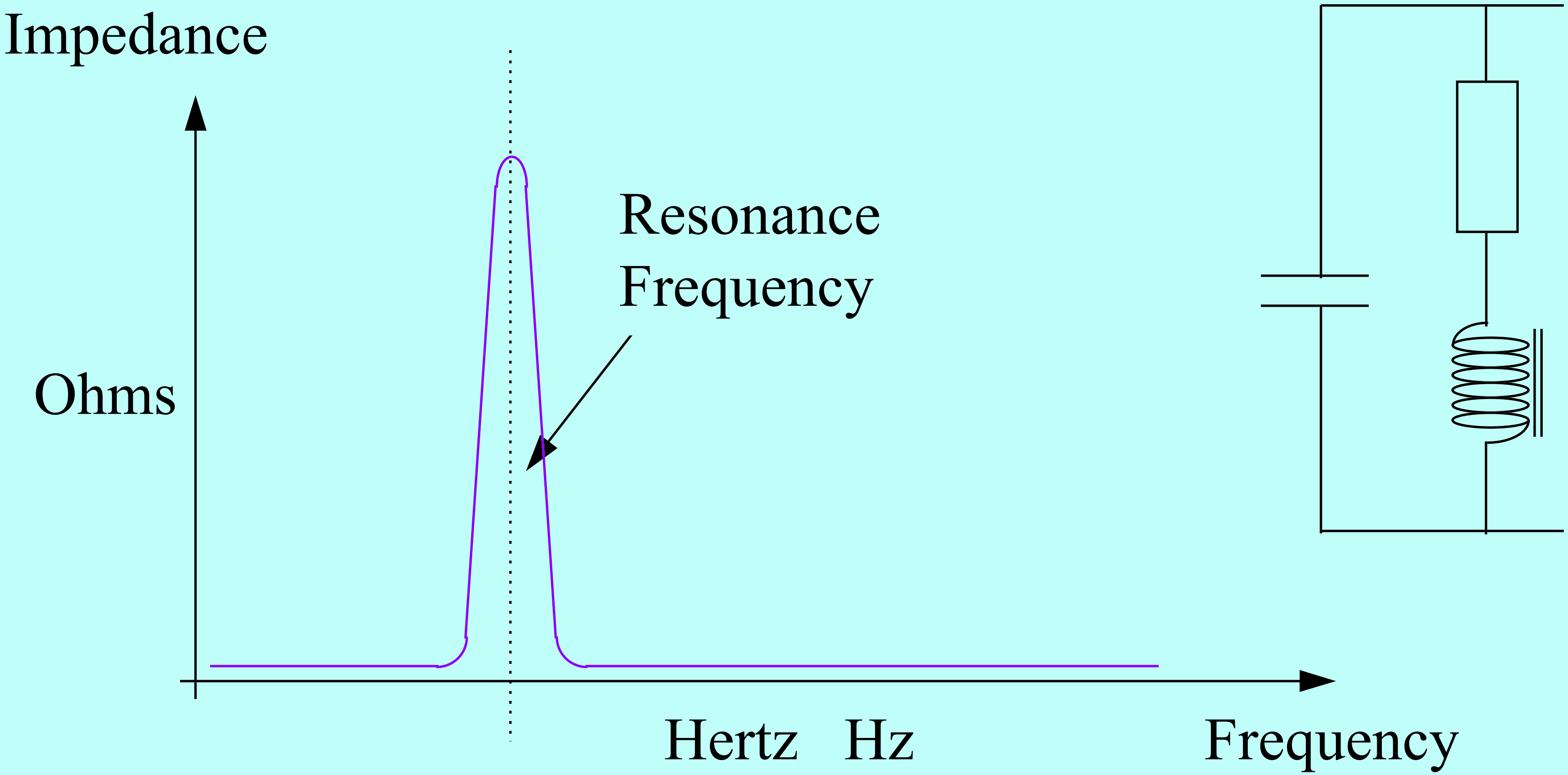
AC Theory.

- Relationship between Series RLC and Frequency.
- Note: effect when XL = XC (Resonance)



AC Theory.

- Relationship between Parallel RLC and Frequency.
- Note: effect when XL = XC (Resonance)

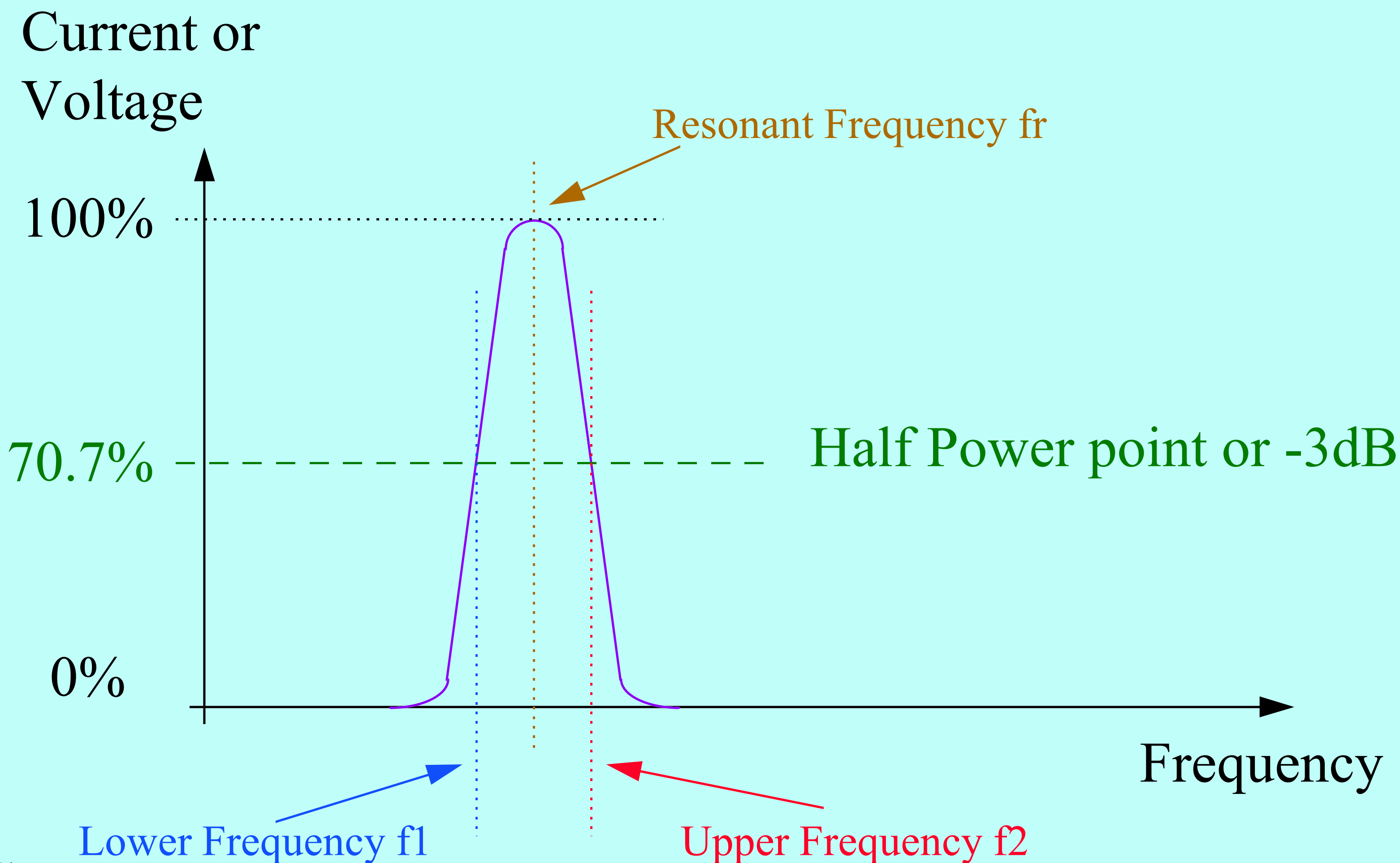


AC Theory.

- Bandwidth of RLC circuits.
- At resonance the RLC circuit will allows a range of frequencies to pass or block around the center frequency f_0 . This range is called the Bandwidth.
- The Bandwidth is measured at 70.7% voltage or current output point, (-3db) or half power point
- Bandwidth $BW = R/2\pi L$ or f_0/Q
- Qualify factor or Q is calculated from
- $Q = XL/R$
- A high Q indicates a smaller bandwidth a low Q indicated a larger bandwidth.

AC Theory.

- Bandwidth of a tuned circuit.
- Bandwidth BW = f2 - f1 or calculated by $R/2\pi L$



The Decibel

The Decibel.

- Power Gain can calculated from :-
  - Power Gain = Power Out / Power in
- If we wish to calculate the gain of a system with many sub-modules (some Amplifying {making the signal bigger} and some Attenuating {making the signal smaller}) the process becomes rather tedious because each individual module's Output is calculated by multiplying its Input by its Gain.
- However if we convert the Gain of each module to a logarithmic form (x^n) then the overall Gain of any system can be calculated by just adding the powers of each of the individual Gains.

The Decibel.

- Relationships:-
- Power Gain is calculated from :-
  - Power Gain = (Power Out / Power in)
- Power Gain in Bels is calculated from :-
  - Power Gain = $\log_{10}$ (Power Out / Power in)
- Power Gain in decibels is calculated from :-
  - Power Gain = $10 \log_{10}$ (Power Out / Power in)
- Why use Base 10 Logs? Because our hearing has a Base 10 relationship with respect to sound levels.

The Decibel.

- Gain in decibels (using Current Ratios) =
  - $10 \log_{10} ((I^2out*Rout) / (I^2in*Rin))$
  - $10 [\log_{10} ((I^2out / I^2in) * (Rout / Rin))]$
  - $10 [\log_{10} ((I^2out / I^2in) + \log_{10} (Rout / Rin))]$
  - $10 [2 \log_{10} ((Iout / Iin) + \log_{10} (Rout / Rin))]$
  - Only if Rout = Rin then
    - $10 [2 \log_{10} ((Iout / Iin) + \log_{10} 1)]$
    - however; note that $\log_{10} 1 = 0$ so
    - Gain = $10 [2 \log_{10} ((Iout / Iin))]$
    - or the more common re-written form :-
    - Gain = $20 \log_{10} (Iout / Iin)$

The Decibel.

- Gain in decibels (using Voltage Ratios) =
  - $10 \log_{10} ((V^2out / Rout) / (V^2in / Rin))$
  - $10 \log_{10} ((V^2out / Rout) * (Rin / V^2in))$
  - $10 [\log_{10} ((V^2out / V^2in) * (Rin / Rout))]$
  - $10 [\log_{10} ((V^2out / V^2in) + \log_{10} (Rin / Rout))]$
  - $10 [2 \log_{10} ((Vout / Vin) + \log_{10} (Rin / Rout))]$
  - Only if Rout = Rin then (Remember $\log_{10} 1=0$)
    - $10 [2 \log_{10} ((Vout / Vin) + \log_{10} 1)]$
    - Gain = $10 [2 \log_{10} ((Vout / Vin))]$
    - or the more common re-written form :-
    - Gain = $20 \log_{10} (Vout / Vin)$

The Decibel.

- The decibel is a ratio and not suitable for specifying an Output unless it is referenced to some defined Input.
- An amplifier with an Output of 30dB means little unless you know what the input is.

  Output = *1000
- Common Used References :-
  - dBm Output referenced to 1mW
  - dBW Output referenced to 1W
  - dBμV Output referenced to 1μV

Noise

What is Noise?

Noise.

- An unwanted component in an Output signal.
- Sources of Noise
  - Internal (Generated within the equipment itself)
  - External (generated by an External source)
- Types of Noise
  - Thermal Agitation Noise
  - Interference and Crosstalk
  - Semiconductor Noise
    - Shot Noise
    - Partition Noise
    - 1/f noise or Flicker Noise

What is Noise?

Noise.

- Thermal Agitation Noise
  - As temperature rises above -273°C some electrons in the outer shells of the atoms gain sufficient energy to leave their orbits. These electrons drift randomly around the material. If a number of electrons all move in the same direction at the same time then a noise current is developed.
  - r.m.s noise $V_n = \sqrt{(4kTBR)}$ where :-
    - k = Boltzmann's constant = $1.38 * 10^{-23}$ J/K
    - T = Absolute temperature of conductor
    - B = Bandwidth and R = Resistance in Ohms

What is Noise?

Noise.

- Thermal Agitation Noise
  - r.m.s noise $Vn = \sqrt{(4kTBR)}$ where :-
    - k = Boltzmann’s constant = $1.38 * 10^{-23}$ J/K
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- Calculate noise voltage produced in a resistance of 68KΩ in a 10MHz bandwidth, temperature =22^{o}C

What is Noise?

Noise.

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    - T = Absolute temperature of conductor
    - B = Bandwidth and R = Resistance in Ohms

- Calculate noise voltage produced in a resistance of 68KΩ in a 10MHz bandwidth, temperature =22^{o}C

- $Vn = \sqrt{(4 * (1.38 * 10^{-23})*(273 + 22) * 10^{7} * 68*10^{3})}$

- Noise Voltage = Vn = 105.2289μV

What is Noise?

Noise.

- Interference
  - Can be split into two types :-
    - Electromagnetic interference (e.m.i)
    - Radio-frequency interference (r.f.i).
    - Where :-
      - (e.m.i) is usually low frequency, high energy.
      - (r.f.i) is usually high frequency, low energy.
  - Typical sources of interference are:- anything that causes electrical sparks (motors , switches, domestic appliances, etc.), fluorescent lights and, some types of power supply (switch mode).

What is Noise?

Noise.

- Crosstalk
  - This is caused when signals in one circuit are unintentionally coupled to another circuit due to their close relative physical proximity.
  - For example PCB tracks or wires in a wire loom coupled through capacitance or inductive effect.
  - Crosstalk interference can also be propagated through common power supplies or power supply connections.

What is Noise?

Noise.

- Semiconductor Noise
  - Shot Noise
    - Noise created in a bipolar transistor as charge carriers cross the PN junction
    - Shot noise current = In = Ö(2 e Idc B)
    - where :-
    - e = the charge of a single electron = 1.6 * 10-19
    - Idc = the d.c current flowing across the junction.
    - B = Bandwidth (Hz) over which the noise is measured.
    - Shot noise is white (all frequencies.)

What is Noise?

Noise.

- Semiconductor Noise
  - Partition Noise
    - Noise created when the current splits after passing through the emitter junction.
    - Note (Ie = Ib + Ic)
  - Flicker Noise
    - Noise caused by fluctuations of conductivity of the semiconductor material. This generated noise in inversely proportional to frequency

Switches

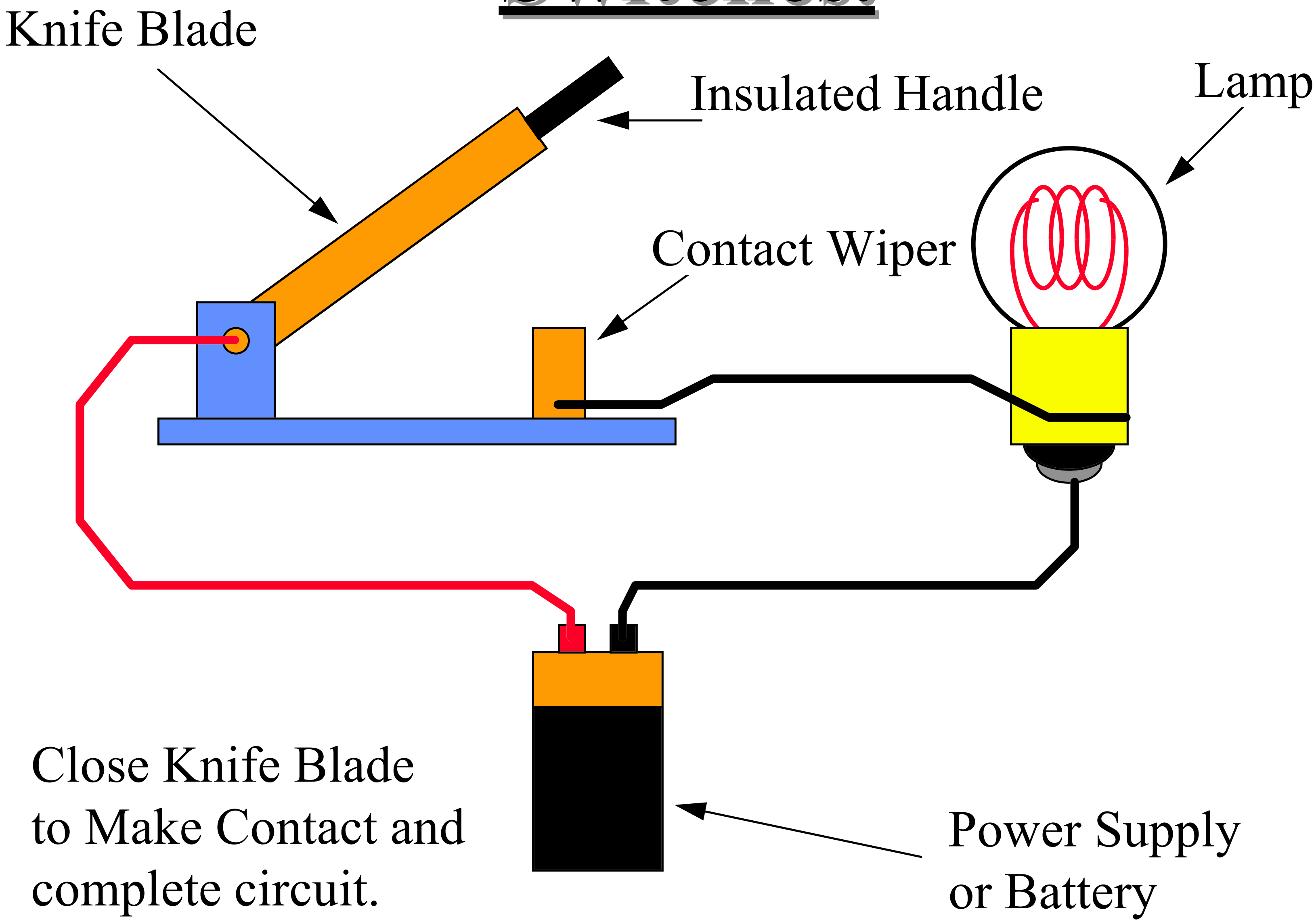
Switches.

- A switch is an electrical device that can enable current to flow into a circuit or can break the flow to a circuit.
- They come in different styles:-
- Push to Make.

- This connection needs activation to enable current to flow into the circuit .
- Push to Break.

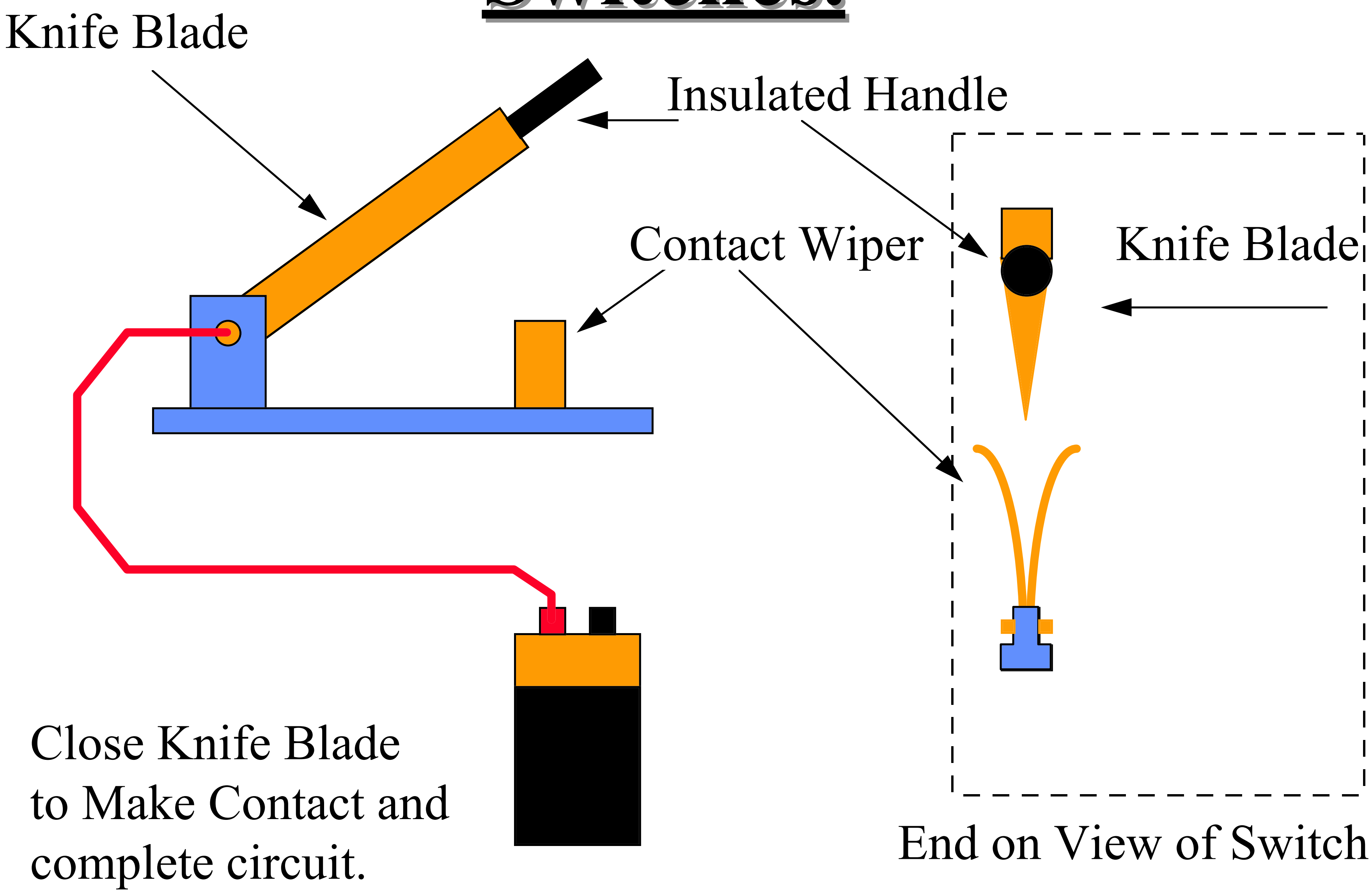
- This connection needs mechanical action to disable current flow into the circuit.

Switches.



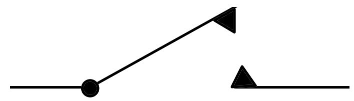
Close Knife Blade
to Make Contact and
complete circuit.

Switches.

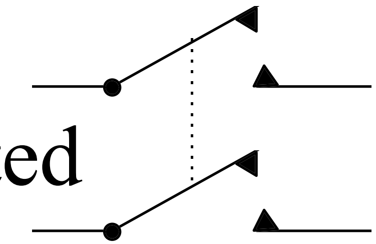

Knife Blade
Insulated Handle
Contact Wiper
Knife Blade
Close Knife Blade
to Make Contact and
complete circuit.
End on View of Switch

Switches.

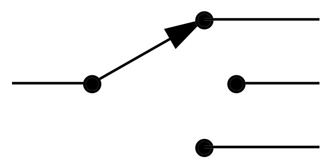
- A Switch can also come in different variants.
- Single Pole Single Throw.



- ie one set of connections.
- Double Pole Single Throw.



- Two circuits mechanically connected
- Single Pole Triple Throw.
- ie one connection set with three routing options.



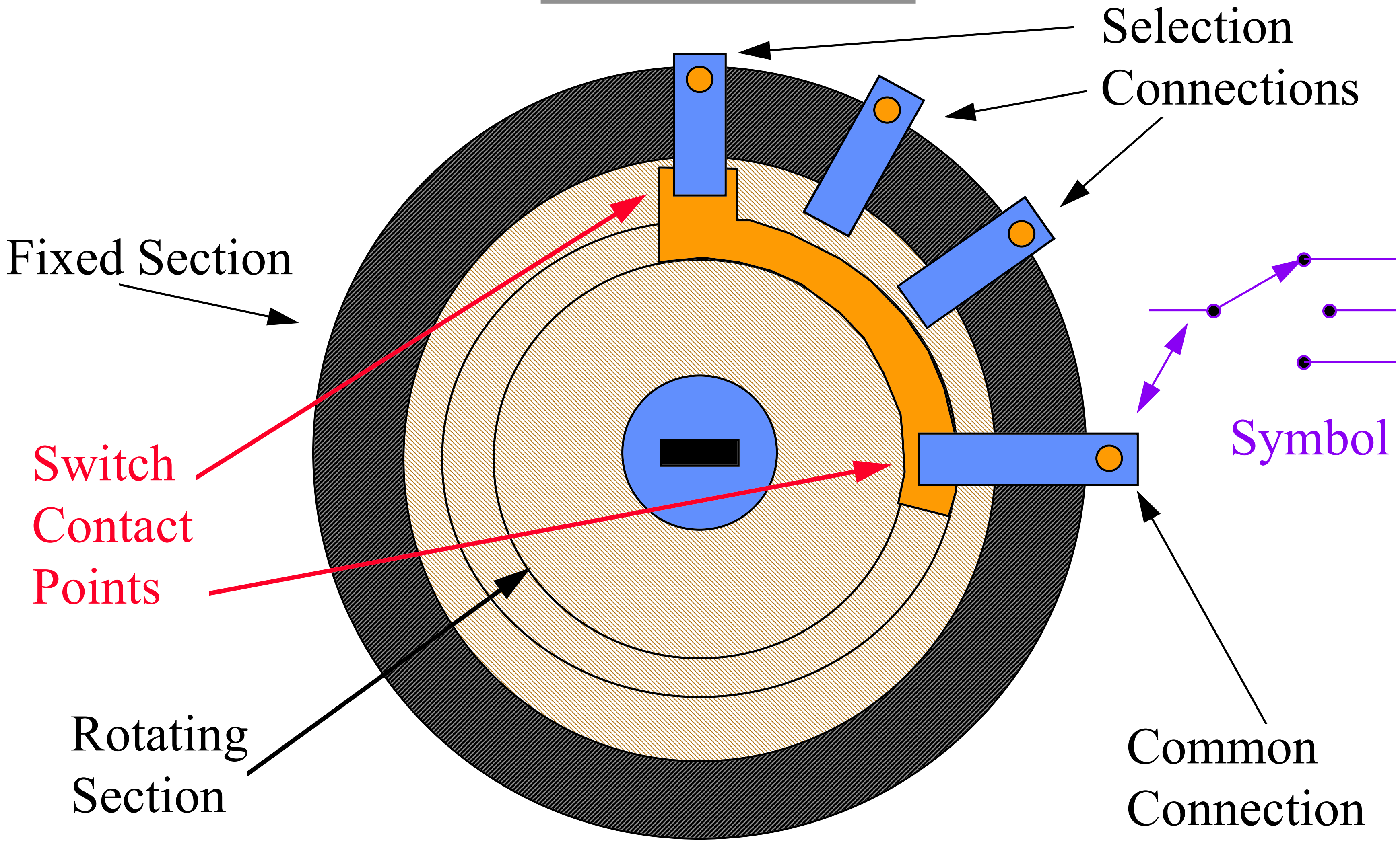
Switches.

