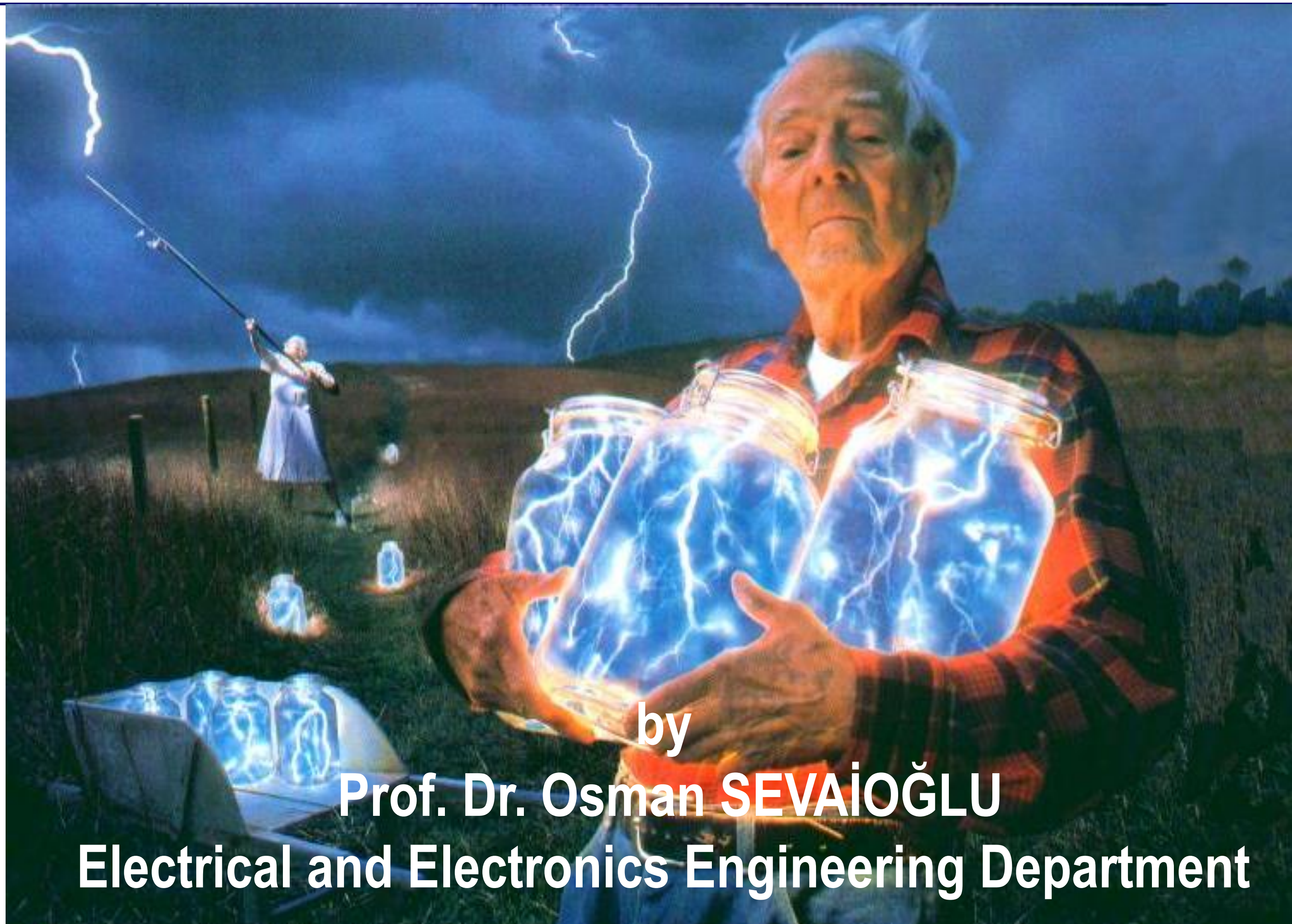
METU

Basic Principles of Electricity

Basic Principles of Electricity



by

Prof. Dr. Osman SEVAİOĞLU

Electrical and Electronics Engineering Department

Course Syllabus

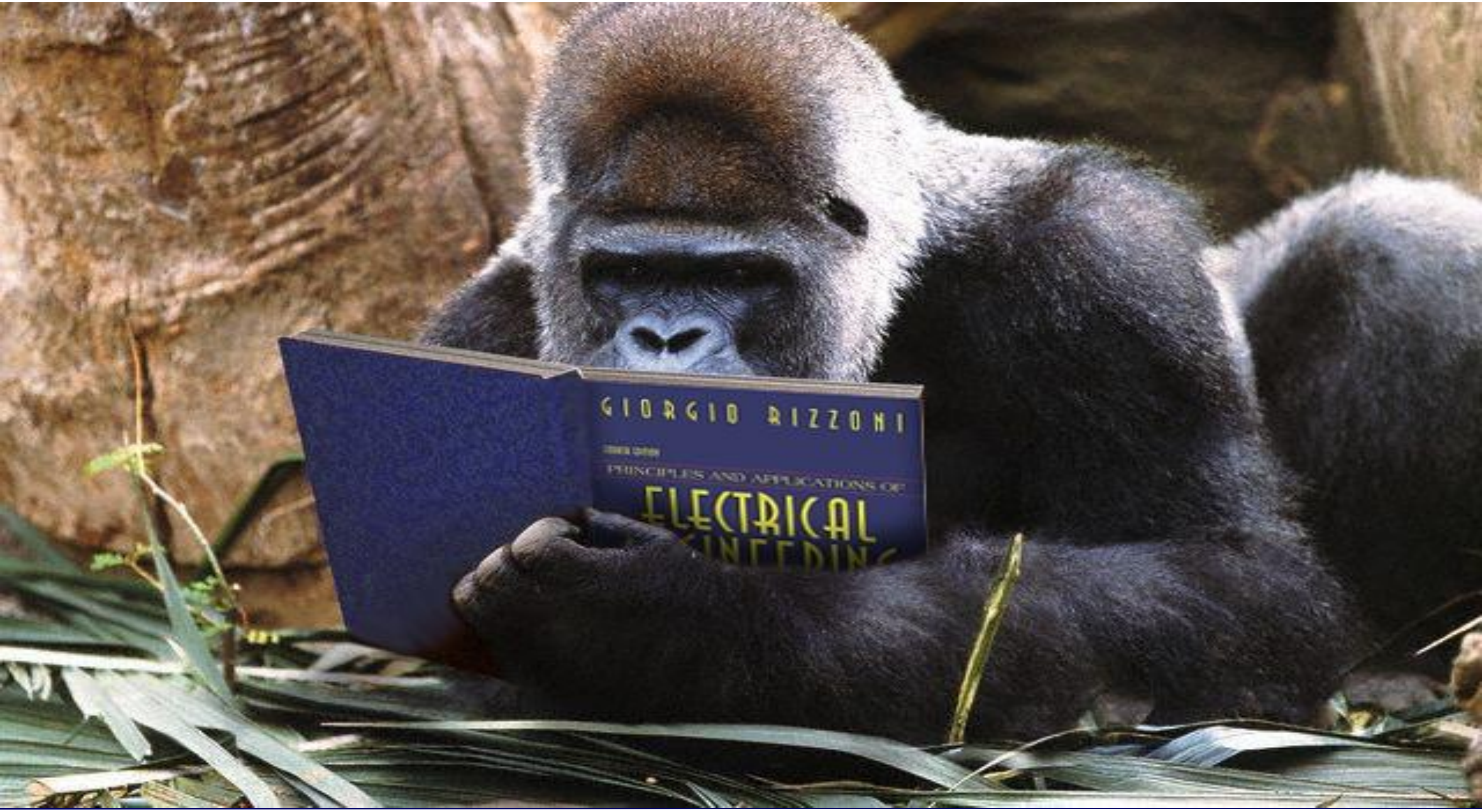
EE 209
Fundamentals of Electrical and Electronics Engineering (3-0)3

- Basic Principles of Electricity,
- Circuit Analysis,
- AC Circuits,
- AC Power,
- Phasors,
- Three Phase Systems,
- Transformers,
- Magnetic Circuits,
- Electrical Safety

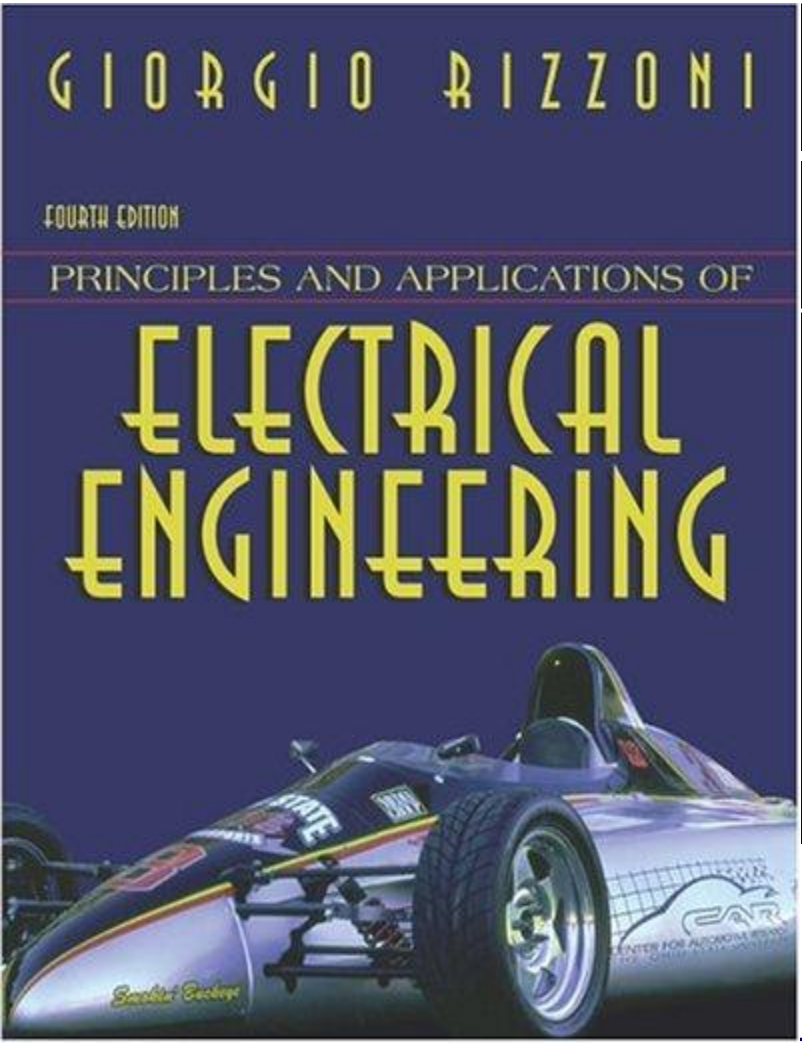
(Offered to non-EE students only)

Prerequisite: PHYS 106 or consent of the department.

Book for the Course



Book for the Course



Principles and Applications of Electrical Engineering, 4/e

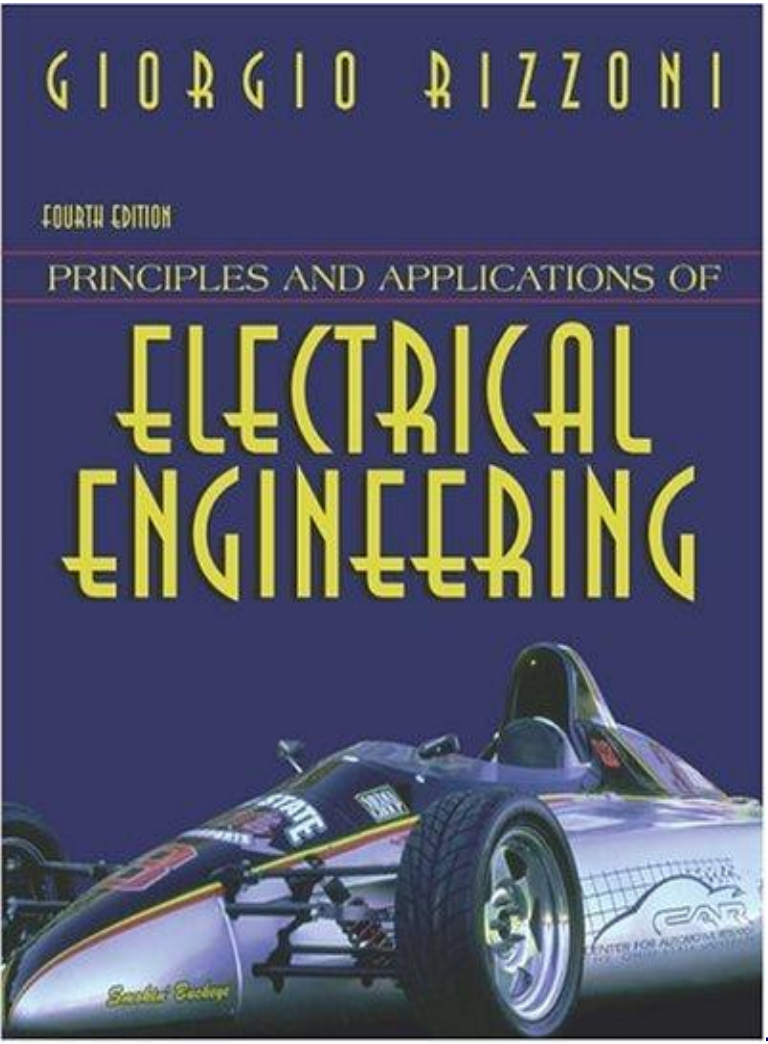
Giorgio Rizzoni
The Ohio State University

Mc. Graw Hill Book Company,

ISBN: 0072463473
Copyright year: 2003
999 Pages
Available in Reserve Division of the Middle East Technical University Central Library

Basic Principles of Electricity

Course Syllabus



Chapters to be Covered

- Basic Principles of Electricity,
- Circuit Analysis,
- AC Circuits,
- AC Power,
- Phasors,
- Three Phase Systems,
- Transformers,
- Magnetic Circuits,
- Electrical Safety

Basic Principles of the Course

Examinations

Two midterm examinations and a final exam

Midterm Exam 1	(Three questions, equal credits, 90 min)	20 %
Midterm Exam 2	(Three questions, equal credits, 90 min)	20 %
Final Exam	(Four questions, equal credits, 120 min)	30 %
Attendance		30 %
		+

Total		100 %

Homework

No homeworks will be assigned

You are advise to examine;

- the homeworks in the book,
- examination questions that will be distributed

Basic Principles of the Course

Examinations

- Midterm examinations will cover all the material taught until the examination date,
- Final Examination will cover the overall course material,
- Announced exam schedule can neither be changed nor discussed after it has been settled,
- Duration of the examination will never be extended,
- Questions will never be allowed during the examination

Basic Principles of the Course

Make-up Examinations

- Will be given only to those students with valid documented excuse,
- Requests for make-up exam that does not include a valid documented excuse will be rejected,
- A single make-up exam will be given to all students with legitimate rights for the exam,
- Exam will be carried out in an officially settled date and hour,
- Exam will not be repeated, i.e. Make-up of make-up will not be performed,
- Students will be responsible for answering the questions only from the parts covered in the exam that they have missed

Questions and Solutions of the Previous Examinations

Exam Questions and Solutions

- A file including all exam questions and solutions is available,
- A file including the questions and solutions of all the previous examinations will be submitted to a student who is elected by the class for photocopying and distributing this file to the class,
- This student will be responsible for the toll collection and distribution activity

In case that there is no valunteer for the job, the task will be cancelled !

Yahoo Group for the Course

http://groups.yahoo.com/group/ee209/

Yahoo Group for the course is;

http://groups.yahoo.com/group/ee209/

This group is intended to be the main communication medium for information exchange and storage for the course

Enrollment to this group is compulsory ---

All students are obliged to subscribe to this group by using the procedure described in the next page

E-mail Group

Enrollment

To subscribe from the group, send an email to:
ee209-subscribe@yahoogroups.com

To unsubscribe from the group, send an email to:
ee209-unsubscribe@yahoogroups.com

E-mail Group

Nicknames (User Ccodes)

<u>Nicknames</u>

Please choose nicknames that reflect your personal identity, i.e. your surname and/or name and/or you name and surname augmented.

Please do NOT choose improper or annoying nicknames, such as; “Arizona Tigers”, “diabolic, “best friend”, “miserable(68)” etc. that does not reflect your personal identity

E-mail Group

Communication

All questions, suggestions, complaints, demands, requests and other communication concerning the course should be directed to the e-mail communication address of the group:
ee209@yahoogroups.com

The Course Instructor keeps the right of not answering some or all of the questions, suggestions, complaints, demands, requests forwarded in this mail group, in case that it is not necessary, or not relevant, or not possible

E-mail Group

Rules of Communication

In your e-mails;

- Be polite,
- Start your letter with; “Dear Group Members” or “Dear Friends” and end with; “With best regards”
- Do not use disturbing abbreviatons, such as “slm” for “selam”,
- Do not discuss your own personal, social or academic problems,
- Do not be aggressive to the Group members and to Course Instructor,
- Do not discuss subjects not relevant to the course, (such as last match of Fenerbahçe)

People who violate the above rules will be deleted from the group

E-mail Group

Group Moderators

Course Instructor is the Main Moderator of the e-mail Group.

Assistant Moderator

An assistant moderator who is familiar with the management of yahoogroups activities, will be elected and appointed for managing the group from valunteer candidates in the class during the first hour. Moderators have identical authorities in group management in all respects

Problems

Complaints and Expressions

Complaints and expressions concerning your;

- personal,
- Social,
- Academic

problems will never be listened, nor be appreciated nor be interested.

- Your personal, social and academic problems will never be an influencing factor in grading,
- Your personal, social and academic problems will not be taken into account at all

This course is NOT a proper platform for expressing your own problems, negative or positive human feelings, such as, crying, complaining, hating, admiring, or any other physiologic, psychological expressions

E-mail Group

Office Hours

Unfortunately, there will not be any chance for office hour

- Please do not refer my office for any reason,
- and do not blame for that.

E-mail Group

Telephone Calls

<u>My GSM No: 0 532 384 78 65</u>

Telephone calls for concerning your personal, social and academic problems will neither be listened, nor be appreciated nor be interested

E-mail Group

Weekly Course Schedule (Three hours/week)

	Monday	Tuesday	Wednesday	Thursday	Friday
08:40					
09:40					
10:40		EE 209 Group 03 (ME), G-203			
11:40		EE 209 Group 03 (ME), G-203			
12:40		EE 443, D 131		EE 209 G-102	
13:40					
14:40					
15:40				EE 443, D 131	
16:40				EE 443, D 131	
17:40					

Announced schedule can be discussed

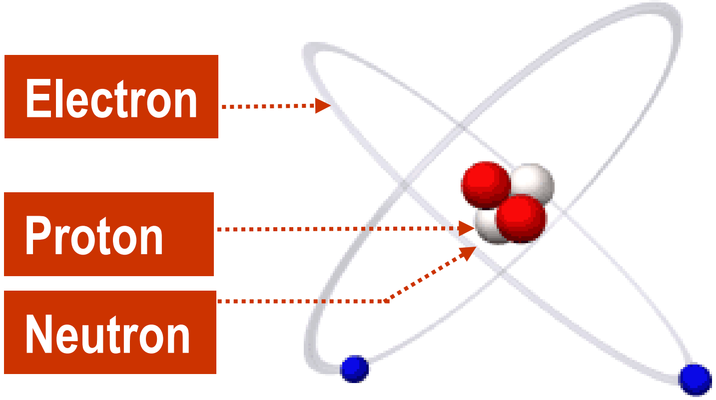
Basic Principles of Electricity

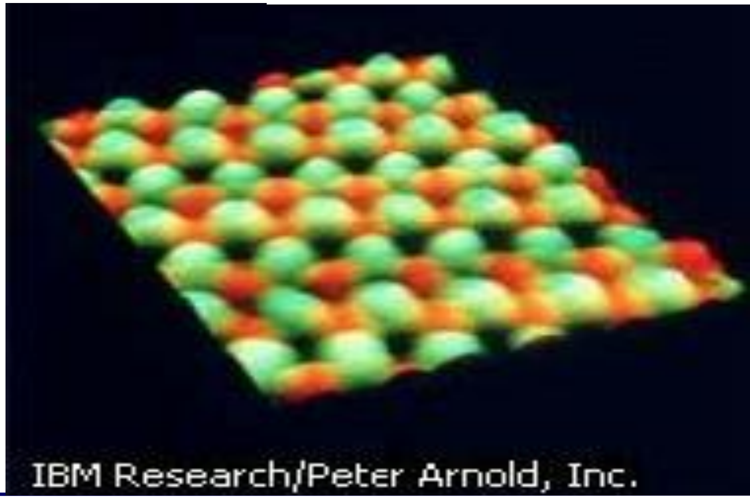
Atom

Structure of atom

Electron is assumed to be negatively charged
Proton is assumed to be positive charged

Helium Atom





Electrical Charge

Definition

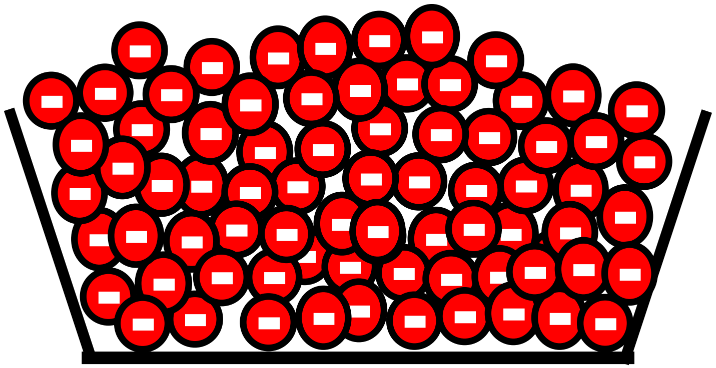
Unit of Electrical Charge Coulomb

6.3×10^{18} electrons $\triangleq$ 1 Coulomb

or

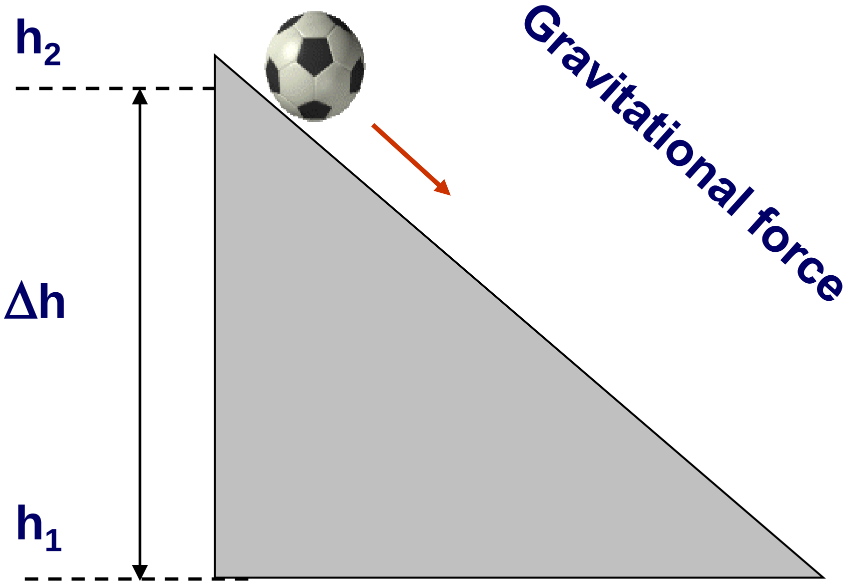
Electrical charge / electron = $1/(6.3 \times 10^{18})$ Coulomb