- Common codes used:-
- Single Pole Single Throw becomes SPST
- Double Pole Single Throw becomes DPST
- Single Pole Triple Throw becomes SPTT
- It it quite common for the connections of switches to be made up from multiples of twelve i.e. Double Pole Six Way, Triple Pole Four Way, Single Pole Twelve Way.

Switches.

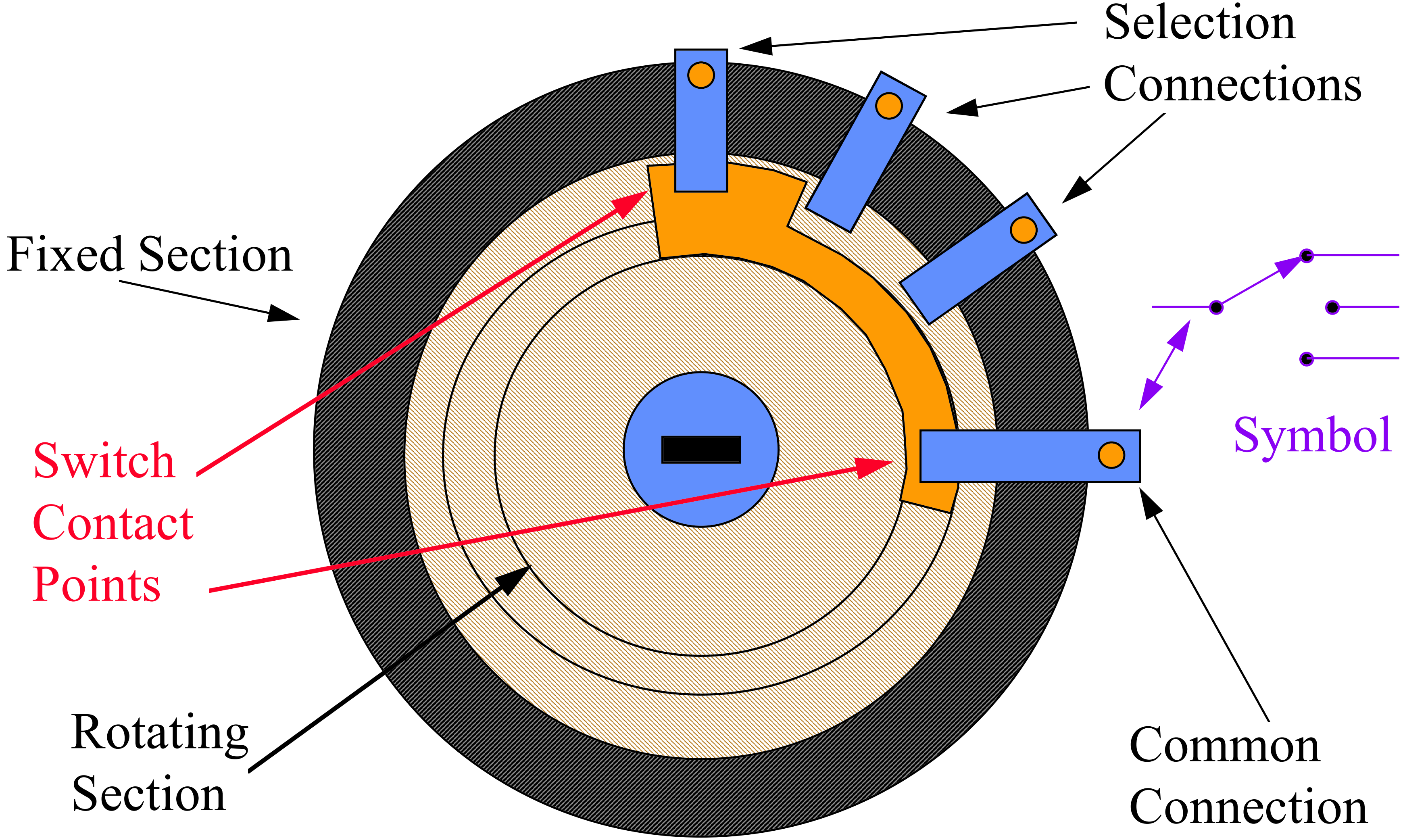
- Other Switching Variants:-
- Break before Make.
- This version disconnects a circuit before the next circuit is enabled
- Make before Break.
- With this version during the change over period both circuit will be connected for a short period.

Switches.



A Basic Wafer Switch Single Pole Three Way (Break Before Make)

Switches.



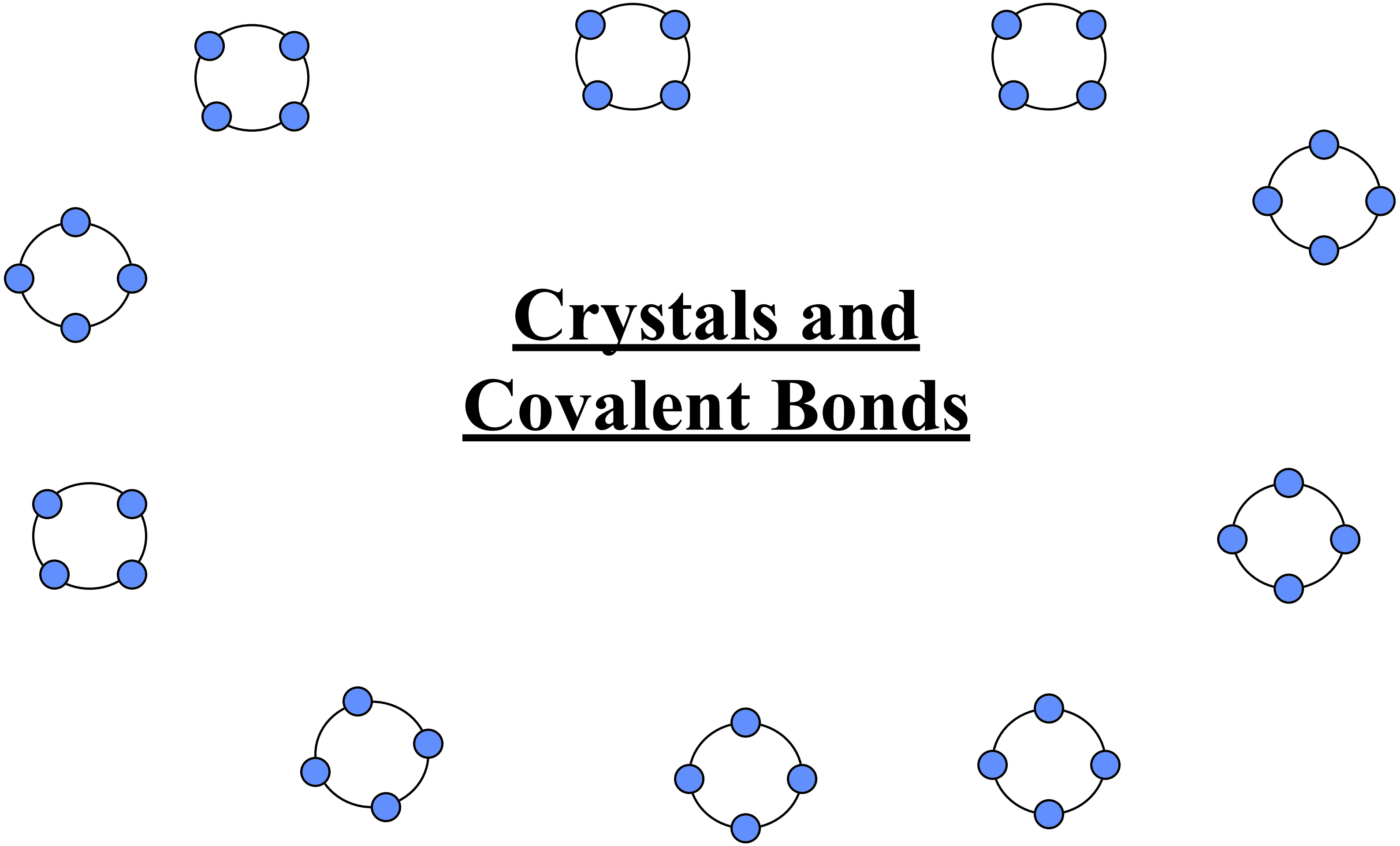
A Basic Wafer Switch Single Pole Three Way (Make Before Break)

Semi-Conductors

Semi-Conductors.

Introduction to Semi-Conductors.

Semi-Conductors.



Crystals and Covalent Bonds

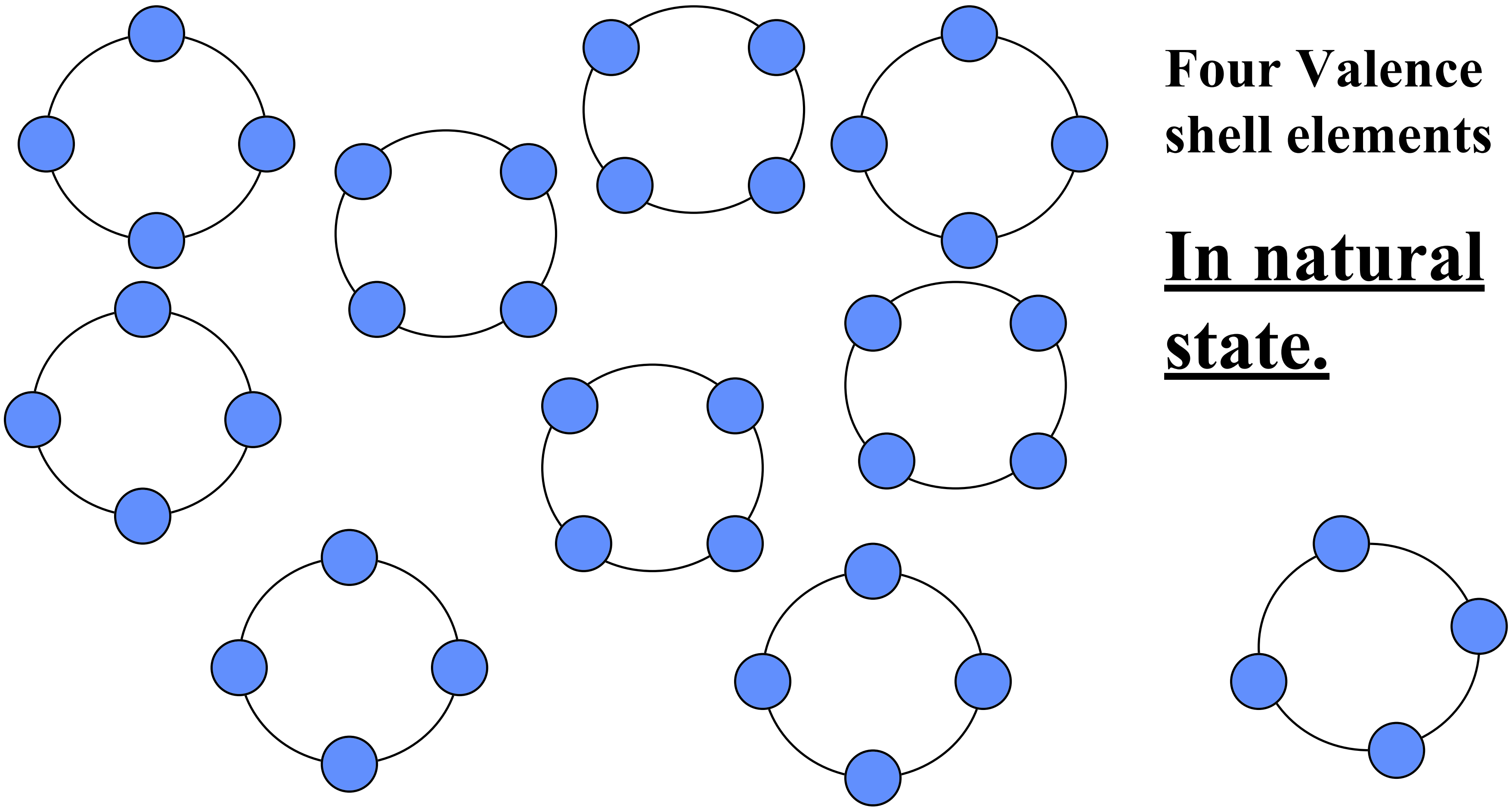
Semi-Conductors.

Covalent Bonds

Silicon Si
Germanium Ge
Carbon C

Four Valence shell elements

In natural state.



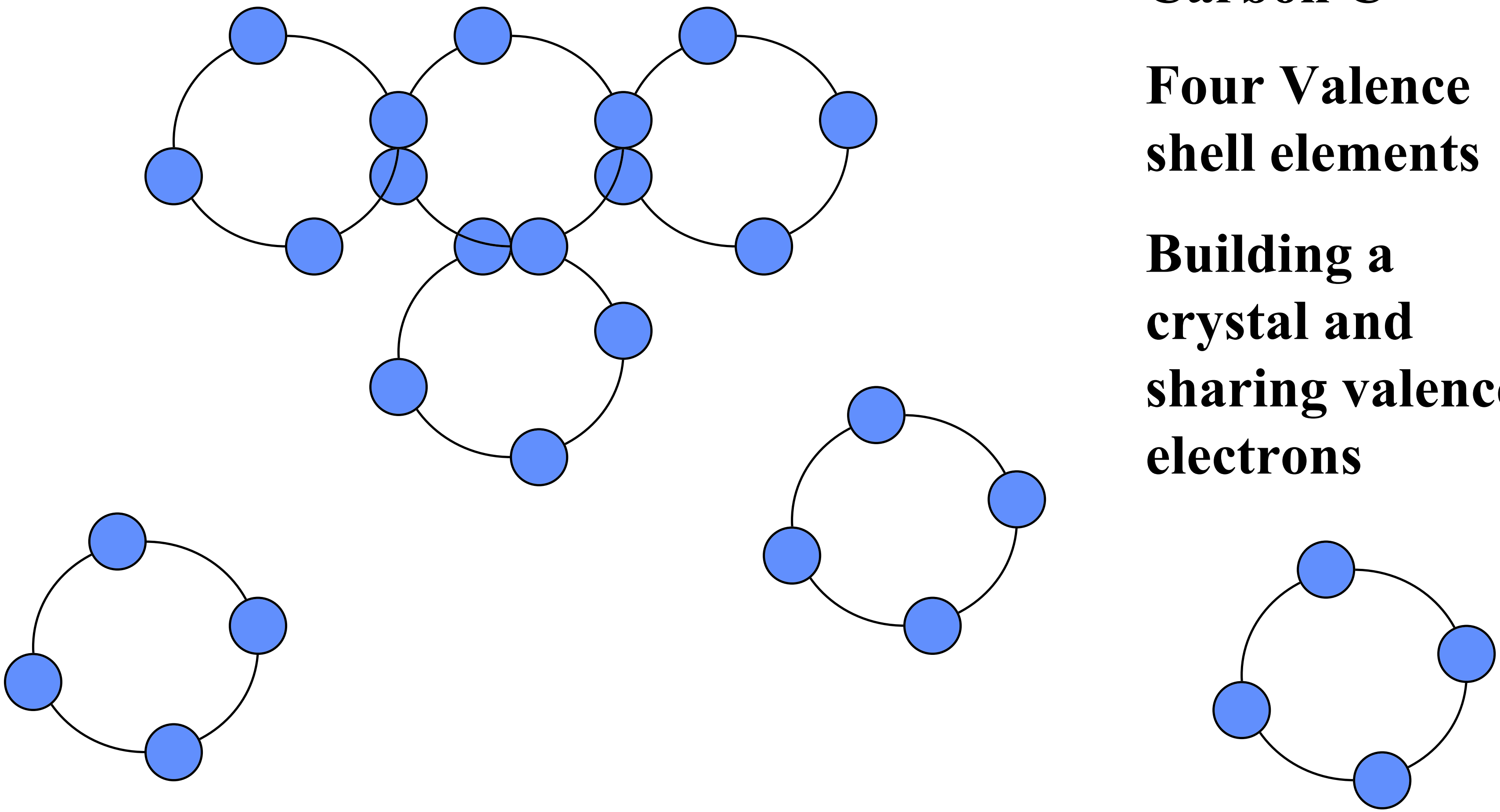
Semi-Conductors.

Covalent Bonds

Silicon Si
Germanium Ge
Carbon C

Four Valence shell elements

Building a crystal and sharing valence electrons



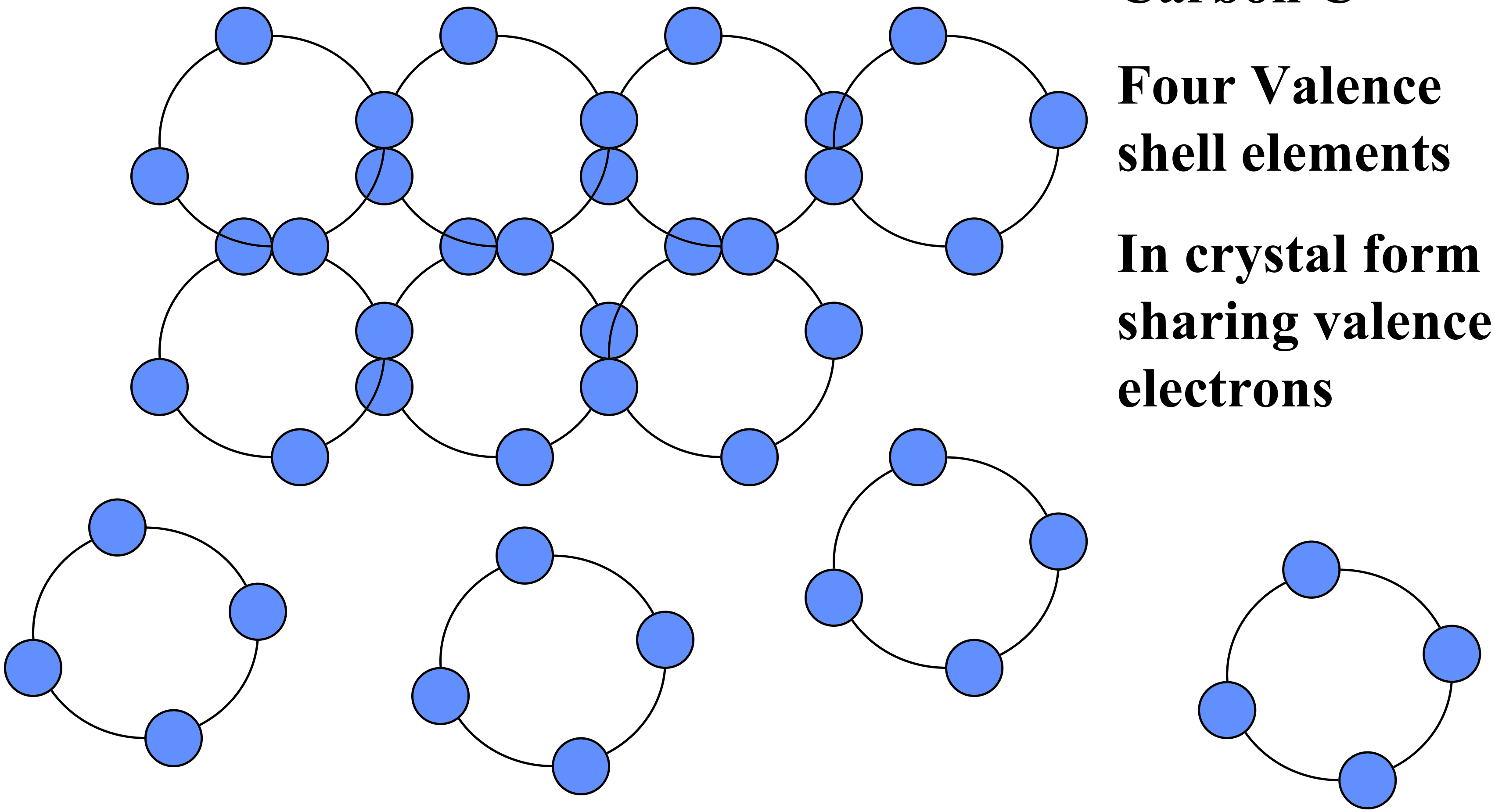
Semi-Conductors.

Covalent Bonds

Silicon Si
Germanium Ge
Carbon C

Four Valence shell elements

In crystal form sharing valence electrons



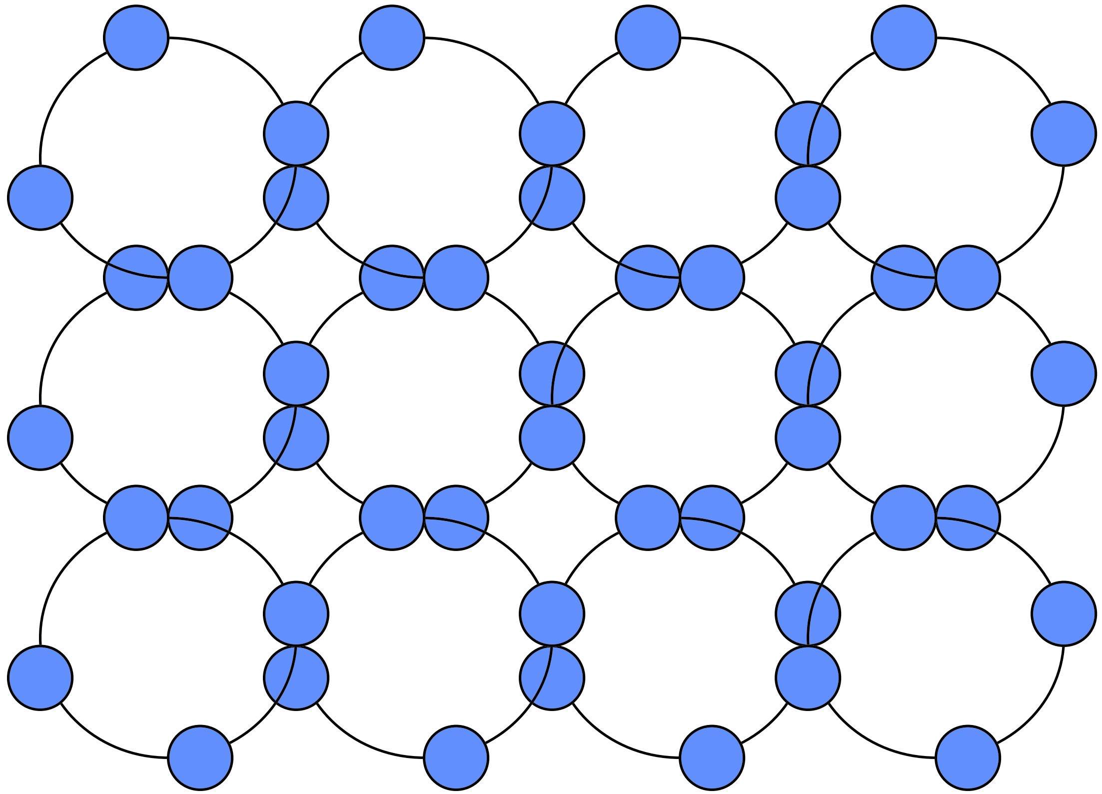
Semi-Conductors.

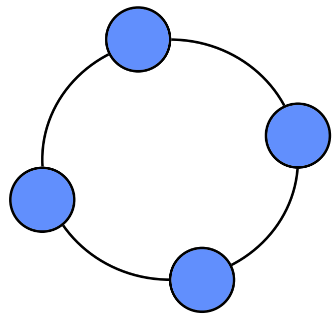
Covalent Bonds

Silicon Si
Germanium Ge
Carbon C

Four Valence shell elements

In crystal form sharing valence electrons

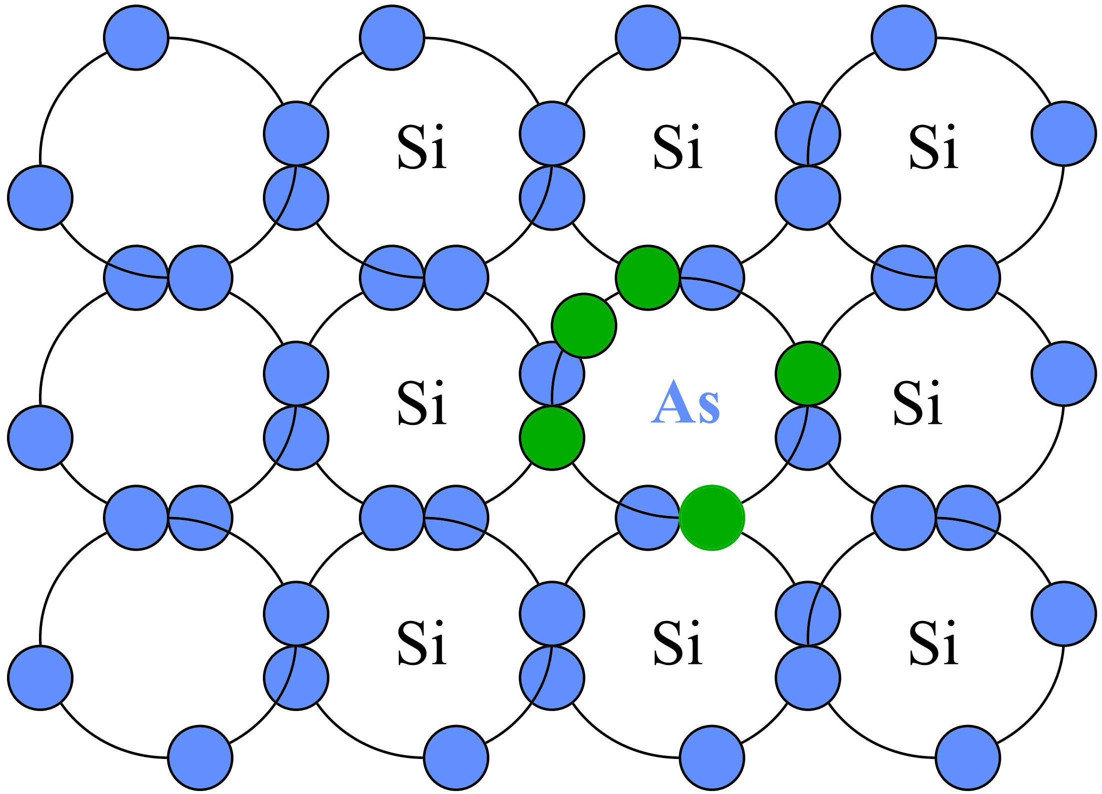




Note Eight electrons in outer shell . . . type of Insulator.

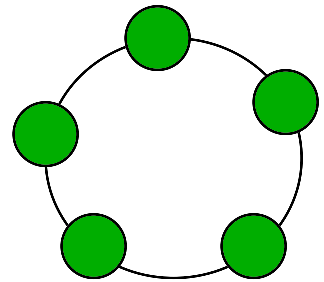
Semi-Conductors.

Covalent Bonds



Doping the Crystal with a pentavalent elements.

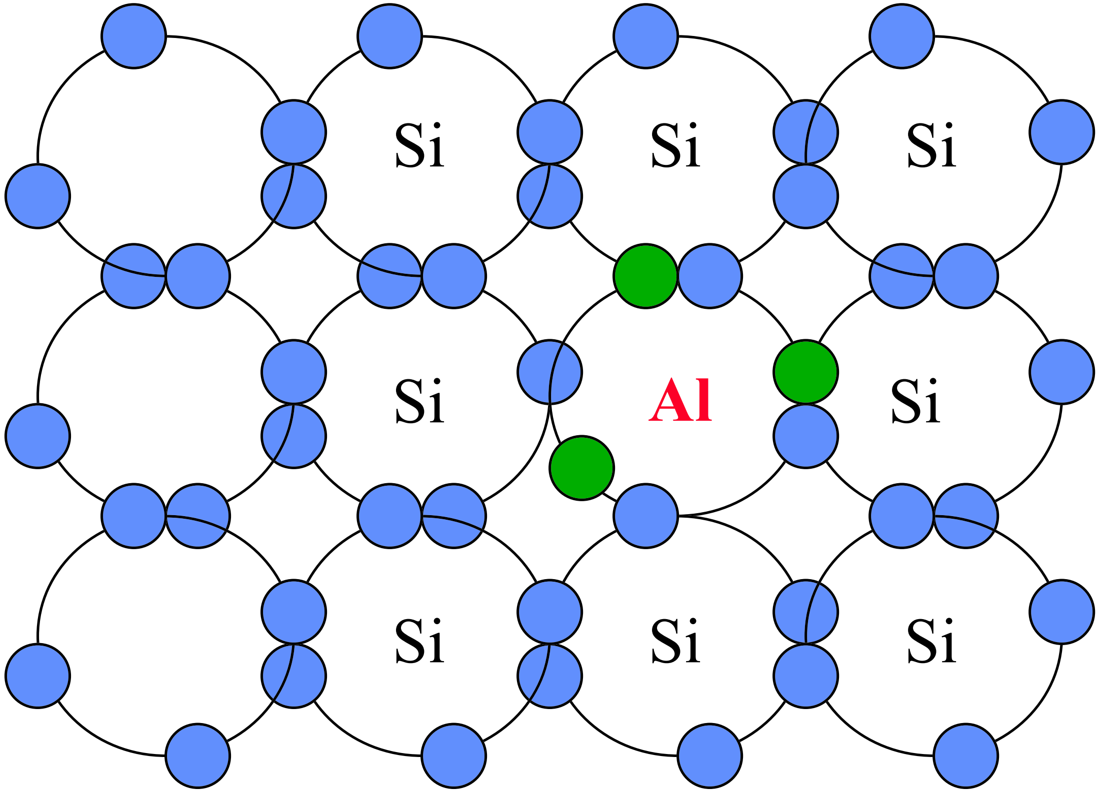
Arsenic As
Phosphorus P
Antimony Sb



Overall Charge One extra electron more therefore **Negative**

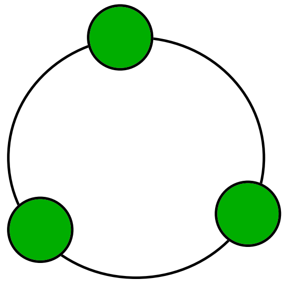
Semi-Conductors.

Covalent Bonds



Doping the Crystal with a trivalent elements.

Aluminum Al
Boron B
Gallium Ga



Overall Charge One extra electron less therefore **Positive**.

Semi-Conductors.

Partial Summary

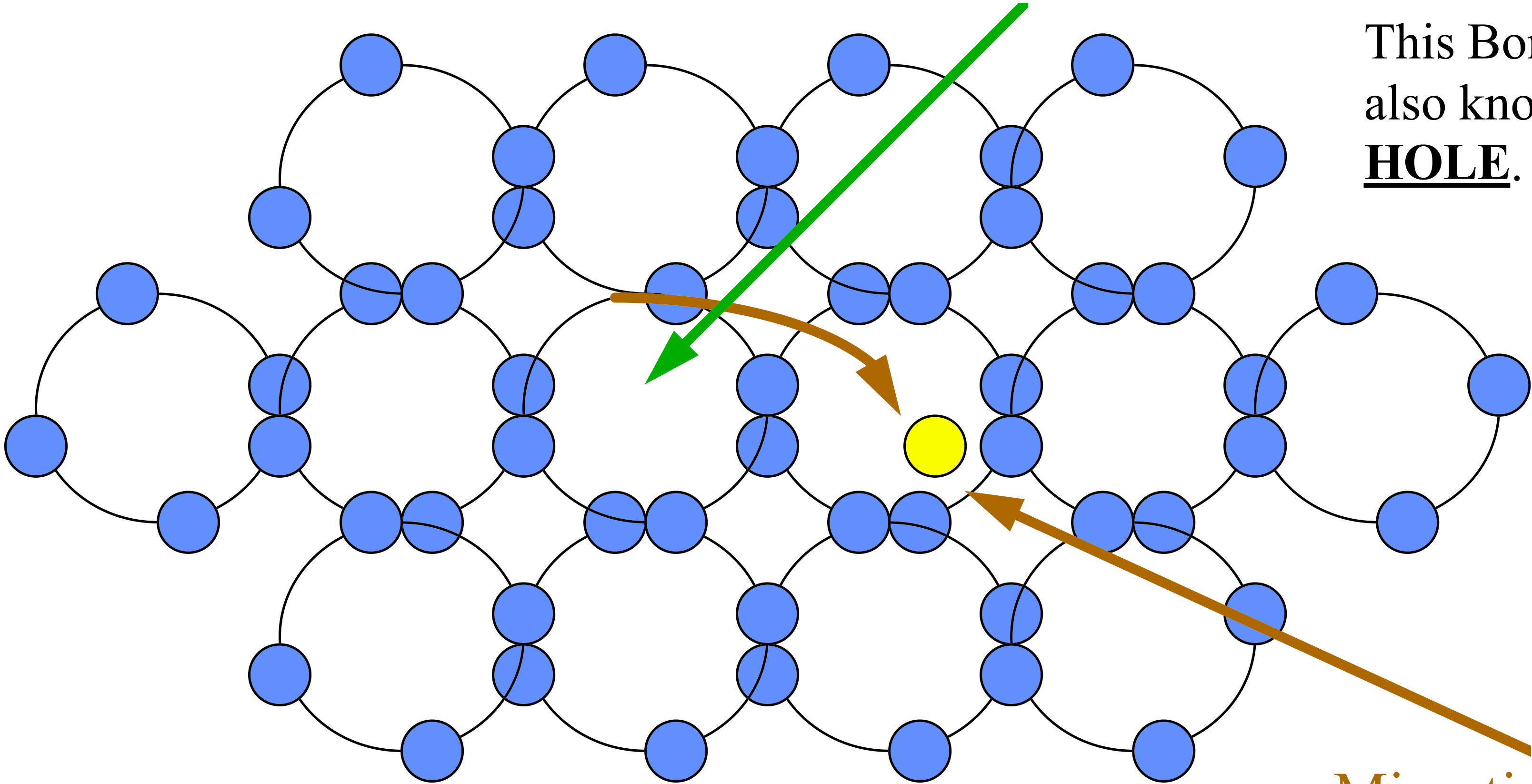
- Doping can produce two distinct types of Semiconductor.
- One type has an excess of electrons and is called "N" type material. (Why ? .. Because electrons have a (Negative) charge)
- The other type has a shortage of electrons and is called "P" type material. (Positive)
- The electrons in these materials are referred to as the "Majority" Carriers. ..... However

Semi-Conductors.

Covalent Bonds

This part of a Bond Area has one electron **less** so its overall charge is **Positive**.

This Bond Area is also known as a **HOLE**.



Migration Path

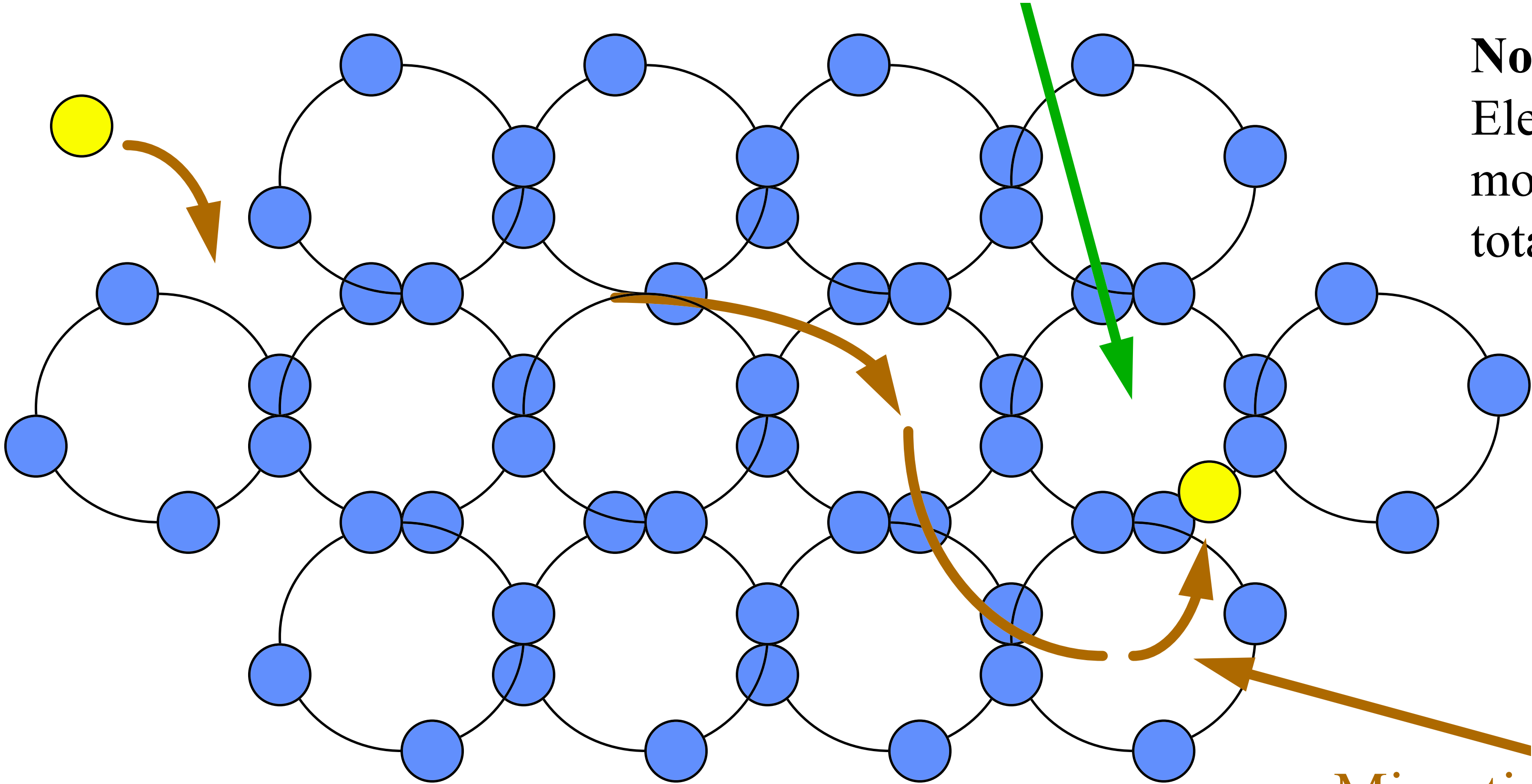
Electron Migration due to Heat (Minority Carriers).

Semi-Conductors.

Covalent Bonds

This part of a Bond Area now has one electron **more** so its overall charge becomes Negative.

Note. The Electron movement is totally random



Migration Path

Electron Migration due to Heat (Minority Carriers).

Semi-Conductors.

The Three Semiconductor Material Types

P Type Material

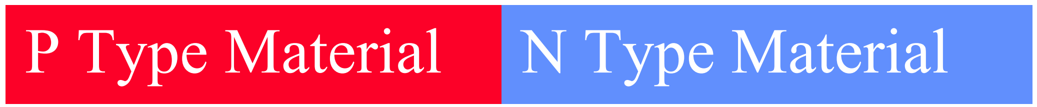
N Type Material

Intrinsic Type Material

The **P** and N materials are the MAJORITY carriers of that material, however there will always be a small percentage of MINORITY carriers of the opposite type within the structure caused by movement due to heat etc.

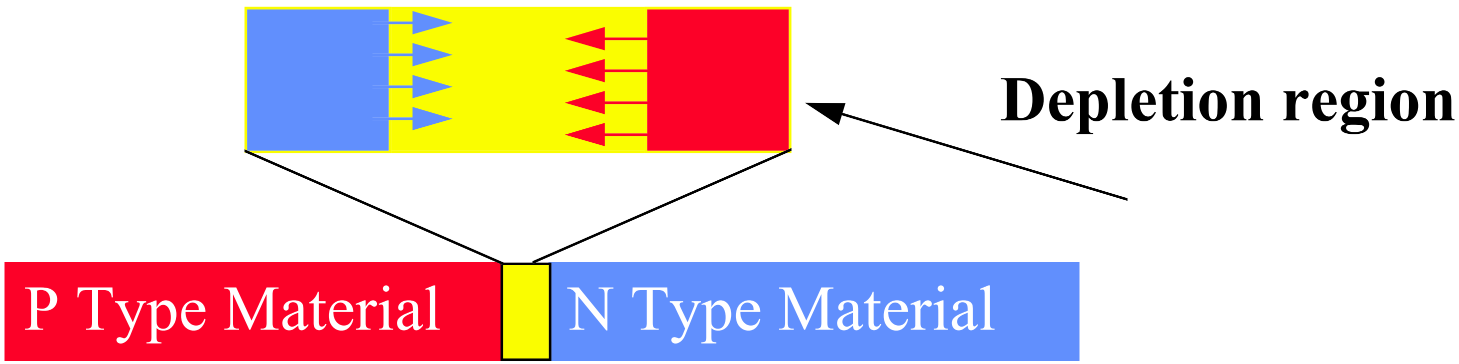
Semi-Conductors.

The PN Junction



The majority carriers diffuse across the junction creating a barrier until the potential repels any further diffusion.

This is known as the depletion region.



Silicon @25^{o}C is 0.6 to 0.7V , Germanium = 0.3V

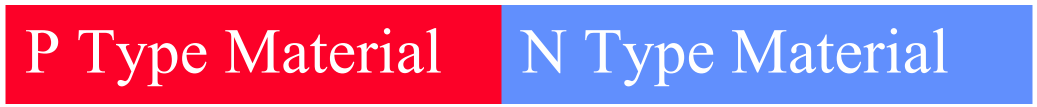
Move on to Transistors and Diodes

Transistors and Diodes

Junction Diodes

Transistors and Diodes.

The PN Junction review



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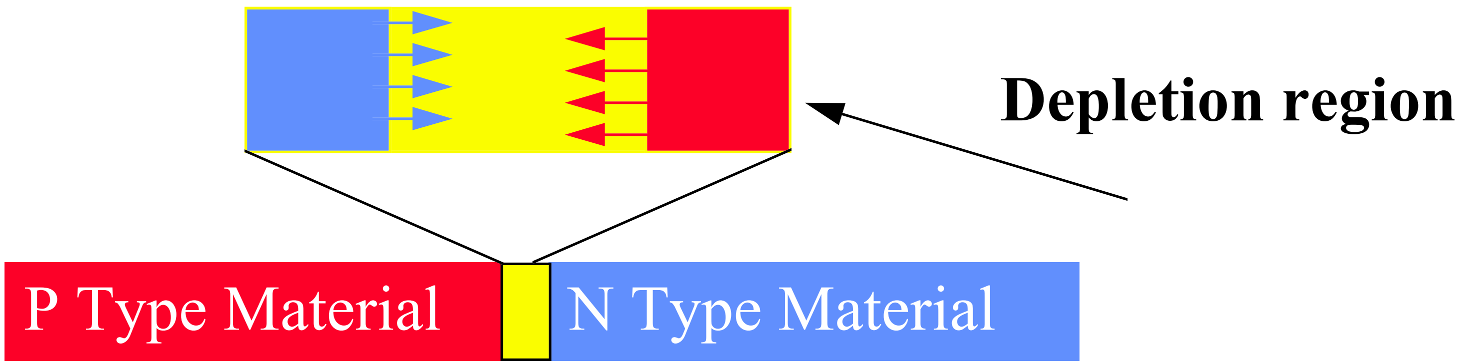
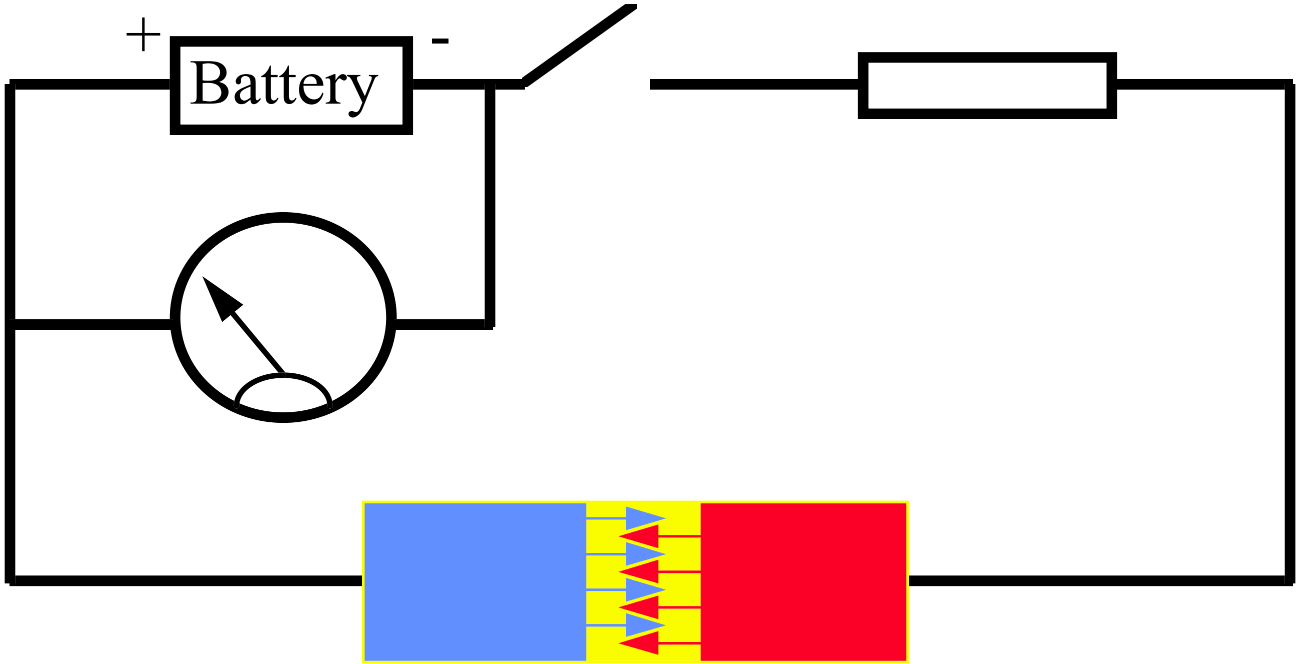


Silicon @25^{o}C is 0.6 to 0.7V , Germanium = 0.3V

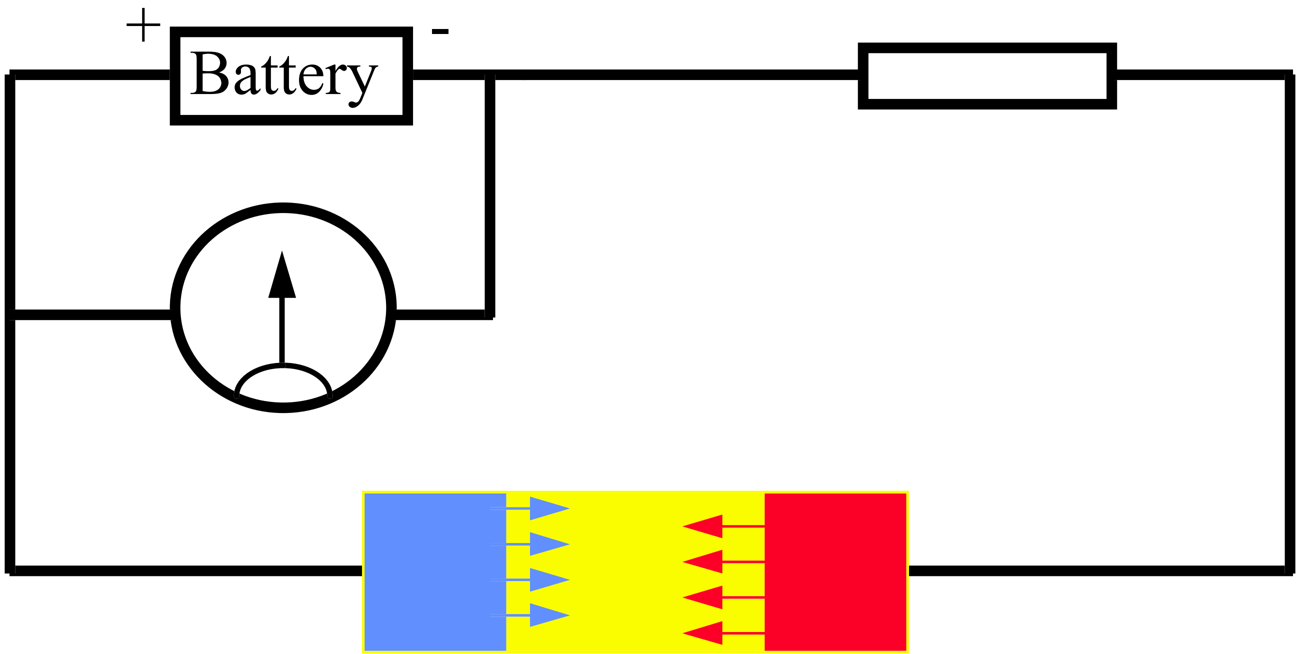
Transistors and Diodes.



With no applied voltage the depletion barrier will typically be about 0.6 - 0.7 Volts for Silicon. The width is set by the ambient temperature which effects the Majority Carriers migration.

What happens when a Reverse Polarity is applied to a PN junction ?