$= 1.602 \times 10^{-19}$ Coulomb



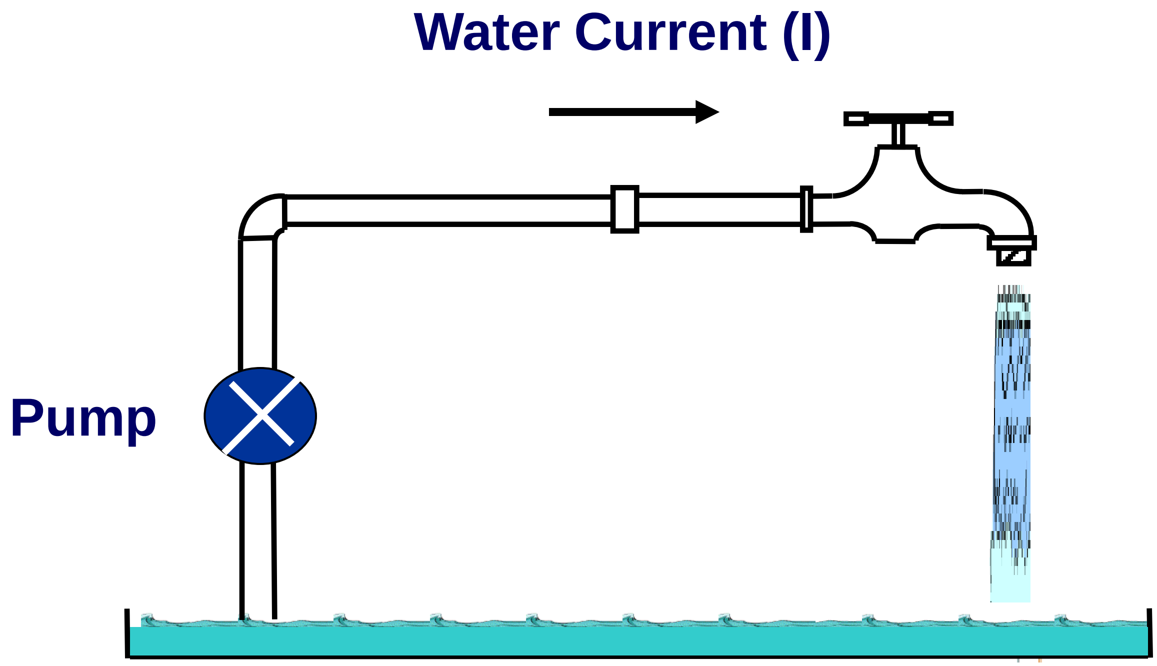
Basic Principle of Circuit

Mechanical Example | **Inclined Surface**



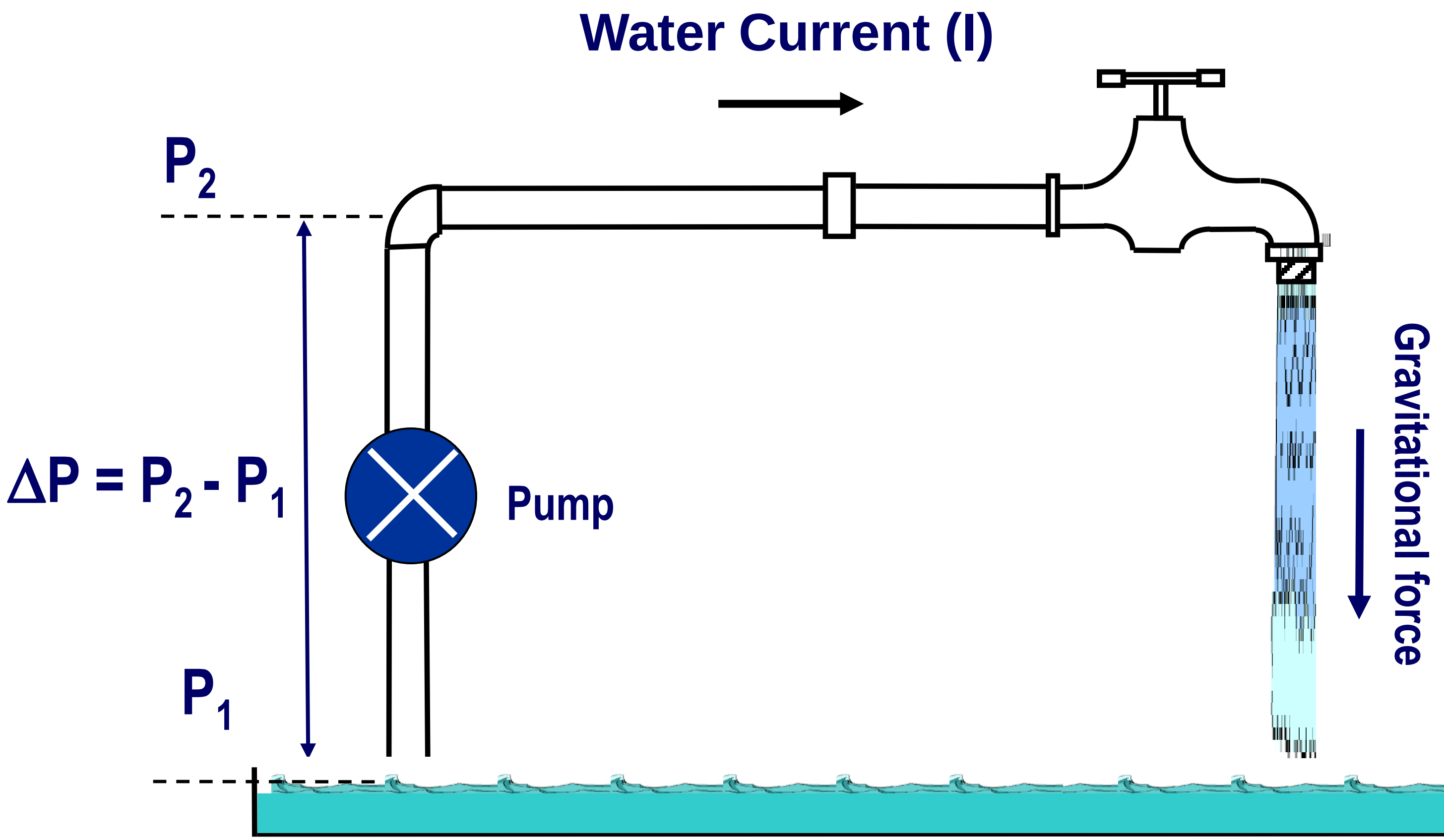
Basic Principles of Electricity

Water Circuit

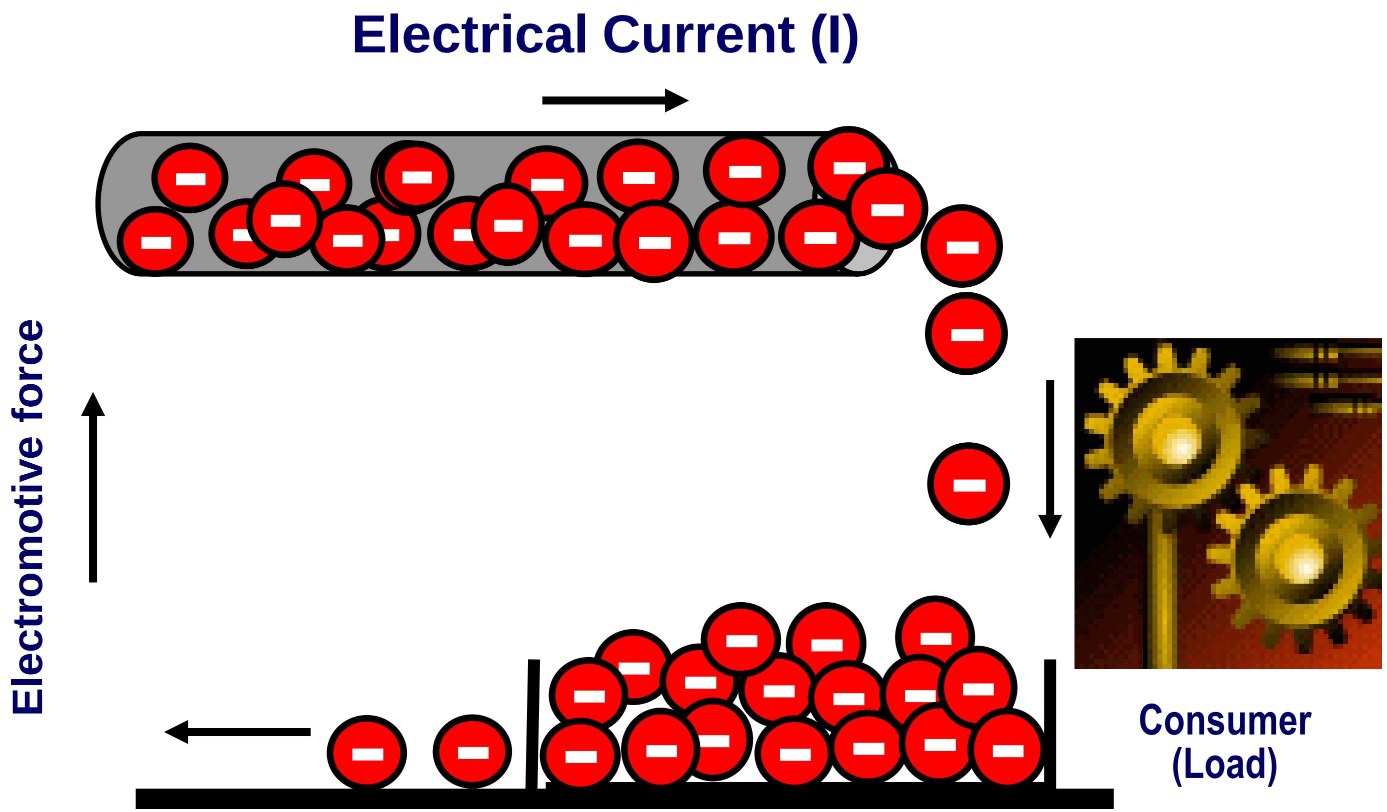


Water Current = Volume (m^3) / sec

Water Circuit

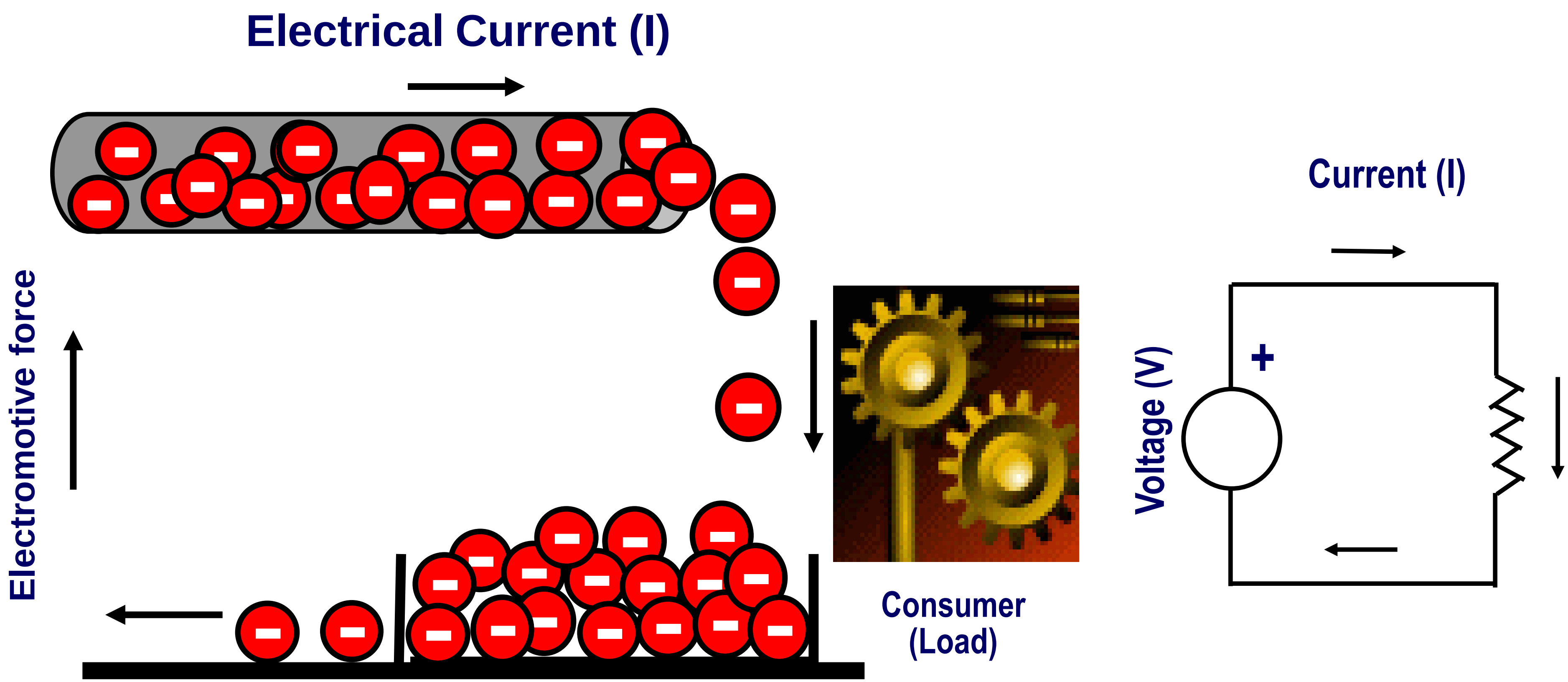


Electrical Circuit



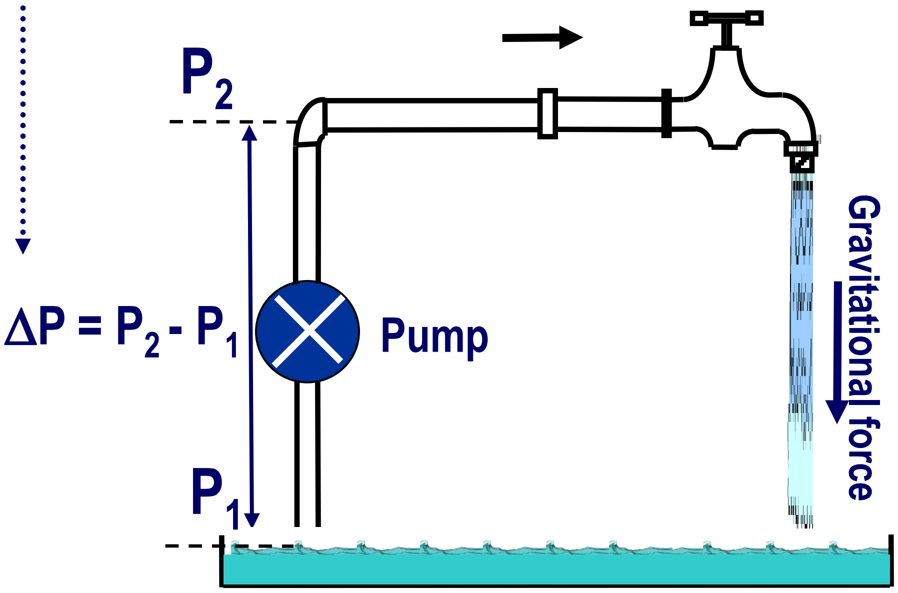
Electrical Current = No. of electrons / sec
= 1 Coulomb / sec
6.3 x 10^{18} electrons / sec = 1 Amper

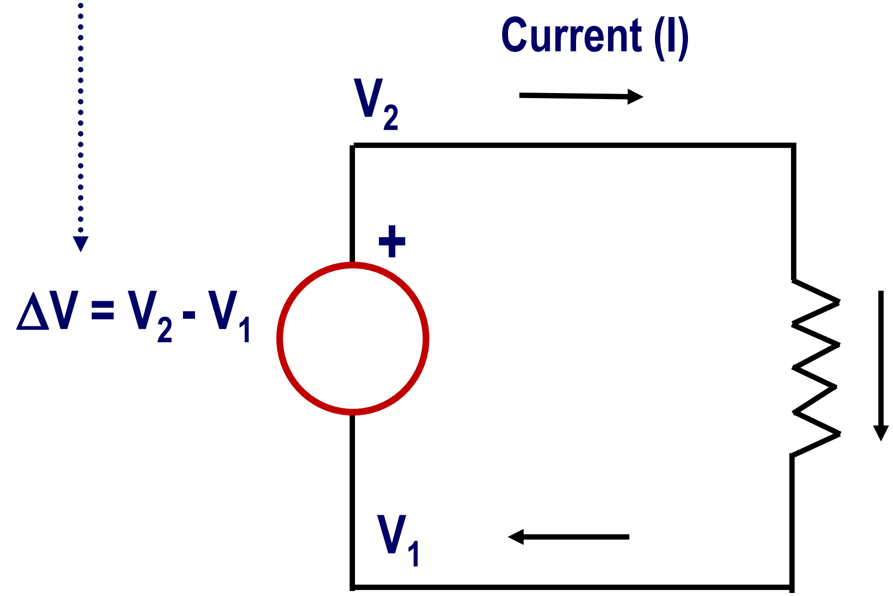
Electrical Circuit



Voltage Difference

Pressure Difference	Voltage Difference





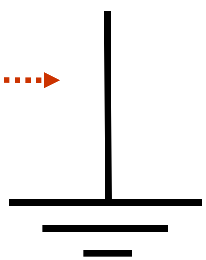
Ground Node (Earth Point)

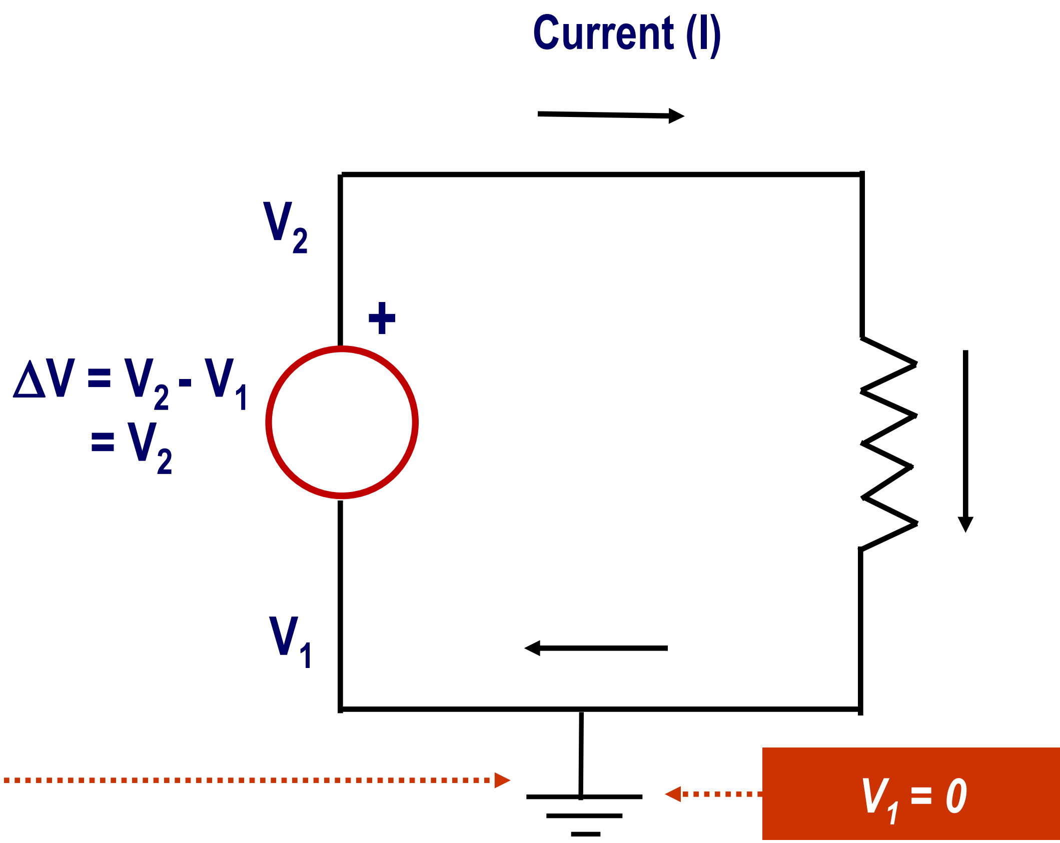
Definition

Ground Node is the point (junction) at which the voltage is assumed to be zero

All other voltages takes their references with respect to this ground node

Representation	*Ground Node*





Ground Node (Earth Point)

Definition

Ground Node is the point (junction) at which the voltage is assumed to be zero

All other voltages takes their references with respect to this ground node

Ground Node (Black Terminal)

Measured Node (Red Terminal)

Electrical Current

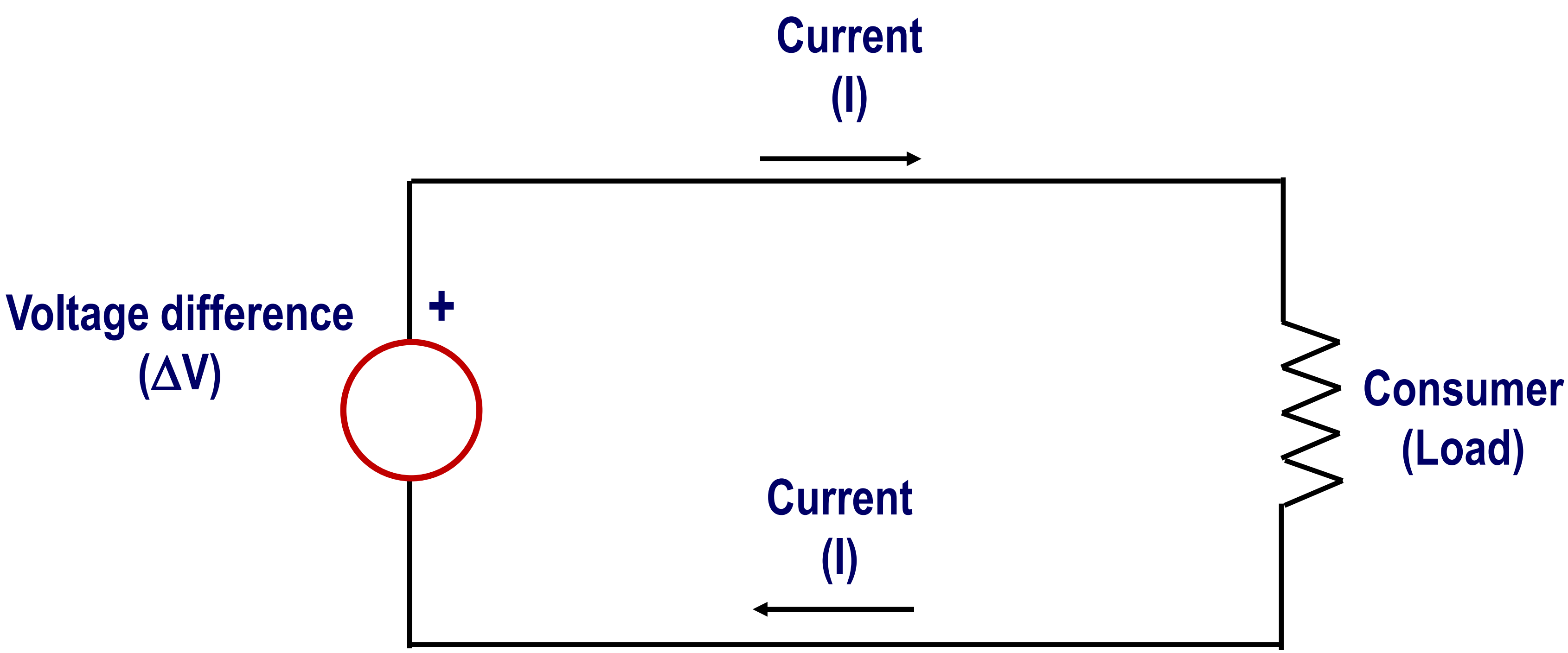
Current = no. of electrons transferred / time duration

$I = \Delta Q / \Delta t$

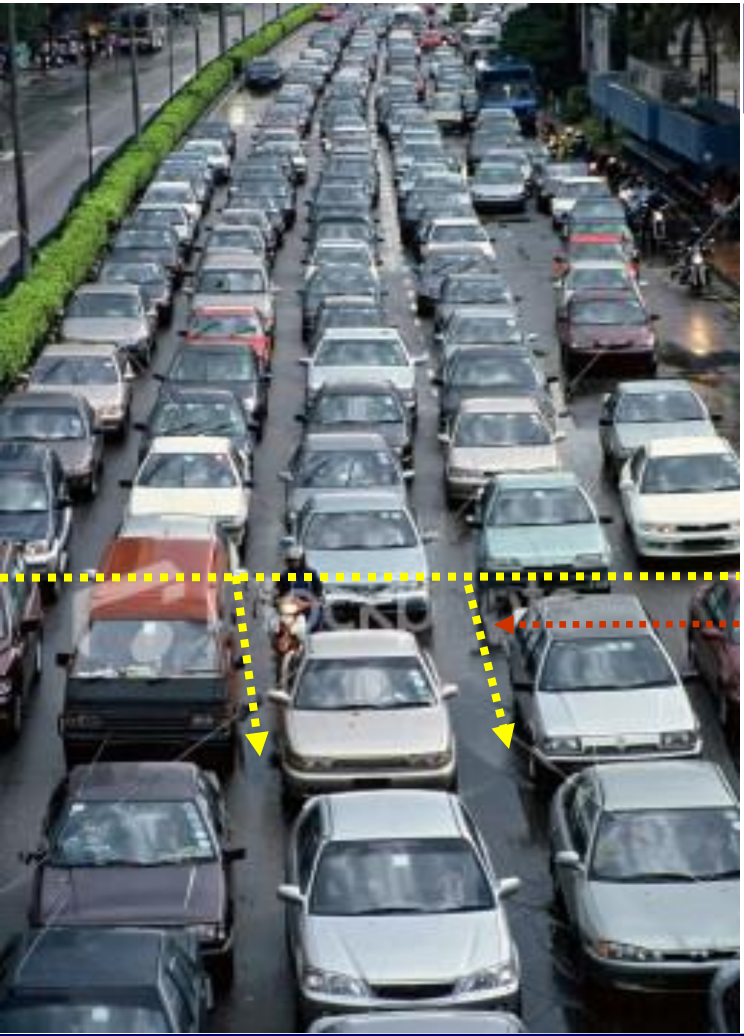
1 Amp = 1 Coulomb / 1 Seconds

Charge = Current x Time duration

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



Traffic Current

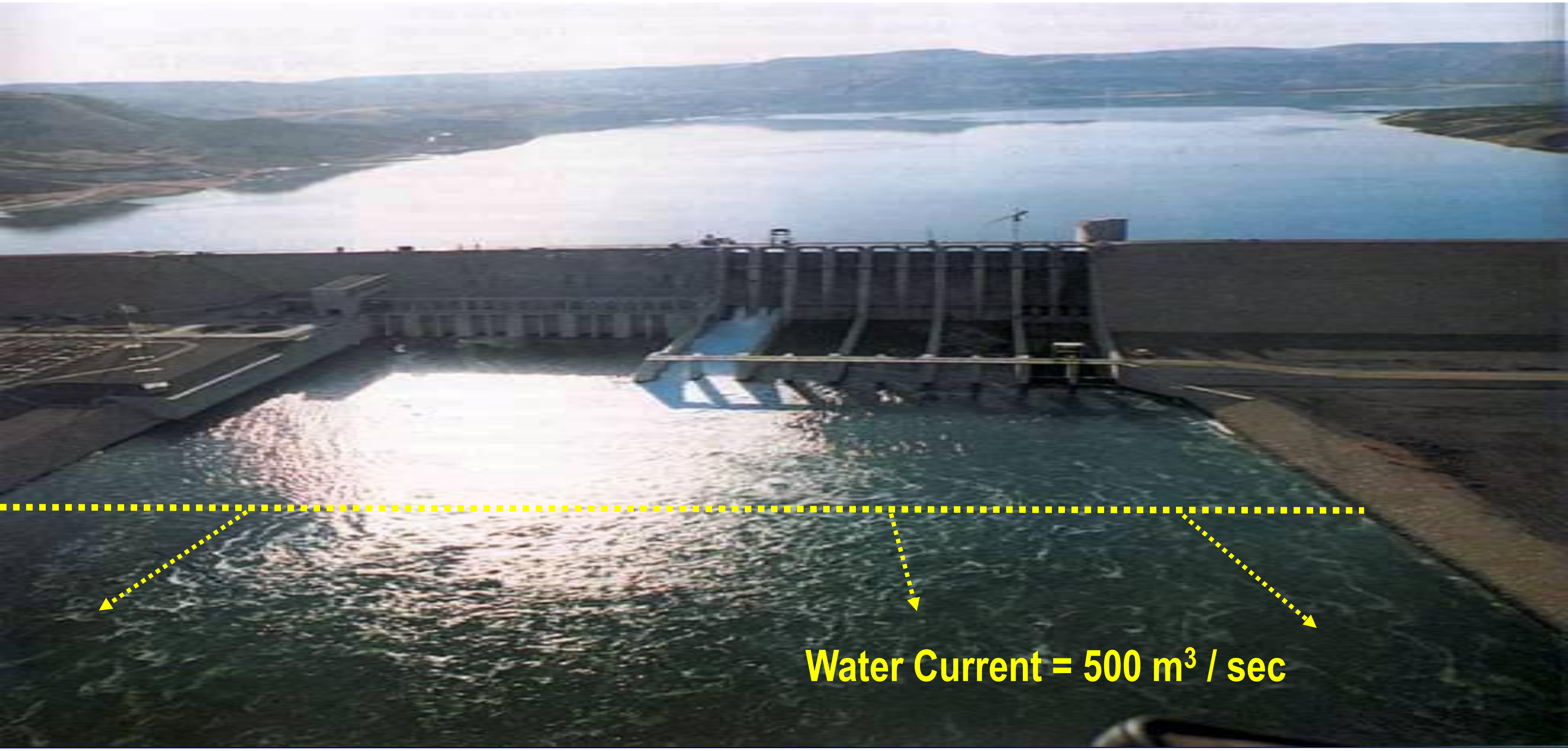


Cars Flowing in a Highway

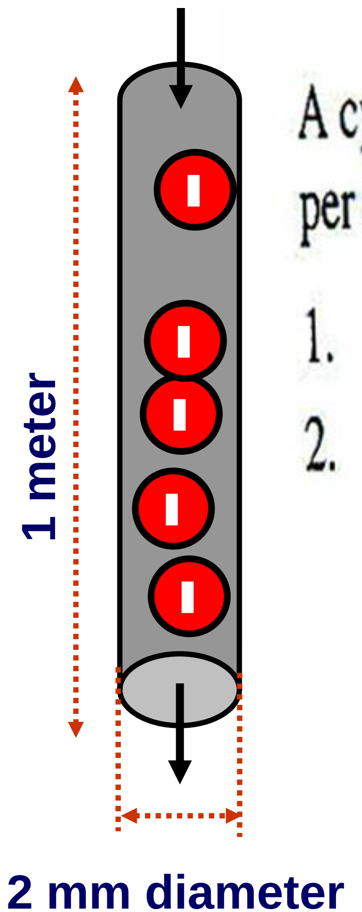
Traffic Current = Cars / minute

Water Current

Birecik Dam (672 MW)



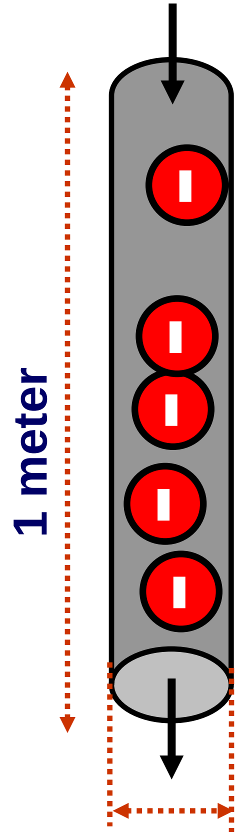
Example: Electrical Current



A cylindrical conductor is 1 m long and 2 mm in diameter and contains 10^{29} free carriers per cubic meter.

1. Find the total charge of the carriers in this wire.
2. If the wire is used in a circuit, find the current flowing in the wire if the average velocity of the carriers is 19.9×10^{-6} m/s.

Example: Electrical Current



Solution:

1. In order to compute the total charge contributed by the electrons, we first need to compute the volume of the conductor.

$$\text{Volume} = \text{Length} \times \text{Cross-sectional area}$$

$$= \pi r^2 L = \pi \left(\frac{2 \times 10^{-3}}{2}\right)^2 (1)$$

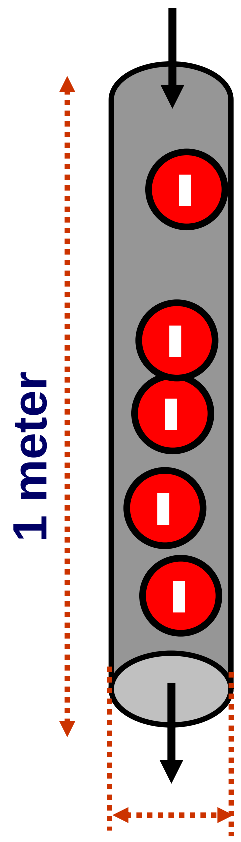
Next we compute the charge by determining the total number of charge carriers in the conductor as follows:

$$\text{Charge} = \text{Volume} \times \frac{\text{Charge}}{\text{Unit volume}}$$

$$Q = \pi \left(\frac{2 \times 10^{-3}}{2}\right)^2 (1)(-1.602 \times 10^{-19}\ \text{C})\left(10^{29}\ \frac{\text{carriers}}{\text{m}^3}\right)$$

$$= -50.33 \times 10^3\ \text{C}$$

Electrical Current



2. If the carriers move with an average velocity of 19.9×10^{-6} m/s, the magnitude of the total current flow in the wire can be computed by considering that current is the flow of charge per unit time:

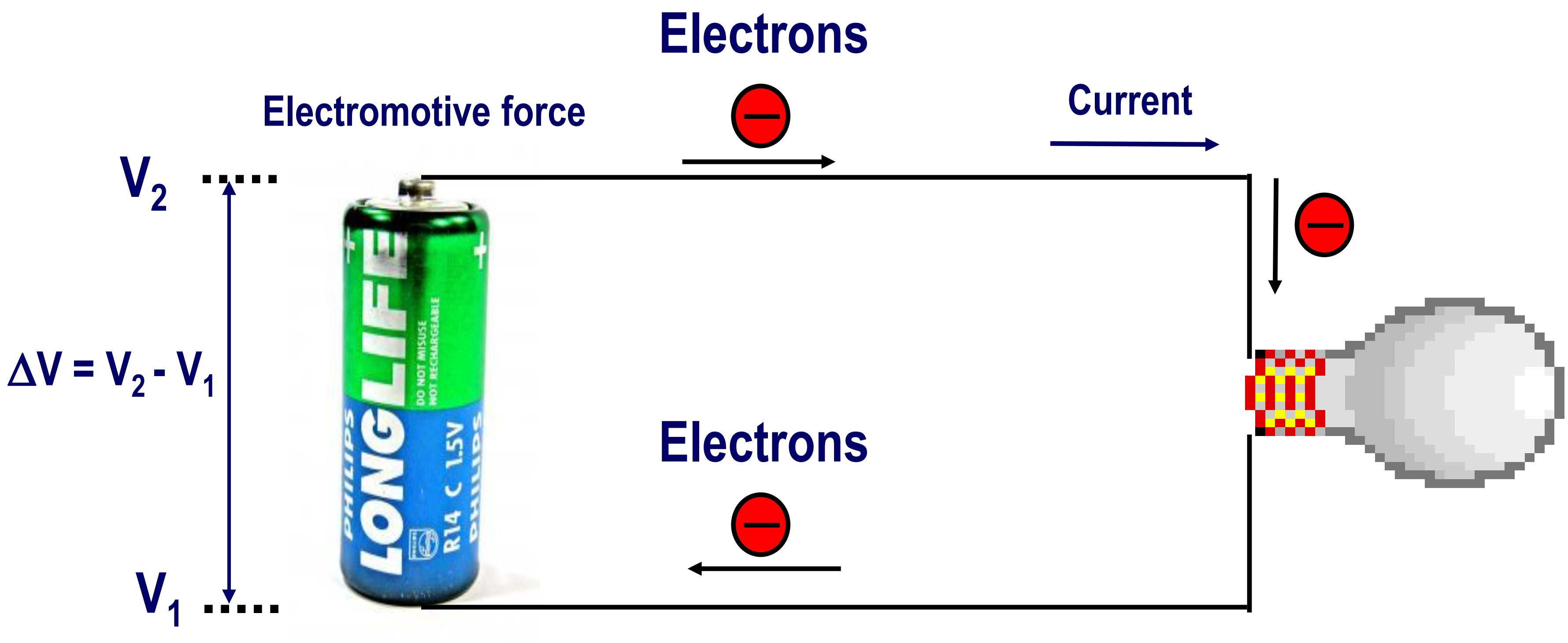
$$\text{Current} = \text{Charge density per unit length (C/m)} \times \text{Carrier velocity (m/s)}$$