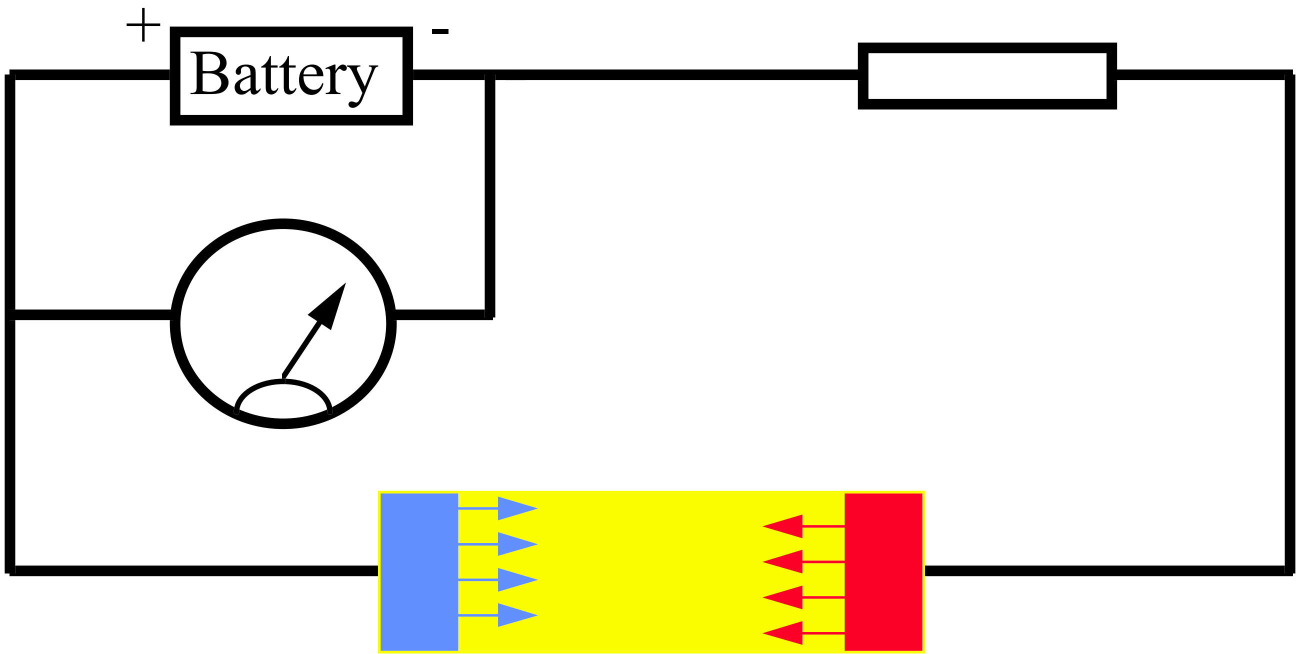
Transistors and Diodes.



By increasing the Reverse Polarity the Majority carriers extend the width of the depletion region. This is also known as a Reversed bias.

The effect when a Reverse Polarity is applied to a PN junction.

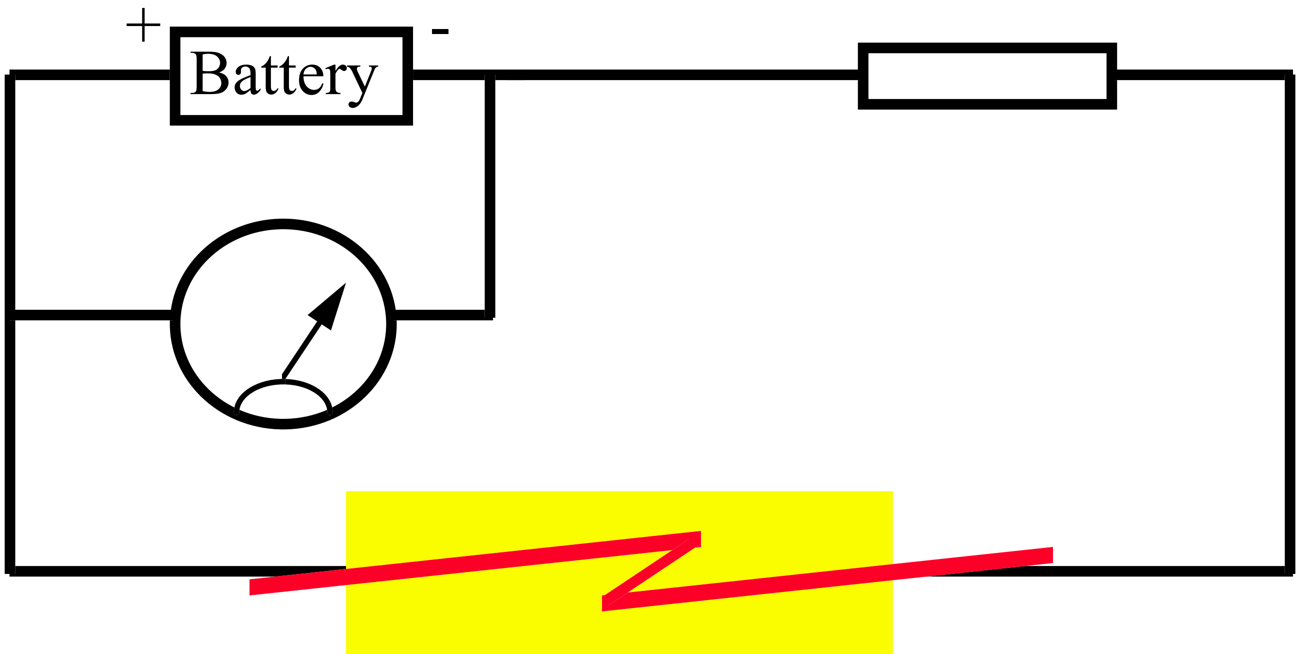
Transistors and Diodes.



Increasing the Reverse Polarity further the Majority carriers continue to extend the width of the depletion region. The limit is the Peak Inverse Voltage (PIV) when the device structure breaks down.

The effect when a Reverse Polarity is applied to a PN junction.

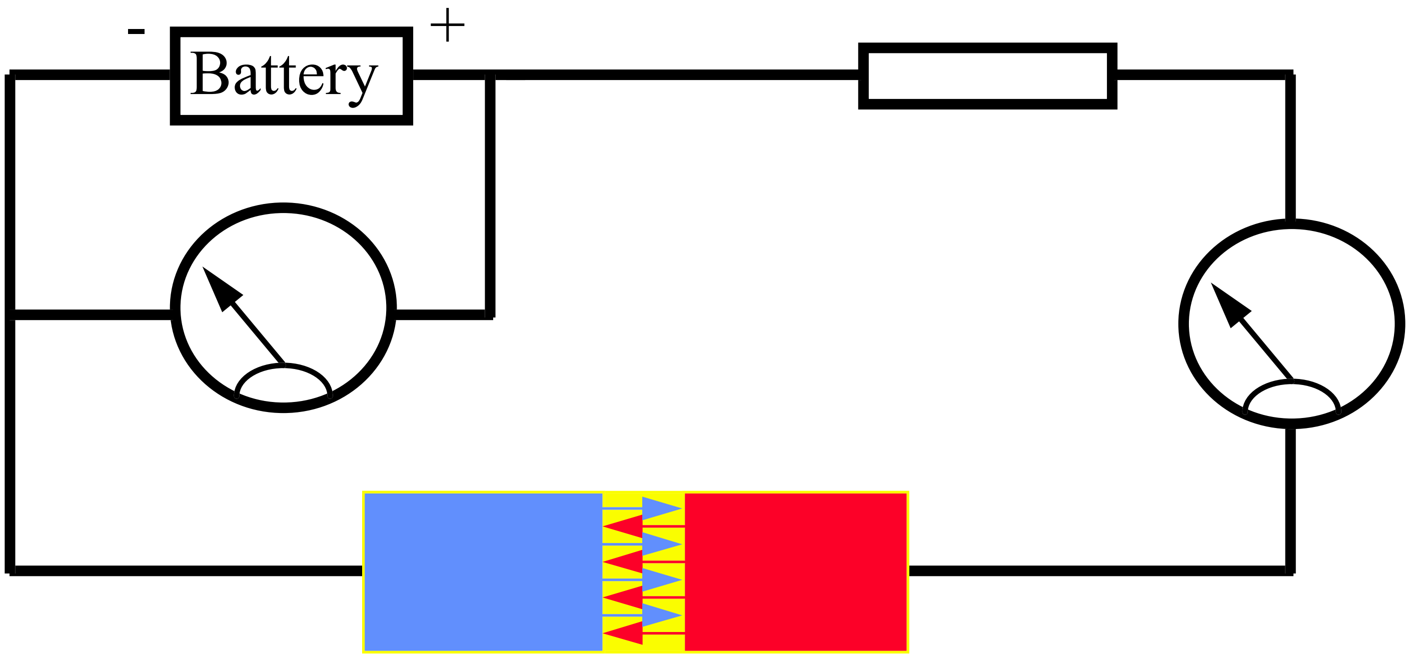
Transistors and Diodes.



Increasing the Reverse Polarity further (>PIV) the device structure is destroyed forever (Structure becomes Open or Short Circuit) due to excessive current flowing through the device.

What happens a Forward Polarity is applied to a PN junction?

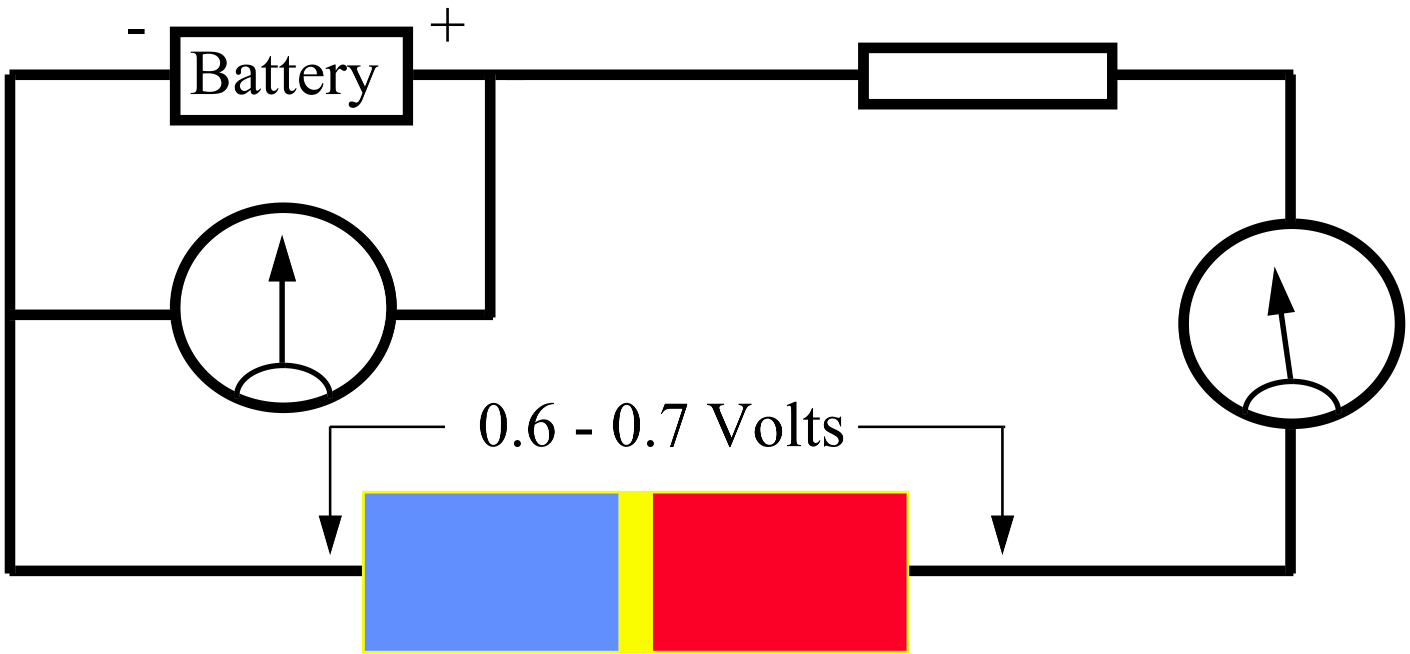
Transistors and Diodes.



Whilst applied voltage is below the depletion barrier voltage (0.6 - 0.7 Volts for Silicon). The current flow is insignificant however the width of the depletion region will becomes narrower.

The effect when a Forward Polarity is applied to a PN junction.

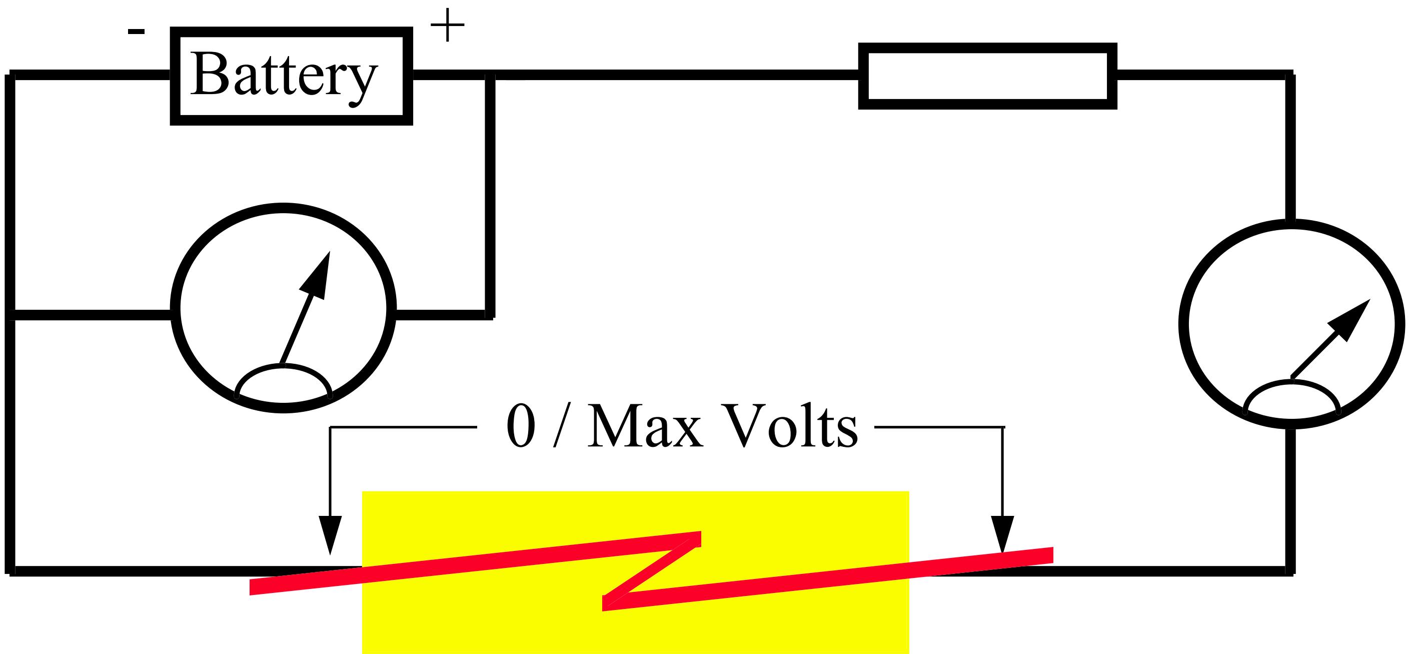
Transistors and Diodes.



When applied voltage is above the depletion barrier voltage (0.6 - 0.7 Volts for Silicon) current flows. The depletion barrier voltage at this point is now measurable across the device.

The effect when a Forward Polarity is applied to a PN junction.

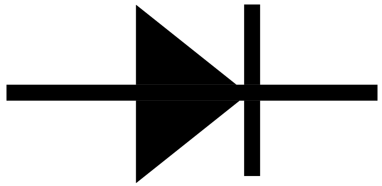
Transistors and Diodes.



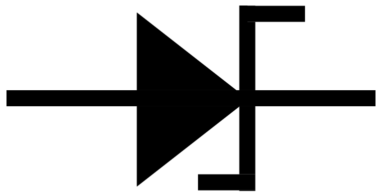
Significantly increasing the Forward Polarity can also destroy the device structure (Structure becomes Open or Short Circuit) due to excessive current flowing through the device..

 The effect when excessive Forward Polarity is applied to junction.

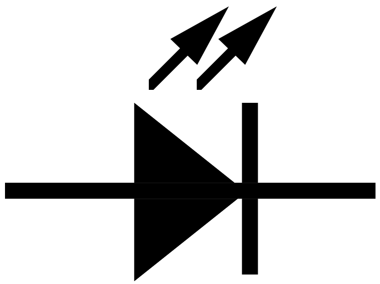
Transistors and Diodes.



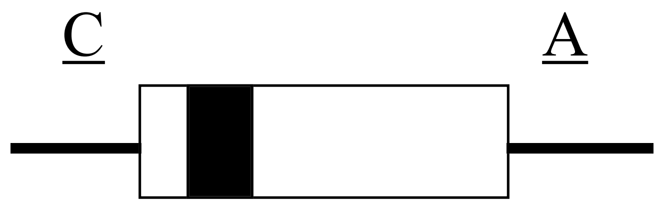
The Symbol for a Diode.

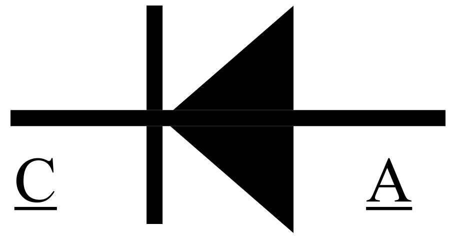


The Symbol for a Zener Diode.



The Symbol for a Light Emitting Diode (LED).

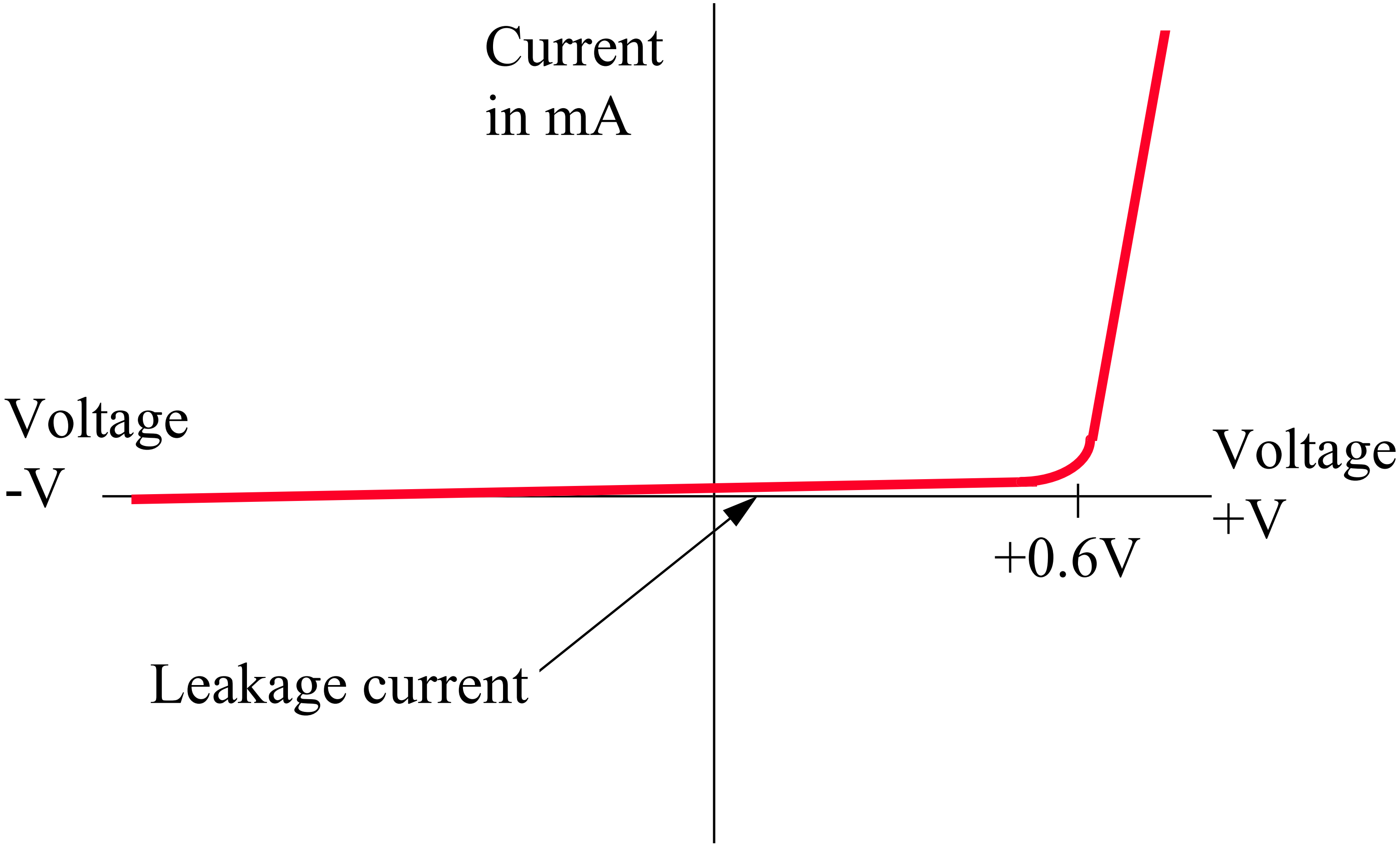




A = Anode the **Positive** + end

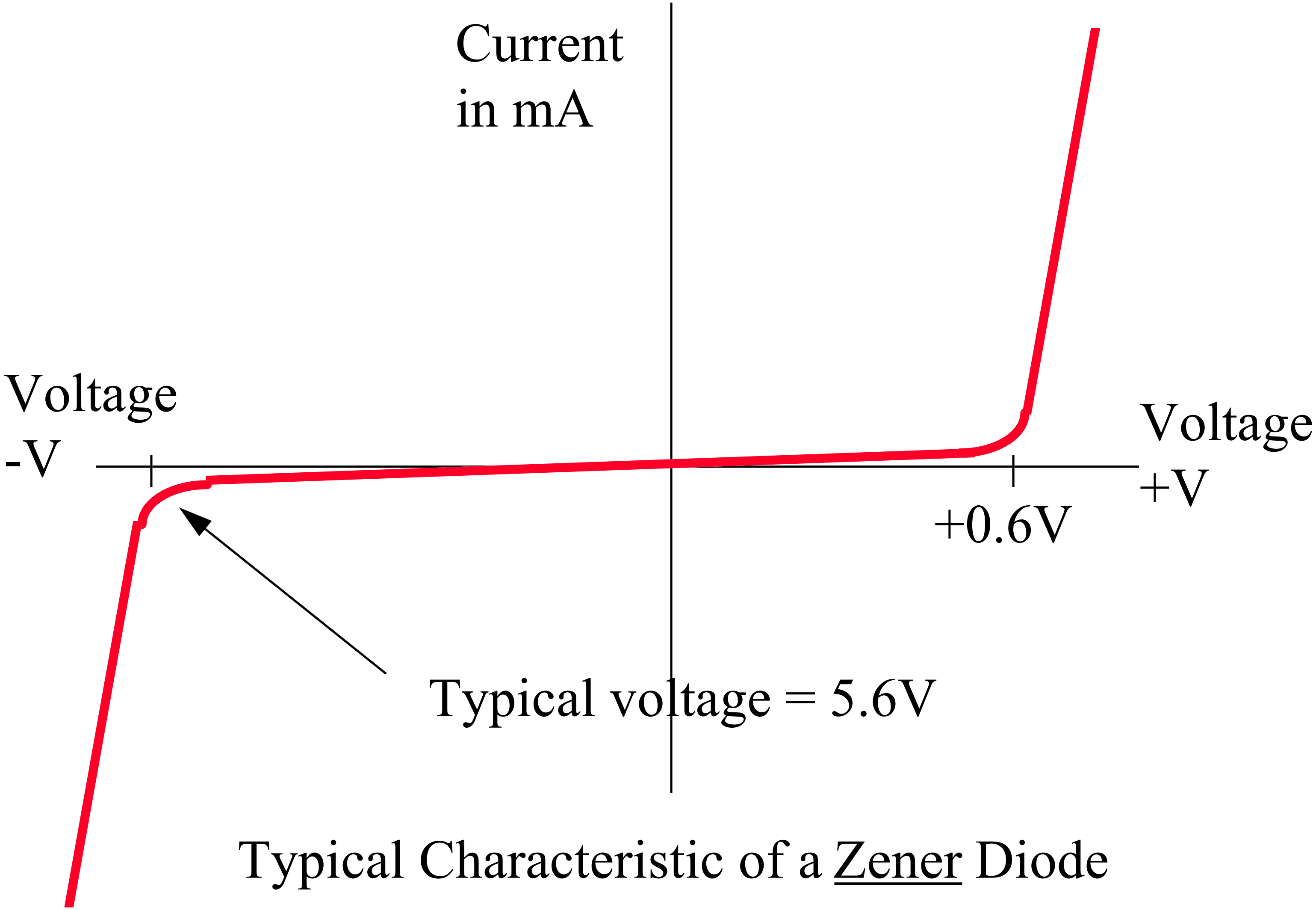
C = Cathode the **Negative** -end.

Transistors and Diodes.



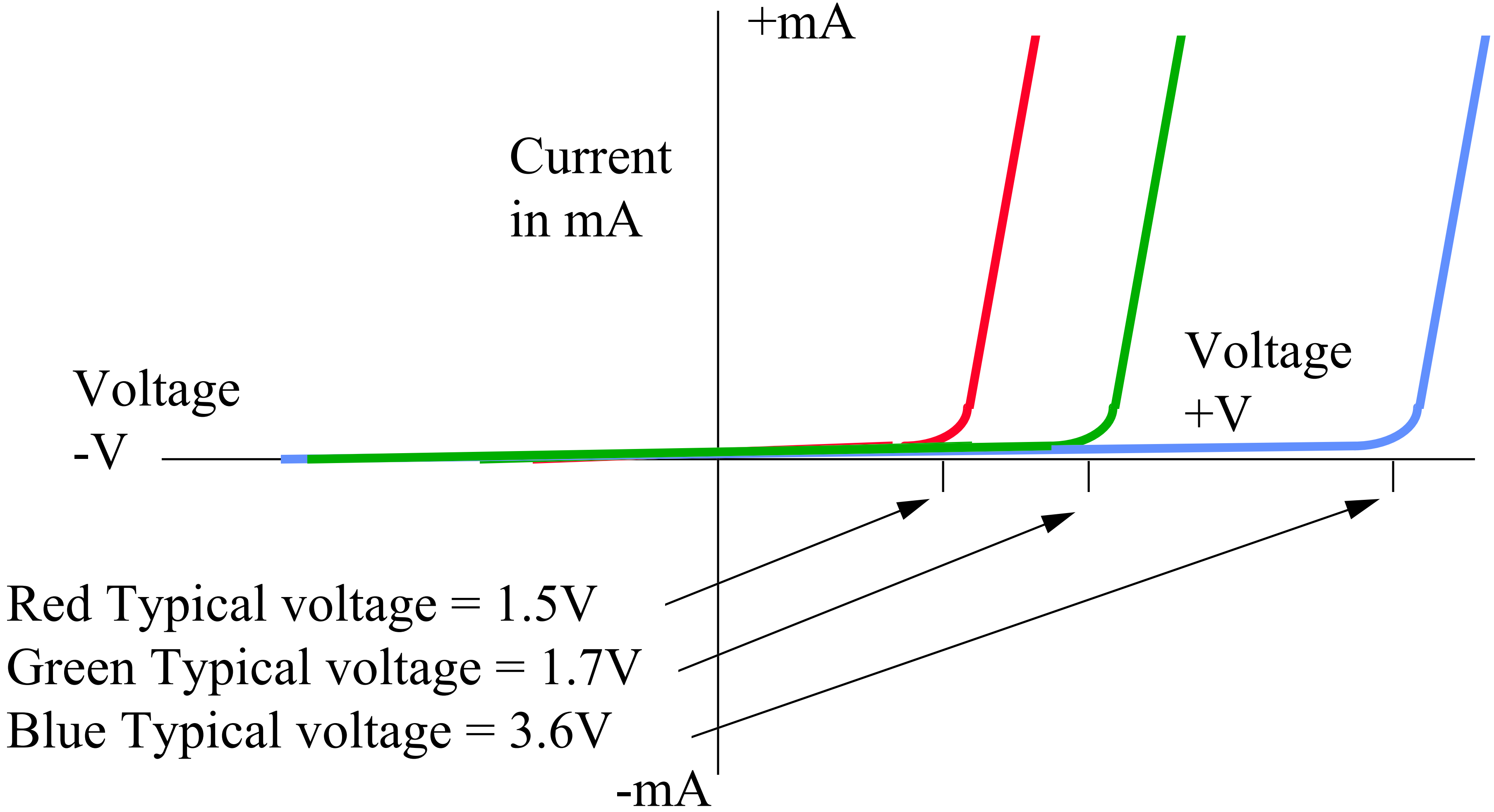
Typical Characteristic of a Silicon Diode

Transistors and Diodes.



Typical Characteristic of a Zener Diode

Transistors and Diodes.



Typical Characteristics of a Light Emitting Diodes

Transistors and Diodes.

Summary

- When a Diode is reversed biased no current will flow.
- If excess **Reverse bias** is applied to a semiconductor junction the device will breakdown.
- If **too much** current flows through a junction then the device will be destroyed.

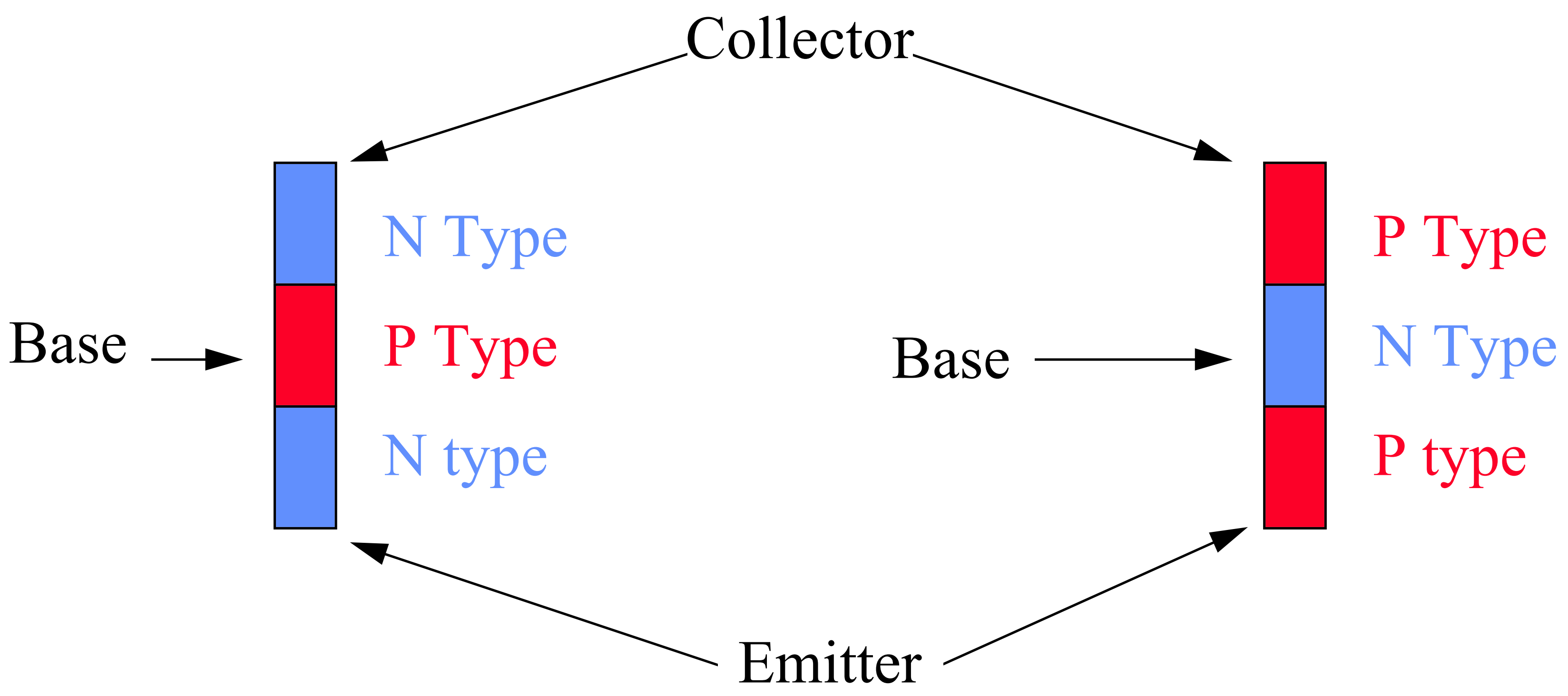
Bipolar Junction Transistors

Transistors and Diodes.

- The next development phase was to build three layer semiconductors and this gave the possibility of two variants.
- The variants were identified from their construction i.e. PNP and NPN.

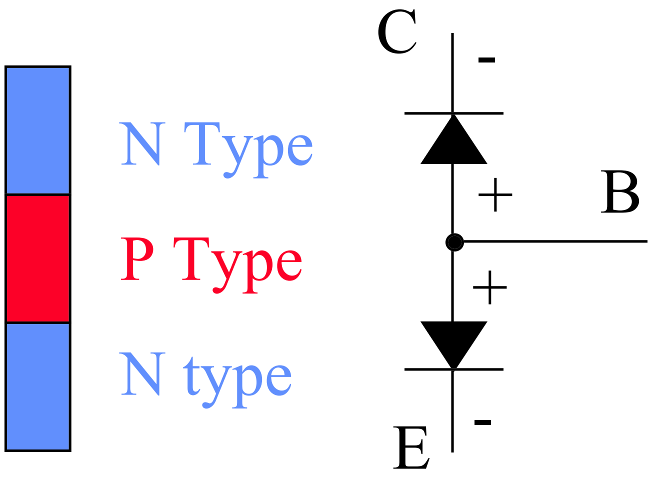
Transistors and Diodes.

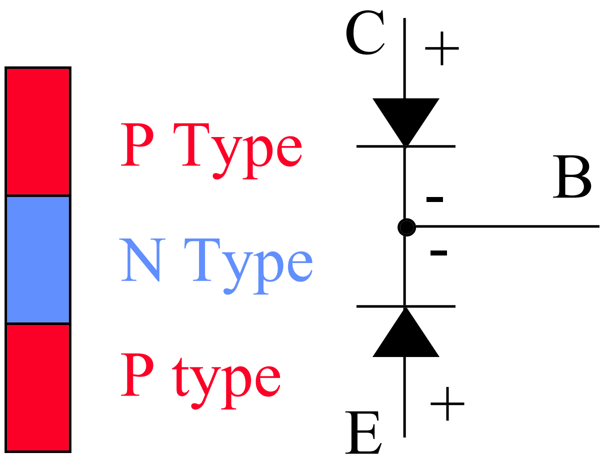
- The sections of each construction were also named (based on their function)
  i.e. Collector, Base and Emitter.



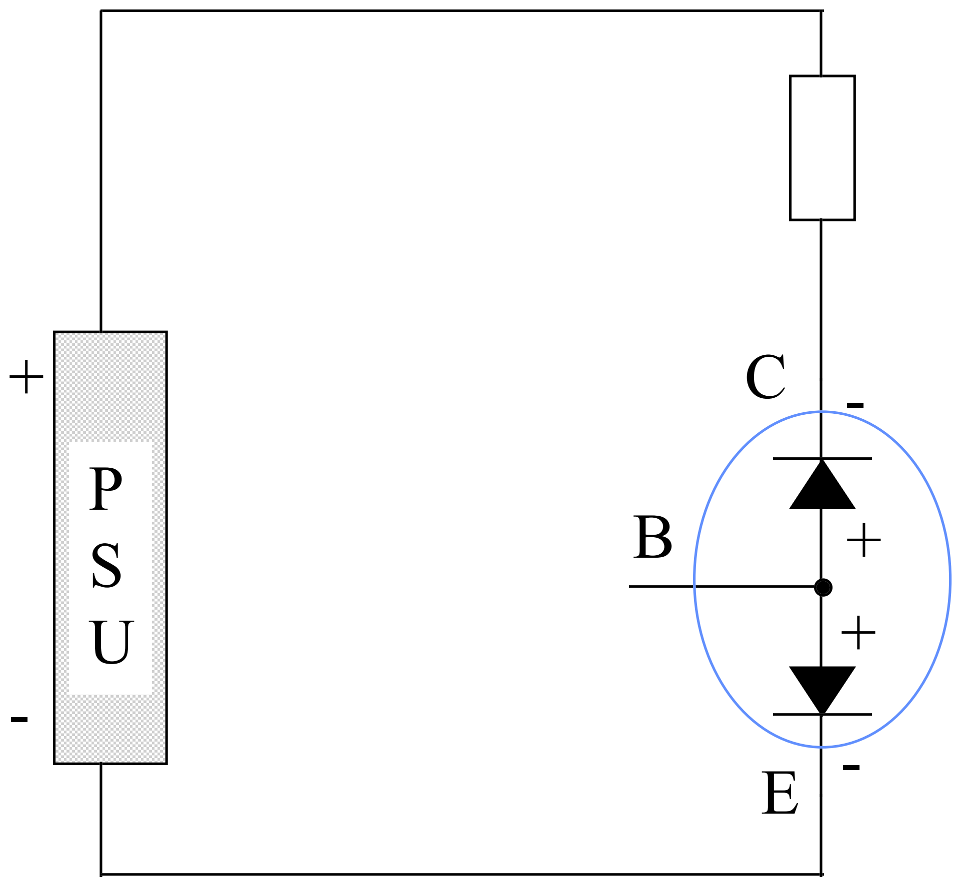
Transistors and Diodes.

- This three layer structure / construction in some ways behaves like two back to back diodes.
- No current can flow between Emitter and Collector when the Base is left floating.





Transistors and Diodes.

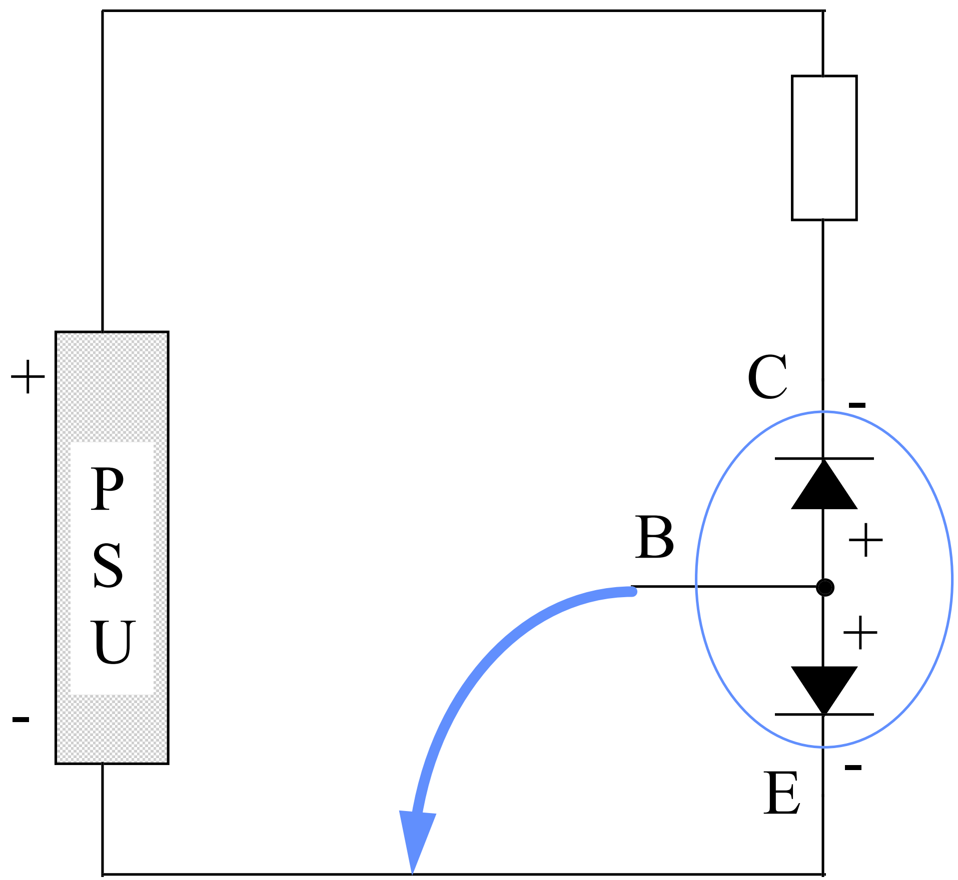


No current flows through the circuit when the Base is left floating.

However

The NPN Transistor Device.

Transistors and Diodes.

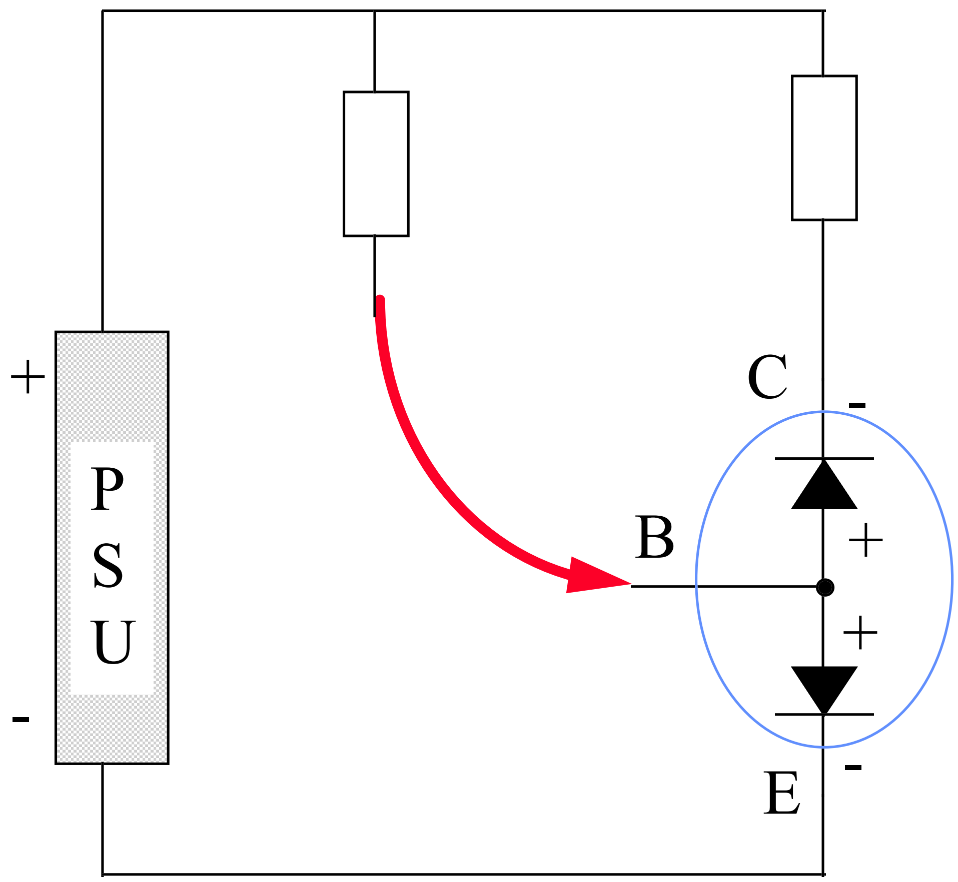


When the Base is connected to the Emitter or to a Negative voltage.

The lower diode will remain Reversed Biased and NO current will flow through the circuit.

The NPN Transistor Device.

Transistors and Diodes.



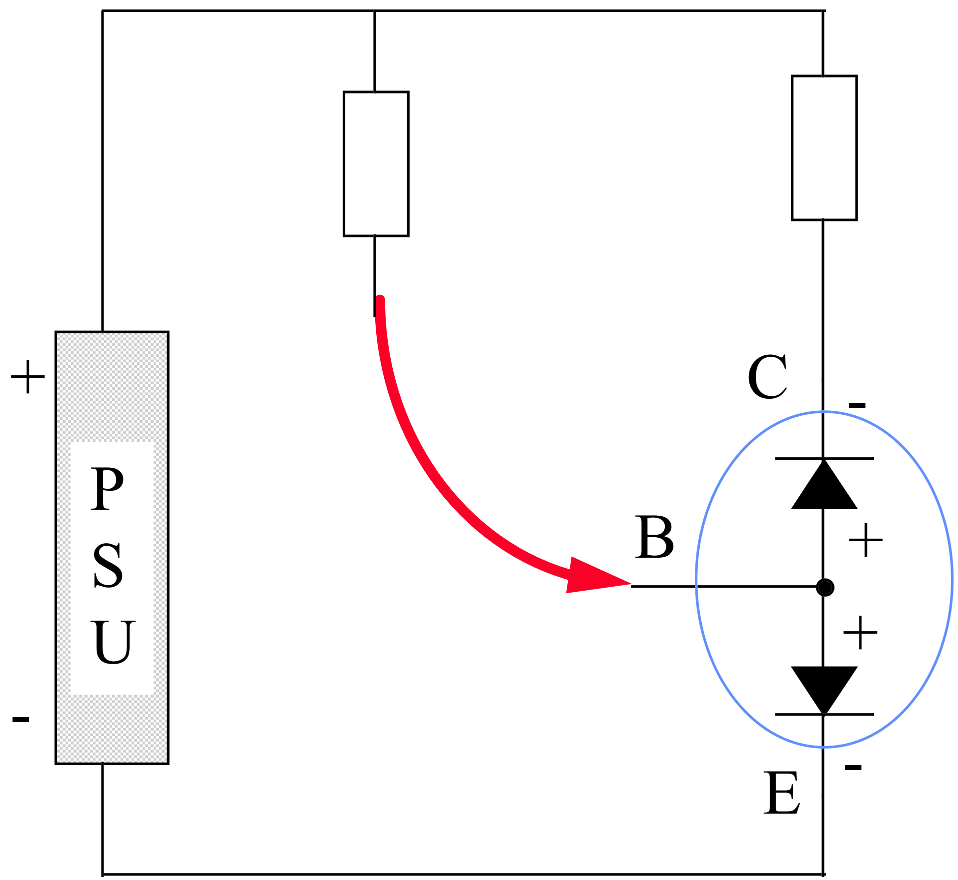
When the Base is connected to the Collector or to a Positive voltage.

The lower diode will become Forward Biased and current will flow from Base to Emitter.

Due to the very close proximity of the upper diode junction (same layer) the two outer N Type layers behave as if they are connected.

The NPN Transistor Device.

Transistors and Diodes.



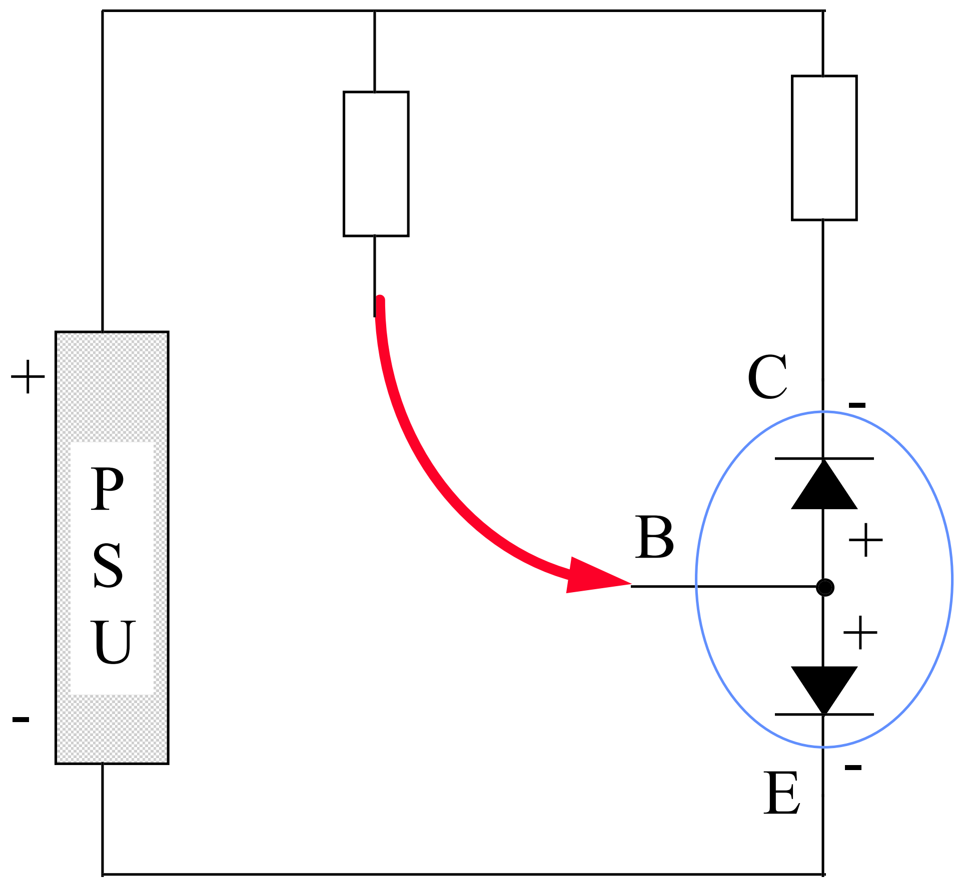
Current can now also flow from Collector through the Base to the Emitter.

It is the amount of current flowing from the Base to the Emitter that controls how much current will flow from Collector to the Emitter.

The PNP process is the same except that the Polarities applied to the Collector and Emitter are Reversed.

The NPN Transistor Device.

Transistors and Diodes.



This process leads to the following calculations.

$Ie = Ic + Ib$

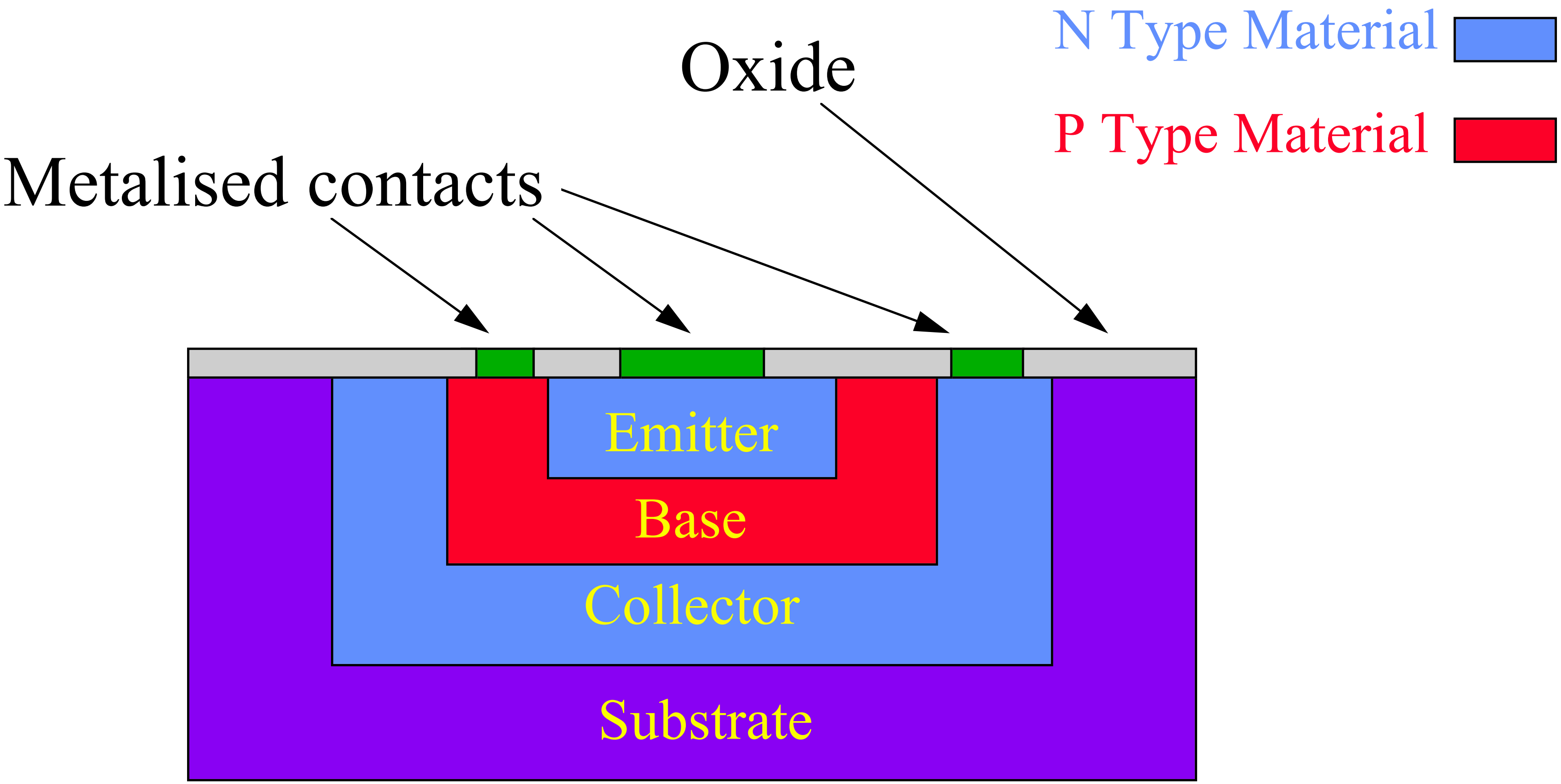
Where :-
Ie = Emitter Current
Ic = Collector Current
Ib = Base Current

Current gain of Transistor
$hfe = Ic / Ib$

The NPN Transistor Device.