$$= \frac{50.33 \times 10^{3}}{1} \times 19.9 \times 10^{-6}$$

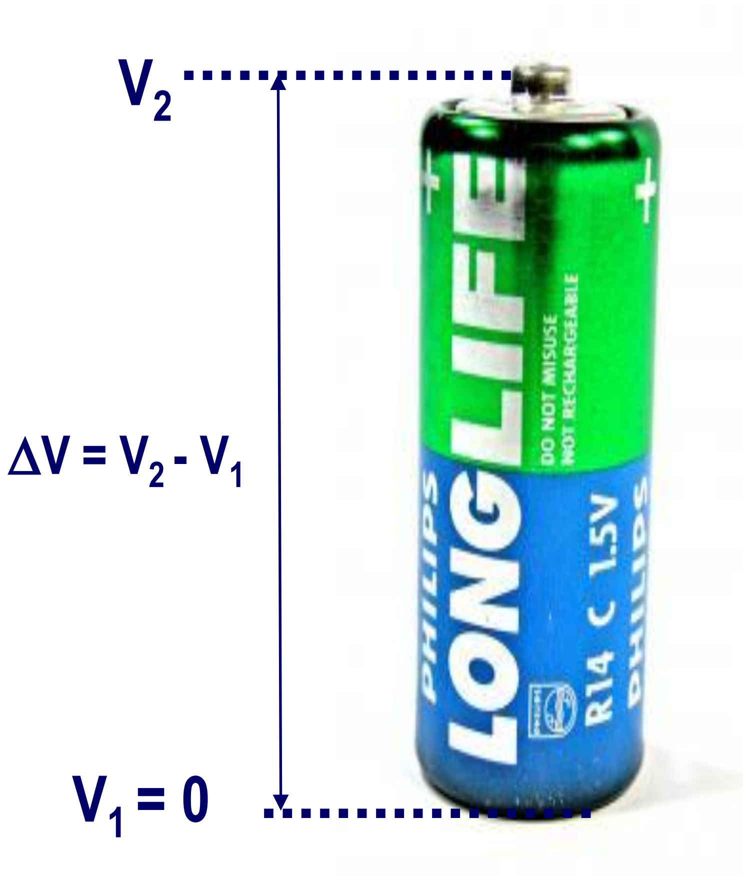
$$= 1\ \text{A}$$

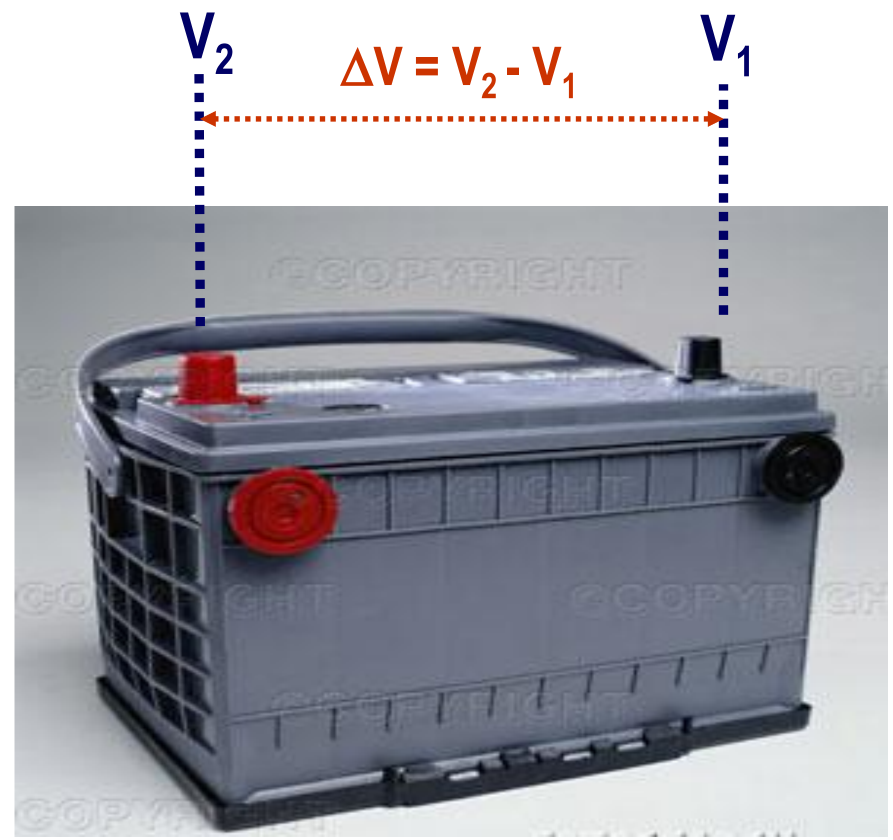
Basic Principles of Electricity

Electrical Current - Basic Principle

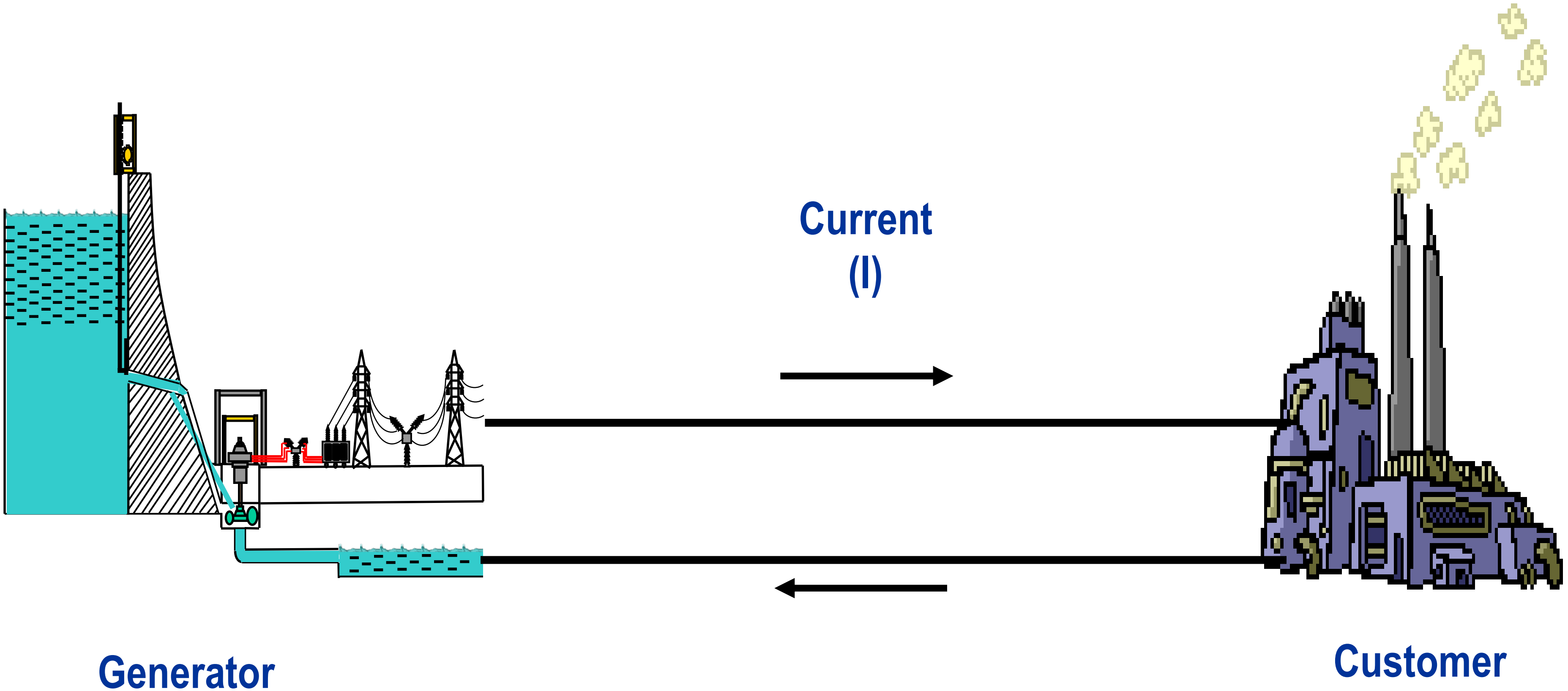


Electrical Current
DC (Direct Current) Sources





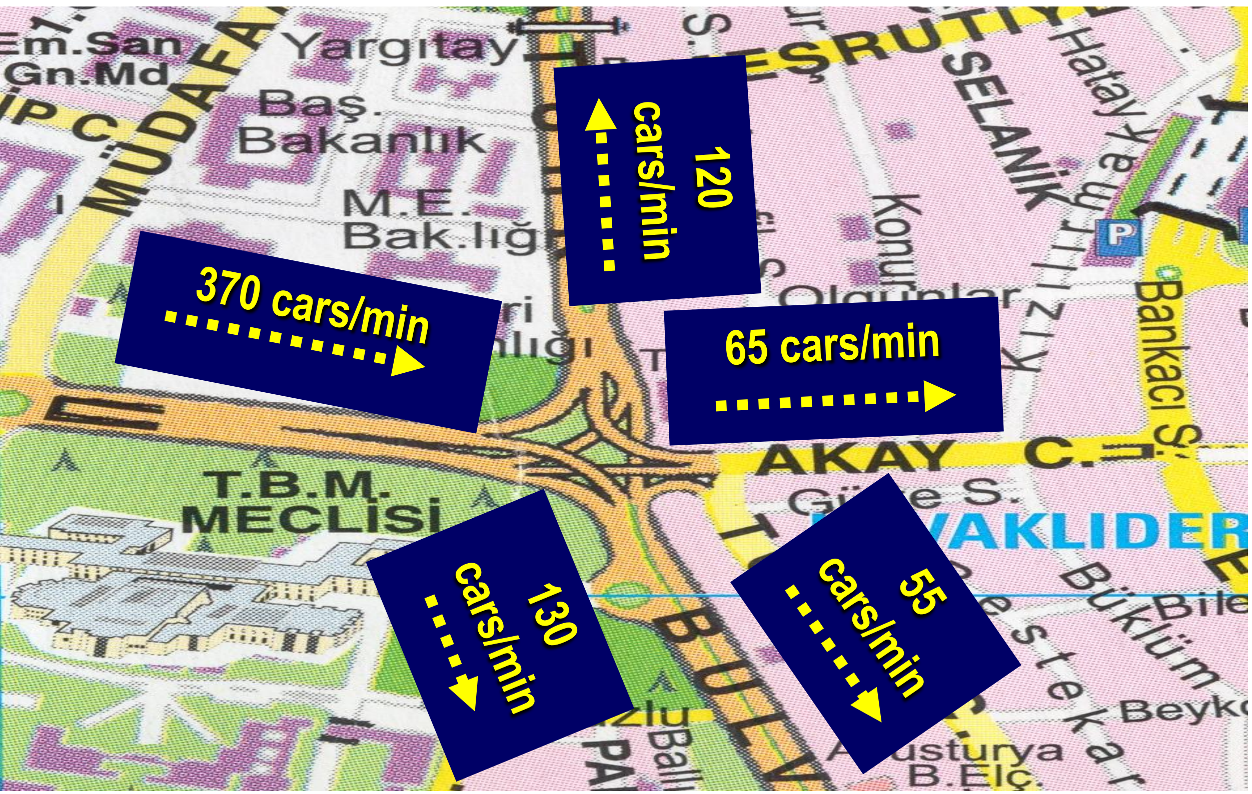
Simple AC Circuit



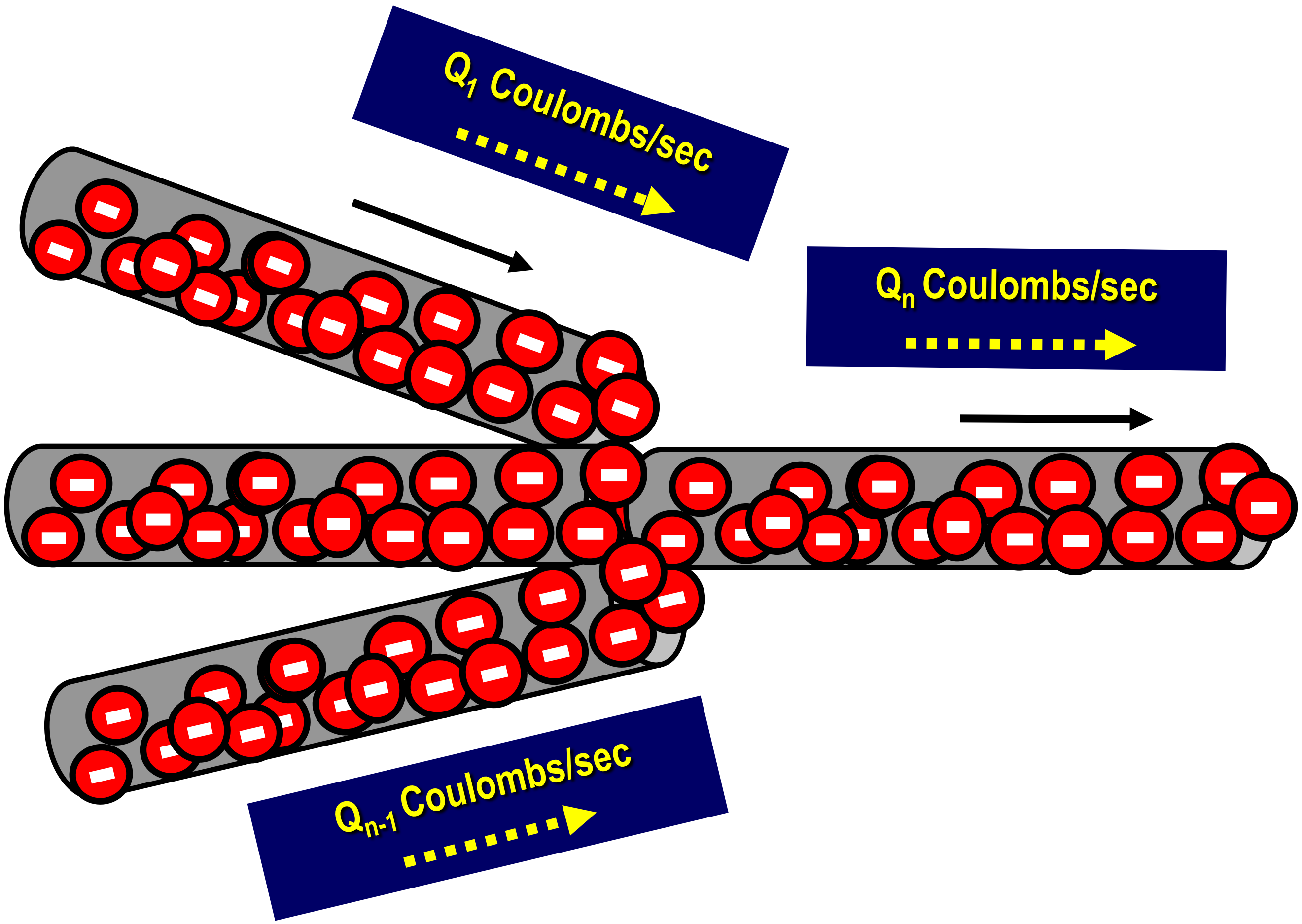
Basic Principles of Electricity

Kirchoff's Current Law (KCL)

Basic Principle	Balance
Σ Cars entering = Σ Cars leaving	**Cars entering:** 370 **Cars leaving:** 120 65 55 130 + ---------- 370



Kirchoff's Current Law (KCL)



Charges entering

Q_1

Q_2

Q_{n-1}

\+ ------------

Q_{in}

Charges leaving

$Q_{out} = Q_n$

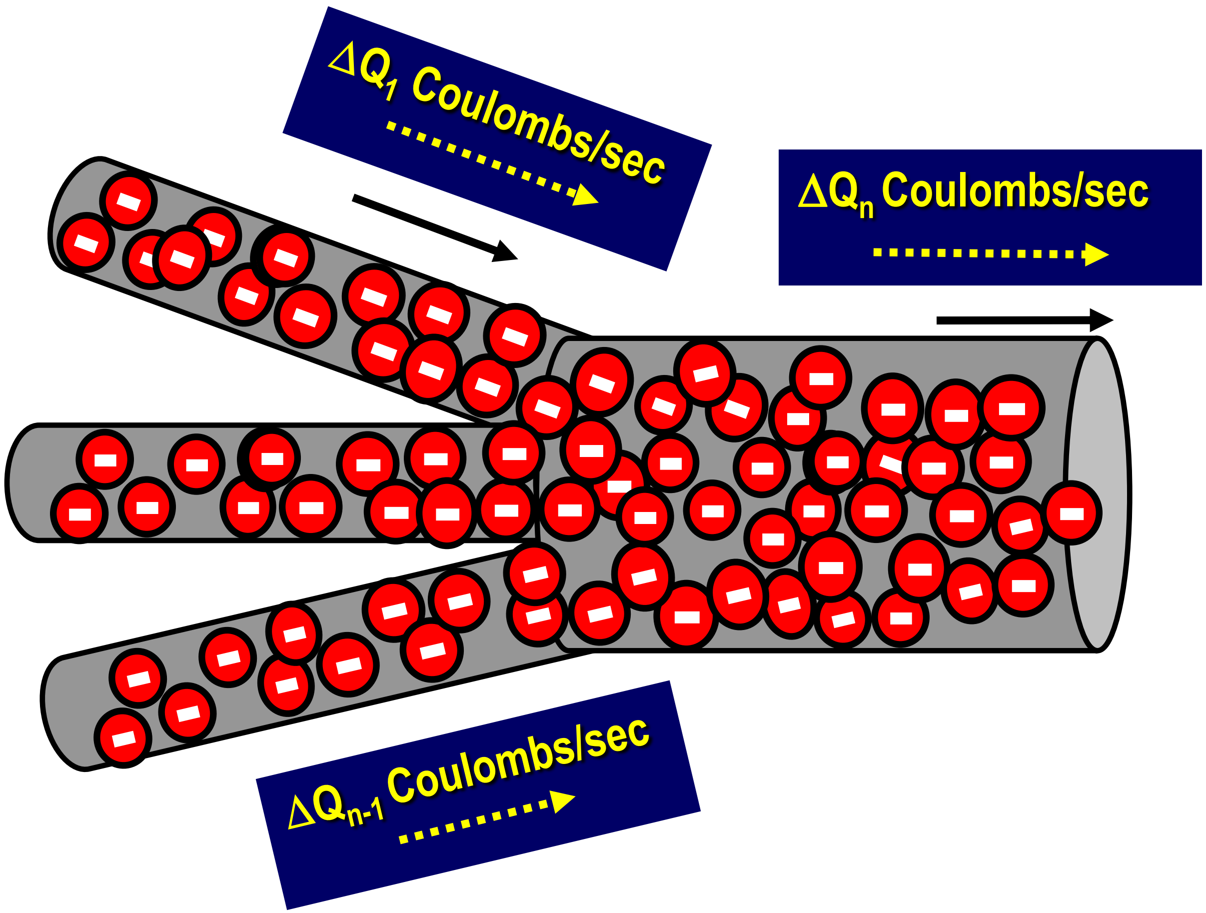
Balance

$Q_{in} = Q_{out}$ or

$Q_{in} - Q_{out} = 0$ or

$\Sigma\ Q = 0$

Kirchoff's Current Law (KCL)



or

$$\Sigma\ \Delta Q = 0$$

or

$$\Sigma \Delta Q\ /\ \Delta t = 0$$

or

$$\sum_{i=1}^{i=n} I_i = 0$$

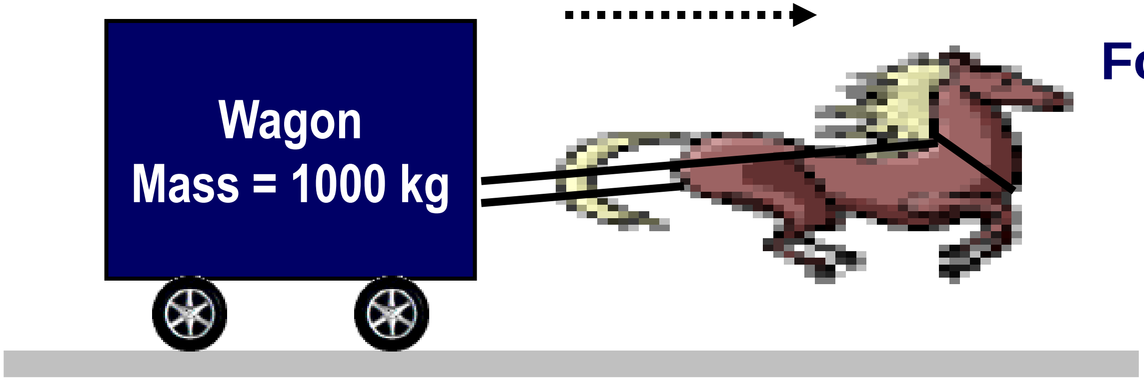
Kirchoff's First Law
or
<u>Kirchoffs Current Law</u>

Mechanical Force

Definition	$F = m \times a$
Force needed to accelarate 1 kg of mass to 1 meter / sec^2 is defined as 1 Newton	
1 Newton = 1 kg x 1 meter / sec^2 *1000 Newton = 1000 kg x 1 meter / sec^2*	

Accelaration = 1 m/sec^2

Force = 1000 Newton

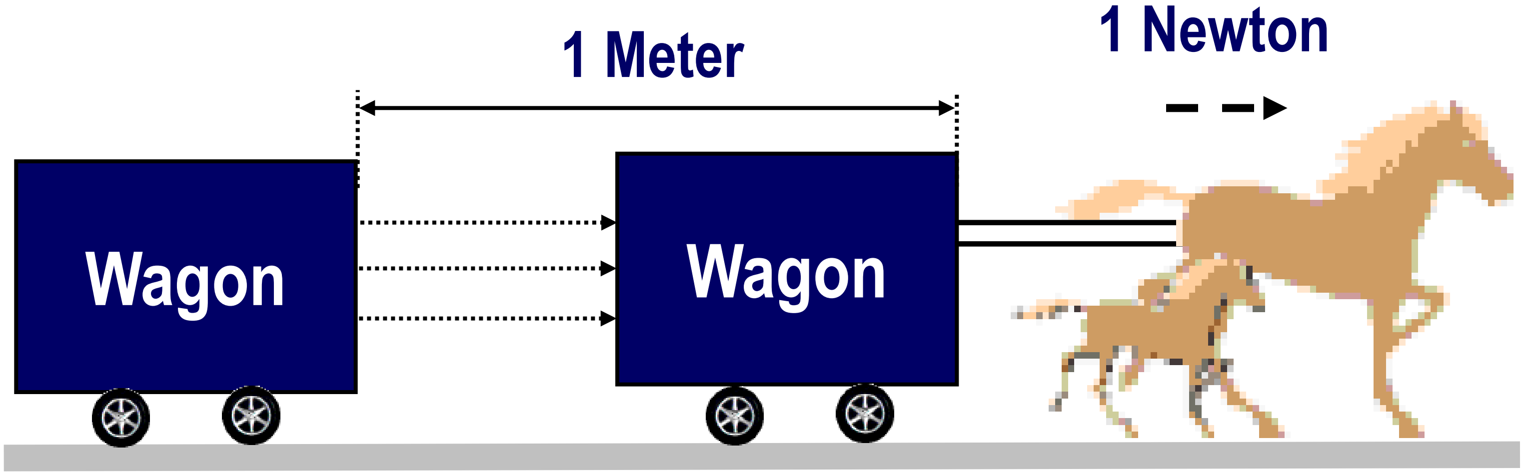


Mechanical Energy

Definition

1 Joule = 1 Newton x 1 Meter

1 Joule is the energy needed to move a mass 1 meter by using 1 Newton force



Power

Definition

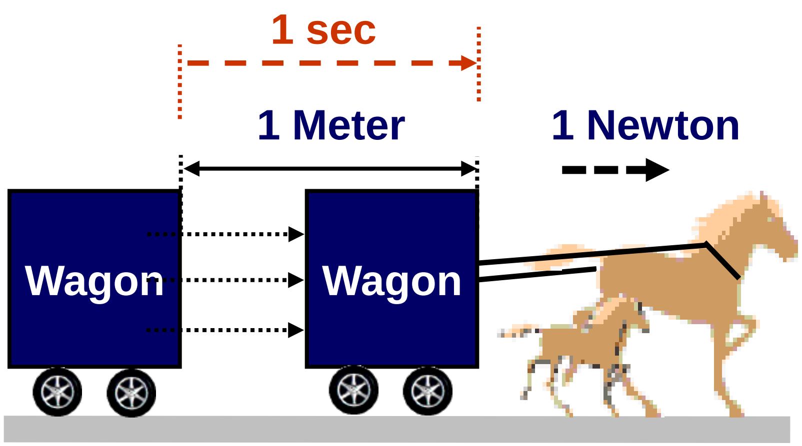
Power is the work done within a certain unit of time, i.e. one second or one hour

Power = Energy / Duration

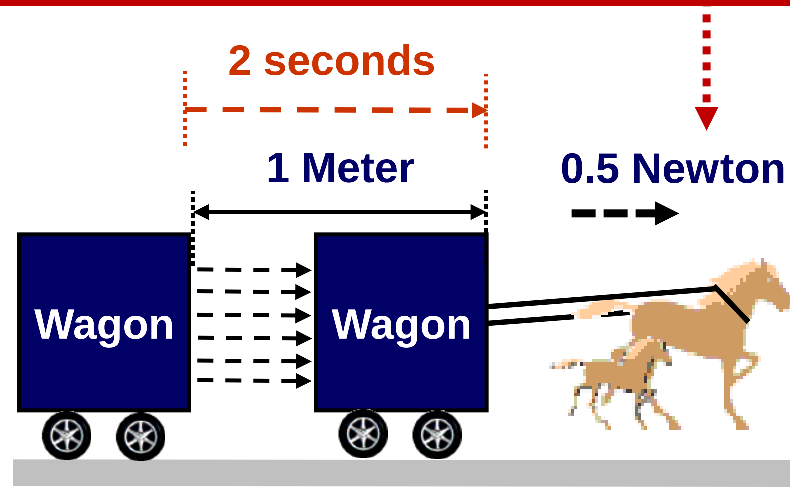
= 1 Joule / sec

Please note that force (and hence power) of the <u>weak horse</u> shown below is half of the first, but the work done (energy spent) is the same, i.e.

Energy = 2 seconds x 0.5 Newton x 1 meter



Energy = 1 Joule, Power = 1 Joule / sec.



Energy = 1 Joule, Power = 1 Joule / 2 sec.

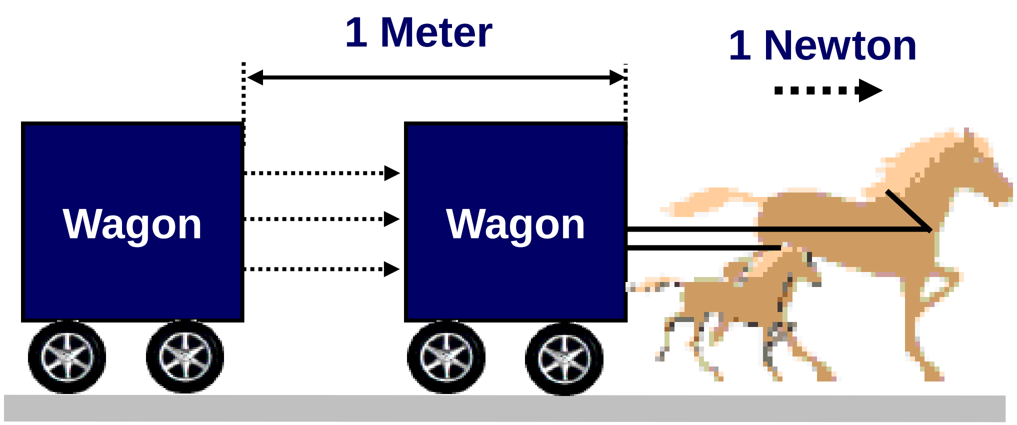
Mechanical Energy vs Electrical Energy

Equivalance

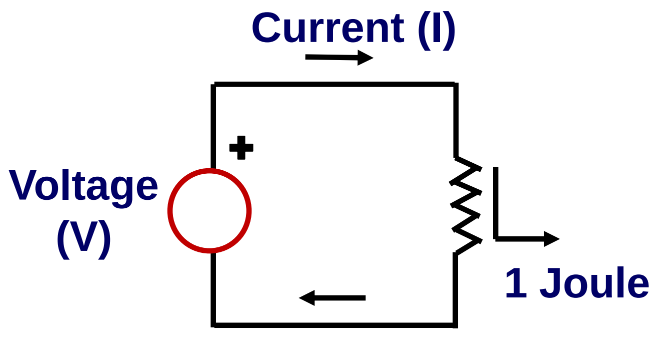
Mechanical Energy = Electrical Energy

Mechanical Work = Electrical Work

The same amount of energy may be spent out by using electricity



Mechanical Energy (Work) = 1 Joule



Electrical Energy (Work) = 1 Joule

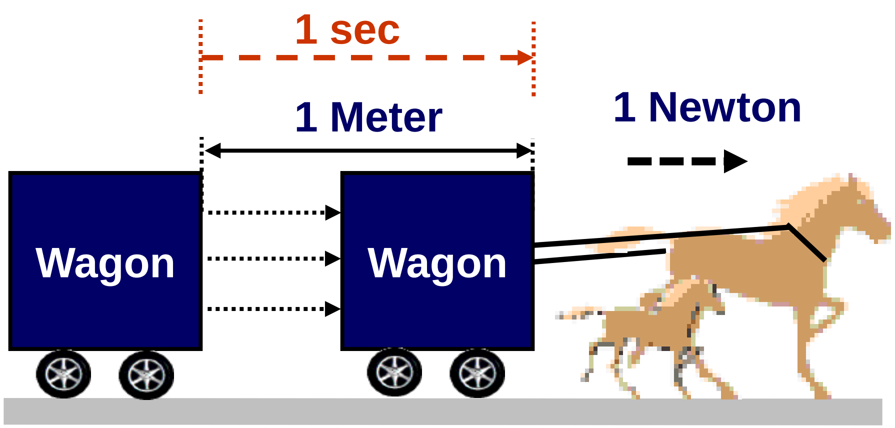
Electrical Power

Definition

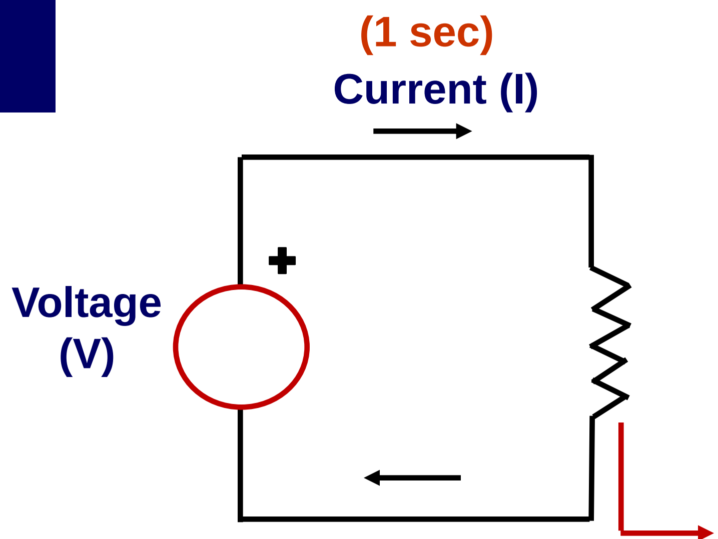
Similar to mechanical power, electrical power is the work done within a certain unit of time, i.e. one second or one hour

Elecrical Power = Electrical Energy / Duration

= 1 Joule / sec



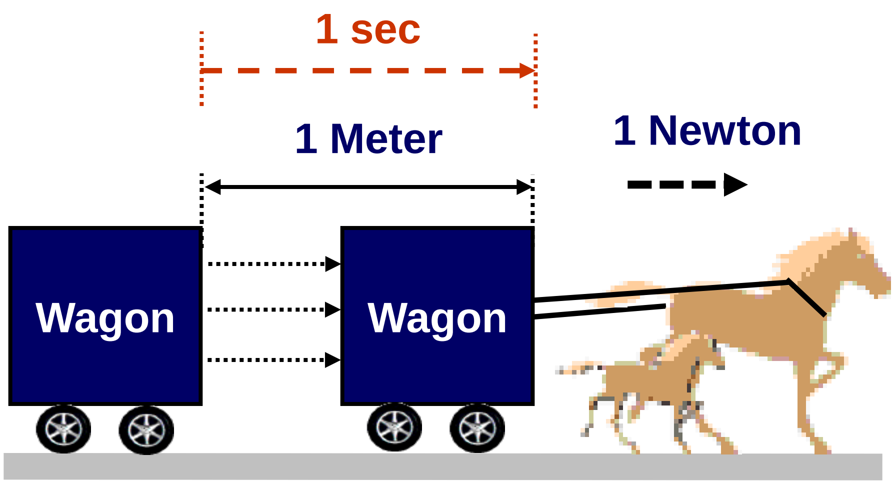
Mechanical Power = 1 Joule / sec.

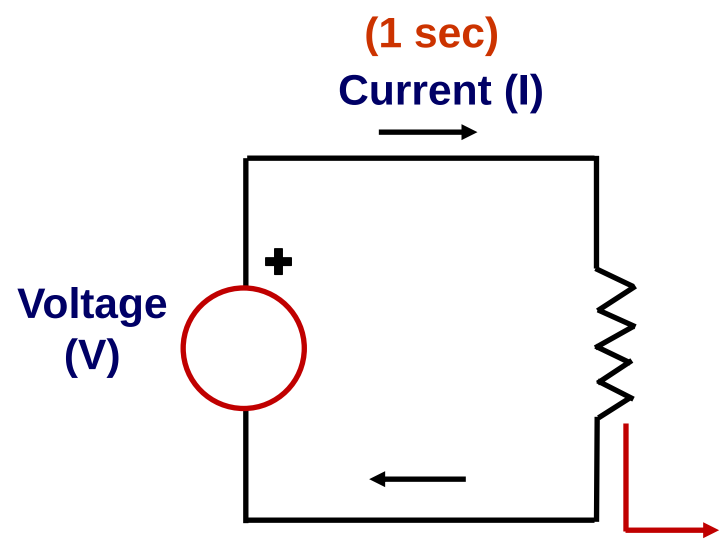


Electrical Power = 1 Joule / sec.

Equivalence of Mechanical and Electrical Powers

Equivalance	*Mechanical Power = Electrical Power*



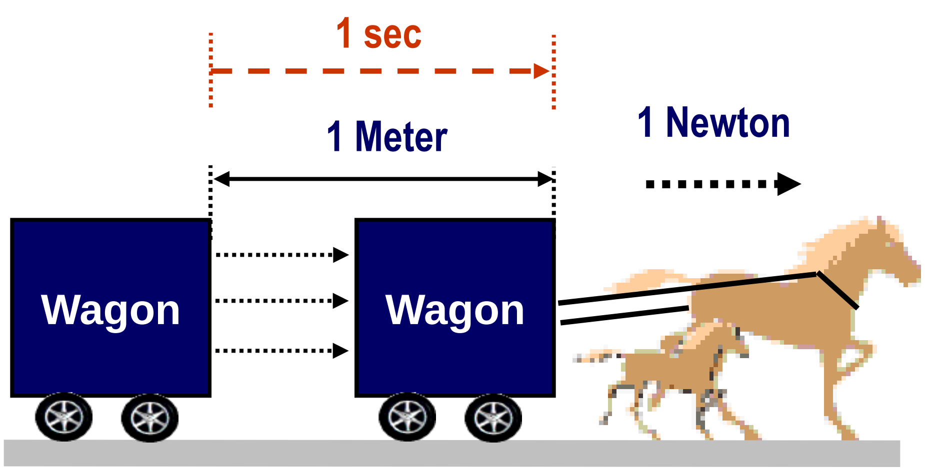


Mechanical Power = 1 Joule / sec.

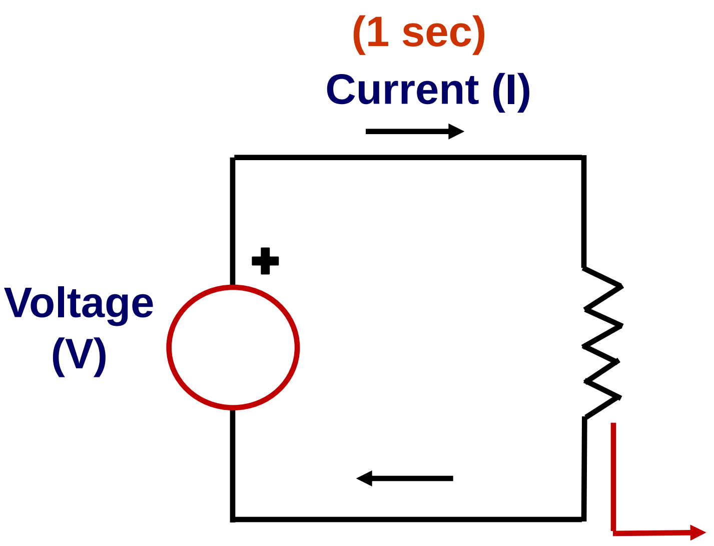
Electrical Power = 1 Joule / sec.

Electrical Power

Definition	
1 Joule / second = 1 Watt (1 Joule energy is spent within 1 second)	*1 Joule = 1 Watt x second* *1 Horse Power = 746 Watts = 0.746 kWatt*



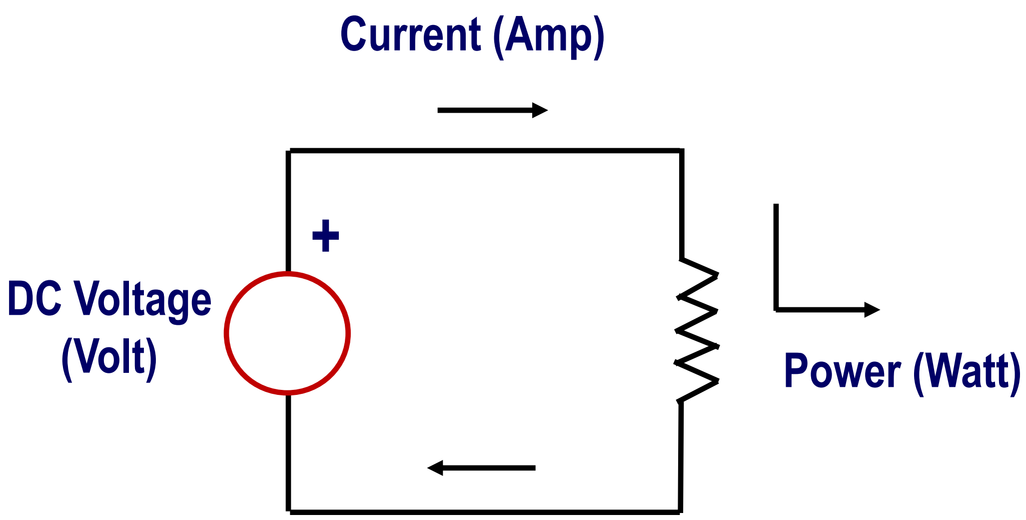
1 Joule / sec = 1 Watt



Electrical Power = 1 Joule / sec. = 1 Watt

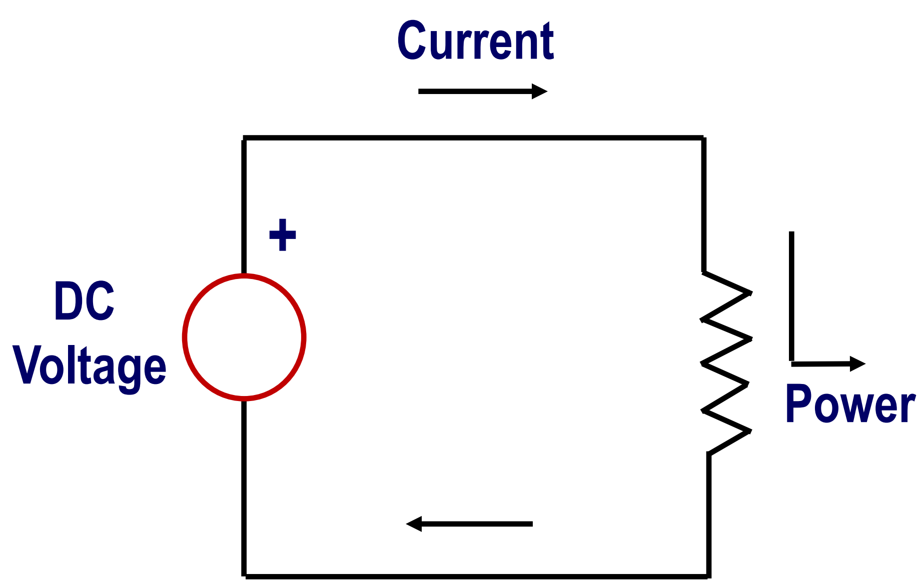
Electrical Power

Definition	*Power = Voltage x Current*
P = V x I *(Watt) = (Volt) x (Amp)*	



Voltage

Definition
Power = Voltage x Current *or* *P = V x I*
Voltage = Power / Current *or* *V = P / I*



Voltage

Definition

Power = Voltage x Current

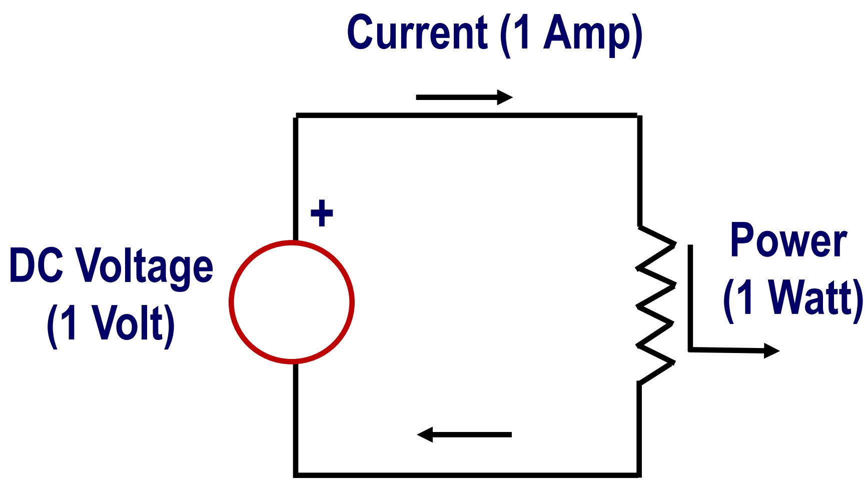
or

Voltage = Power / Current

or

V = P / I

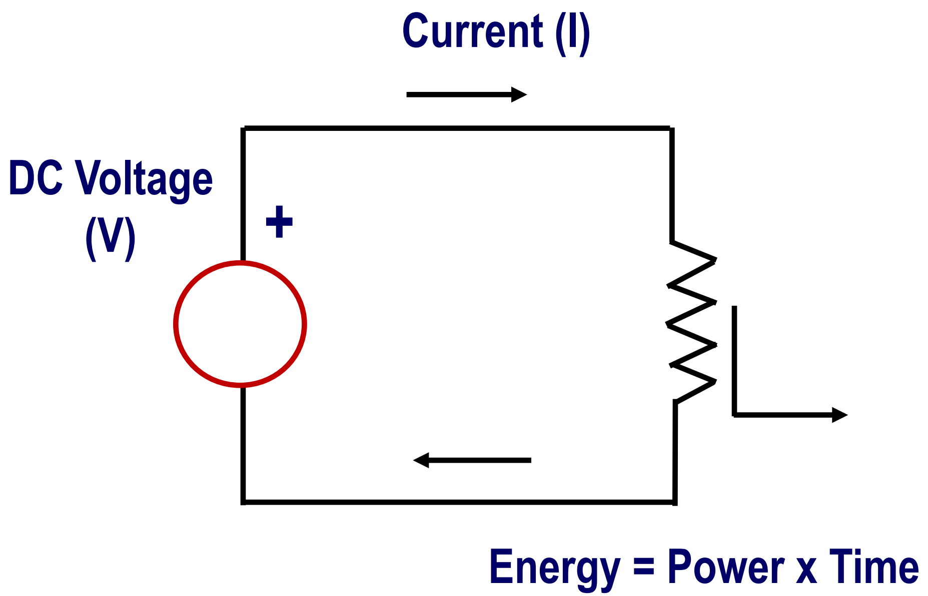
1 Volt = 1 Watt / 1 Amp



Electrical Energy

Definition

Energy = Power x Time
(Watt-sec) (Watt) (second)



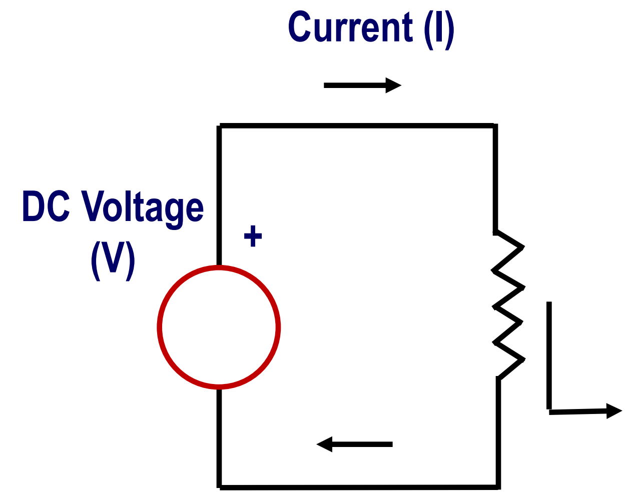
Unit of Electrical Energy

Definition

1 KiloWatt = 1000 Watts
1 Hour = 3600 seconds

Energy	=	Power	x	Time
(Watt-sec)		(Watt)		(second)
Energy	=	Power	x	Time
(KiloWatt-hour)		(KiloWatt)		(hour)
x 1000		x 1000		x 3600

1 KiloWatt - hour = 1000 x 3600 Watt x seconds
= 3 600 000 Joules



Energy = Power x Time

Electrical Energy

Example

Calculate the monthly payment for the energy consumed by the lamp shown on the RHS

Source voltage is 220 Volt
Current drawn by the lamp is 5 Amp
Price of electrical energy is 12 Cents / kWh

Power = Voltage x Current

P = V x I

P = 220 x 5 = 1100 Watts

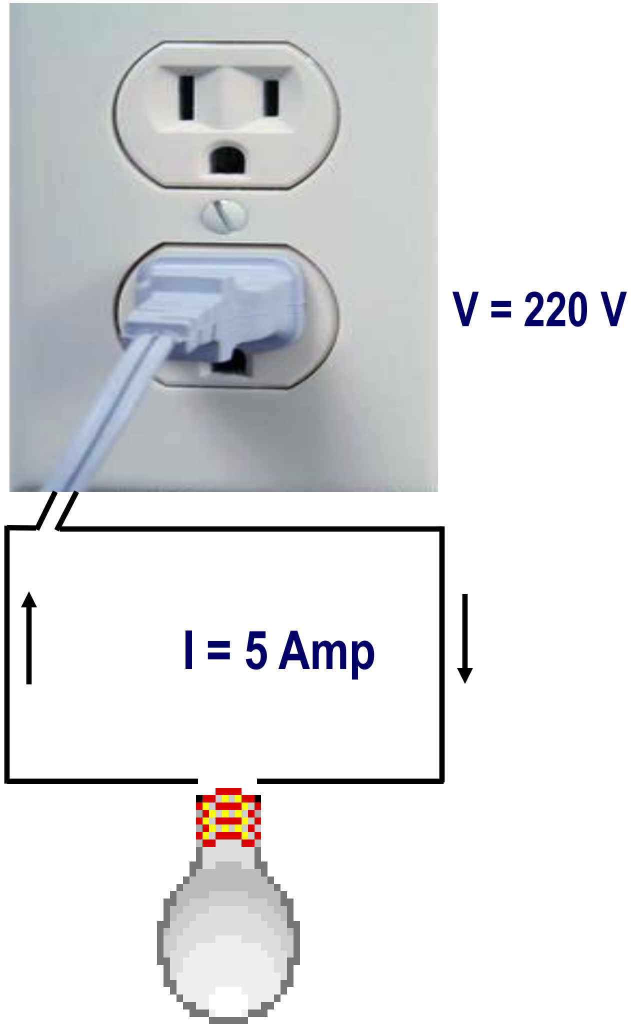
Energy = P x Δt

= 1100 Watts x (24 hours /day x 30 days/month)

= 792000 Watt hours = 790.2 kWh

Monthly payment = 790.2 x 12 Cents / month

= 90.504 USD = 122 .1 YTL / month



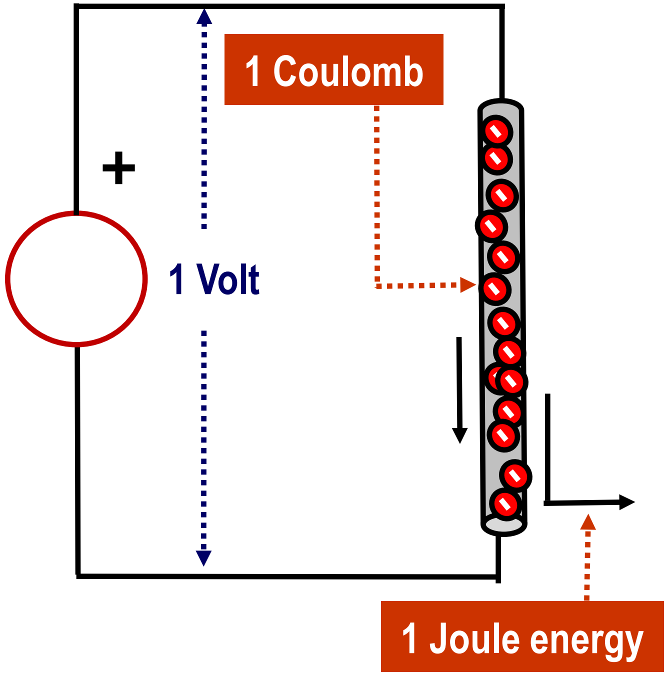
Alternative Definition of Voltage

1 Volt = 1 Watt / 1 Amp
= (1 Joule /sec) / 1 Amp
= 1 Joule / (1 Amp x sec)
= 1 Joule / 1 Coulomb (*)

(*) Remember that 1 Amp = 1 Coulomb / 1 sec

1 Volt is the voltage needed;

- to move 1 Coulomb of electrical charge,
- to spend 1 Joule of energy for this movement in a conductor



Alternative Definition of Voltage

1 Volt = 1 Joule / 1 Coulomb

Please note that time parameter does not appear in the above equation, implying that it is arbitrary

<u>Case-1</u>

<u>Let t = 1 sec</u>

Then, I = 1 Coulomb / 1 sec = 1 Amp

P = V x I = 1 Volt x 1 Amp = 1 Watt

Energy = P x t = (1 Joule / sec) x sec = 1 Joule

<u>Case-2</u>

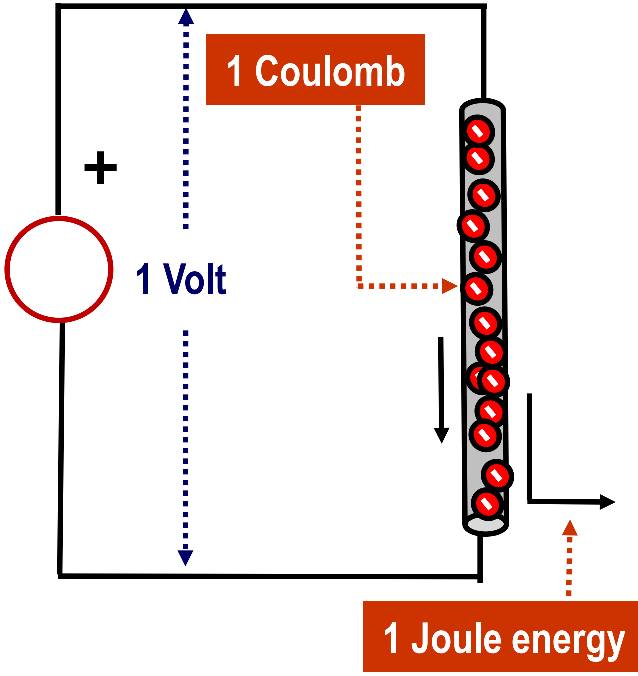
<u>Let now t = 2 sec</u>

Then, I = 1 Coulomb / 2 sec = 0.5 Amp

P = V x I = 1 Volt x 0.5 Amp = 0.5 Watt

= Energy / 2 = 0.5 Joule / sec

Energy = P x t = 0.5 x 2 = 1 Joule again

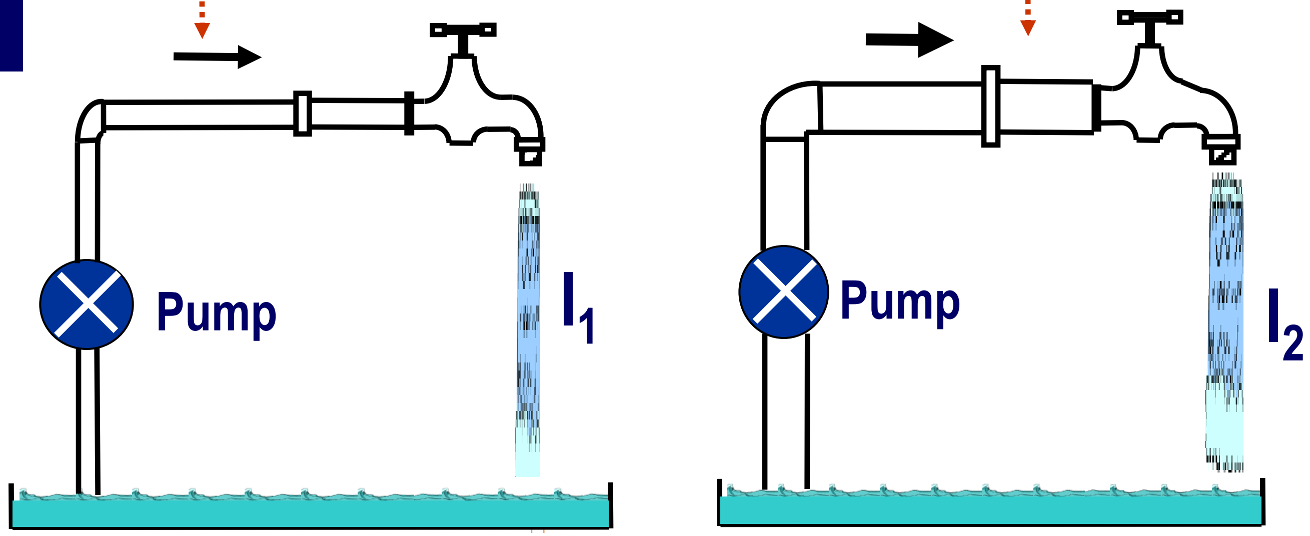


Resistance

Definition

Resistance is the reaction of a pipe against water flow

Resistance R_1 | $R_1 > R_2$ | Resistance R_2



Current I_1 | $I_2 > I_1$ | Current I_2

Resistance

Definition

Resistance is the reaction of a conductor against electrical current

Resistance R_1
Current I_1

Resistance R_2
Current I_1

$R_1 > R_2$ $I_1 < I_2$

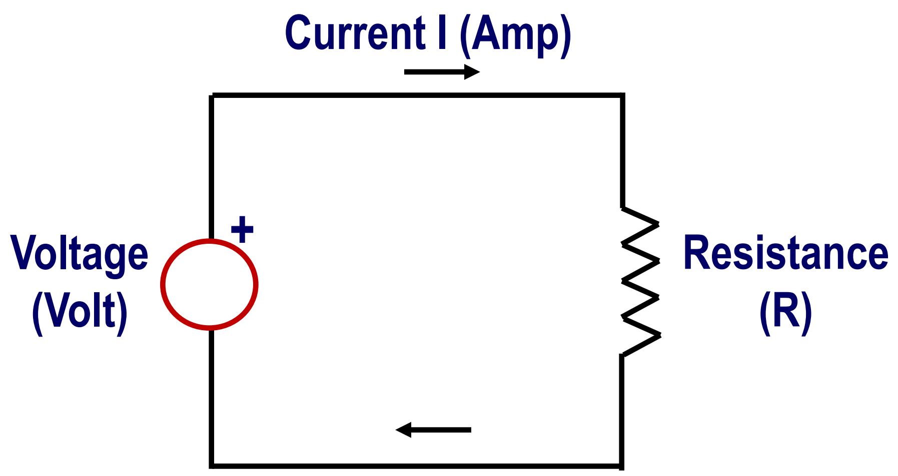
Basic Principles of Electricity

Ohm Law

Basic Principles

Current flowing in the circuit is;

- proportional to voltage,
- inversely proportional to resistance



Hence

<u>Unit of resistance is Ohm</u>

1 Ohm is the resistance that allows 1 Amper to pass at 1 Volts voltage;

1 Ohm = 1 Volt / 1 Amper

$$I = V \;/\; R$$

(Amp) (Volt) (Ohm)

or

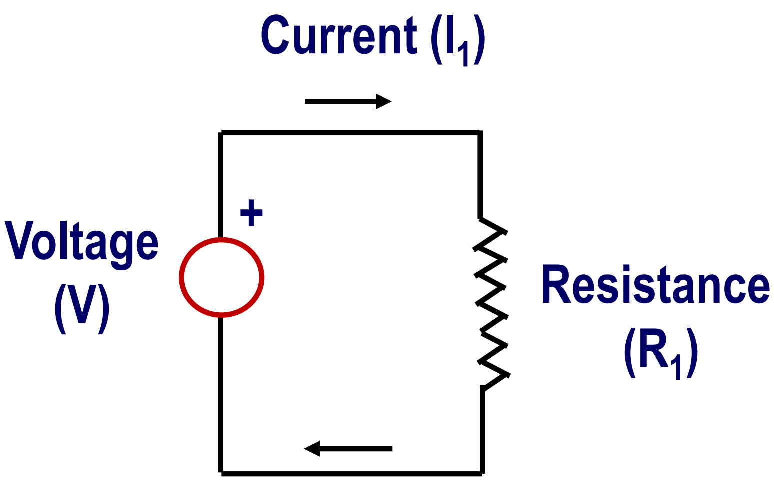
$$V = R \times I$$

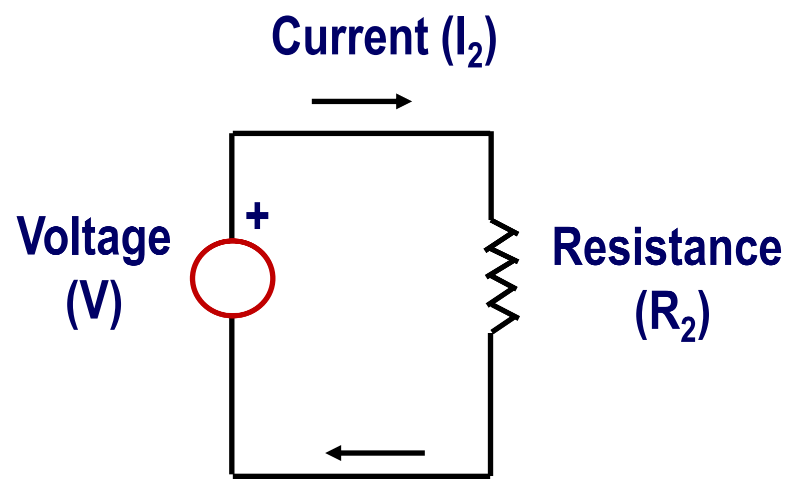
(Volt) (Ohm) (Amp)

Ohm Law

Two circuits with different Resistances, identical voltage sources

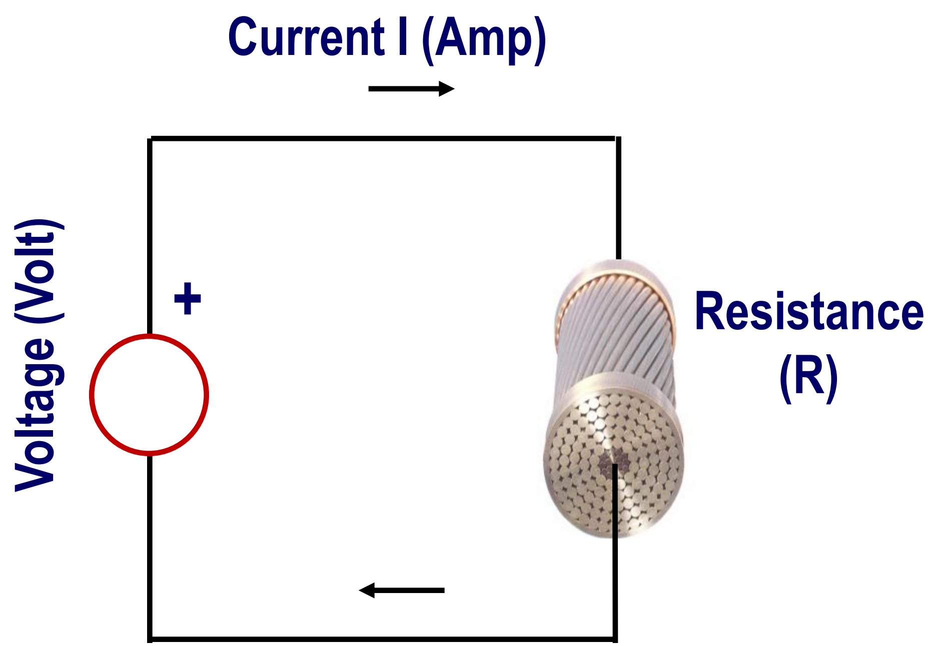
Resistance R_1	$R_1 > R_2$	Resistance R_2





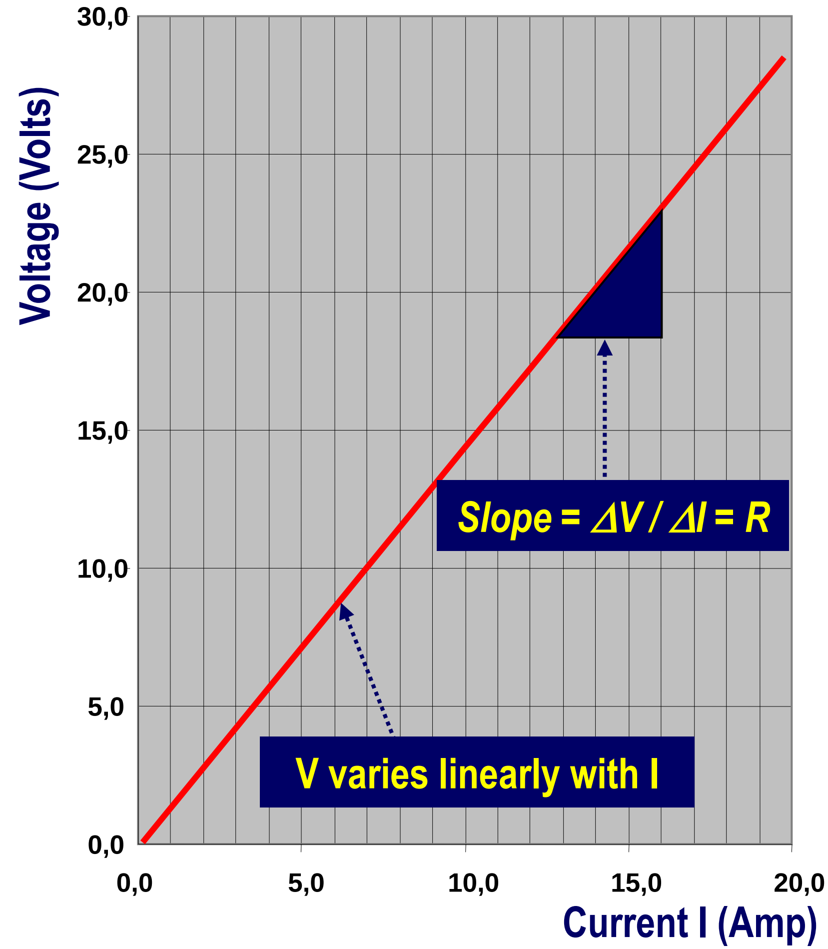
$V / R_1 = I_1$	$I_1 < I_2$	$V / R_2 = I_2$

Ohm Law
V-I Characteristics



$$V = R \times I$$

(Volt) (Ohm) (Amp)



Ohm Law - Example

Question

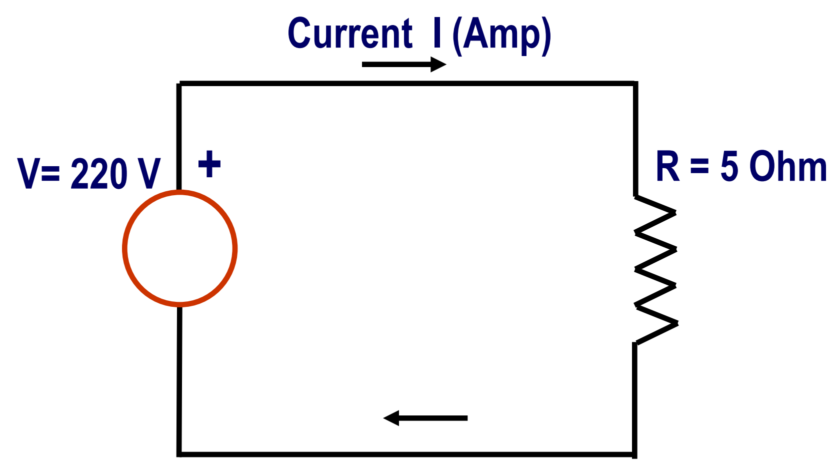
Calculate the current flowing in the circuit shown on the RHS

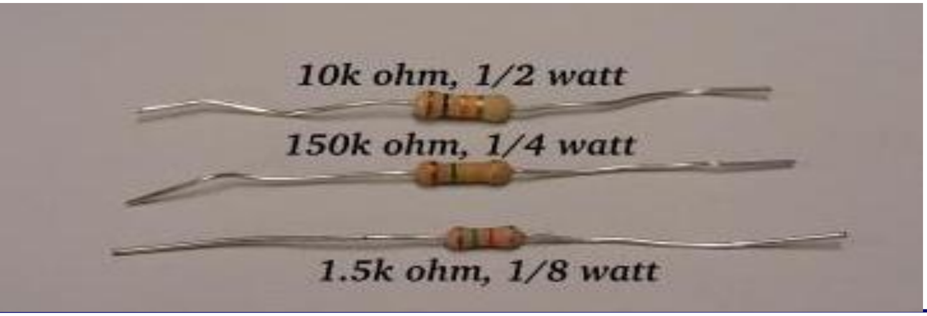
$V = R \times I$

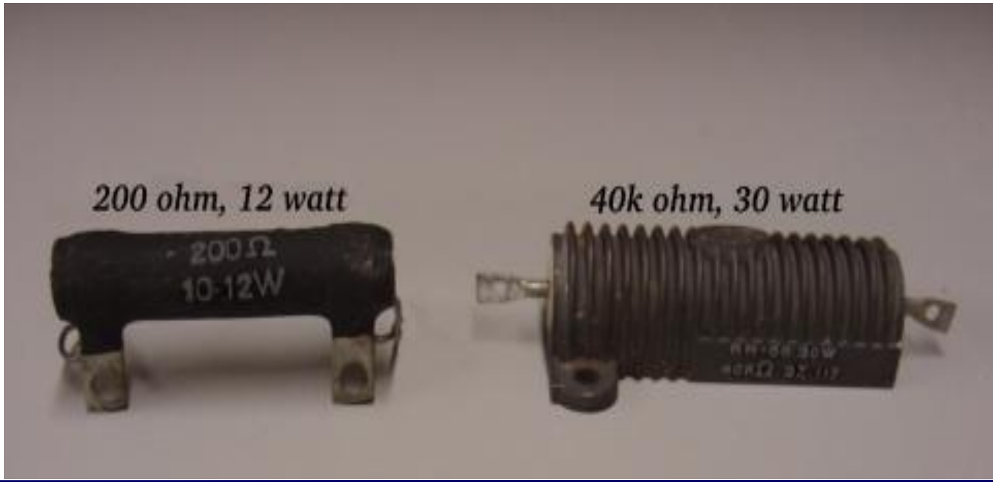
$(Volt) = (Ohm) \times (Amp)$

$I = V / R$

$= 220 / 5 = 44$ Amps







Ohm Law
Nonlinear V-I Characteristics

$$V = R \times I$$

(Volt) (Ohm) (Amp)