Transistors and Diodes.

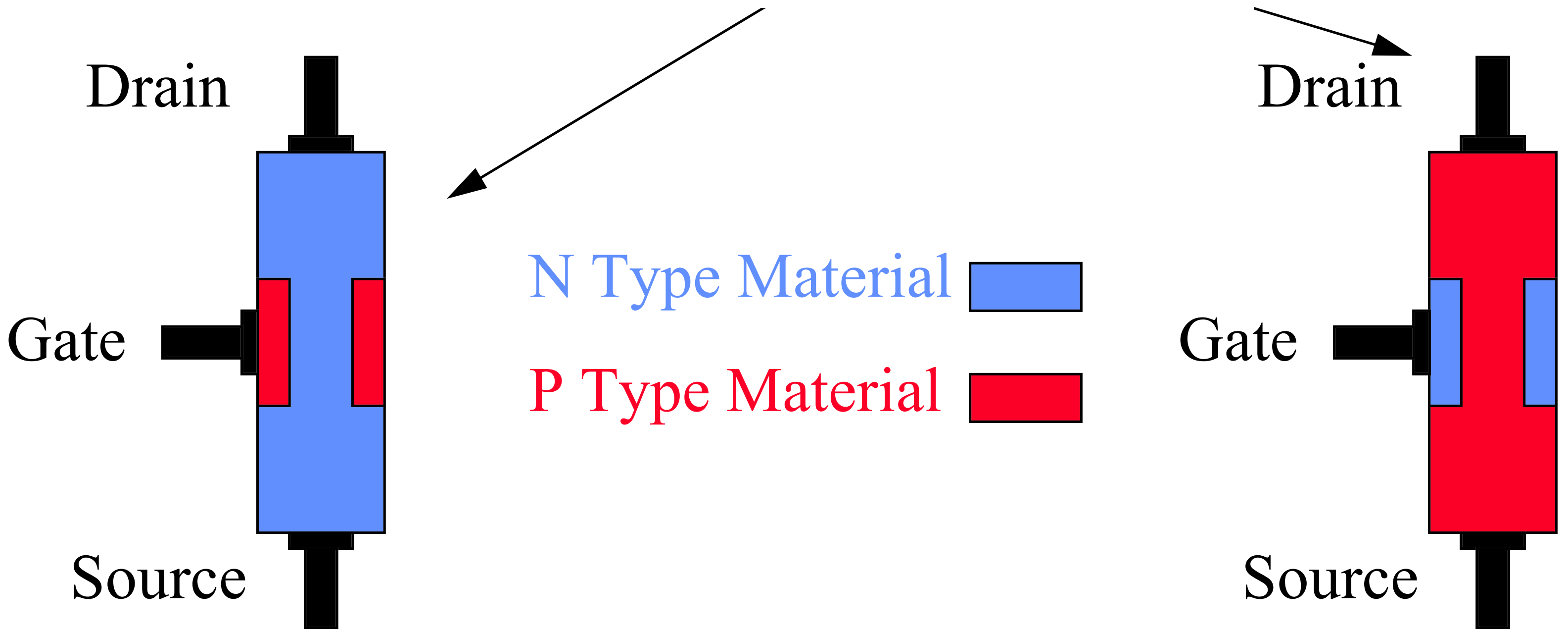
- The Basic epitaxial planar structure.



Junction Field Effect Transistors (JFET)

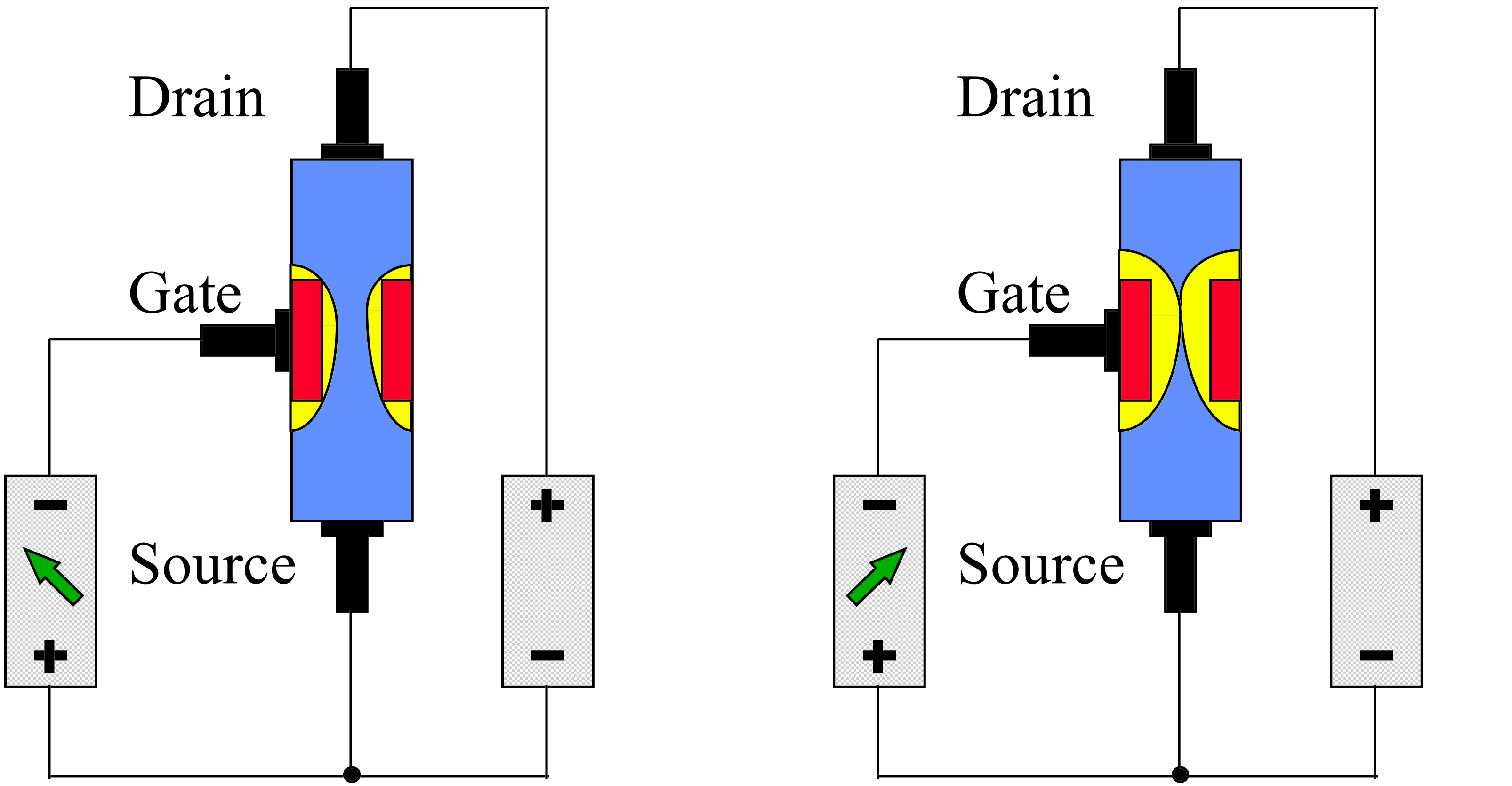
Transistors and Diodes.

- Another development phase was to build single channel device semiconductor and this also gave two the possible variants.
- These variants are identified from their construction i.e. N Channel and P Channel.



Transistors and Diodes.

Field Effect Transistor (FET).



FET Biased for Conduction FET Biased for Maximum Resistance

Metal Oxide Silicon Field Effect Transistors (MOSFET)

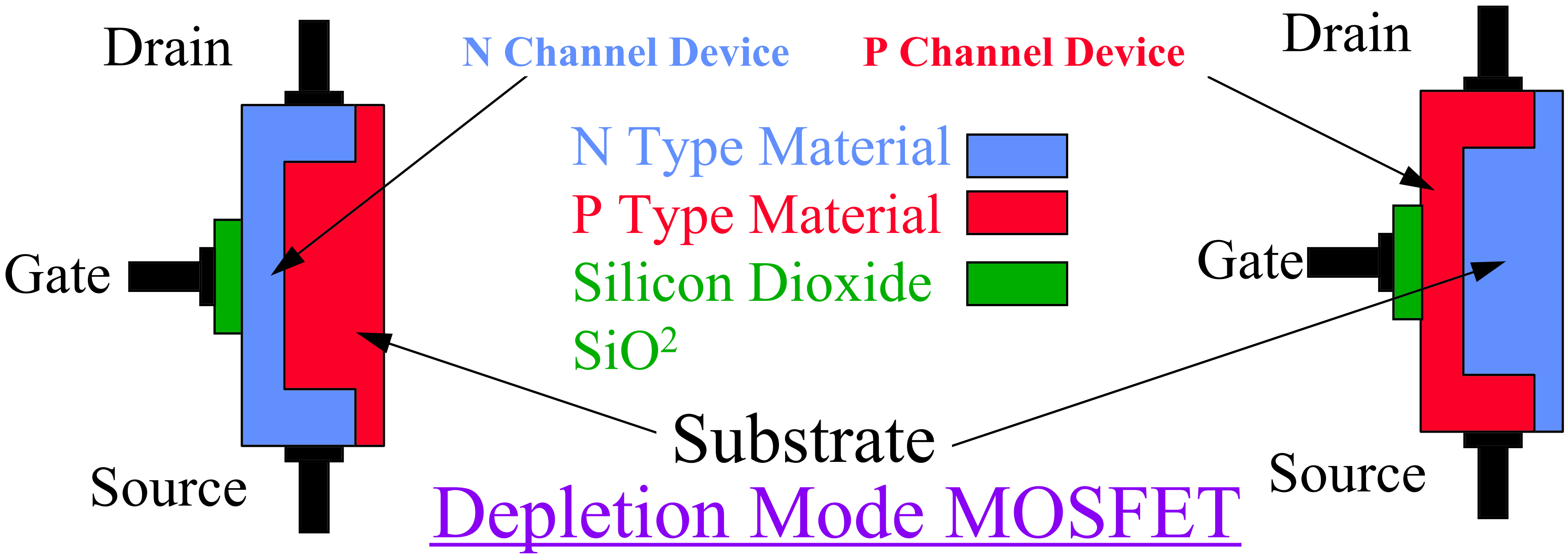
Transistors and Diodes.

MOSFET

Depletion Mode Devices

Transistors and Diodes.

- Another development phase was to build a semiconductor device with no PN junctions giving a number of possible variants.
- These variants are identified again from their construction and Operation.



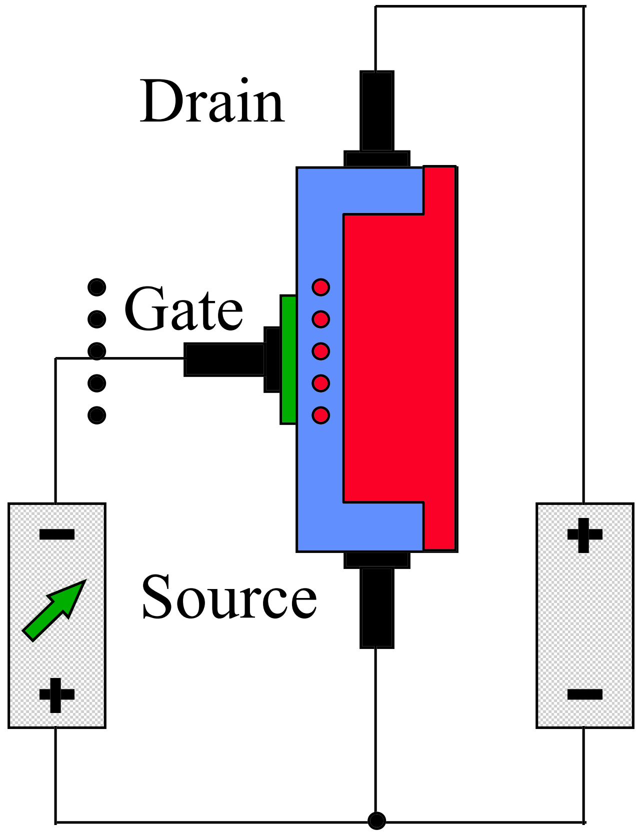
Transistors and Diodes.

Metal Oxide Silicon Field Effect Transistor (MOSFET).

•The Insulated Gate behaves in a similar manner to a Capacitor.

•If a Negative charge applied on the Gate (Black Dots) presents as a Positive (Red Dots) charge in the channel and this charge Repels Conduction Electrons.

•A higher Negative Gate voltage will cause MOSFET resistance to increase. (Depletion Mode)



MOSFET Biased for Maximum Resistance

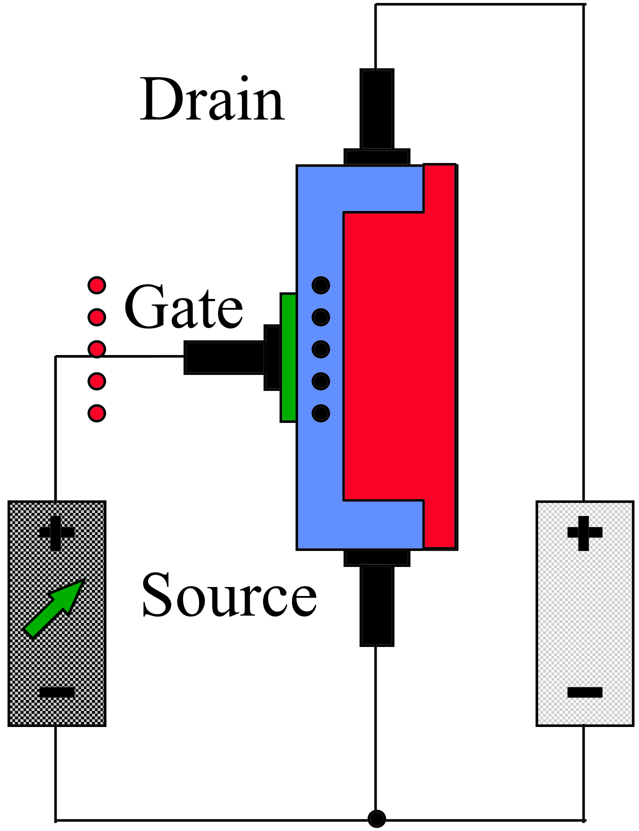
Transistors and Diodes.

Metal Oxide Silicon Field Effect Transistor (MOSFET).

•The Insulated Gate behaves in a similar manner to a Capacitor.

•If a Positive charge applied on the Gate (Red Dots) presents as a Negative charge (Black Dots) in the channel and this charge will Attract Conduction Electrons.

•A higher Positive Gate voltage will cause MOSFET resistance to reduce. (Enhancement Mode)



MOSFET Biased for Minimum Resistance

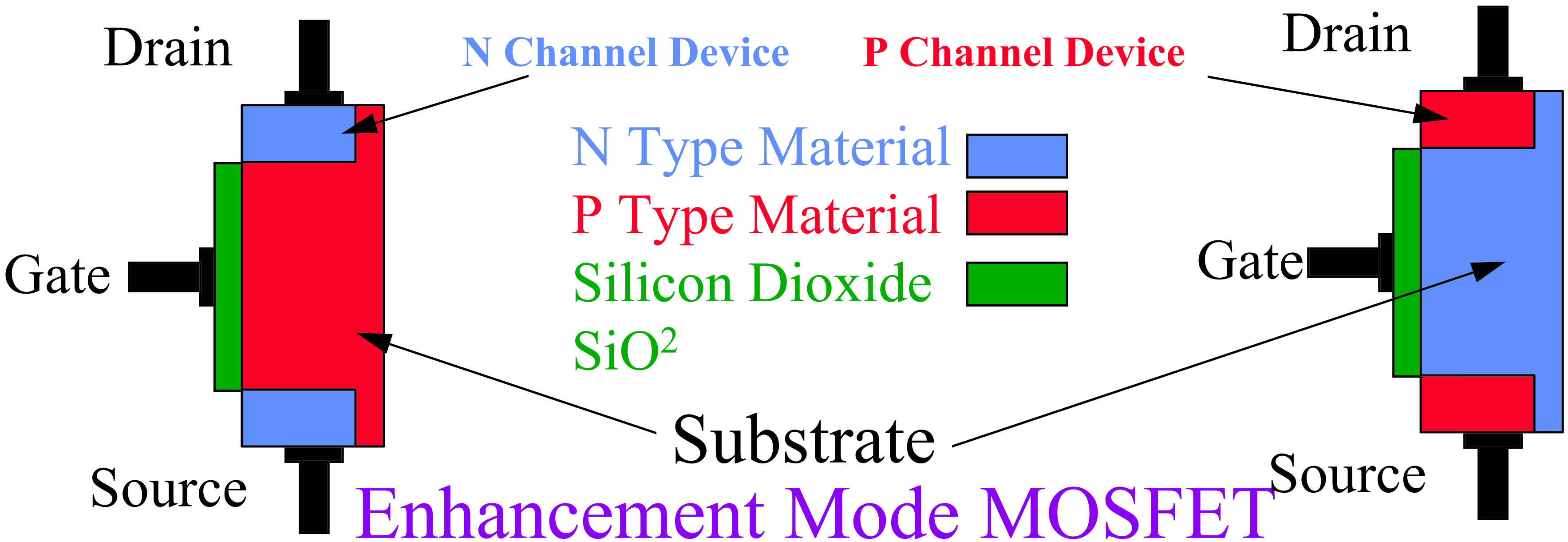
Transistors and Diodes.

MOSFET

Enhancement Mode Devices

Transistors and Diodes.

- Another development phase was to build a semiconductor device with no PN junctions giving a number of possible variants.
- These variants are identified again from their construction and Operation.



Enhancement Mode MOSFET

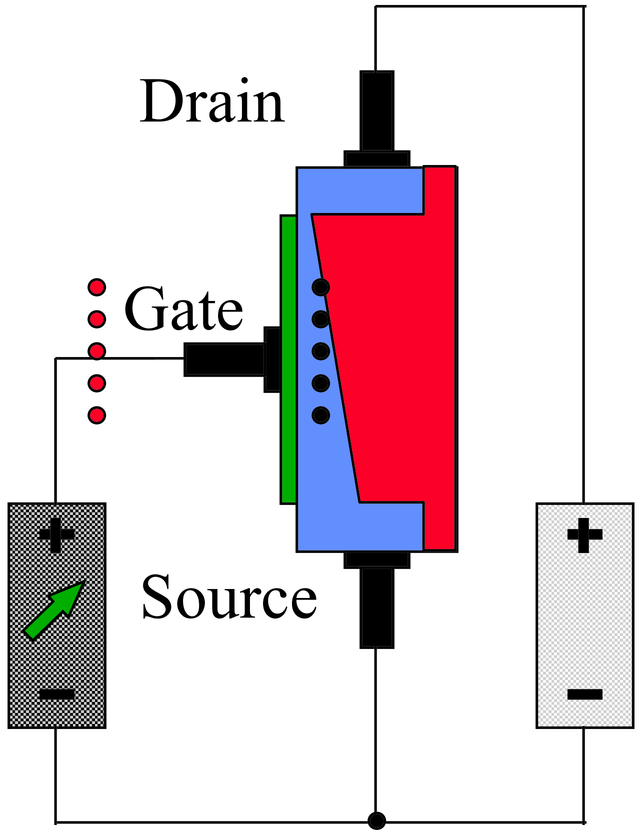
Transistors and Diodes.

Metal Oxide Silicon Field Effect Transistor (MOSFET).

•The Insulated Gate behaves in a similar manner to a Capacitor.

•If a Positive charge applied on the Gate (RED Dots) presents as a Negative (Black Dots) charge in the substrate area and this charge will induce a conduction channel through the device.

•A higher Positive Gate voltage will cause MOSFET resistance to reduce. (Enhancement Mode Only)

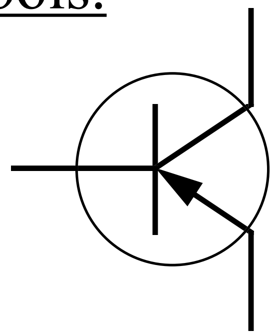


MOSFET Biased for Minimum Resistance

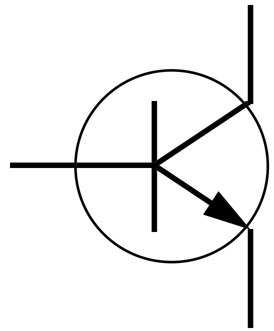
BS Circuit Symbols Transistors Bipolar and FET

Transistors and Diodes.

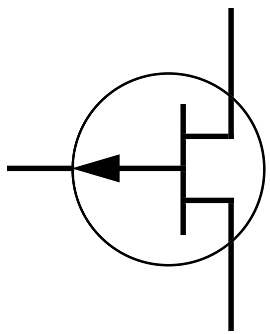
BS Symbols.



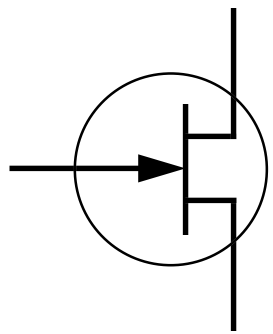
PNP Transistor



NPN Transistor



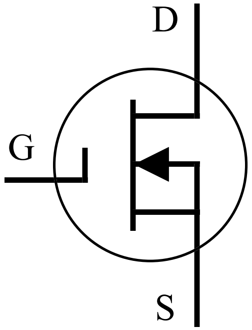
P Channel Junction Field Effect Transistor JFET



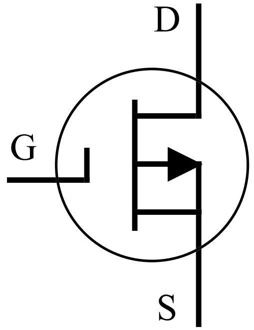
N Channel Junction Field Effect Transistor JFET

Transistors and Diodes.

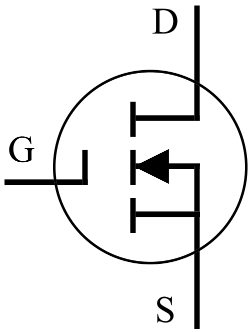
BS Symbols.



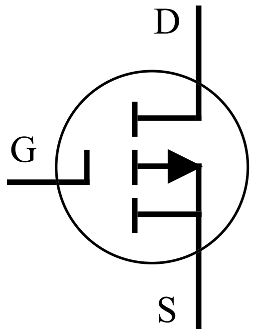
N Channel Depletion mode
D-MOSFET



P Channel Depletion mode
D-MOSFET



N Channel Enhancement mode
D-MOSFET

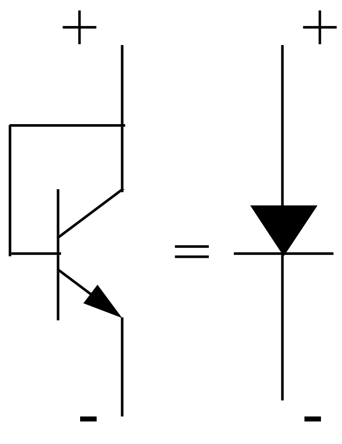


P Channel Enhancement mode
D-MOSFET

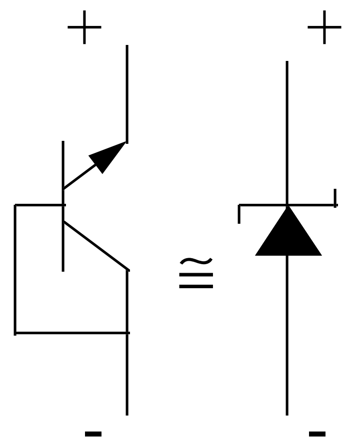
Metal Oxide Silicon Field Effect Transistors MOSFET

Special Circuit Configurations

Transistors and Diodes.