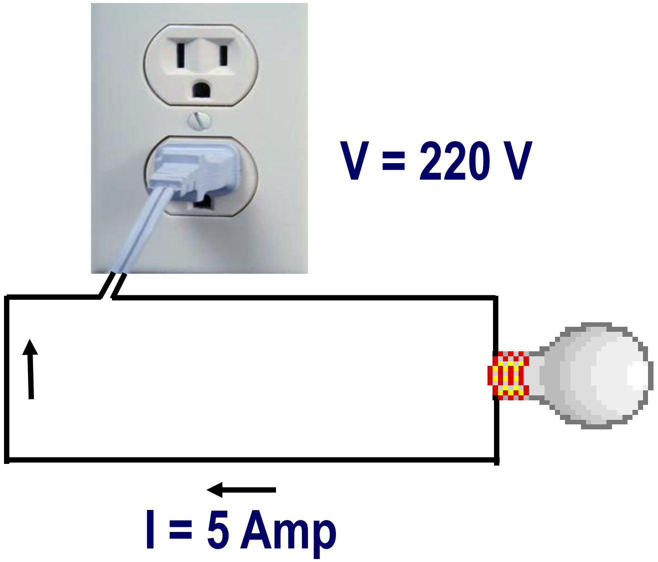
$R = R_0 (1 + \alpha\ \Delta t)$

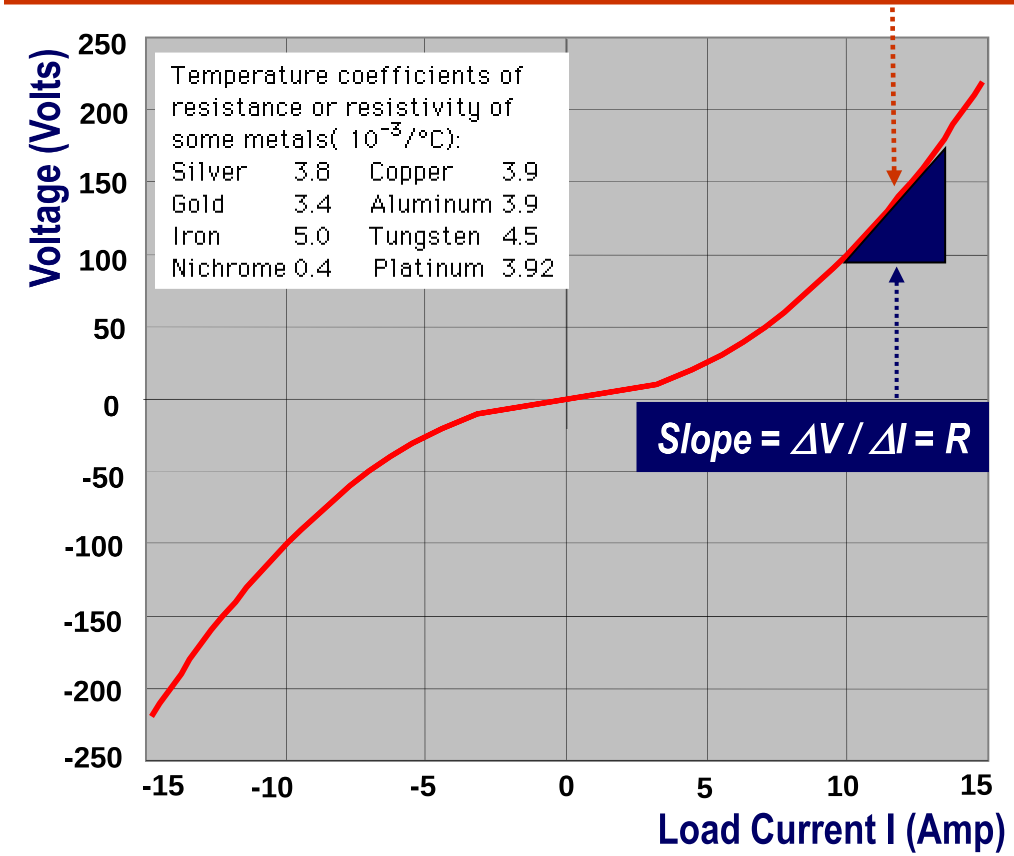
$\Delta t = T - 23\ ^0C$

R_0 = Resistance at 23 ^{0}C

α = The temperature coeff. of the metal

Note that resistance increases with temperature, hence current is reduced





Resistance Formula

Resistance Formula

$$R = \rho\, \ell / A$$

where, R is the resistance of conductor,

ρ *is the resistivity coefficient,*

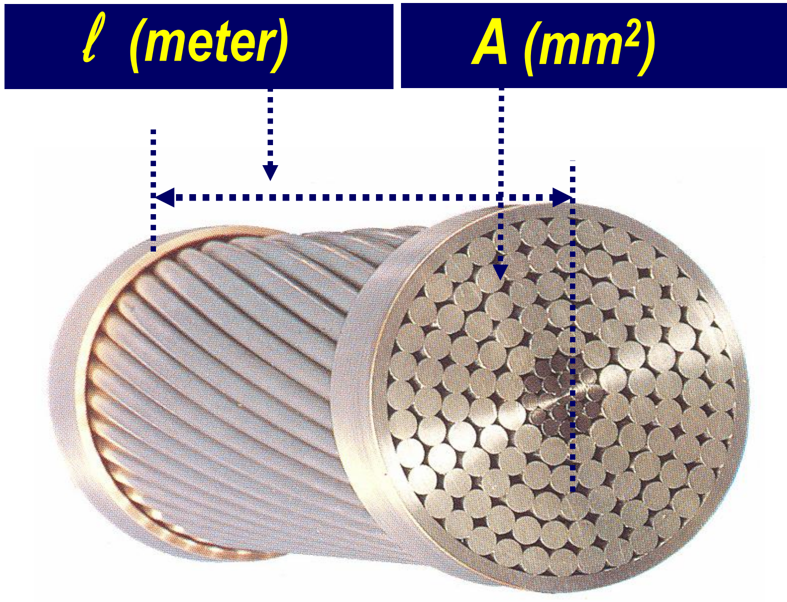
$\rho = 1 / 56$ *Ohm-mm²/m (Copper)*

$1 / 32$ *Ohm-mm²/m (Aluminum)*

ℓ *(m) is the length of the conductor*

A *(mm²) is the cross sectional area of the conductor*

ACSR Conductor (Aluminum Conductor Steel Reinforced)



Resistance Formula

Resistance Formula

Resistance of a cable is proportional to the length and inversely proportional to the cross sectional area of the cable

$$R = \rho \, \ell / A$$

where, R is the resistance of conductor,

ρ is the resistivity coefficient,

$\rho = 1 / 56$ Ohm-mm^2/m (Copper)

$1 / 32$ Ohm-mm^2/m (Aluminum)

ℓ (m) is the length of the conductor

A (mm^2) is the cross sectional area of the conductor

Resistance Formula

Resistance Formula

Aluminum Conductors

Example

Calculate the resistance of a copper cable with length 3200 meters and cross section 240 mm^2

Solution

$$R = (1 / 56)\ 3200 / 240$$
$$= 0.238 \text{ Ohms}$$

Resistance Formula

Resistance Formula

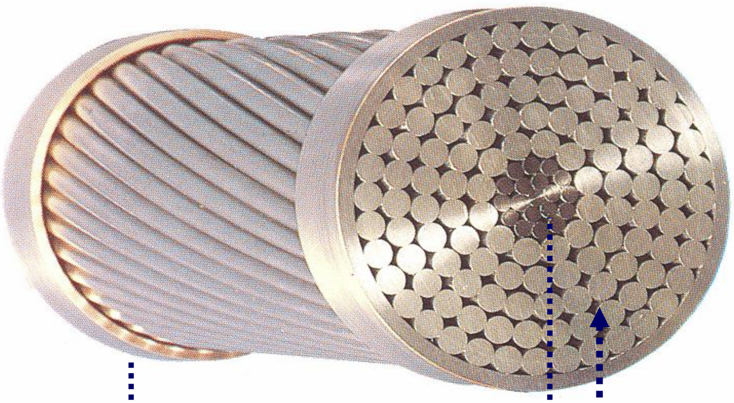
Example

Calculate the resistance of a copper cable with length 3200 meters and cross section 240 mm^2

Solution

$R = (1 / 56)\ 3200 / 240 = 0.238$ Ohms

ACSR Conductor
(Aluminum Conductor Steel Reinforced)



ℓ 3200 (m)

$A = 240\ (mm^2)$

Resistivity Coefficients of Various Metals

Formula

ρ = 1 / 56 Ohms/meter (Copper)
= 0.0178571 Ohm-mm²/m

$$R = \rho \, \ell / A$$

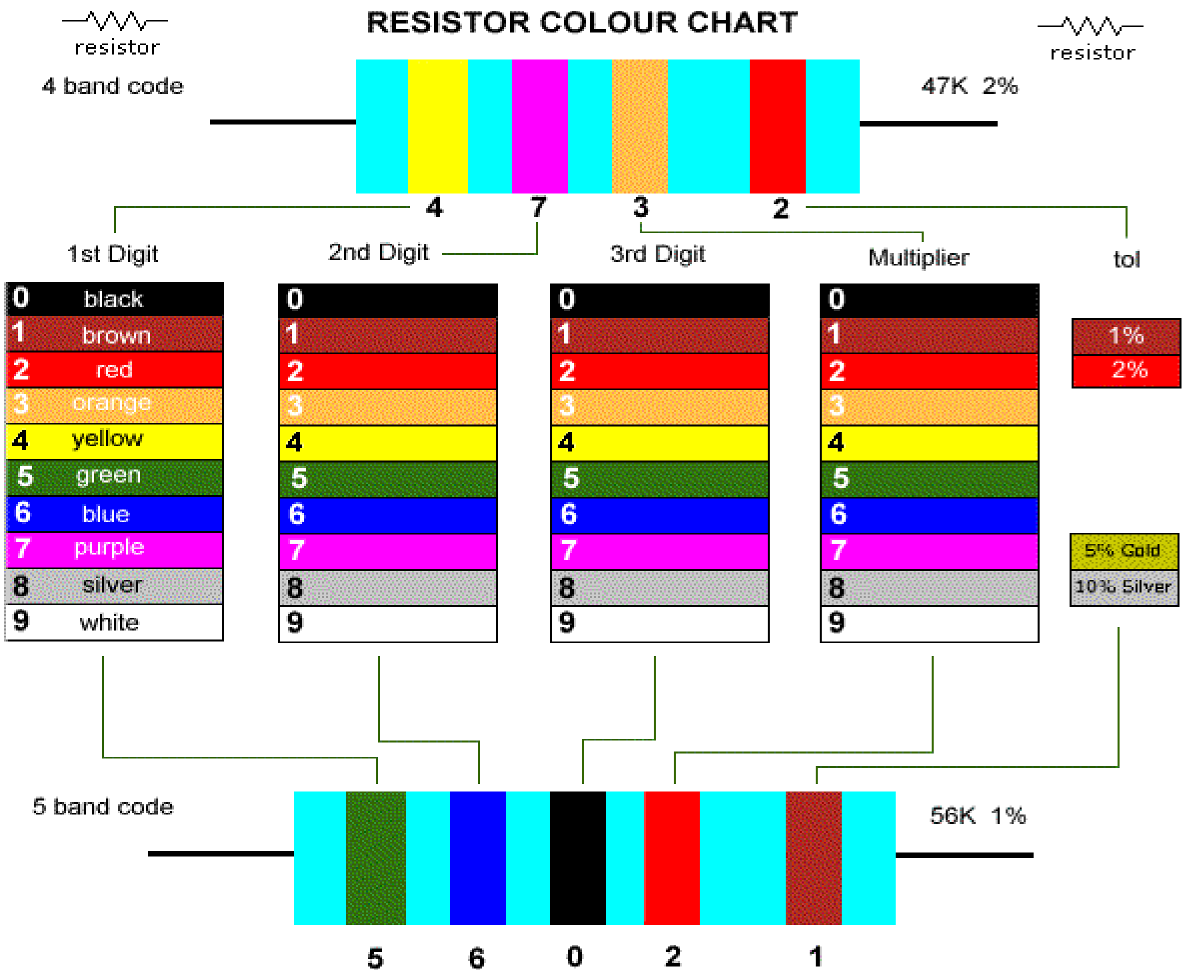
where, R is the resistance of conductor,
ρ is the resistivity coefficient,
ρ = 1 / 56 Ohm-mm²/m (Copper)
1 / 32 Ohm-mm²/m (Aluminum)
ℓ (m) is the length of the conductor
A (mm²) is the cross sectional area of the conductor

Resistivity Coefficients

Material	Resistivity Coefficient	Resistance
	Ohm-mm²/m	Ohms/feet
Silver	0.0162	0.00094
Copper	0.0172	0.00099
Gold	0.0244	0.00114
Aluminum	0.0282	0.00164
Mercury	0.9580	
Brass	0.0700	0.00406
Nickel	0.7800	0.00452
Iron	0.1000	0.00579
Platinium	0.1000	0.00579
Steel	0.1180	0.00684
Lead	0.2200	0.01270

Color Codes for Resistances

Rule



Insulator

Insulator

Insulator is a material with almost infinite resistance

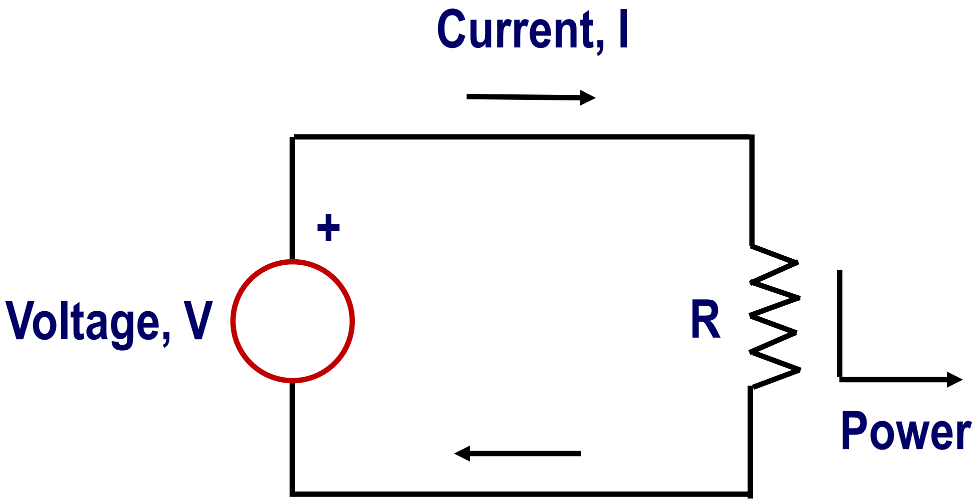
Insulators are used to support HV lines and conductors

In practice, all materials have resistances. Hence, they conduct a certain amount of current when a voltage is applied to the terminals.
Insulator are materials that conduct only a very small amount of current, even when an extremely high voltage is applied to the terminals.

Basic Principles of Electricity

Power dissipation in a Resistance

$$V = R \times I$$
(Volt) = (Ohm) (Amp)



On the other hand, it was shown in this lecture that;

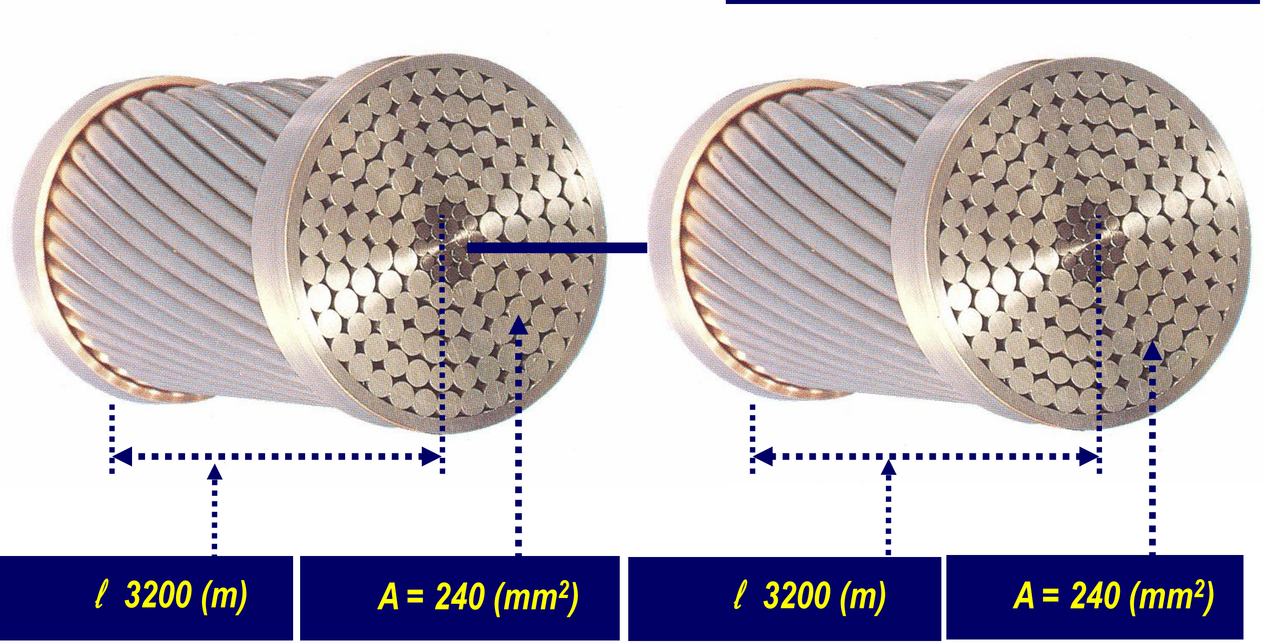
Power = Voltage x Current
or
$$P = V \times I$$

Hence, power dissipation in resistance R is

$$\text{Power} = R \times I \times I = R \times I^2 \quad \text{Watt}$$

Series Connected Resistances

Equivalent Resistance Formula



$R_1 = \rho\, \ell_1 / A_1$

$R_2 = \rho\, \ell_2 / A_2$

Let $A_1 = A_2$

Hence;

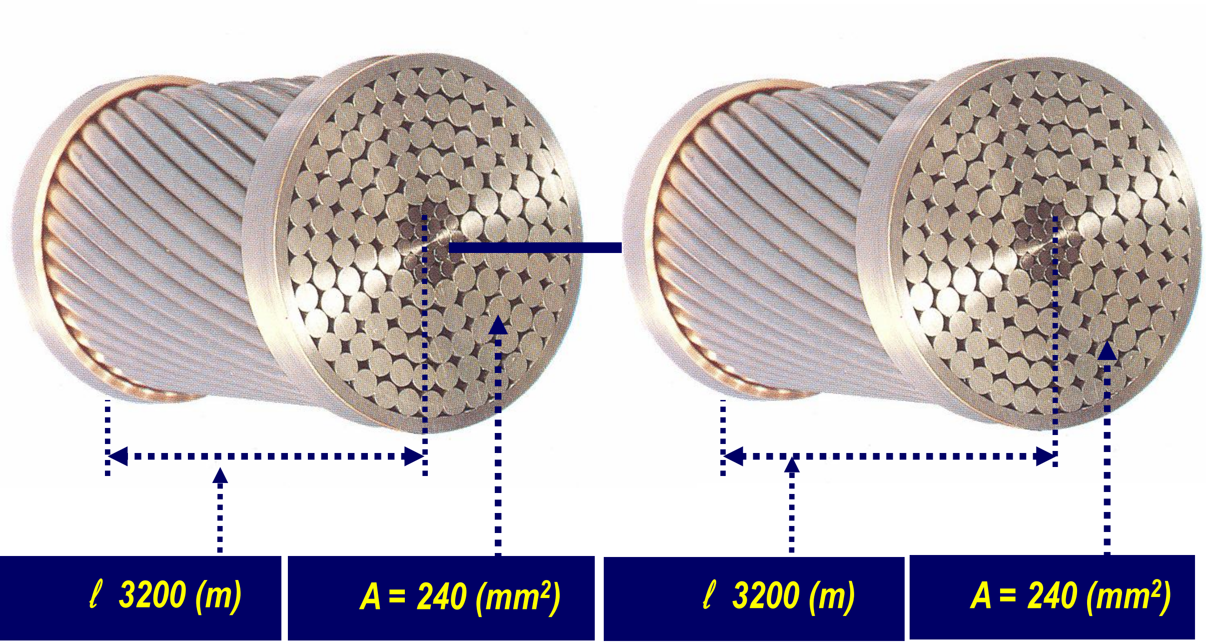
$\ell_{total} = \ell_1 + \ell_2$

$$\begin{aligned} R_{total} &= \rho\, \ell_{total} / A \\ &= \rho\, (\ell_1 + \ell_2) / A \\ &= \rho\, \ell_1 / A + \rho\, \ell_2 / A \\ &= R_1 + R_2 \end{aligned}$$

Series Connected Resistances

Equivalent Resistance Formula

$R_{total} = R_1 + R_2$	Series connected resistances are added

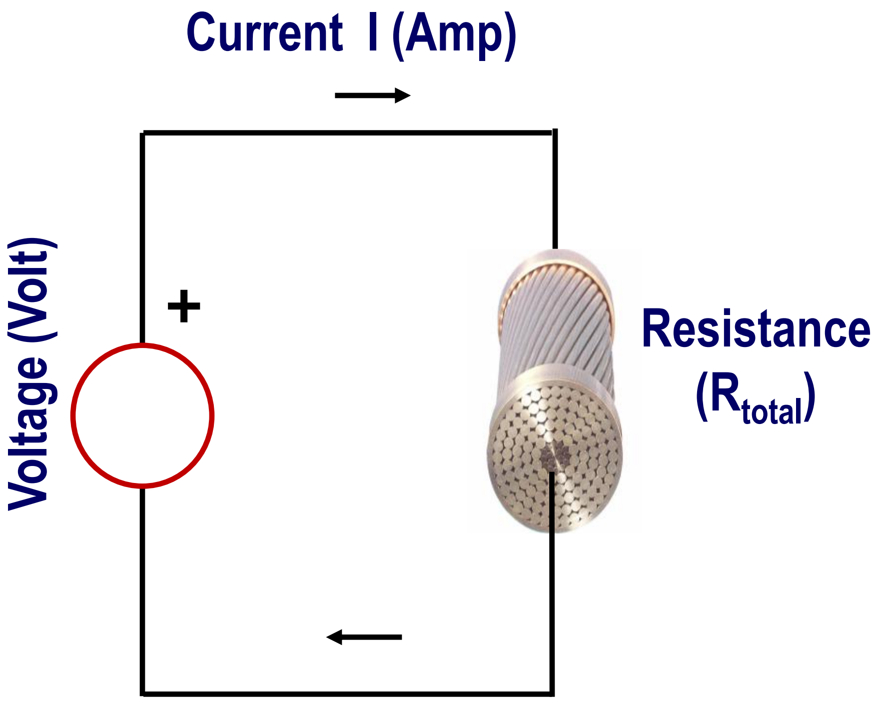


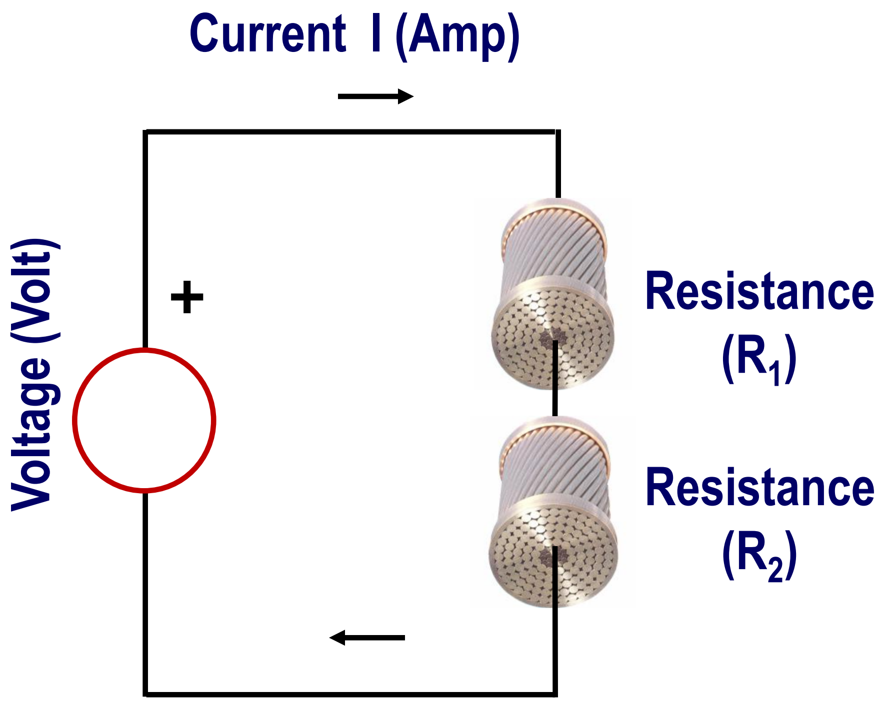
$$R_{total} = R_1 + R_2 + \dots + R_k$$

Basic Principles of Electricity

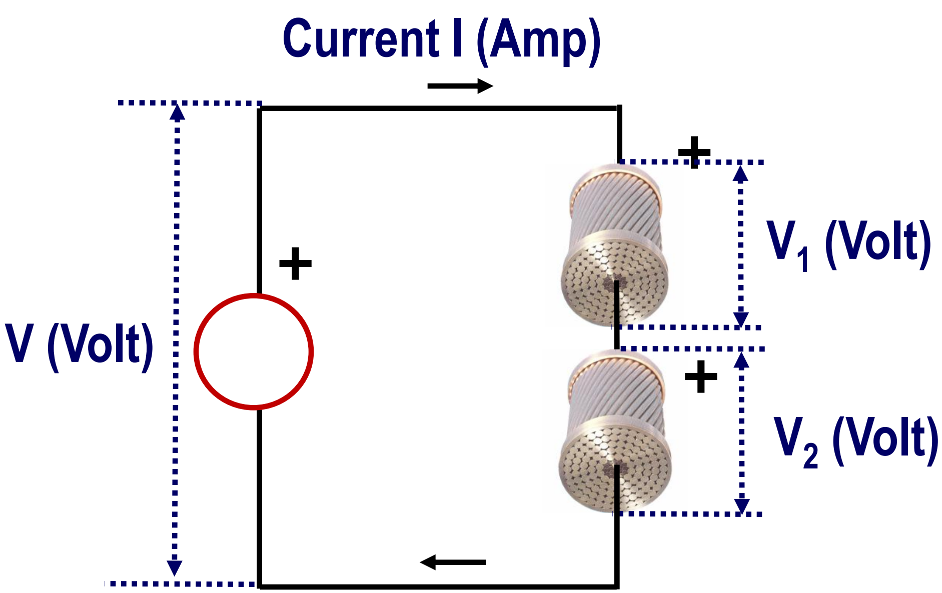
Ohm Law for Series Resistances

$V = R_{total} \times I$ (Volt) (Ohm) (Amp)	$V = R_1 \times I + R_2 \times I$ (Volt) (Volt) (Volt)





Ohm Law for Series Resistances

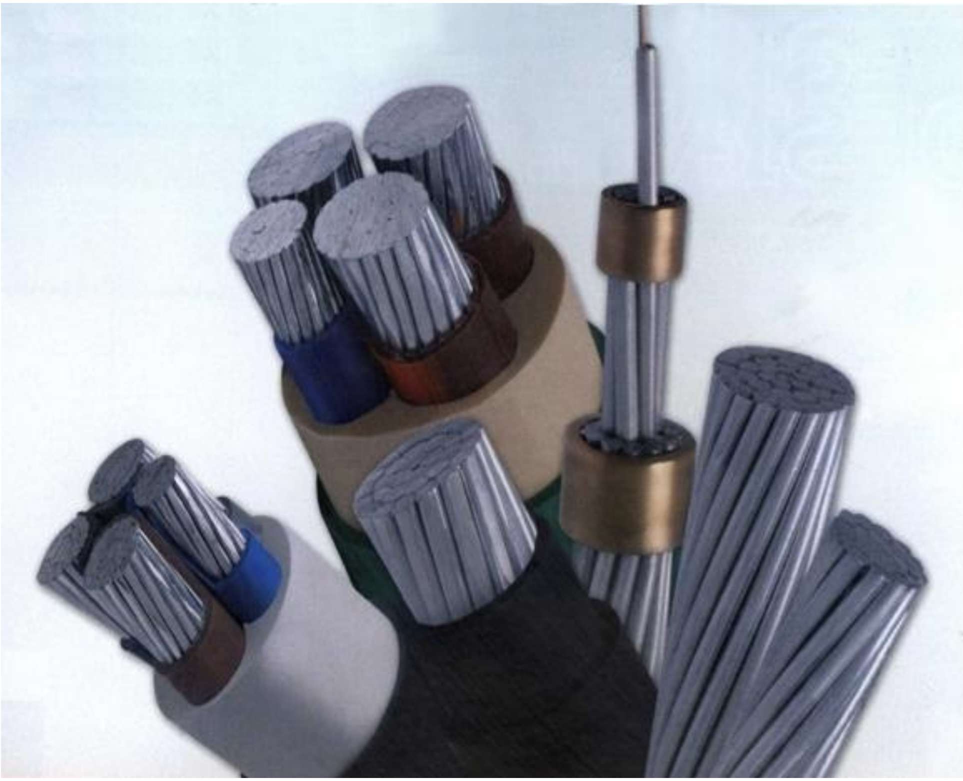


$$V = R_1 \times I + R_2 \times I$$

(Volt) (Volt) (Volt)

$$= V_1 + V_2$$

Aluminum Cables and Conductors



Admittance

Definition

Inverse of resistance is called *"Admittance"*

$$g = 1 / R$$

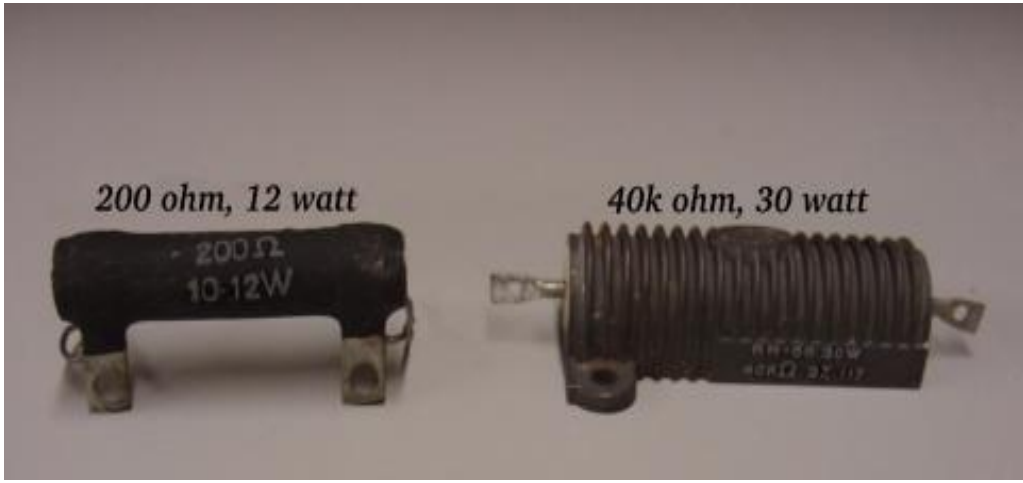
(Siemens) *(1 / Ohm)*

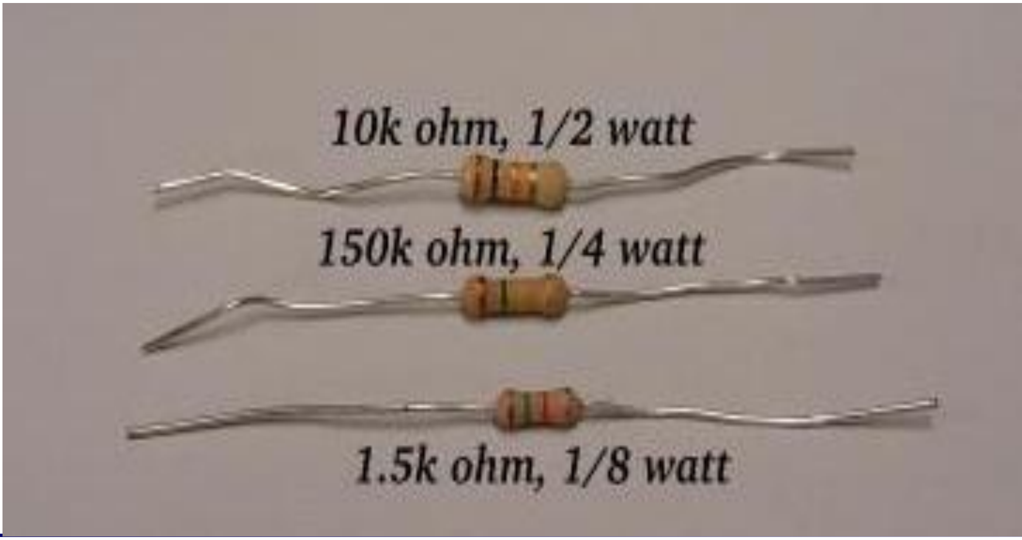
Unit of *"Admittance"* is Siemens

Example

Calculate the admittance of 10 k Ω resistance shown on the RHS

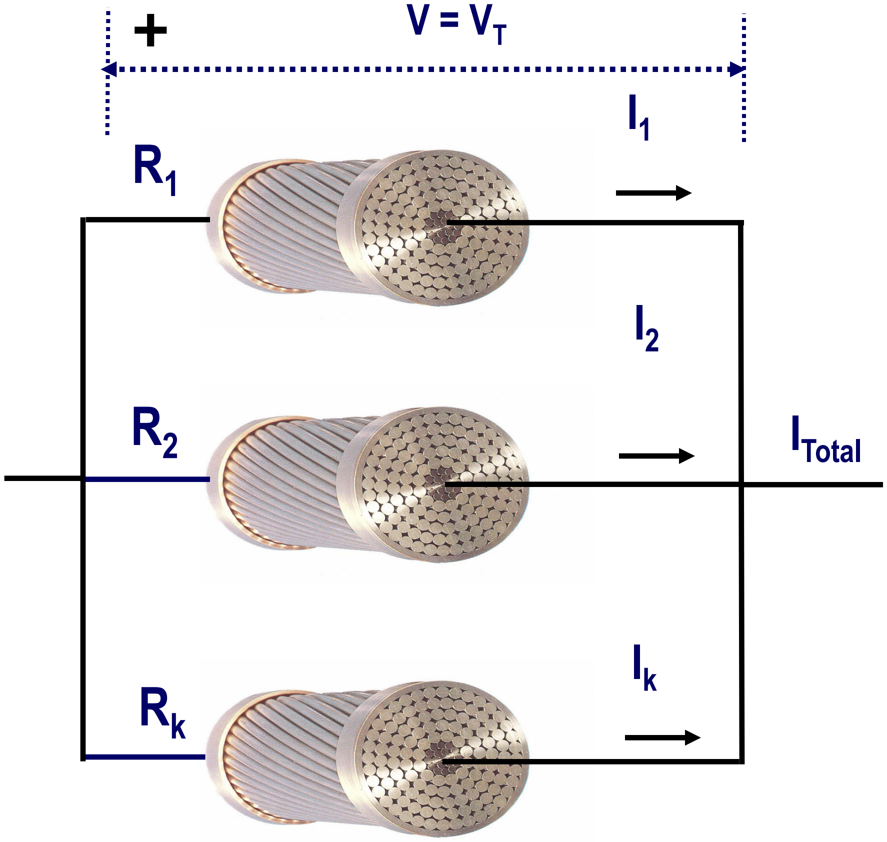
$$g = 1 / 10^4 = 10^{-4} \text{ Siemens}$$

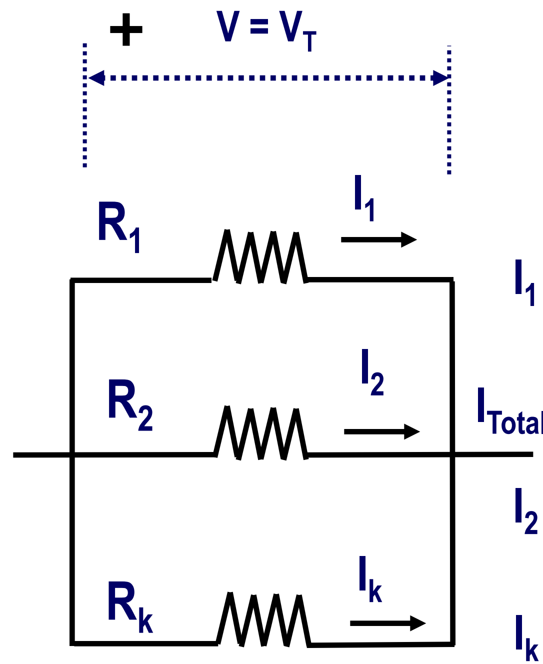




Shunt Connected Resistances

Equivalent Resistance Formula





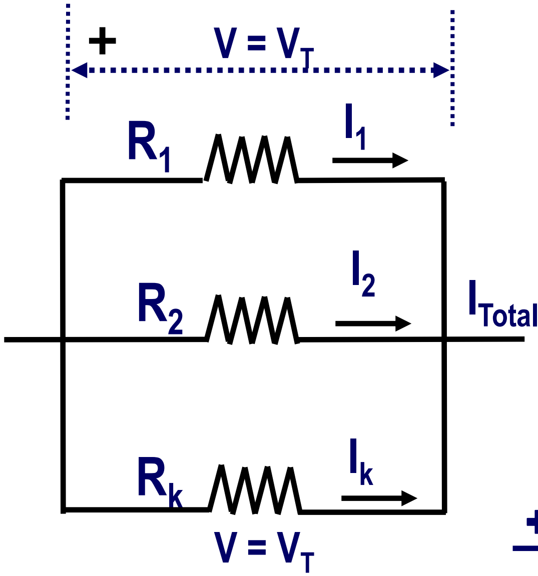
$I_1 = V_T / R_1 = V_T \times g_1$

$I_2 = V_T / R_2 = V_T \times g_2$

$I_k = V_T / R_k = V_T \times g_k$

Shunt Connected Resistances

Equivalent Resistance Formula



$$I_1 = V_T / R_1$$

$$I_2 = V_T / R_2$$

$$I_k = V_T / R_k$$

+

$$I_{total} = V_T(1 / R_1 + 1 / R_2 + \ldots + 1 / R_k) = V_T / R_{equivalent}$$

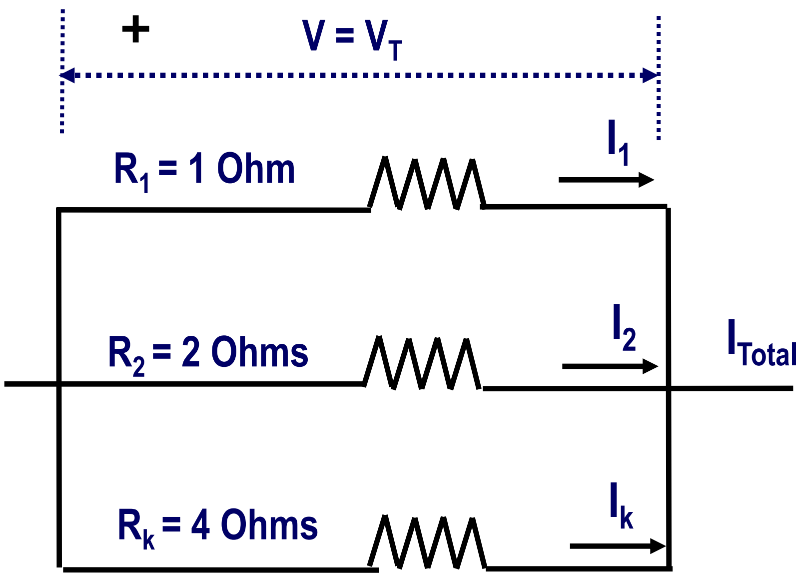
Hence,

$$R_{equiv} = \frac{1}{1 / R_1 + 1 / R_2 + \ldots + 1 / R_k}$$

Shunt Connected Resistances

Example

Find the equivalent resistance of the following connection



$$R_{equiv} = \frac{1}{1/R_1 + 1/R_2 + \ldots + 1/R_k}$$

$$R_{equiv} = \frac{1}{1/1 + 1/2 + 1/4}$$

$$= 1/(7/4) = 4/7 = \underline{0.5714 \text{ Ohm}}$$

Basic Principles of Electricity

Shunt Connected Resistances

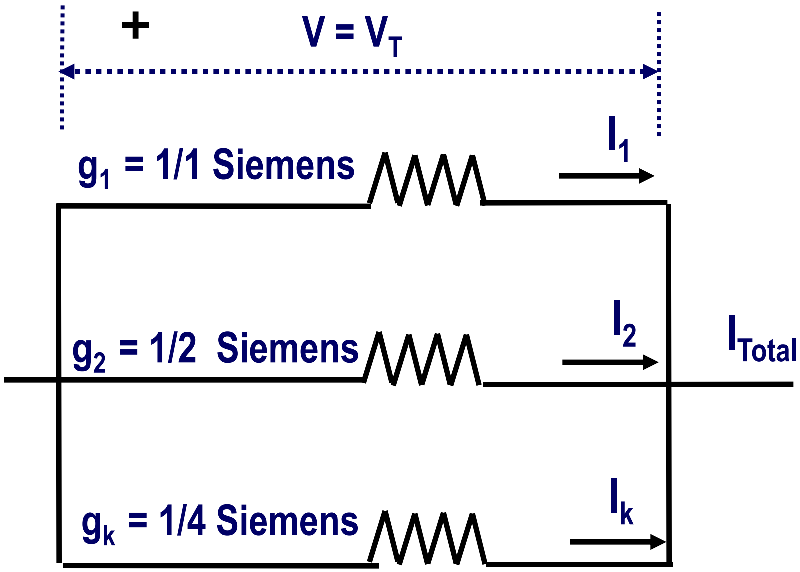
Example

Find the equivalent admittance of the following connection

$$R_{equiv} = \frac{1}{1/R_1 + 1/R_2 + ... + 1/R_k}$$

or

$$1/g_{equiv} = \frac{1}{g_1 + g_2 + ... + g_k}$$



$$\begin{aligned} g_{equiv} &= g_1 + g_2 + g_3 \\ &= 1/1 + 1/2 + 1/4 \\ &= 7/4 \\ &= 1.75 \text{ Siemens} \end{aligned}$$

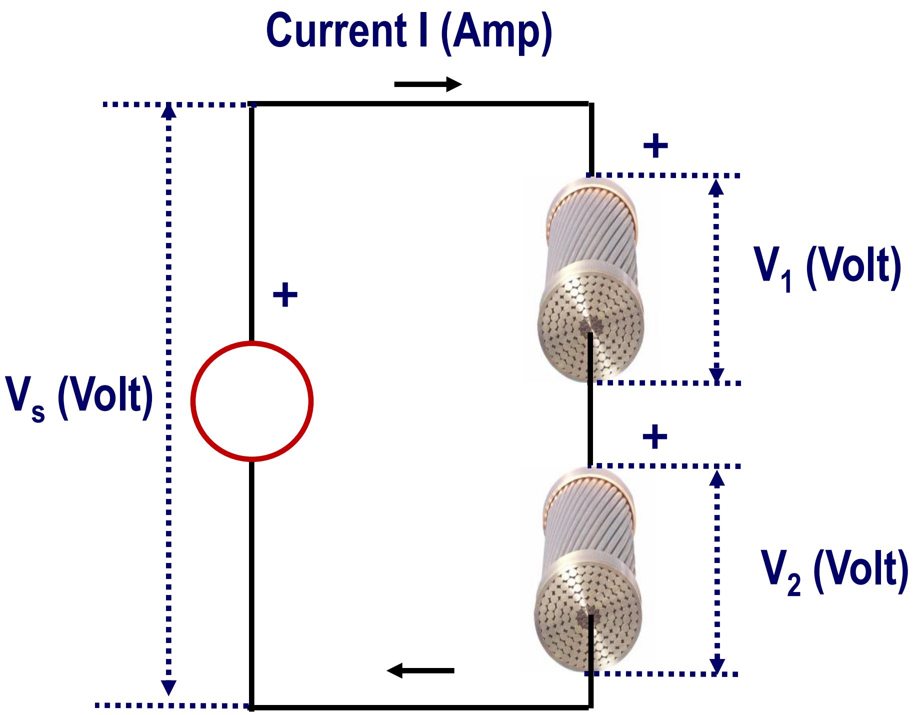
Voltages on Series Connected Elements

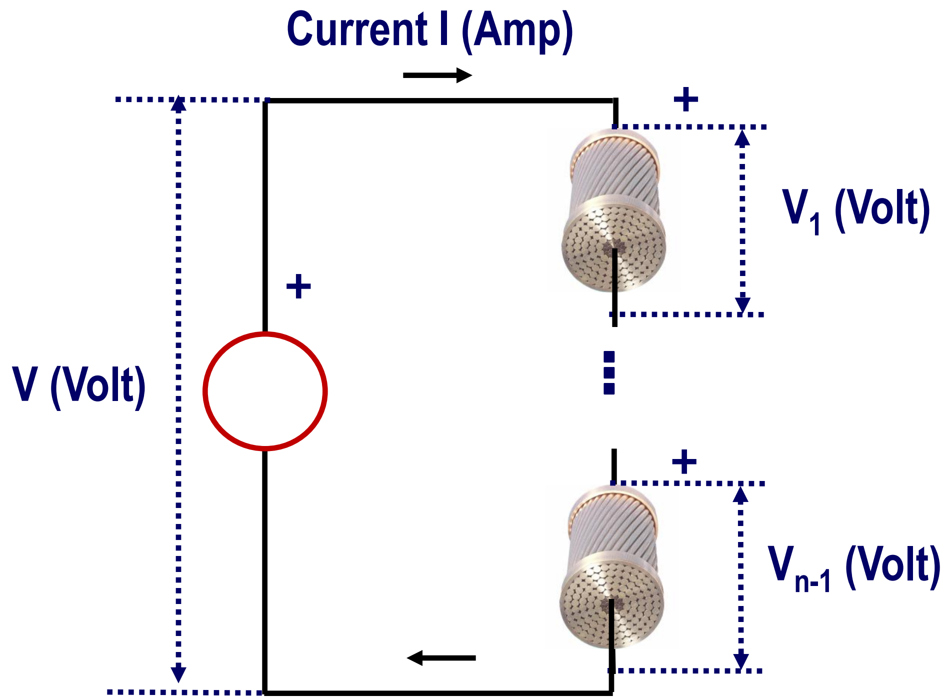
Voltages on series connected elements are added

$$V = V_1 + V_2$$
(Volt) (Volt) (Volt)

or generalizing

$$V = V_1 + \ldots + V_{n-1}$$
(Volt) (Volt) (Volt)





Voltages on Series Connected Elements

Voltages on series connected elements are added

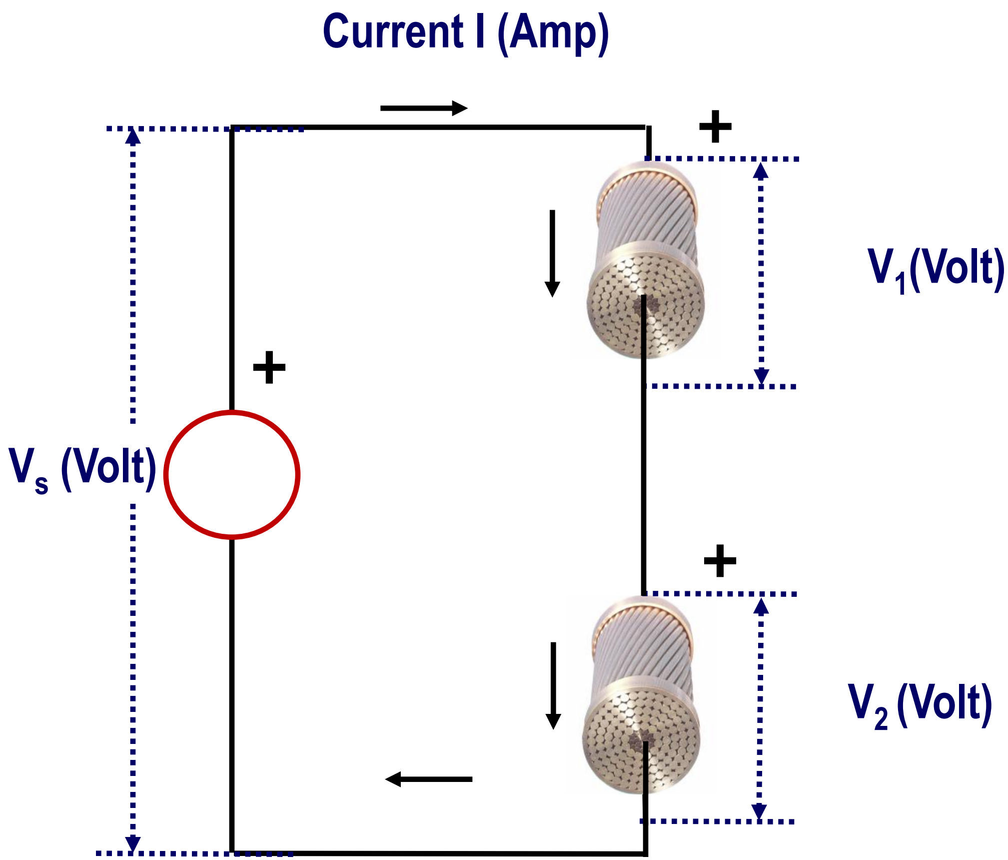
$$V = V_1 + \dots + V_{n-1}$$

(Volt) (Volt) (Volt)

$$V = \sum_{i=1}^{i=n-1} V_i$$

$$V_n - \sum_{i=1}^{i=n-1} V_i = 0$$

$$\sum_{i=1}^{i=n} V_i = 0$$



Kirchoff's Voltage Law (KVL)

Statement

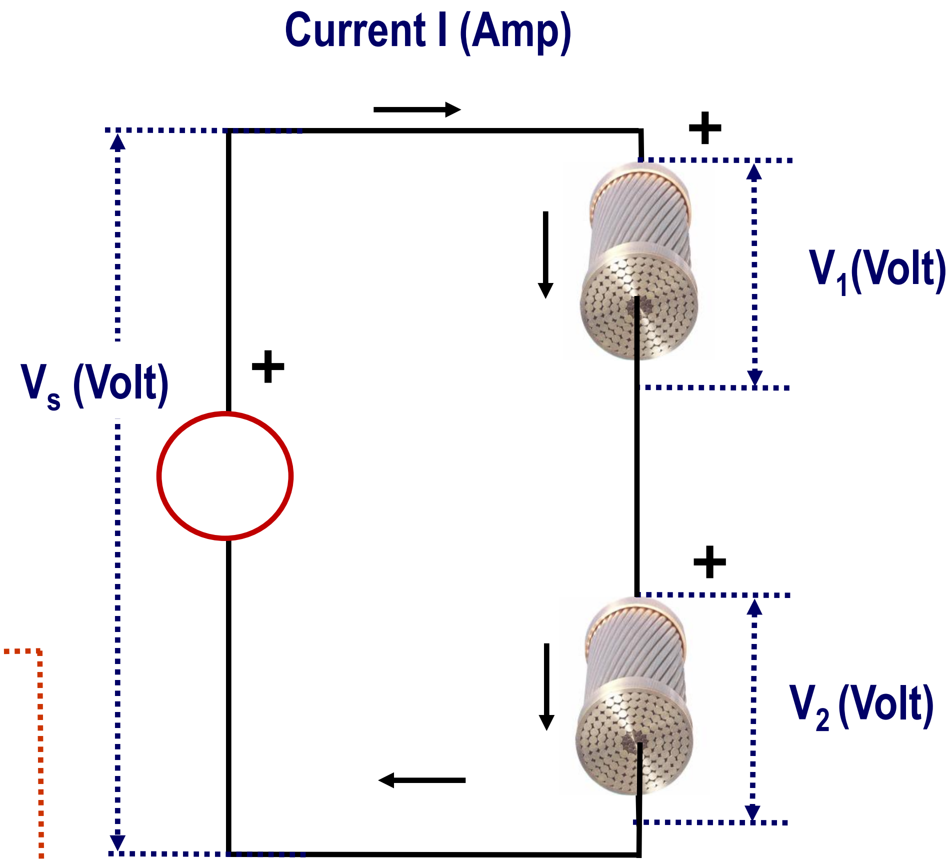
The above result may be expressed as;

Sum of voltages in a closed loop is zero

or

$$\sum_{i=1}^{i=n} V_i = 0$$

Kirchoff's Second Law
or
Kirchoff's Voltage Law



Kirchoff's Voltage Law (KVL)

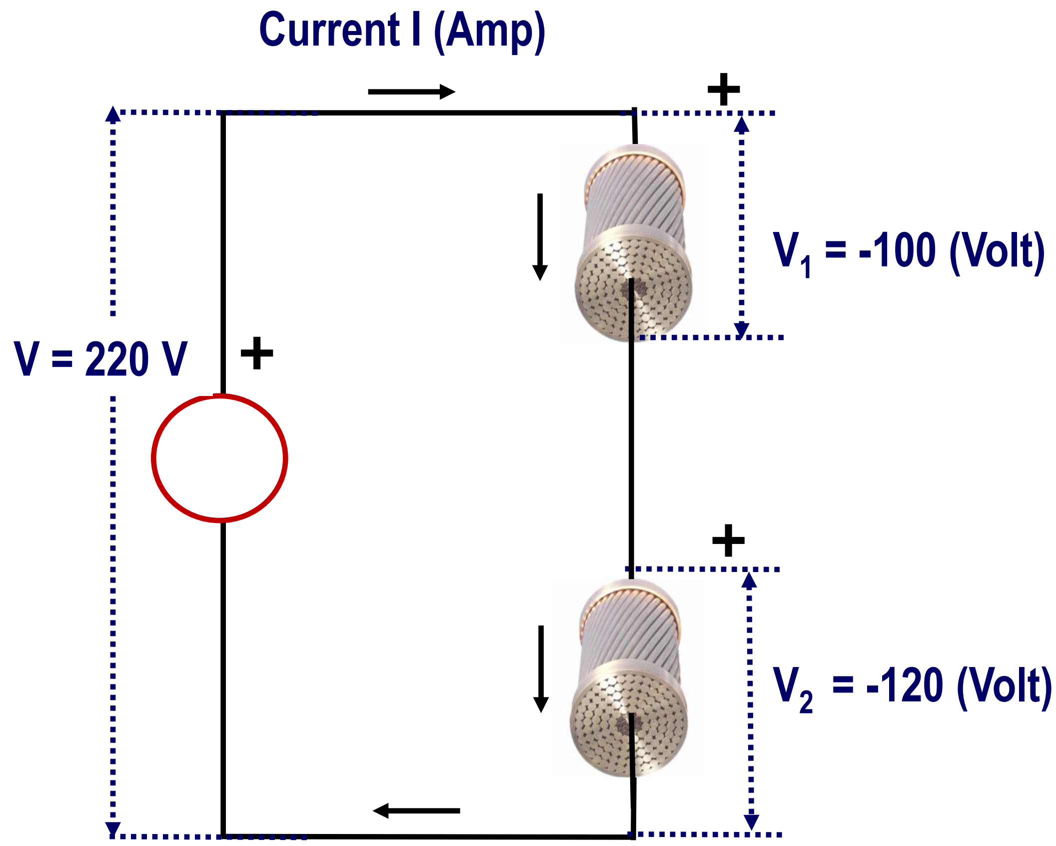
Example

$$\sum_{i=1}^{i=n} V_i = 0$$

$V_s = 220$ Volts

$V_s - V_1 - V_2 = 0$

$220 - 100 - 120 = 0$

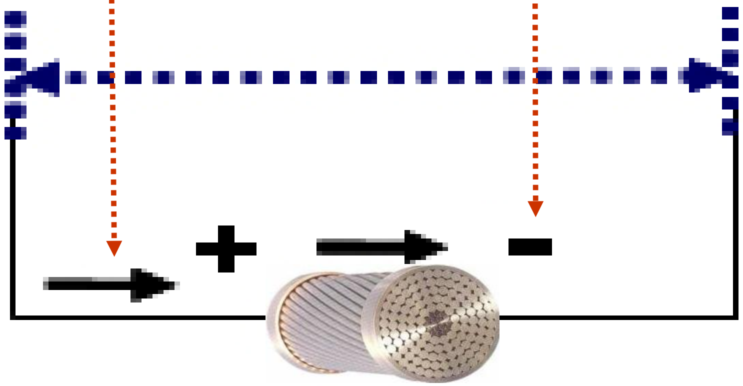


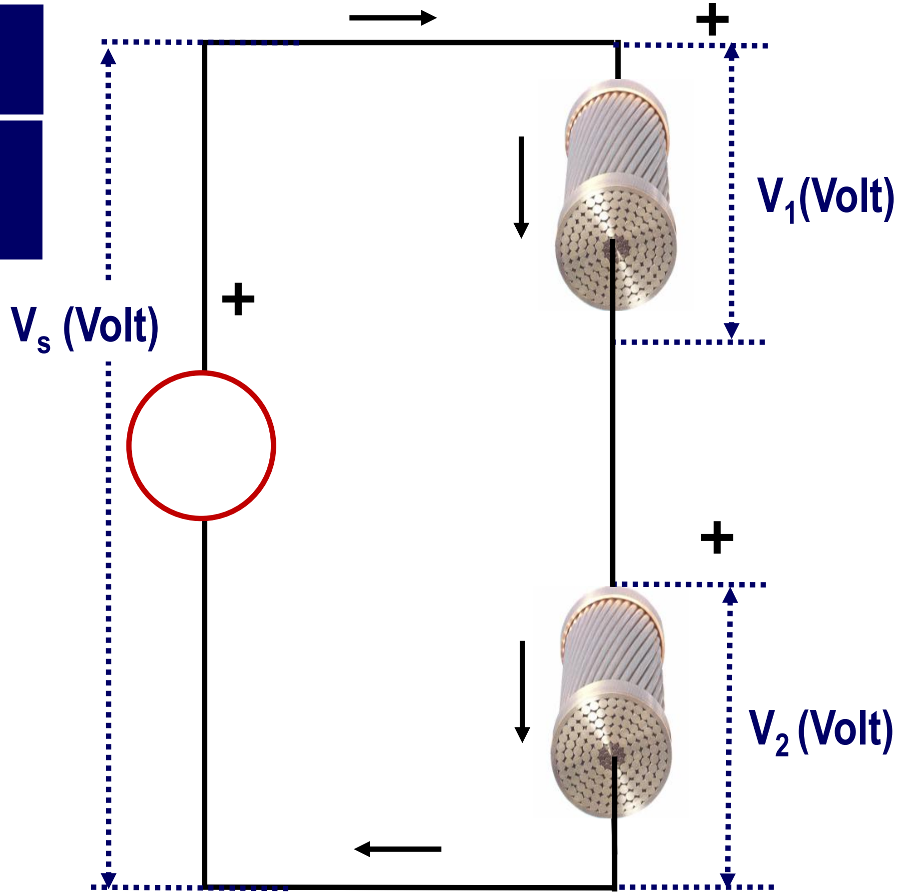
Kirchoff's Voltage Law (KVL)

Simple Rules

Head (pinpoint) of the arrow is negative,
Tail of the arrow is positive

This current is assigned such a direction that it always enters from the '+' side of the resistance

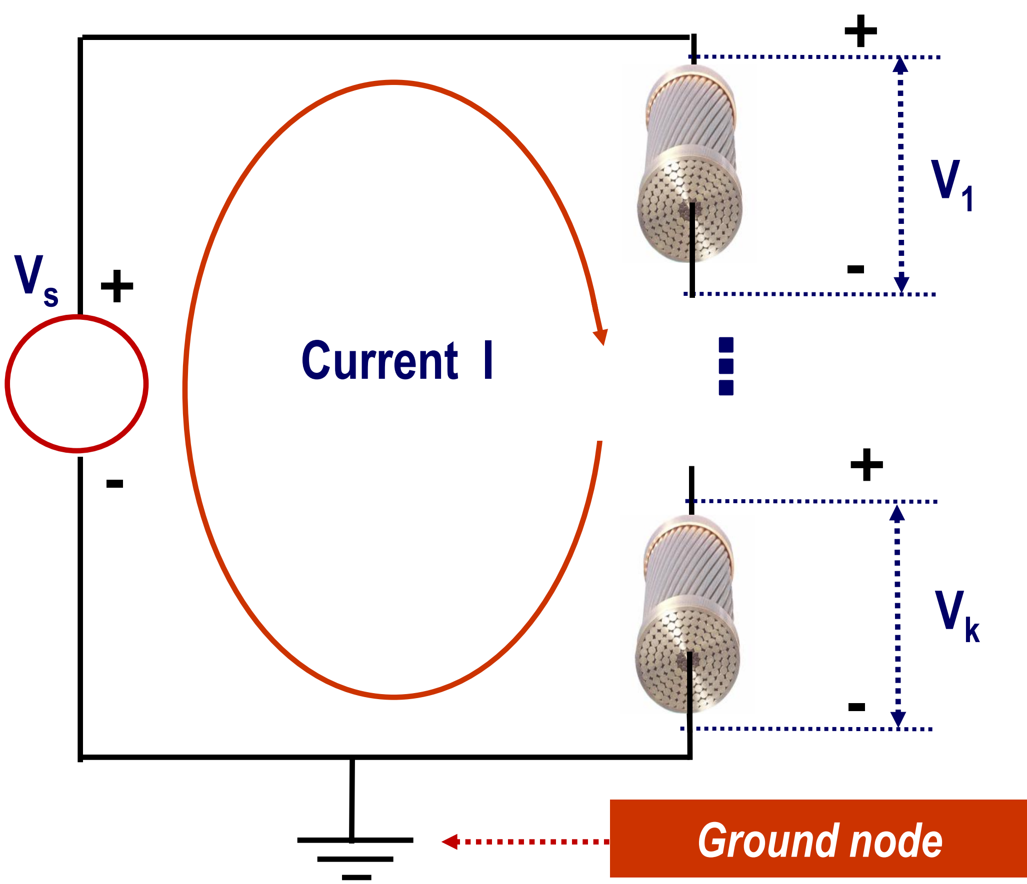




A Simple Rule for applying Kirchoff's Voltage Law (KVL)

A Simple Rule

- Choose a ground node,
- Assume that current I flows clockwise,
- Starting from the ground node, assign "+" and "-" signs to those passive elements (i.e. those elements other than source) in such a direction that the current enters to "+" side and the leaves from the "-" side,
- Assign "+" sign to the that side of the source from which current is leaving



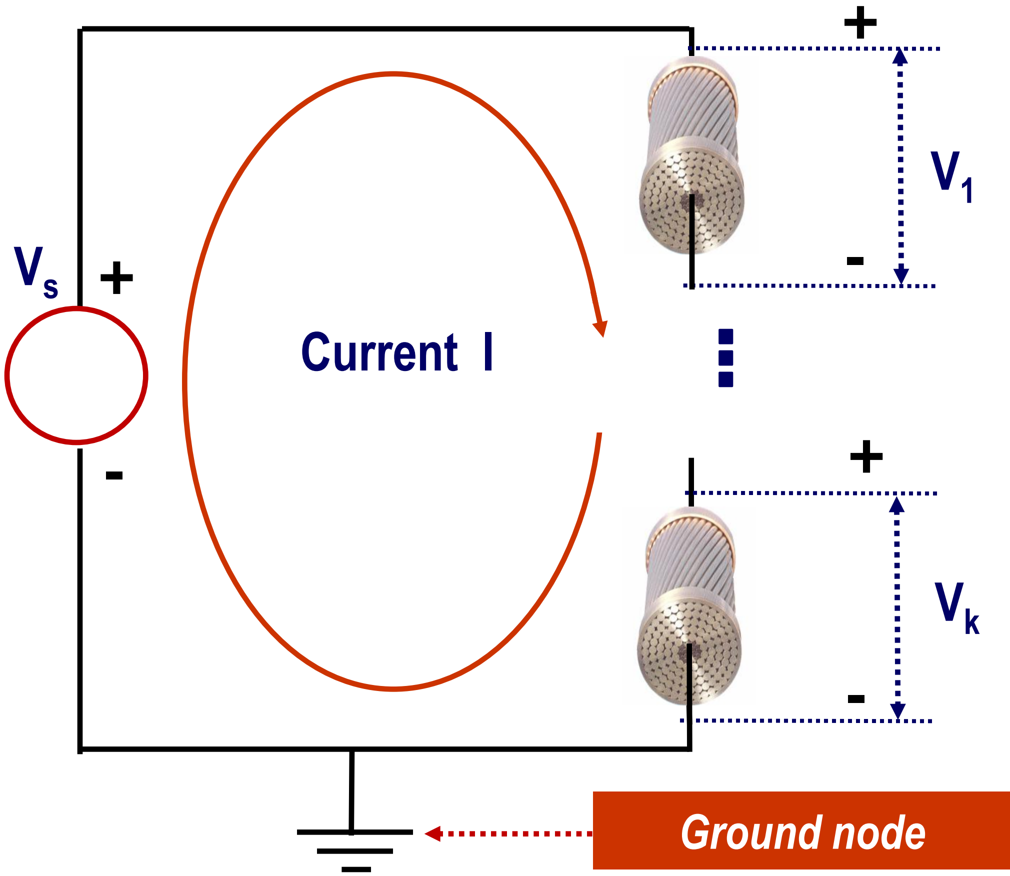
A Simple Rule for applying Kirchoff's Voltage Law (KVL)

A Simple Rule

- Then write down the voltages on each element by using Ohm Law on a path in a clockwise direction,
- Assign "+" sign to those voltage terms in the equation that you pass from "-" to "+",
- Assign "-" sign to those voltage terms in the equation that you pass from "+" to "-",
- Stop and equate it to zero when you come again to the ground node that you have started

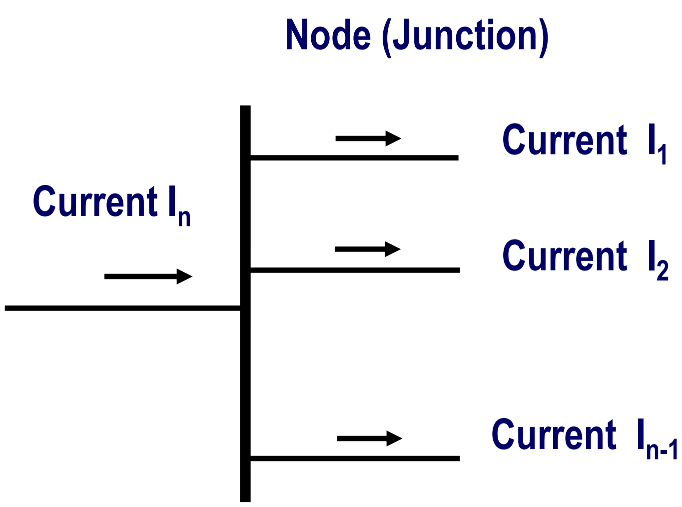
Example;

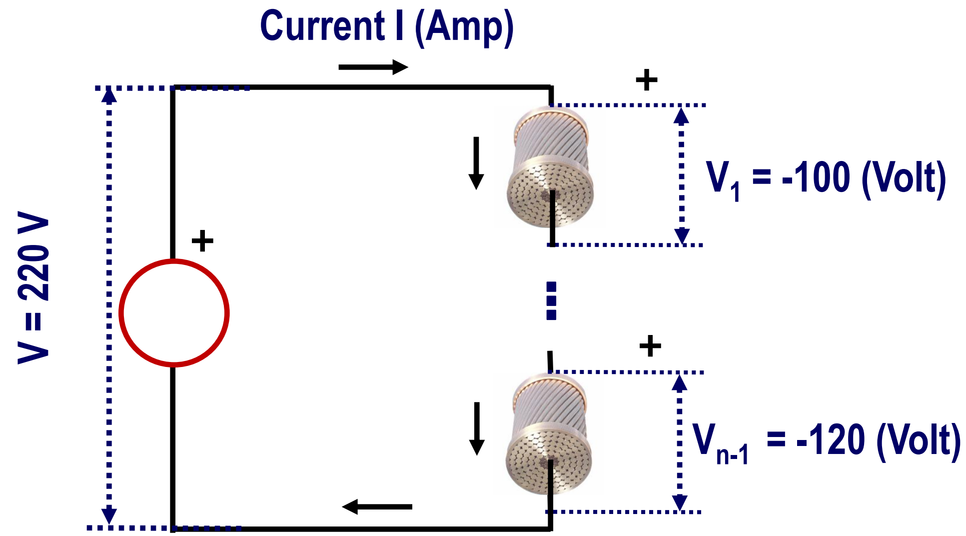
$+V_s - V_1 - V_2 = 0 \longrightarrow V_s = V_1 + V_2$