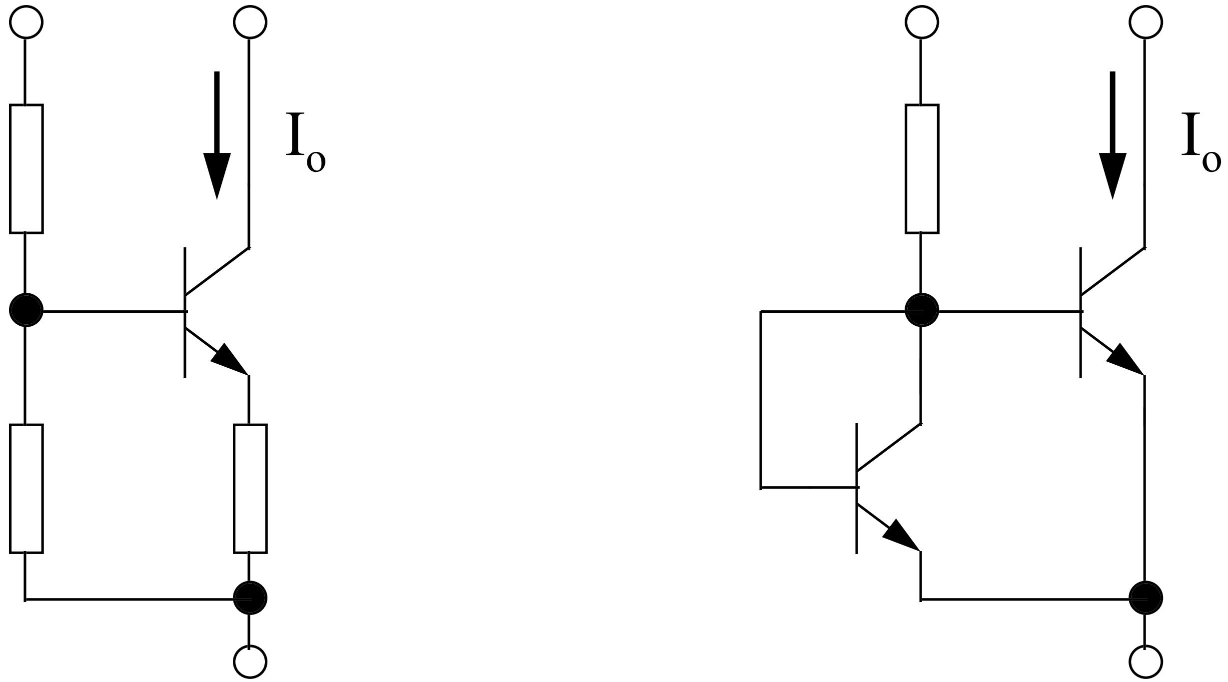


The Transistor configured as a Diode



The Transistor configured as a Zener Diode

Transistors and Diodes.



The Transistor/s configured as a
constant current source.

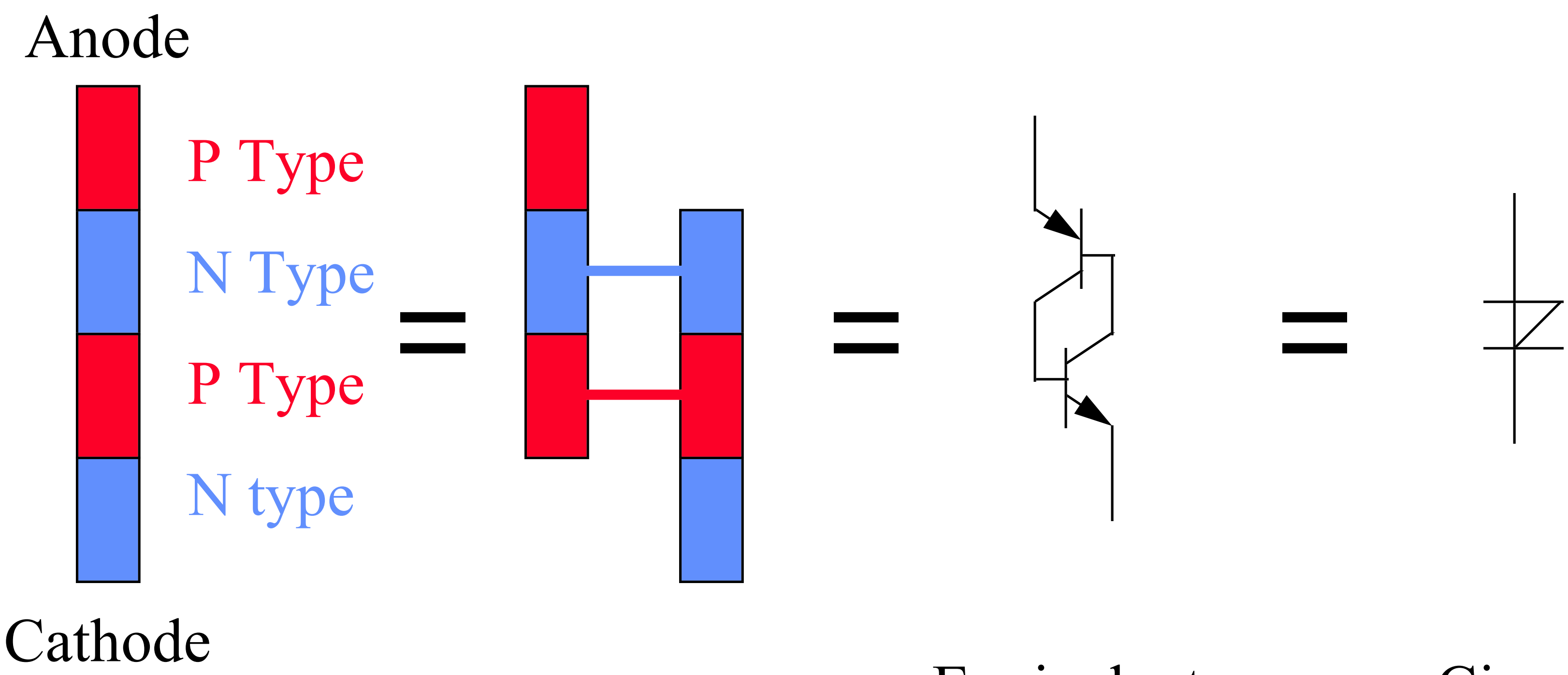
Multi-Layer Devices Diacs , Thyristors (SCRs) and Triacs

Transistors and Diodes.

- General terms related to Diodes :-
- Di = two : ode from electrode (electrical conductor).
- A Diode is a device that usually has two terminals and allows current to flow in one direction only.
- In some applications it can be considered to act like a Switch (Power Control and Digital Circuits).
- The diode can be used to produce a voltage reference.
- The term Rectifier is the generic name used to indicate that a Diode is used for Power applications.
- The term Detection is the generic name used to indicate that a Diode is being used in Low current / High Frequency applications.

Transistors and Diodes.

- The Shockley Diode is a four layer semiconductor device. The geometry of the device defines the emitters and its operational characteristics.



Physical Diagram

Equivalent Diagram

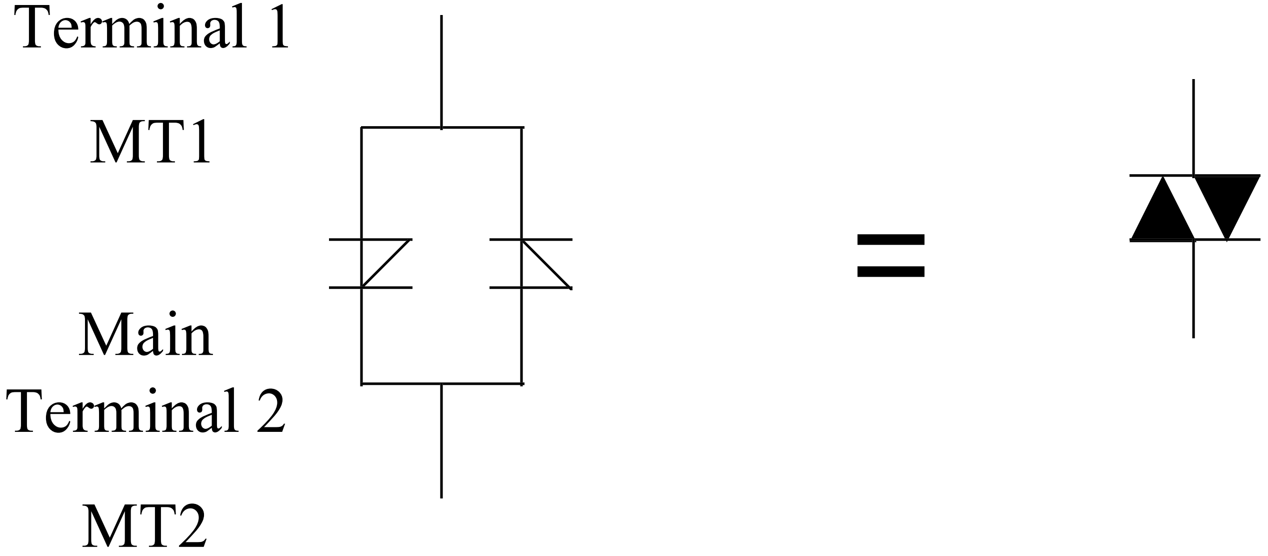
Circuit Symbol

Transistors and Diodes.

- The Shockley Diode (Unidirectional) :-
- Ideal transistors will not conduct however real devices have defined breakover voltages (Collector/Emitter) and also experience leakage.
- If one transistor starts to conduct, normal transistor action will then occur switching on the other causing Positive feedback and the two devices then latch on.
- The Shockley Diode will remain switched on until the current through the device is reduced to a point where one of the transistors reaches the base cutoff point which breaks the Positive feedback loop.
- Summary : High voltage pulse switches device on.

Transistors and Diodes.

- The Diac (Diode for Alternating Current)
- The Diac is built from two Shockley Diodes wired in inverse parallel.

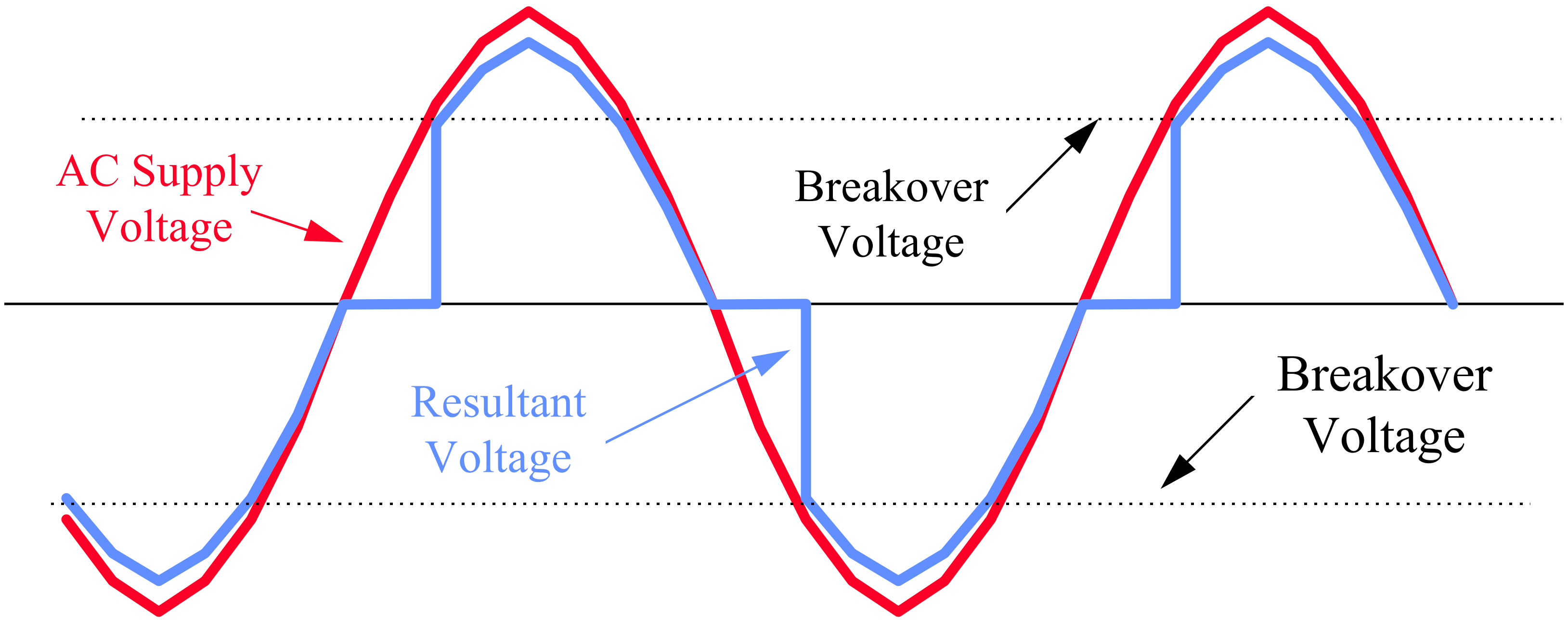


Equivalent Diagram

Circuit Symbol

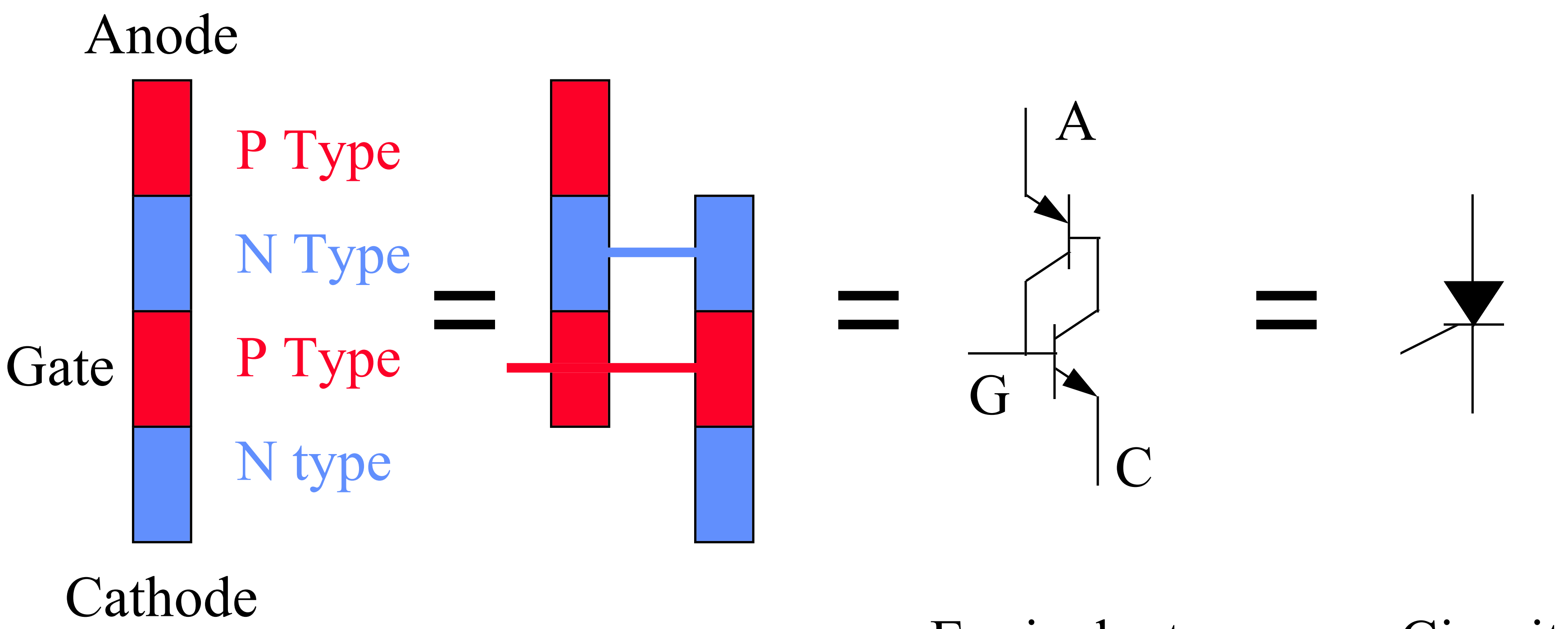
Transistors and Diodes.

- The DIAC (Bi-directional) :-
- With a DC voltage applied the Diac will behave in the same way as a Shockley Diode .
- Summary: AC Operation: effect as shown below.
- Note: This device is rarely used on its own .



Transistors and Diodes.

- The Silicon-Controlled Rectifier (SCR) is a four layer semiconductor device. The geometry of the device defines its operational characteristics.



Physical Diagram

Equivalent Diagram

Circuit Symbol

Transistors and Diodes.

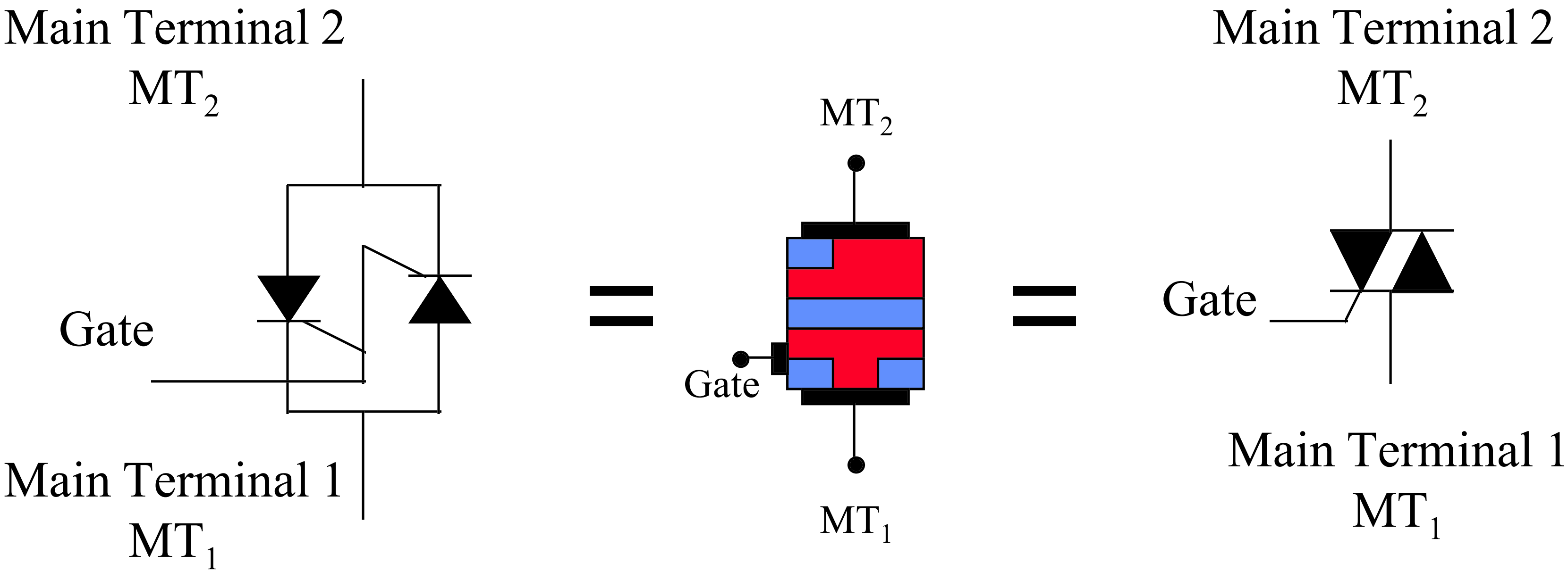
- The Silicon-Controlled Rectifier (SCR) :-
- The operation is identical to that of a Shockley Diode, however, the gate terminal allows an alternative way of triggering the device.
- The breakover voltage of an SCR is much higher than the expected device operational voltage.
- Summary : A small amount of current applied to the Gate of the SCR can control significantly higher current through the device (Anode to Cathode).
- Note: Some SCRs have a inbuilt resistor connected between Gate and Cathode connections to avoid false triggering of the devices.

Transistors and Diodes.

- The Gate Turn Off Thyristor (GTO) :-
- The operation similar to the SCR, however, the GTO uses the gate current to stop the device conducting.
- The gate current may need to be up to 20% of the Anode (load) current to switch the device off.
- Circuit symbol for a GTO or SCR is the same.
- Summary : The geometry of the device ensures that the gain of the NPN transistor is much higher than the PNP transistor and this allows more control to disable the latched state.
- Note: This device us rarely used in general/common circuit applications.

Transistors and Diodes.

- The Triac is built from two SCRs wired in inverse parallel.



Equivalent Diagram

Basic Structure

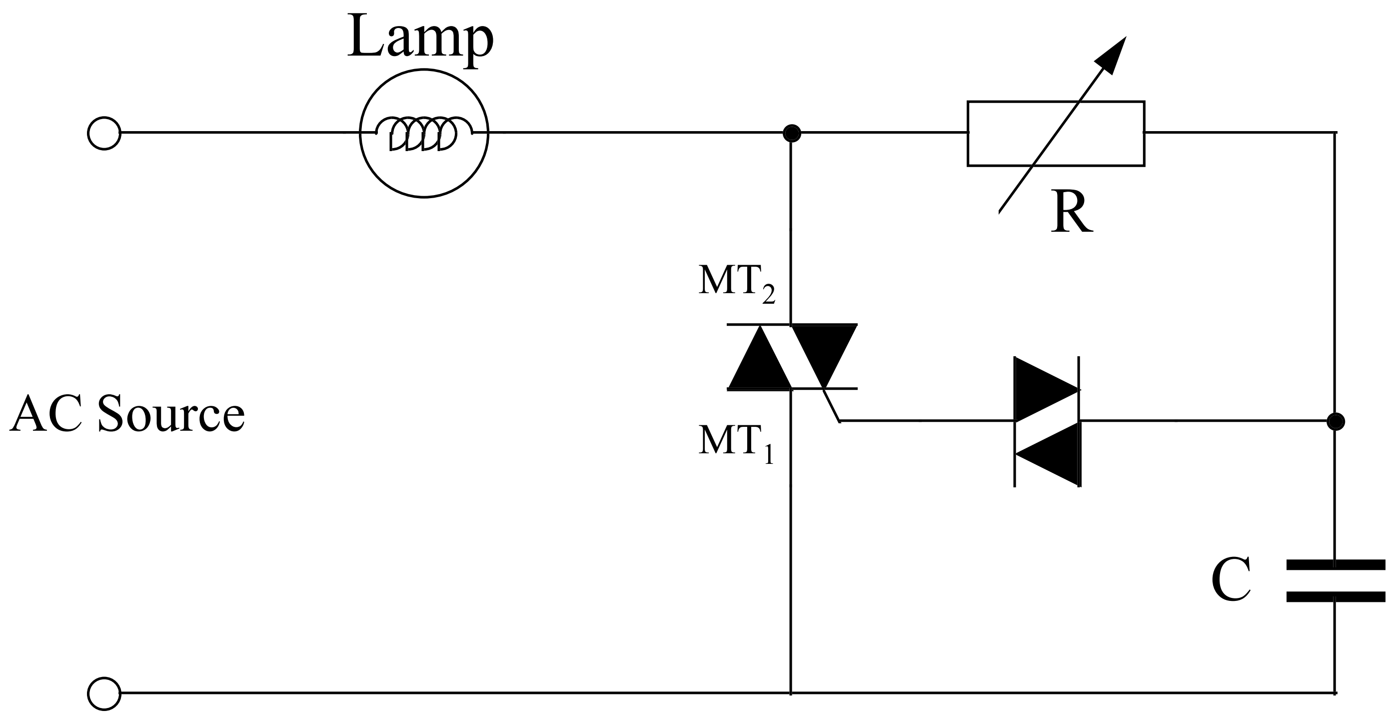
Circuit Symbol

Transistors and Diodes.

- The TRIAC (Triode for Alternating Current) :-
- The operation is similar to two back to back SCRs, however, Triacs tend to NOT trigger symmetrically.
- To overcome this problem a DIAC is usually placed in series with the Triac gate.
- Summary : Used to control AC power in relativity low power applications.
- Note :
  - MT1 and MT2 are NOT interchangeable.
  - To trigger successfully the gate current must come from the MT2 side of the device.

Transistors and Diodes.

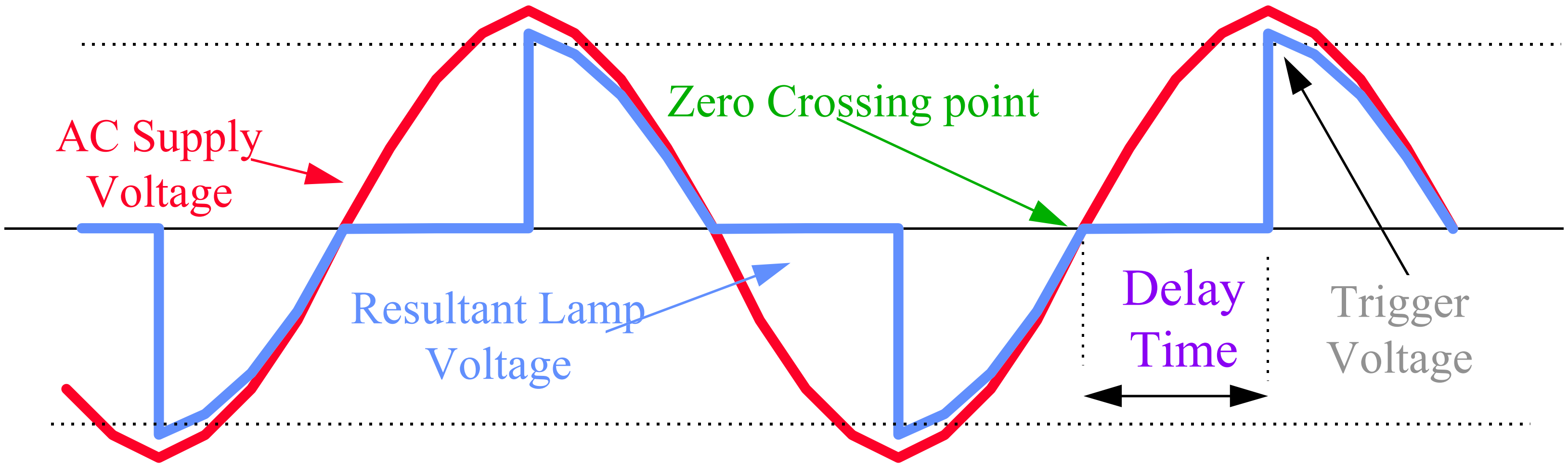
- A typical example of a power control circuit using a Triac.



Note: The quicker the voltage rises across the Capacitor C then the brighter the lamp will become.

Transistors and Diodes.