Summary of Kirchoff’s Laws

Kirchoff’s Current Law (KCL)	Kirchoff’s Voltage Law (KVL)
Algebraic sum of currents entering a junction is zero	*Algebraic sum of voltages in a closed loop is zero*
$\sum_{i=1}^{i=n} I_i = 0$	$\sum_{i=1}^{i=n} V_i = 0$



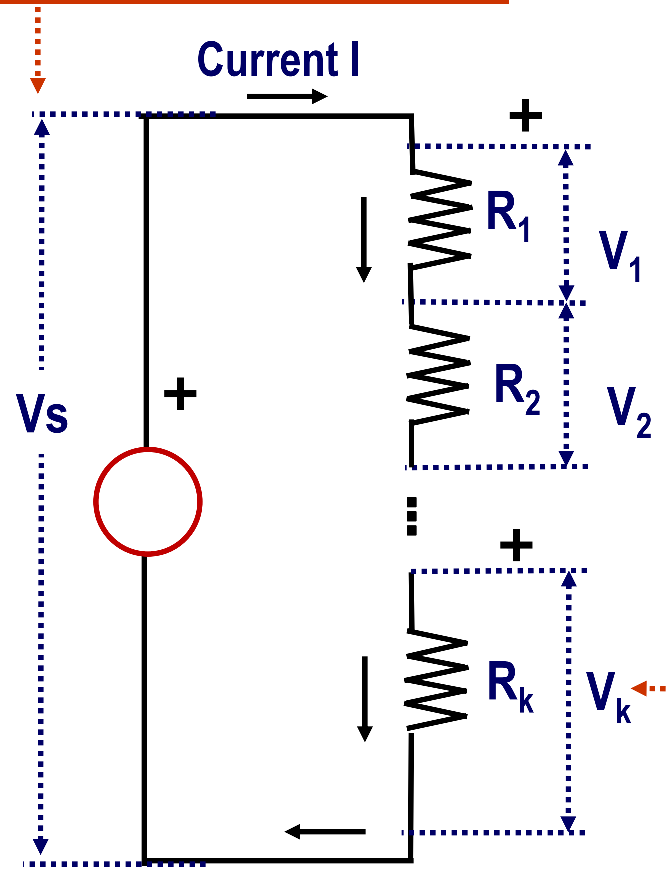


Voltage Division Principle

$$V_1 = R_1 \times I$$
$$V_2 = R_2 \times I$$
$$\ldots$$
$$V_k = R_k \times I$$
$$+ \quad \text{------------------------------}$$
$$V_s = V_1 + V_2 + \ldots V_k$$
$$= (R_1 + \ldots + R_k) \times I$$
$$V_k / V_s = R_k / (R_1 + \ldots + R_k)$$

$$\textit{Voltage Division Ratio} = \frac{R_k}{R_1 + \ldots + R_k}$$

Input Voltage



Output Voltage

$= V_s R_k / (R_1 + .. R_k)$

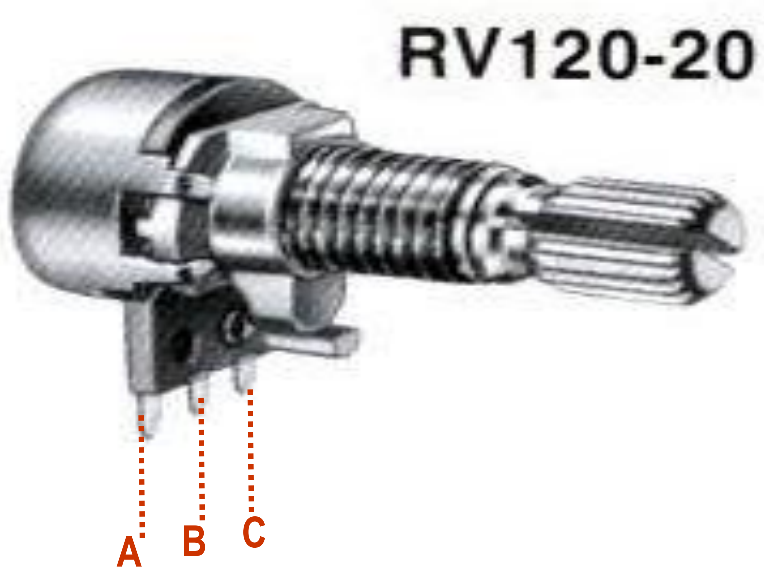
Potentiometer (Voltage Divider)

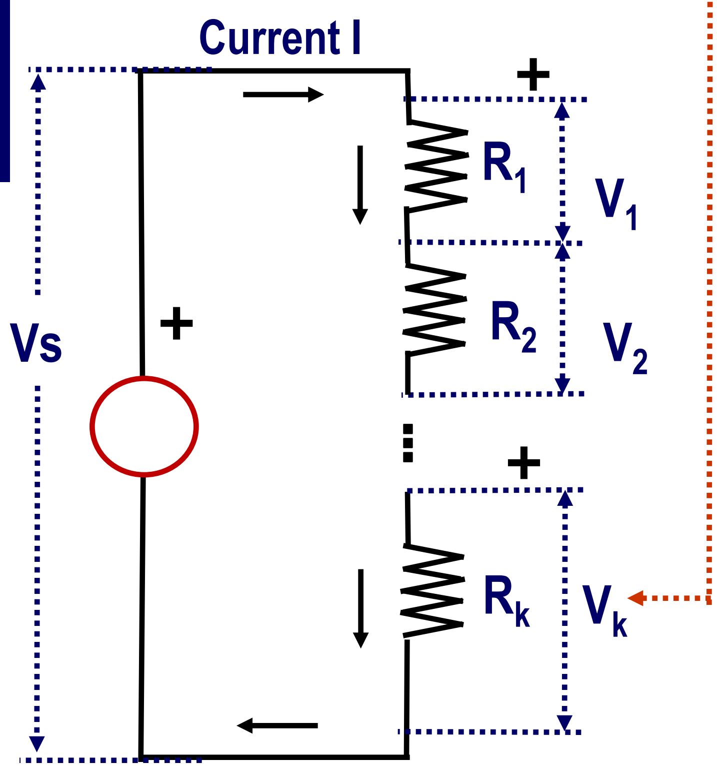
Principle

Input voltage is divided and a certain fraction is given to the output

$$V_k = \frac{R_k}{R_1 + \ldots + R_k} V_s$$

$$\text{Division Ratio} = \frac{R_k}{R_1 + \ldots + R_k}$$



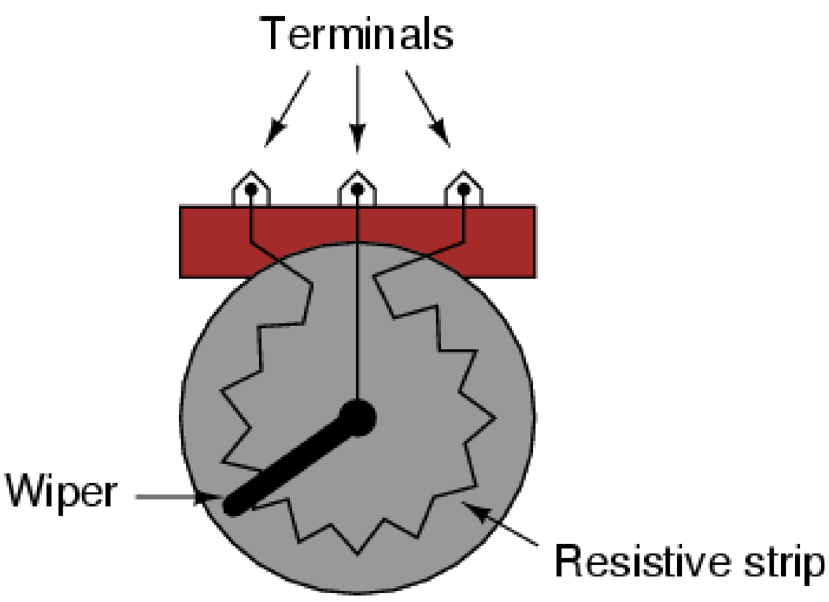


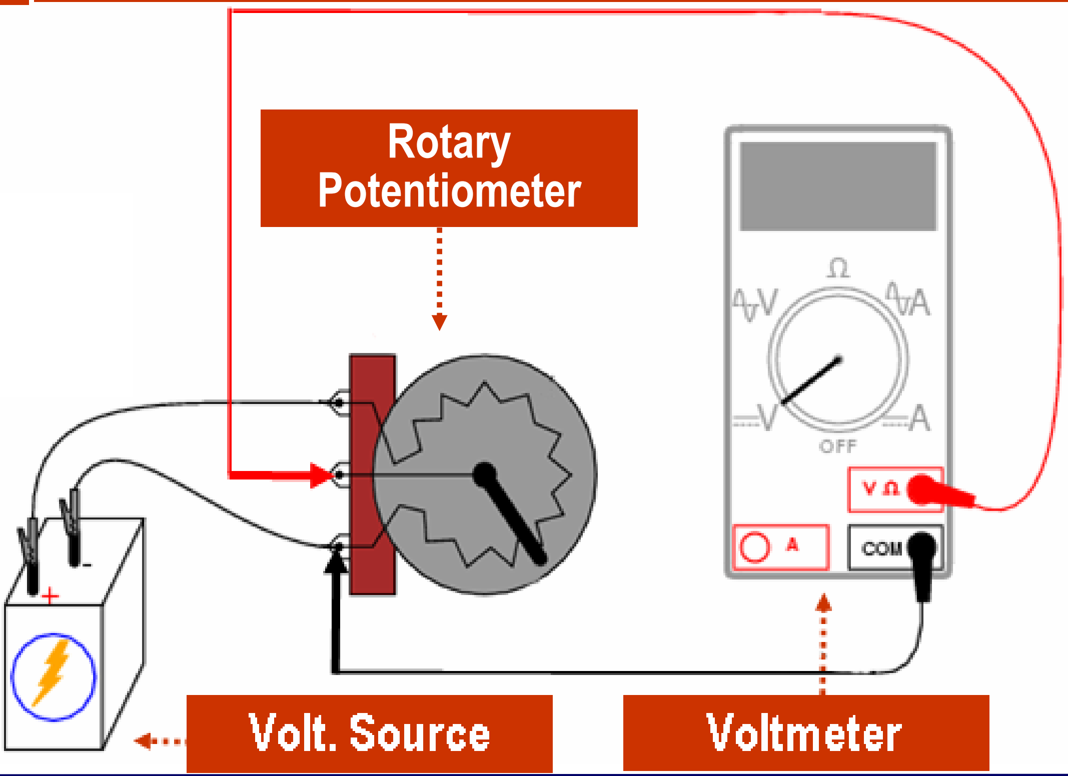
Potentiometer (Voltage Divider)

Circuit Arrangement

$$\text{Division Ratio} = \frac{R_k}{R_1 + \ldots + R_k}$$

Rotary Potentiometer





Current Division Principle

$$I_k = \frac{g_k}{g_1 + \ldots + g_k} I_s$$

$$\text{Division Ratio} = \frac{g_k}{g_1 + \ldots + g_k}$$

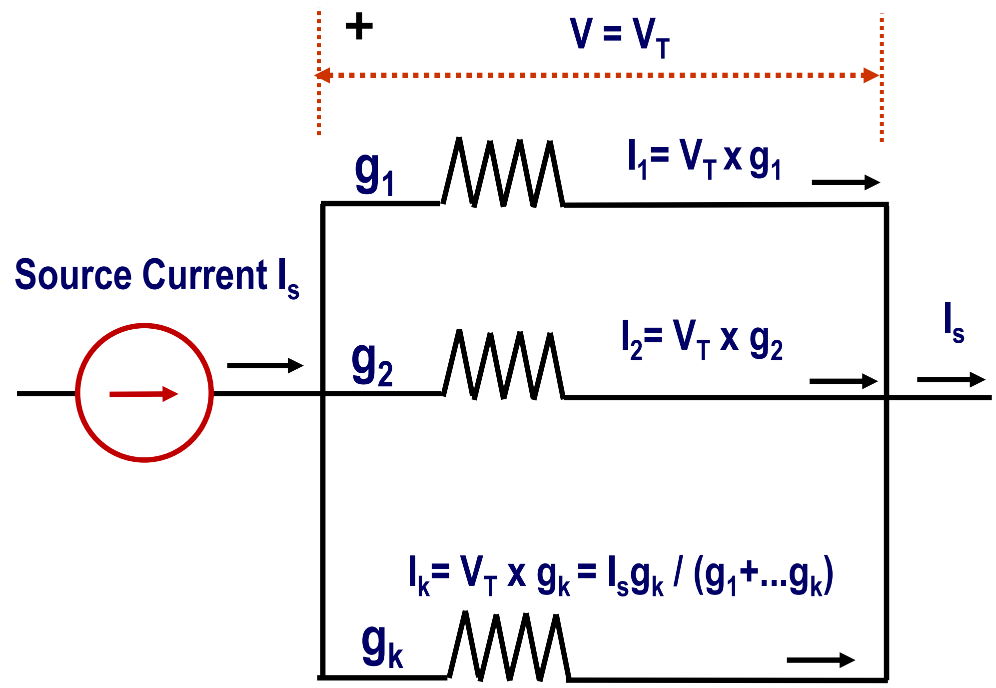
$$V_T \times g_1 = I_1$$
$$V_T \times g_2 = I_2$$
$$\ldots$$
$$V_T \times g_k = I_k$$
+

$$V_T (g_1 + \ldots g_k) = I_1 + \ldots I_k$$

or

$$V_T (g_1 + \ldots g_k) = I_s$$

$$I_k / I_s = g_k / (g_1 + \ldots + g_k)$$



Voltage Sources

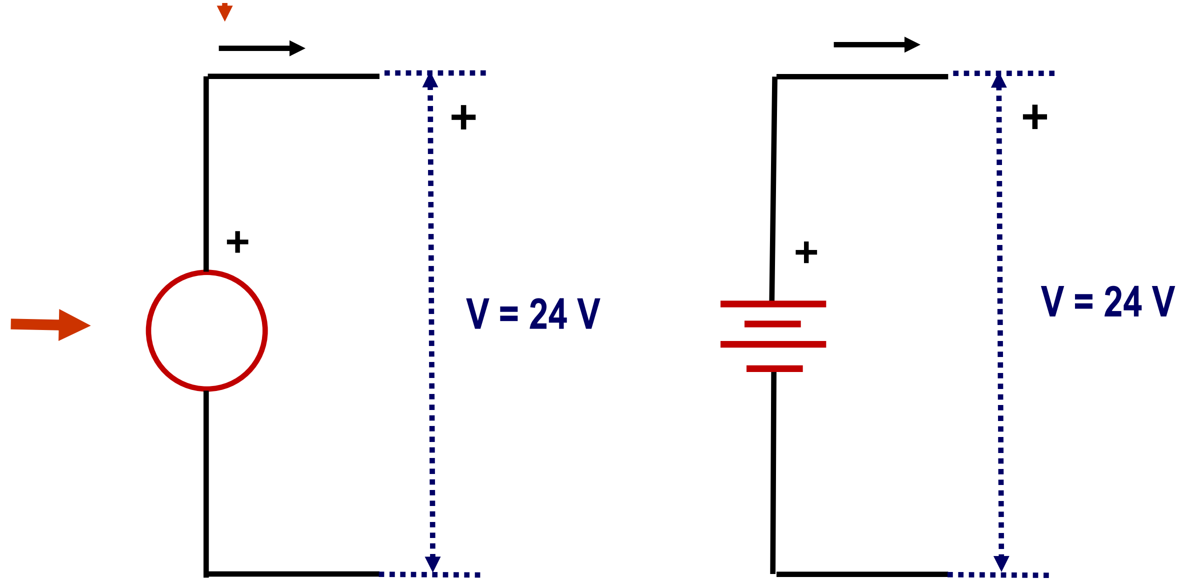
Definition

Voltage source is an element which creates a voltage difference at its terminals

A simple Rule:

Current is assigned such a direction that it always leaves the '+' side of the voltage or current source.

Voltage Source	DC Voltage Source



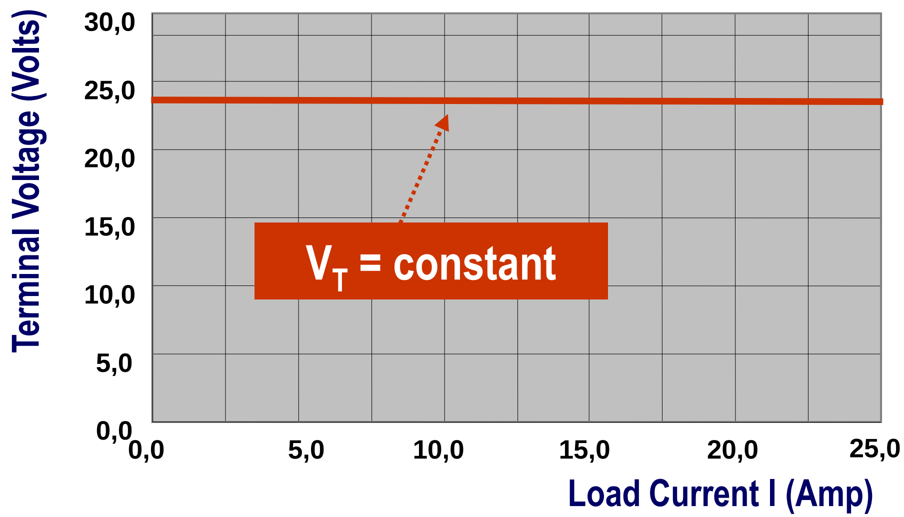
Ideal Voltage Source

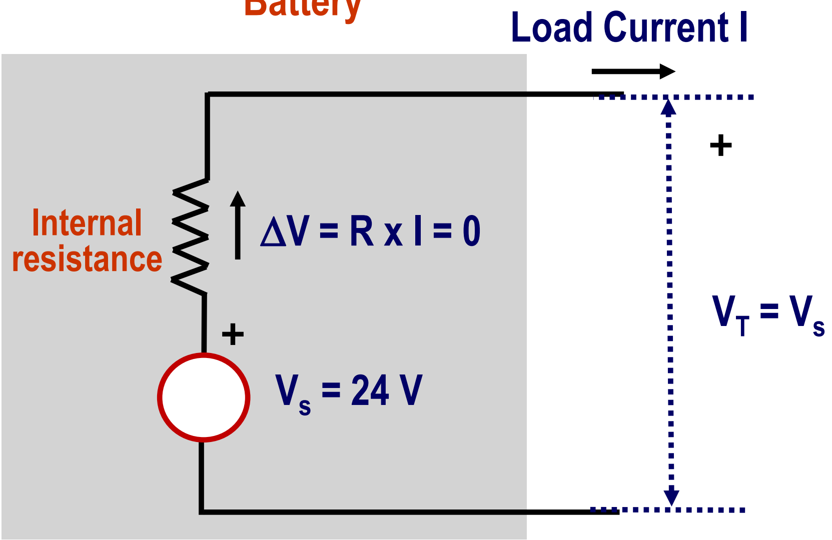
Definition

An ideal voltage source is the one that the terminal voltage does not change with the current drawn

An ideal voltage source has zero internal resistance

Battery





Non-Ideal (Real) Voltage Sources

Definition

A voltage source always has an internal resistance R connected in series with the source

Writing down KVL for the above cct;

$$V_s - \Delta V - V_T = 0$$

or

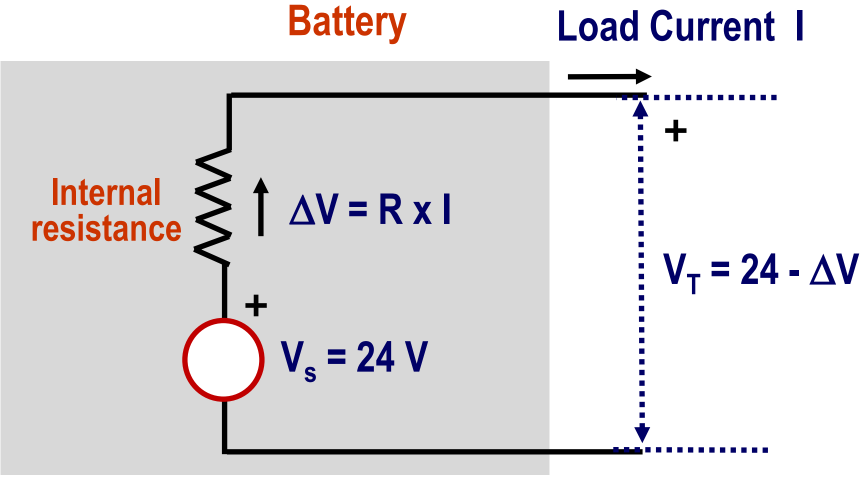
$$V_T = V_s - \Delta V$$

where,

$$\Delta V = R \times I$$

is called "internal voltage drop"

Terminal voltage V_T is reduced by ΔV

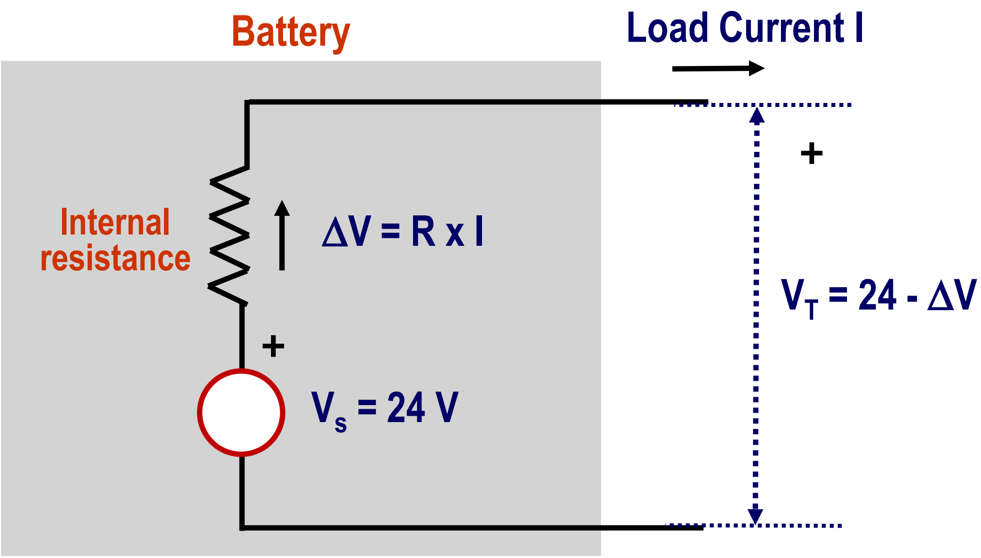


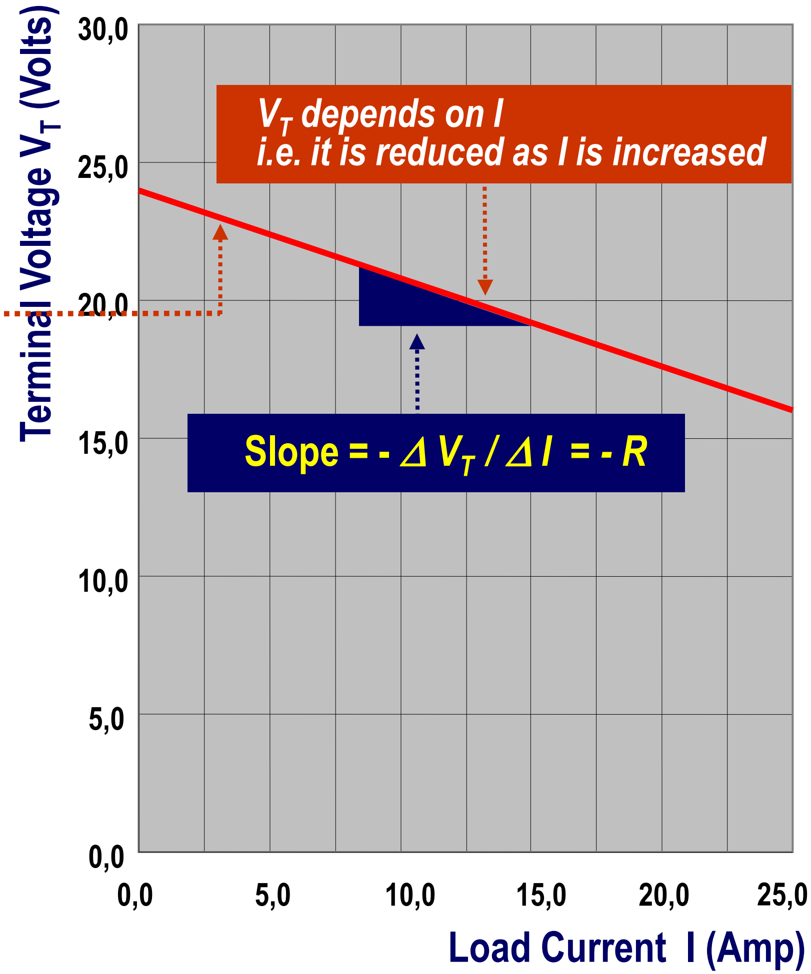
Non-Ideal (Real) Voltage Sources

Definition

Writing down KVL for the above cct;

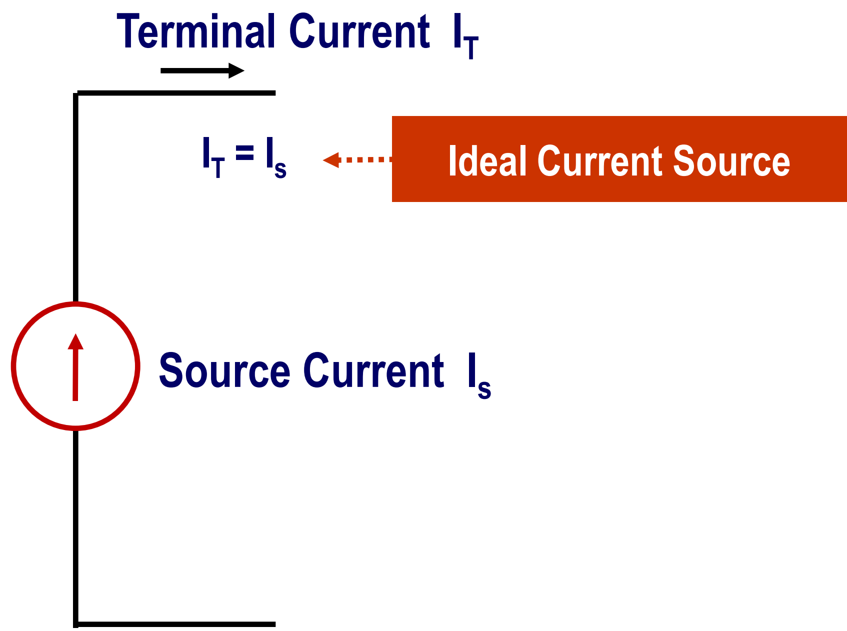
$$V_T = V_s - \Delta V$$
$$= Vs - R \times I$$





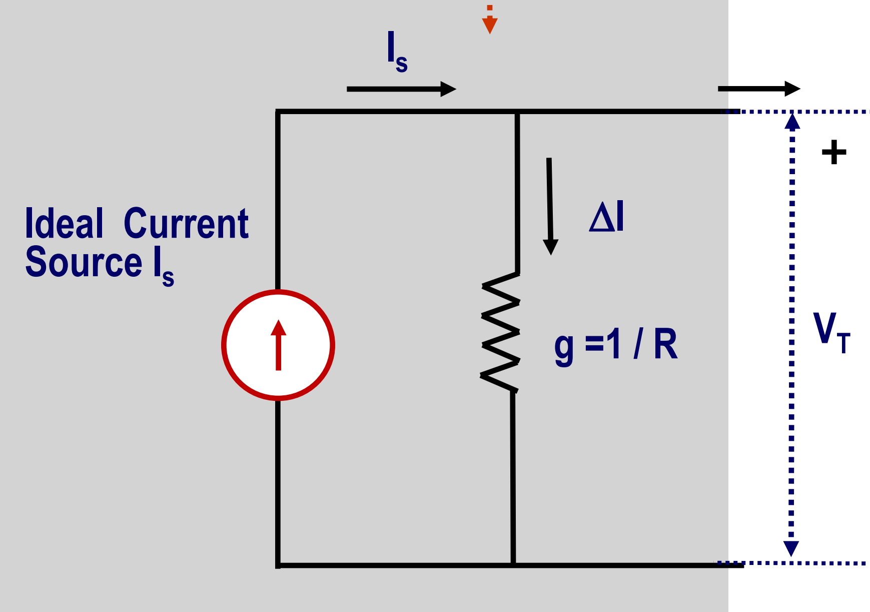
Ideal Current Source

Definition	An ideal current source is an element providing a constant current from its terminals
Ideal Current Source	



Non-Ideal (Real) Current Source

Definition	
Non-Ideal Current Source	A non ideal current source is an element with a current depending on terminal voltage



Terminal Current I_T

$I_T = I_s - \Delta I$

$I_T = I_s - g \times V_T$

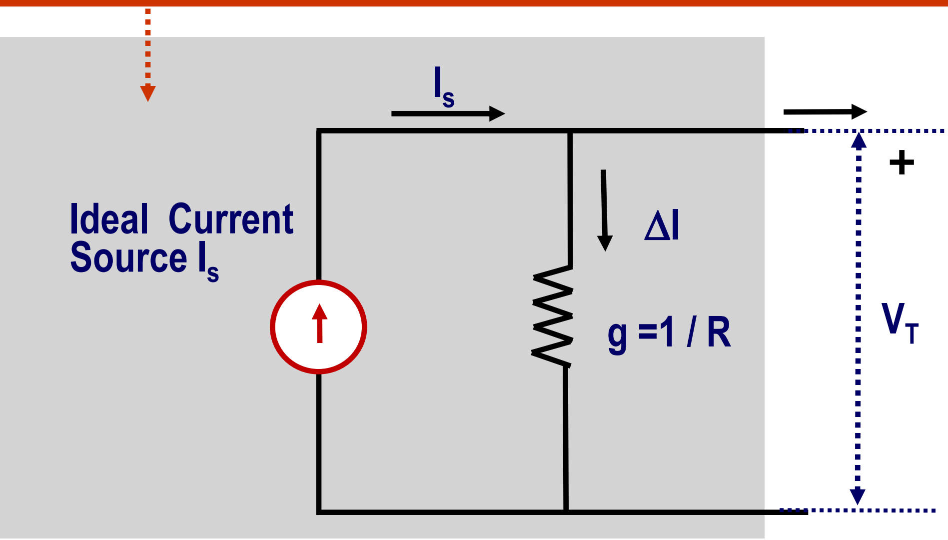
Current Source I_s

Non-Ideal (Real) Current Source

Definition: Non-Ideal Current Source

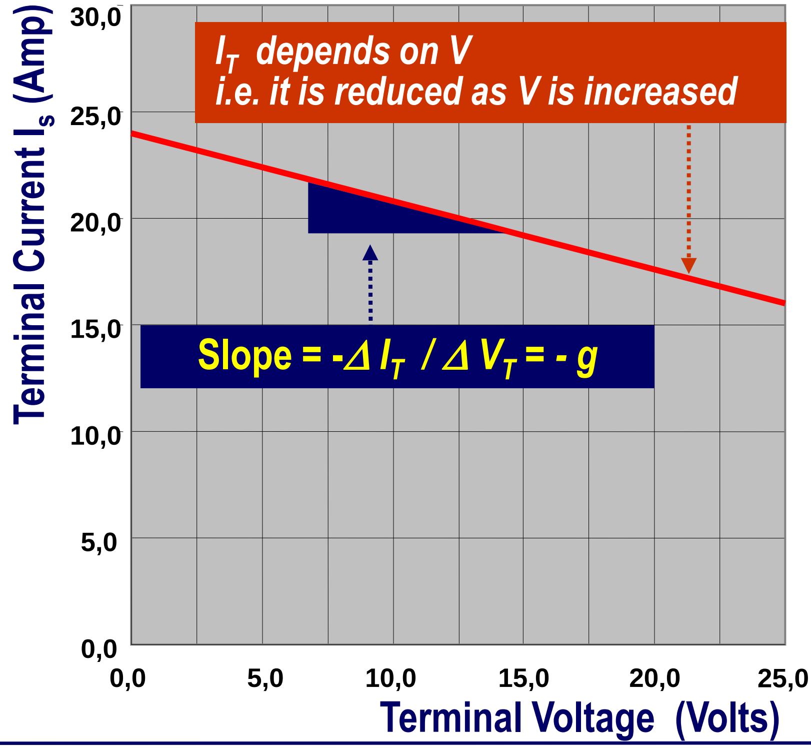
A non ideal current source is an element with a current depending on terminal voltage