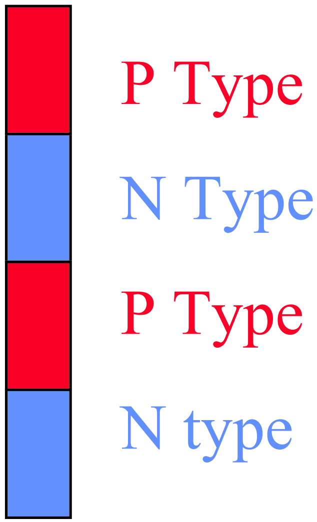
- The Capacitor C charges up at a rate determined by the CR Ratio (R is a variable Resistor).
- When the Trigger Voltage across the Capacitor is sufficient to cause the Diac to breakover the Triac will latch on and the lamp will light.
- The level of brightness will depend how long the Delay Time is before the trigger occurs after the Zero Crossing point of the waveform.



Transistors and Diodes.

- The Shockley Diode is a four layer semiconductor device. The geometry of the device defines the emitters and its operational characteristics.

Anode



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Cathode

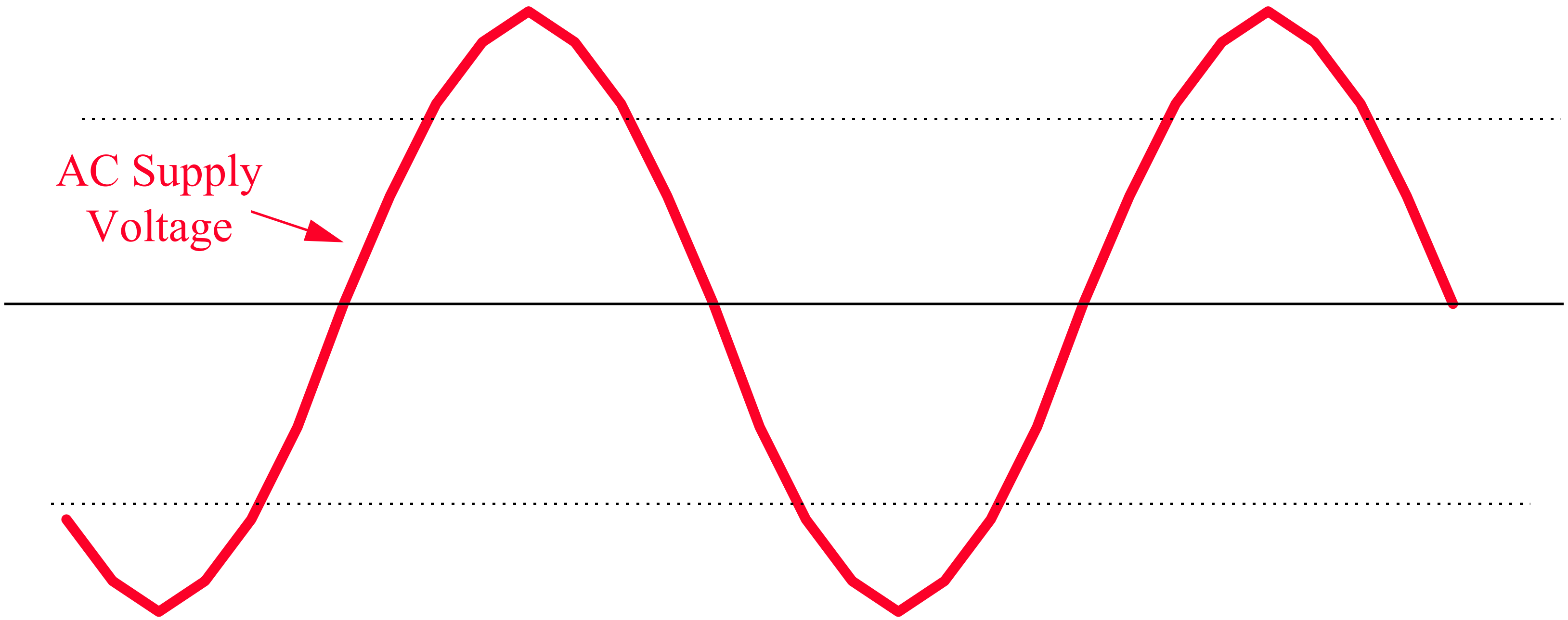
Physical Diagram

Equivalent Diagram

Circuit Symbol

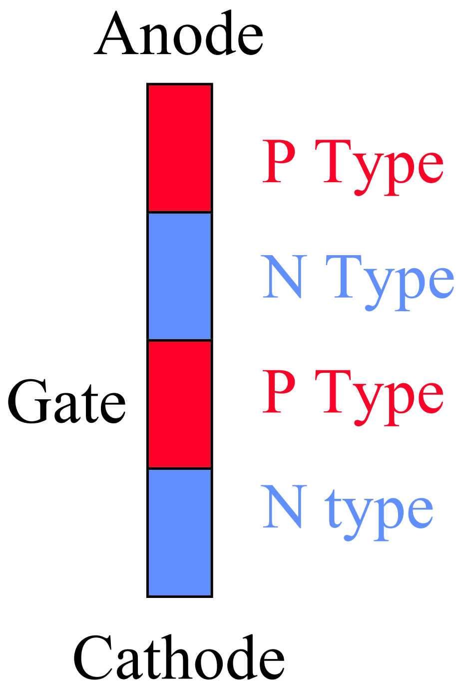
Transistors and Diodes.

- The DIAC (Bi-directional) :-
- With a DC voltage applied the Diac will behave in the same way as a Shockley Diode .
- Summary: AC Operation: effect as shown below.
- Note: This device is rarely used on its own .



Transistors and Diodes.

- The Silicon-Controlled Rectifier (SCR) is a four layer semiconductor device. The geometry of the device defines its operational characteristics.



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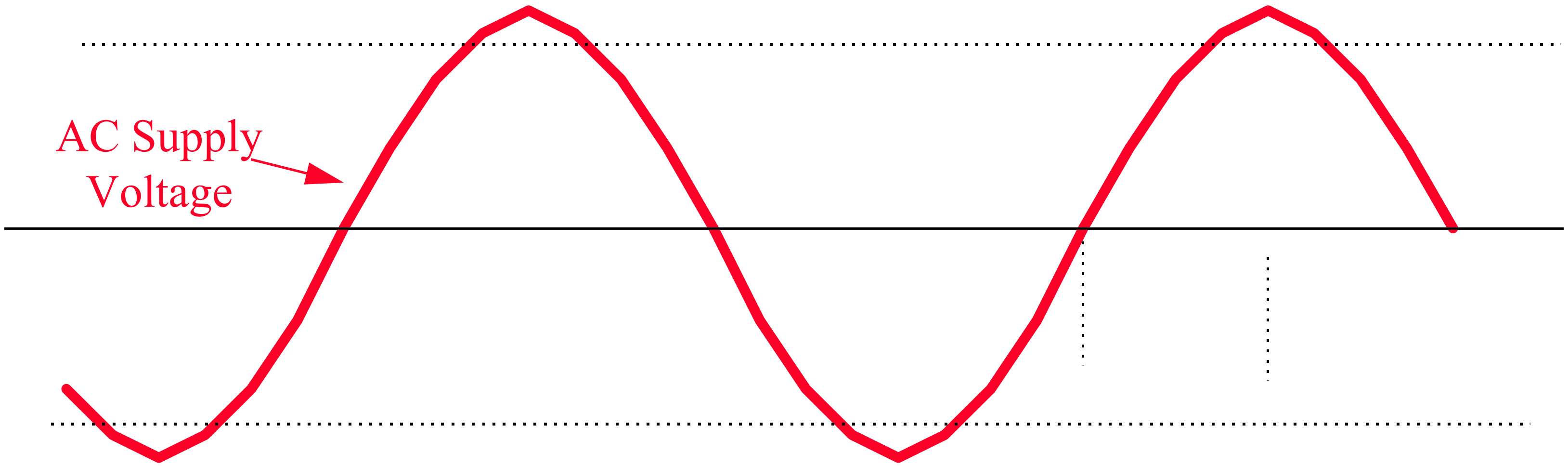
Physical Diagram

Equivalent Diagram

Circuit Symbol

Transistors and Diodes.

- The Capacitor C charges up at a rate determined by the CR Ratio (R is a variable Resistor).
- When the Trigger Voltage across the Capacitor is sufficient to cause the Diac to breakover the Triac will latch on and the lamp will light.
- The level of brightness will depend how long the Delay Time is before the trigger occurs after the Zero Crossing point of the waveform.



Transistors and Diodes.

- The Triac is built from two SCRs wired in inverse parallel.

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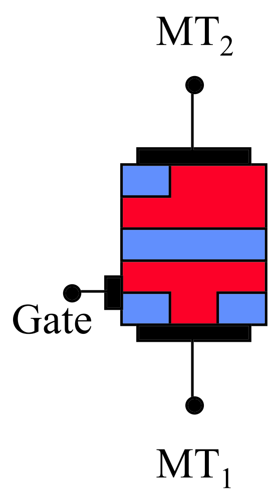

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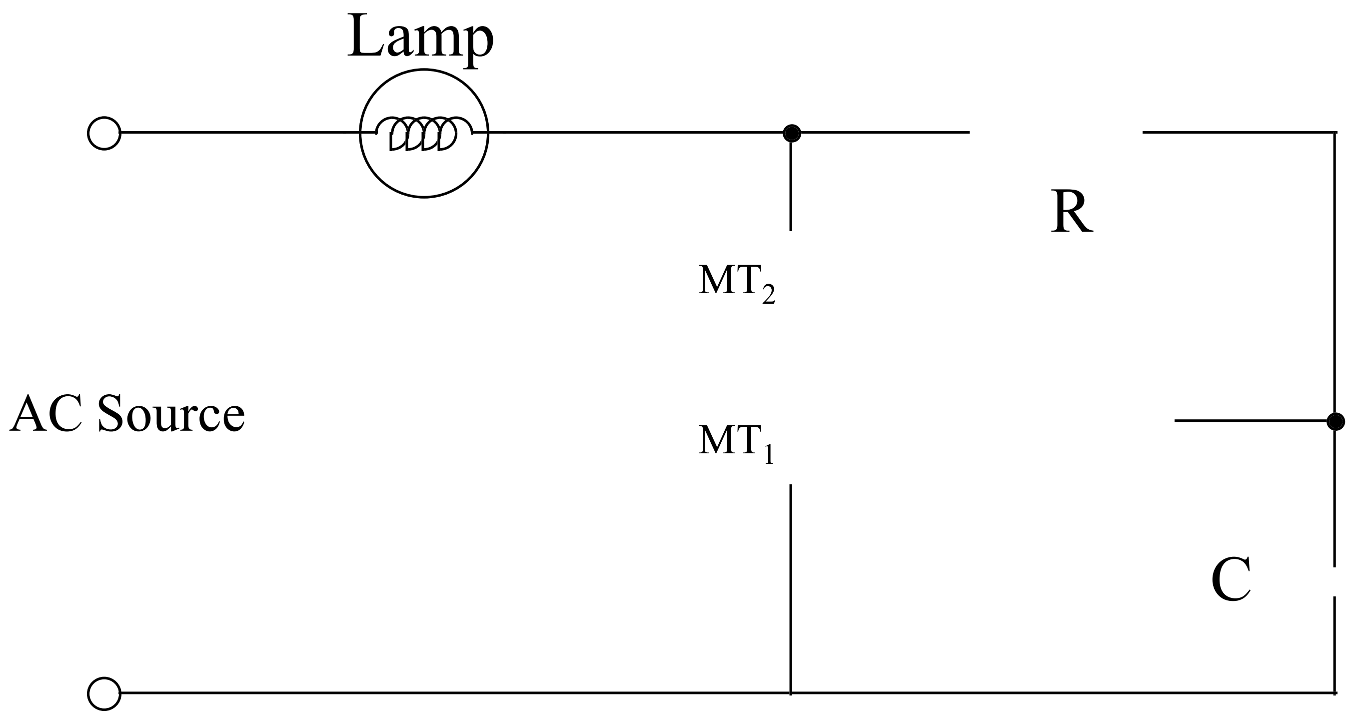
Equivalent Diagram

Basic Structure

Circuit Symbol

Transistors and Diodes.

- A typical example of a power control circuit using a Triac.



Note: The quicker the voltage rises across the Capacitor C then the brighter the lamp will become.

The 555 Timer

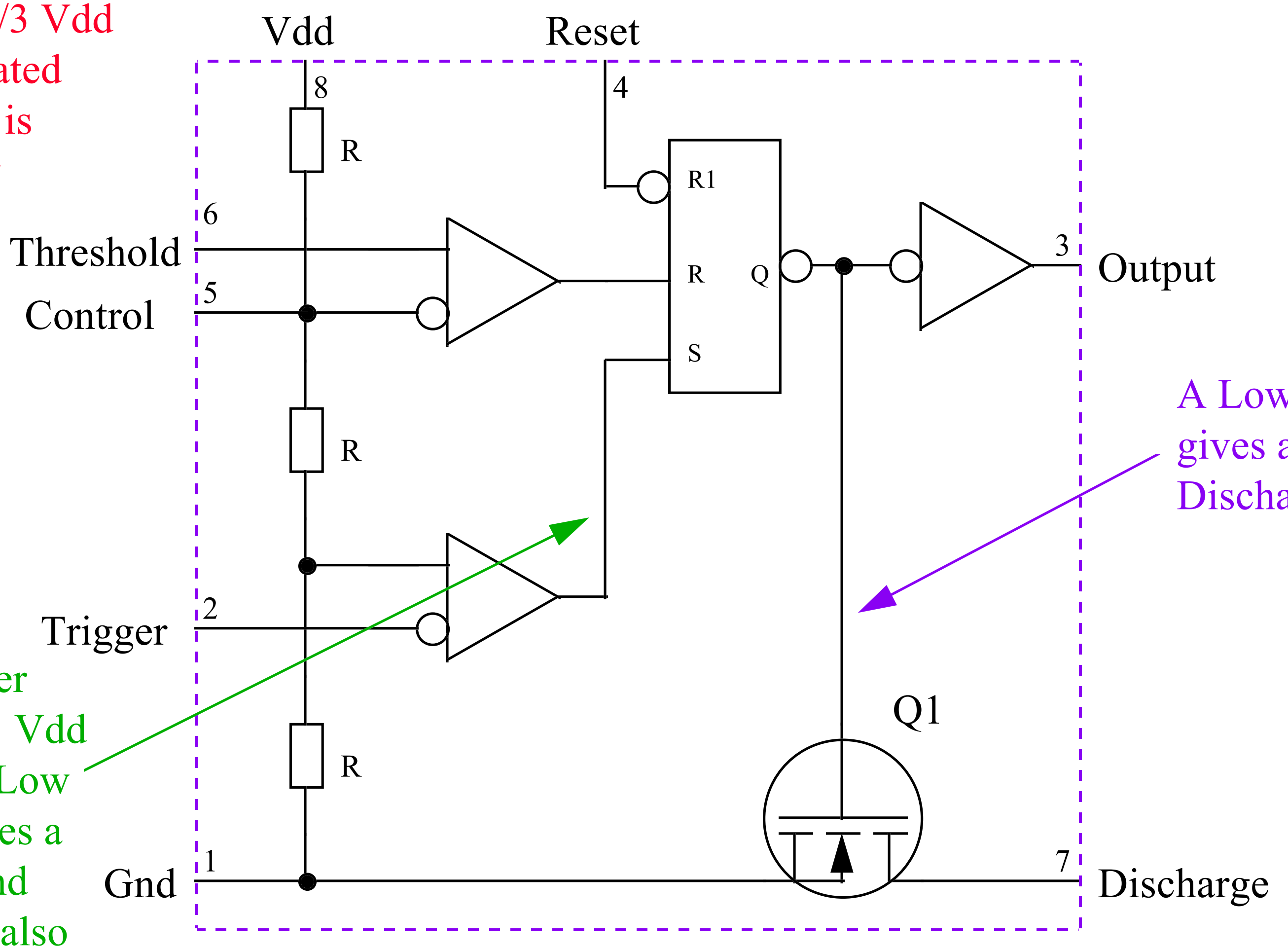
Summary

The 555 Timer.

- A low cost and easy to use component.
- Can be configured as a Monostable using one resistor and one capacitor.
- Can be configured as an Astable using two resistors and one capacitor.
- Can operate up to 2MHz and can be fully compatible with CMOS, TTL and MOS logic.

The 555 Timer.

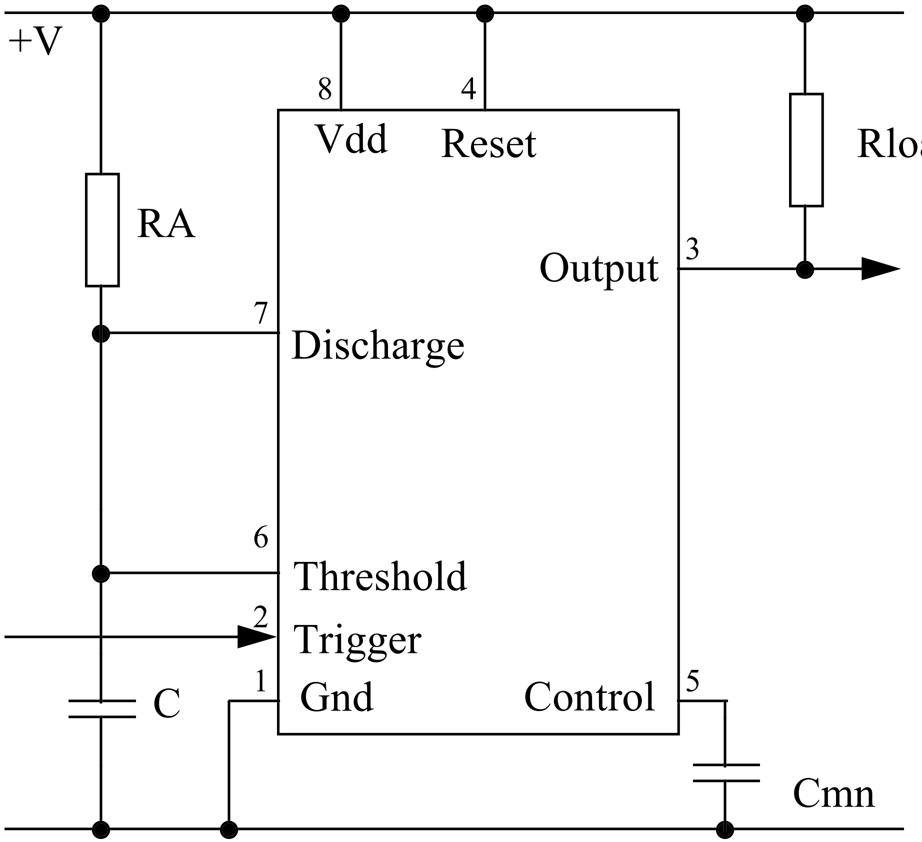
When Threshold reaches > 2/3 Vdd Reset activated and Output is forced Low

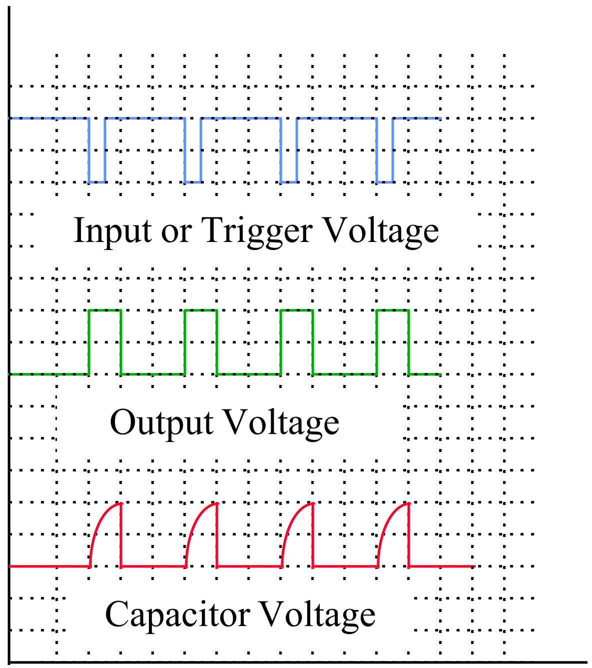


When Trigger reaches <1/3 Vdd or is forced Low then this gives a High here and Output then also goes High.

Functional Block Diagram.

The 555 Timer.

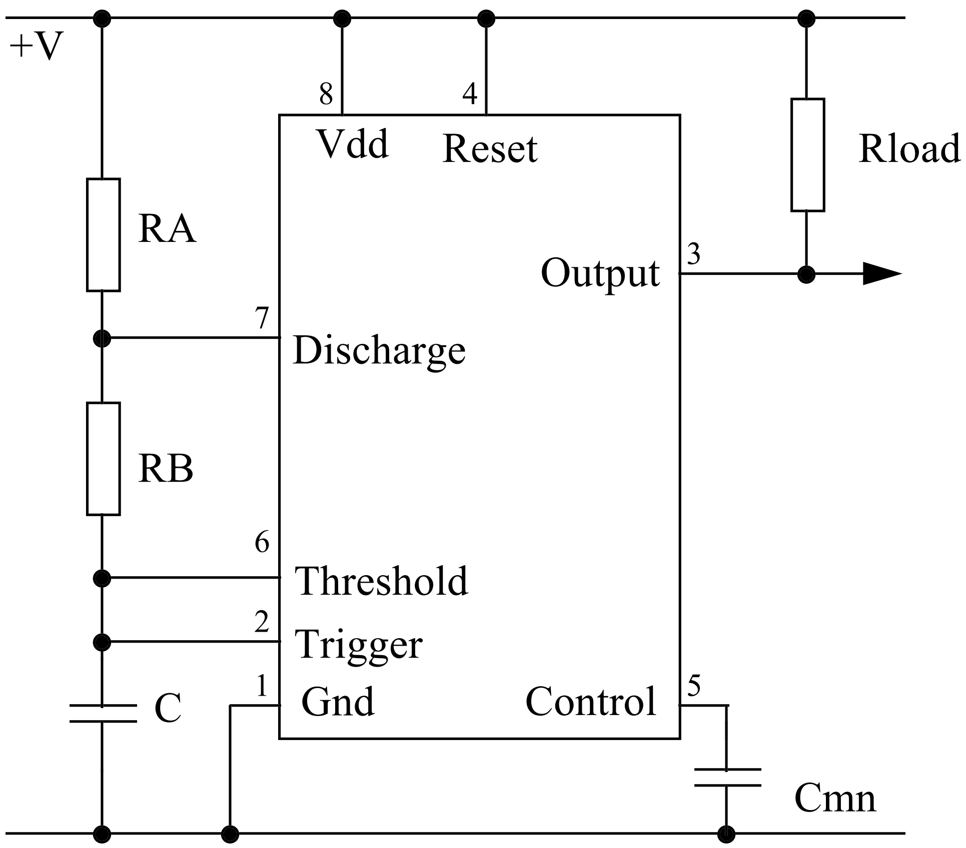


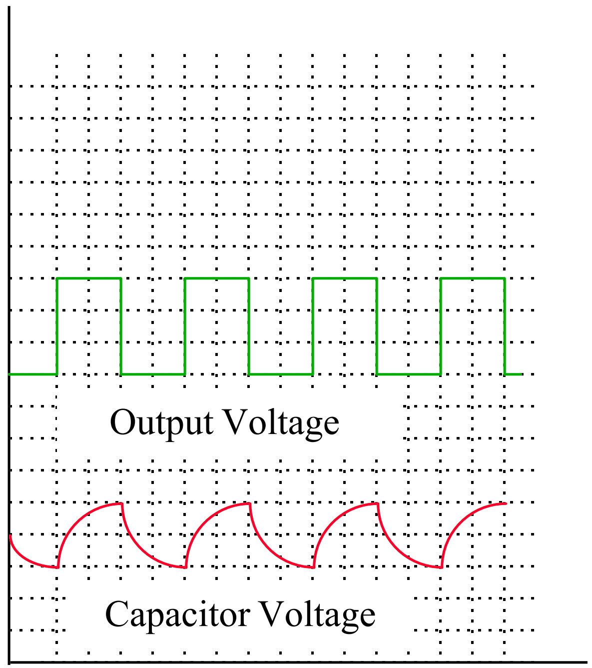


Pulse width = 1.1 * RA* C

555 Configured as a Monostable.

The 555 Timer.





Frequency = 1.44 / (RA + 2RB)C

555 Configured as an Astable.

End Slide

Revision Page

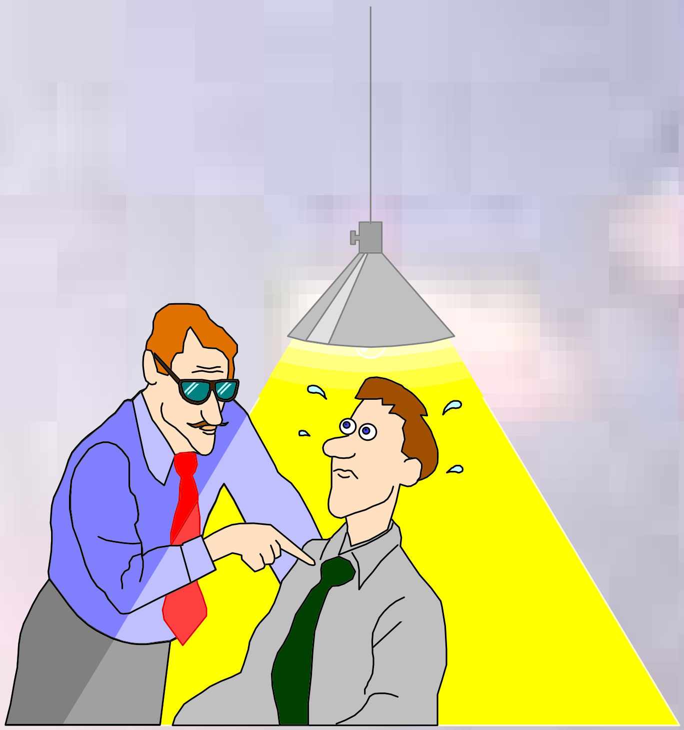
Title BASIC Analogue Electronics.

Author R. J. Spriggs

Last Update 21/July/2011

Version 4.42

Edit 0373



Work in progress