Non-Ideal Current Source



Terminal Current I_T

$$I_T = I_s - \Delta I$$
$$I_T = I_s - g \times V_T$$



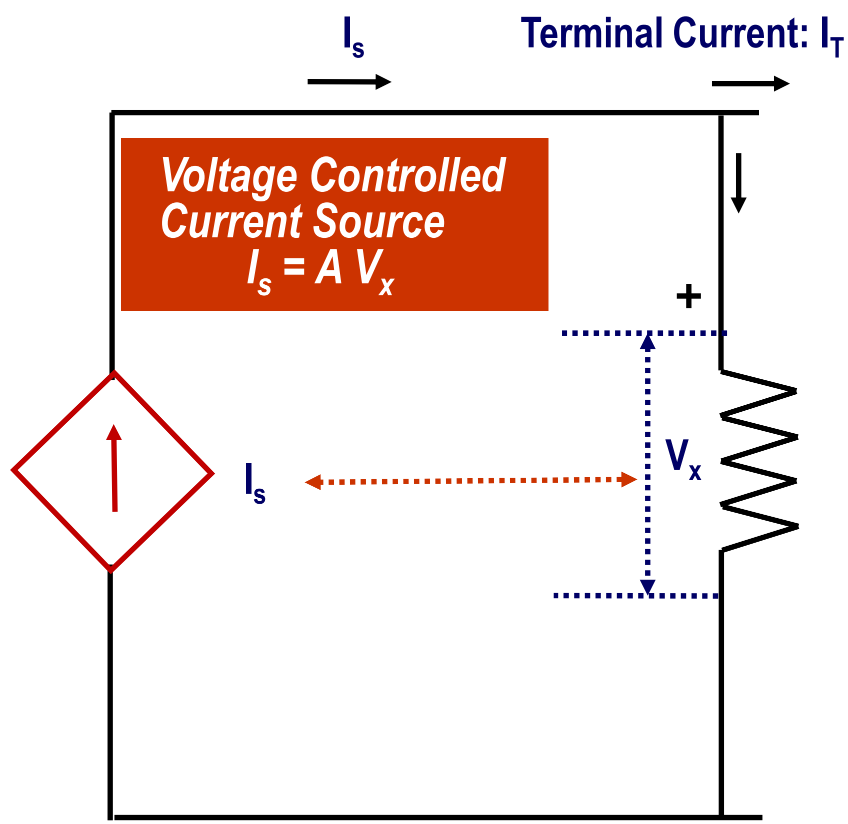
Controlled (Dependent) Sources

Definition: Controlled Sources

A controlled source is an element with a current or voltage depending on any other voltage or current in the circuit

Controlled Source: Current $I_s = A\,V_x$
A = Amplification coefficient

Voltage Controlled Current Source



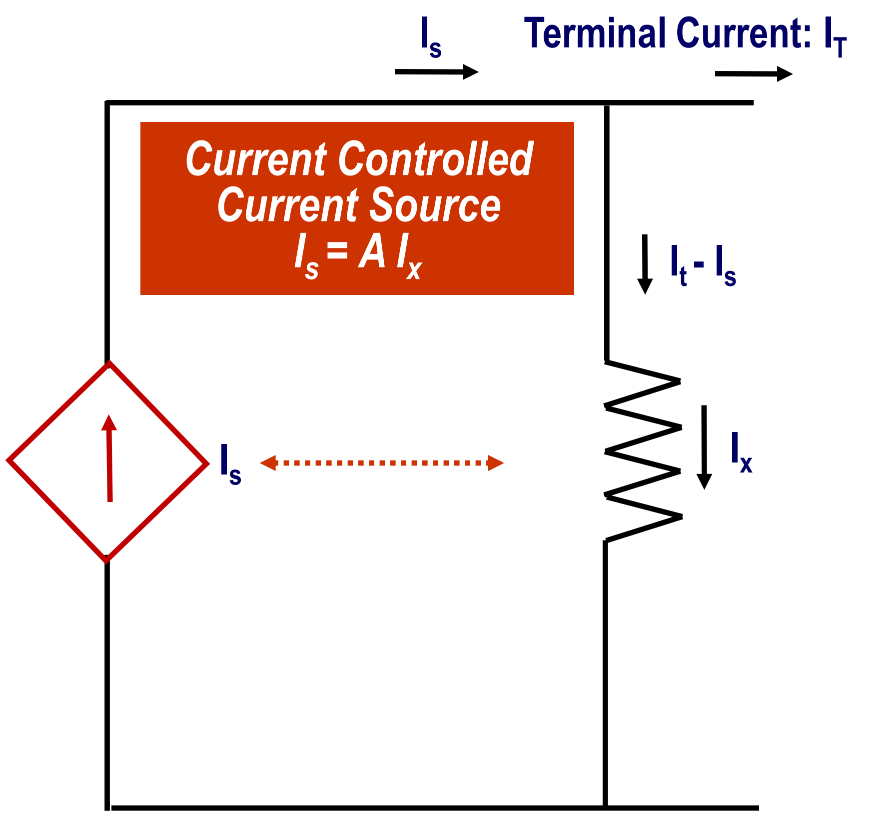
Controlled (Dependent) Sources

Definition: Controlled Sources

A controlled source is an element with a current or voltage depending on any other voltage or current in the circuit

Controlled Source: Current $I_s = A\, I_x$

Current Controlled Current Source



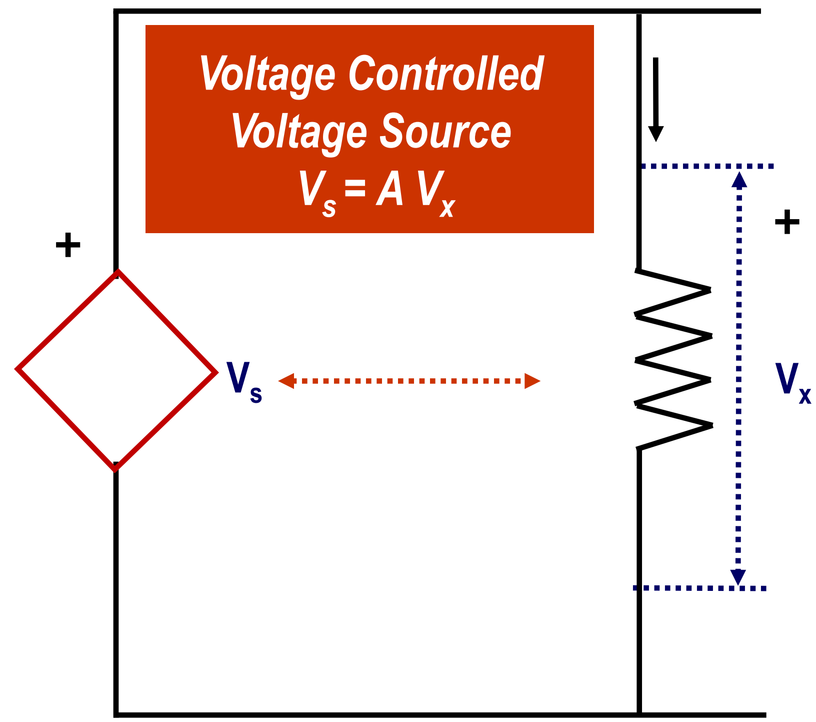
Controlled (Dependent) Sources

Definition: Controlled Sources

A controlled source is an element with a current or voltage depending on any other voltage or current in the circuit

Controlled Source: Voltage $V_s = A\,V_x$

Voltage Controlled Voltage Source



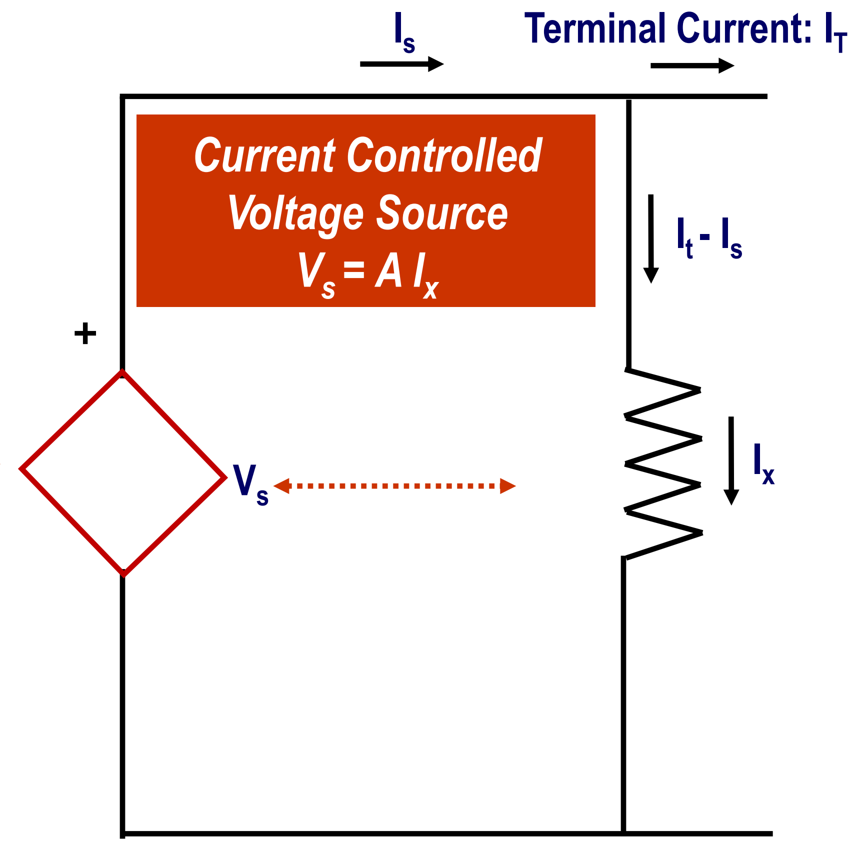
Controlled (Dependent) Sources

Definition: Controlled Sources

A controlled source is an element with a current or voltage depending on any other voltage or current in the circuit

Controlled Source: Voltage $V_s = A\, I_x$

Current Controlled Voltage Source



Example

Question

Solve the circuit on the RHS for current I_x

Solution

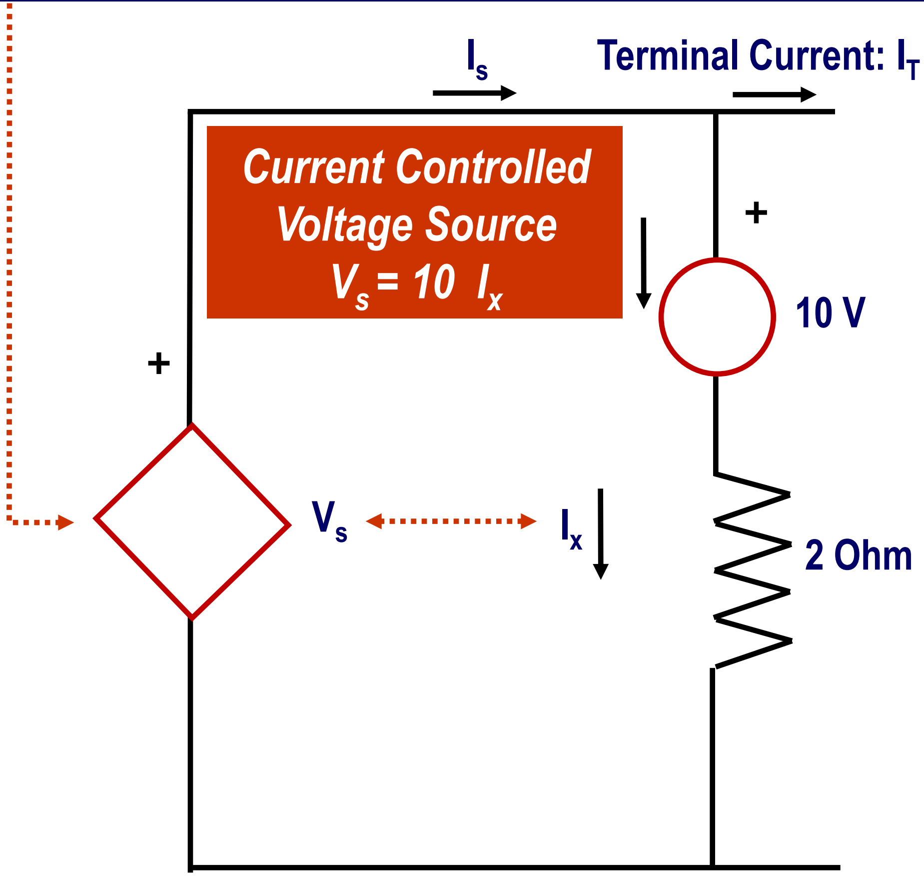
Write down KVL;

$V_s - 10 - 2\,I_x = 0$

$10\,I_x - 10 - 2\,I_x = 0$

$8\,I_x = 10 \rightarrow I_x = 10/8 = 1.25$ *Amp*

Current Controlled Voltage Source



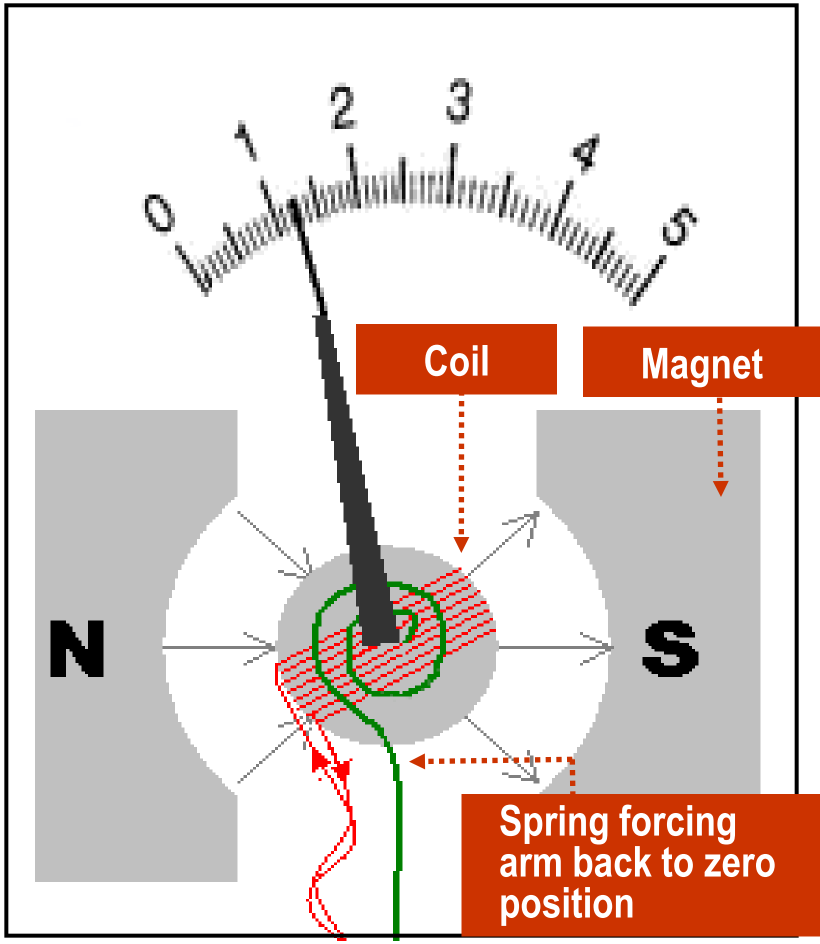
Measuring Devices - Ammeter

An ammeter is a measuring instrument used to measure the flow of electric current in a circuit. Electric currents are measured in amperes, hence the name

The word "ammeter" is commonly misspelled or mispronounced as "ampmeter" by some

The earliest design is the D'Arsonval galvanometer. It uses magnetic deflection, where current passing through a coil causes the coil to move in a magnetic field

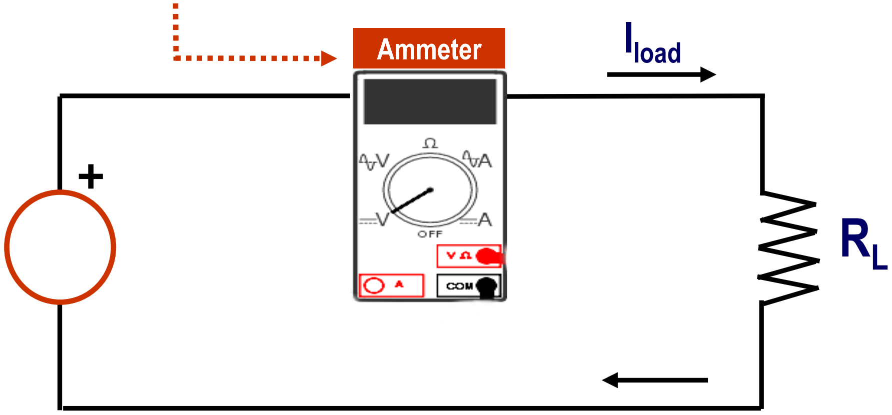
The voltage drop across the coil is kept to a minimum to minimize resistance in any circuit into which the meter is inserted

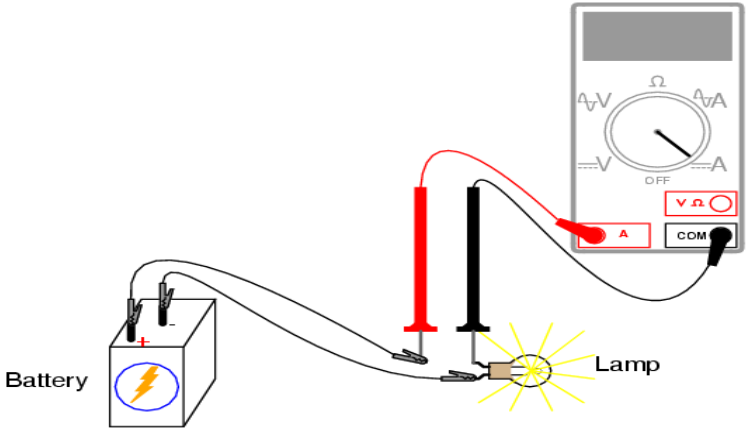


Measuring Devices - Ammeter

Ampere - Volt - Ohm (AVO)Meter

An ammeter is always series connected in the circuit measured

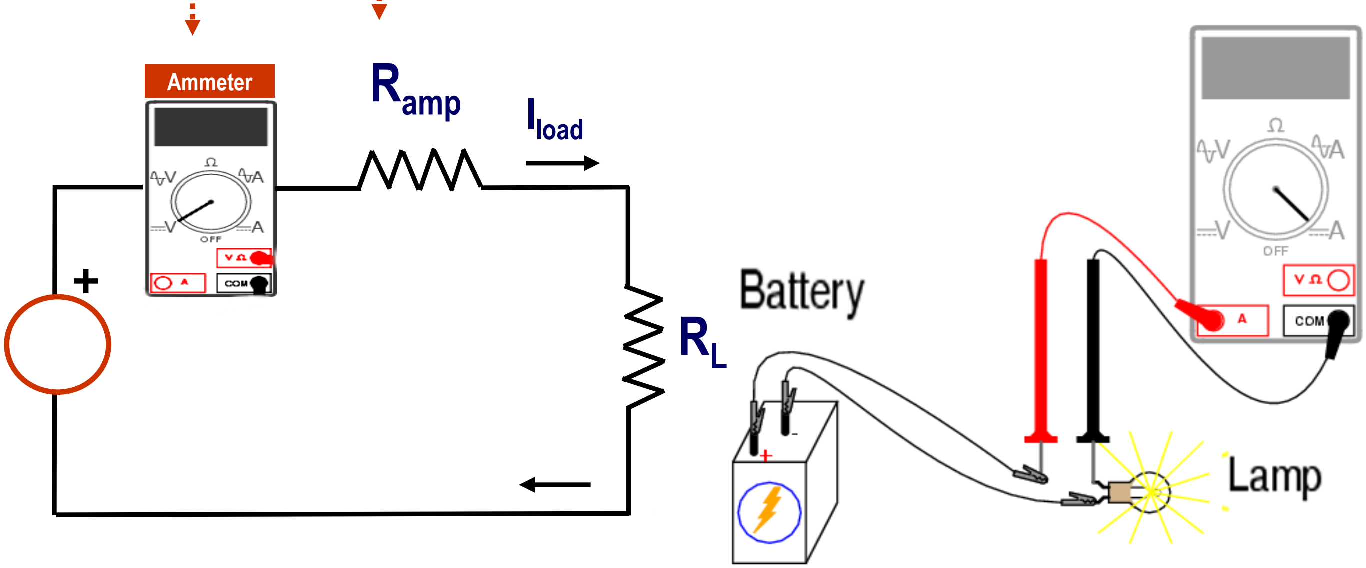




Measuring Devices - Ammeter

An ammeter is always series connected in the circuit measured

Internal Resistance of Ammeter



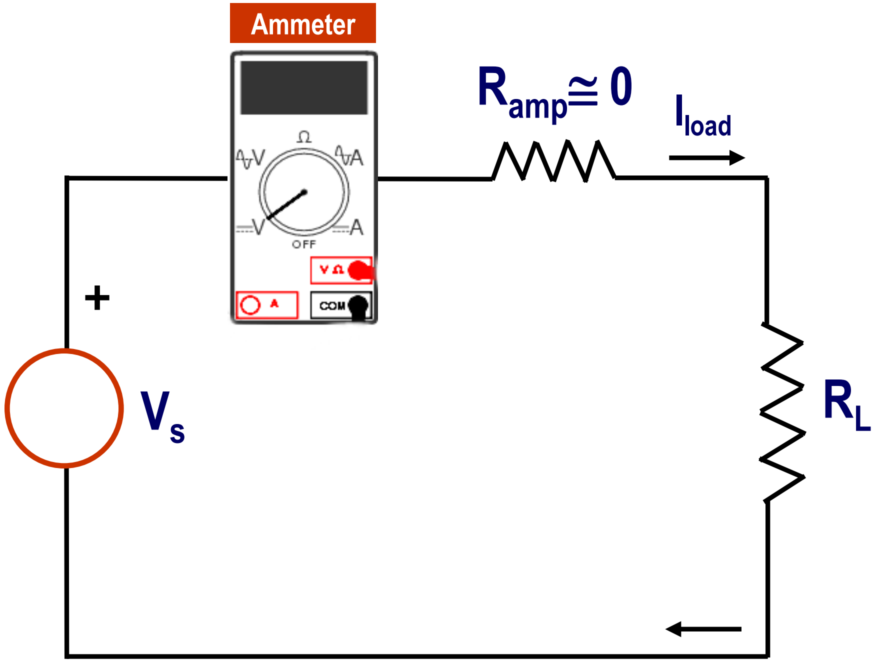
Ideal Ammeter

Definition

An ideal ammeter is the one with zero internal resistance (Short Circuit)

- An ideal ammeter behaves as a short circuit, i.e. $R_{amp} \cong 0$.
- An ideal ammeter has zero resistance so that the measured current is not influenced

No ammeter can ever be ideal, and hence all ammeters have some internal resistance



Ideal Ammeter

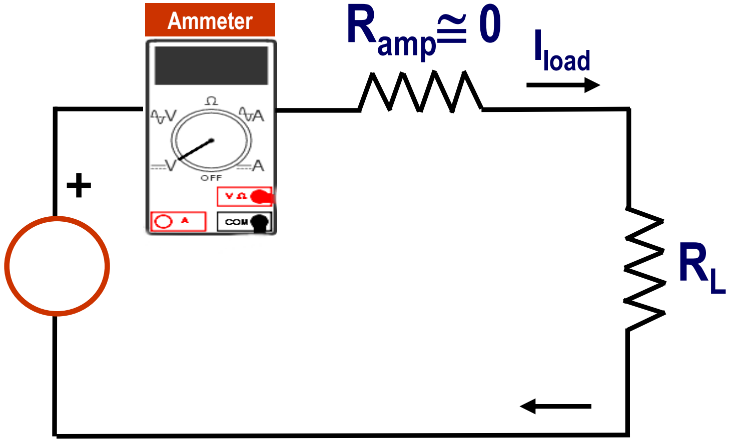
An ammeter should not influence the current measured

$$I = V_s / (R + R_{amp})$$

$$R_{amp} \cong 0$$

Hence,

$$I = V_s / (R + R_{amp}) \cong V_s / R$$



Non-Ideal (Real) Ammeter

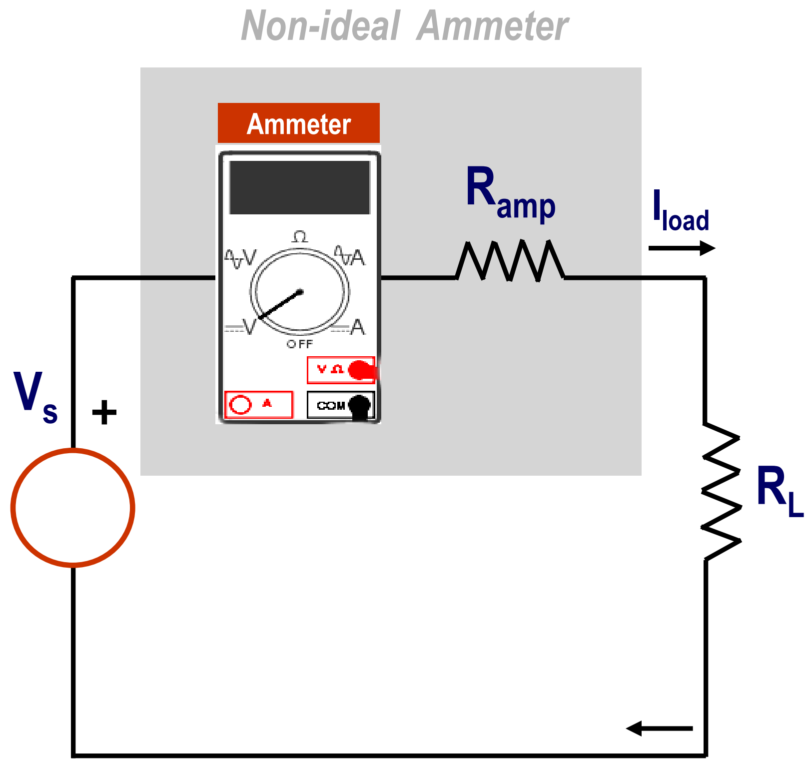
Definition

No ammeter can ever be ideal, and hence all ammeters have some internal resistance

A real (non-ideal) ammeter has always an internal resistance in series

- A non ideal ammeter behaves as a series resistance with: $R_{amp} \neq 0$
- Hence the the measured current is influenced (reduced)

$$\left.\begin{aligned} I_{load} &= V_s / (R + R_{amp}) \\ I_{load} &= V_s / R \end{aligned}\right\} \longrightarrow I_{load} < I_{ideal}$$

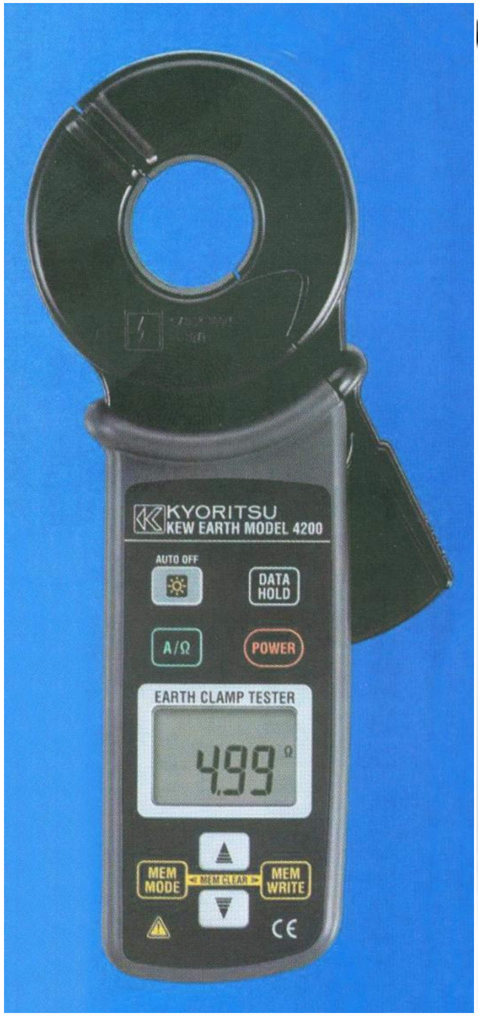


Measuring Devices – Clamp Ammeter

The Need for Clamp Ammeter

Sometimes the electrical service carried out by the circuit may be so vital that it can not be interrupted by breaking the line for a series connection of the ammeter

Ammeter shown on the RHS is a particular design for such circuits to measure current flowing in the circuit as well as resistance without braeaking the circuit



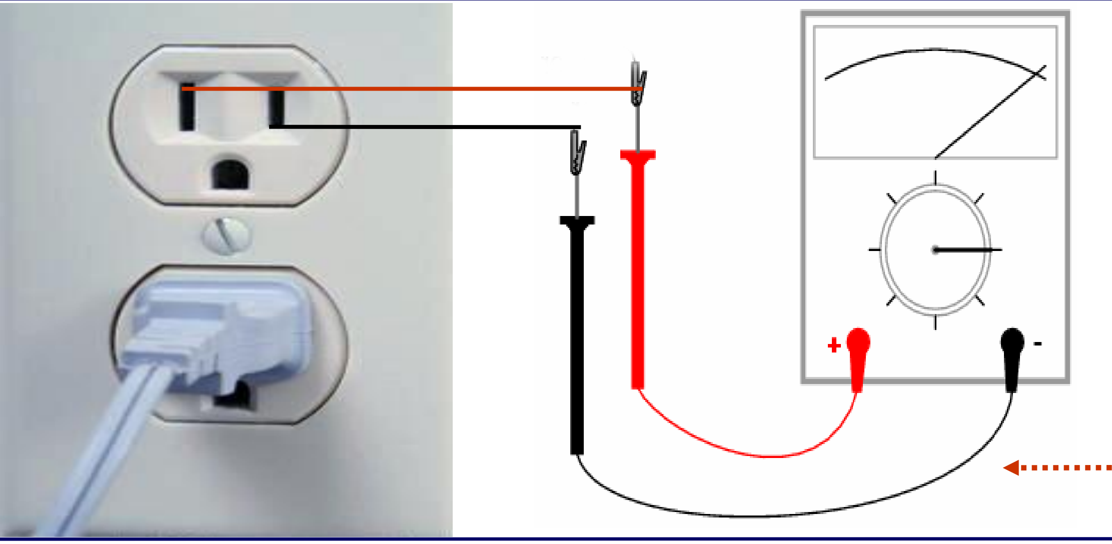
Measuring Devices - Voltmeter

A voltmeter has a high internal resistance so that it passes only a small current

An ideal voltmeter has a very large resistance so that the the circuit in which it has been placed is not disturbed

An ideal voltmeter is an open circuit

However, no voltmeter can ever be ideal, and therefore all voltmeters draw some small current



Voltmeter is always parallel connected to the terminals measured

Measuring Devices - Voltmeter

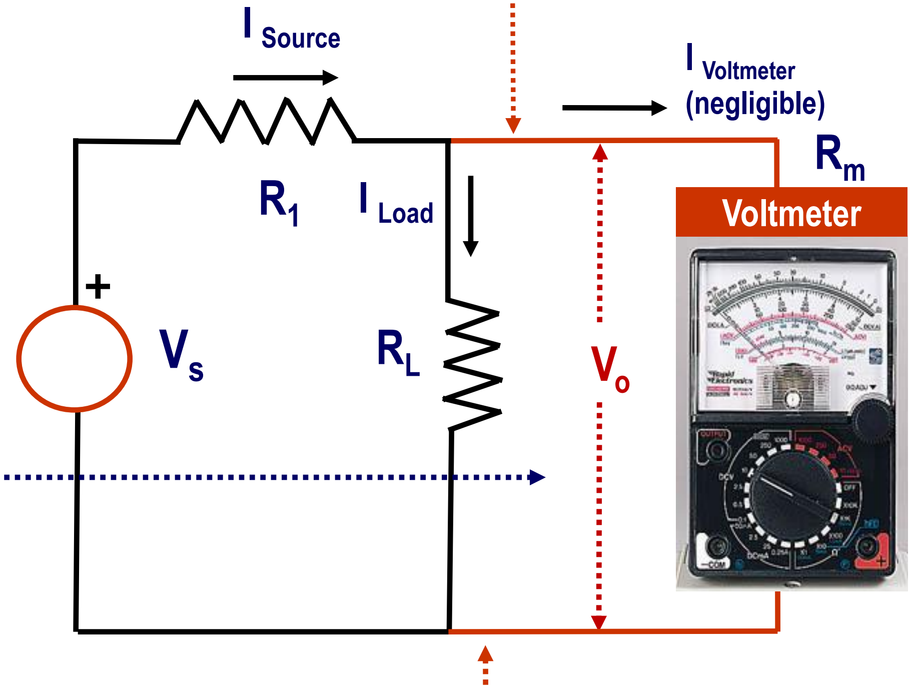
A voltmeter has a high internal resistance so that it passes only a small current

A voltmeter is always shunt (parallel) connected in the circuit that it measures

Measured voltage;

$$V_o = V_s \frac{R_L}{R_1 + R_L}$$

Red lines are not part of the circuit



Voltmeter is always parallel connected to the terminals measured

Ideal Voltmeter

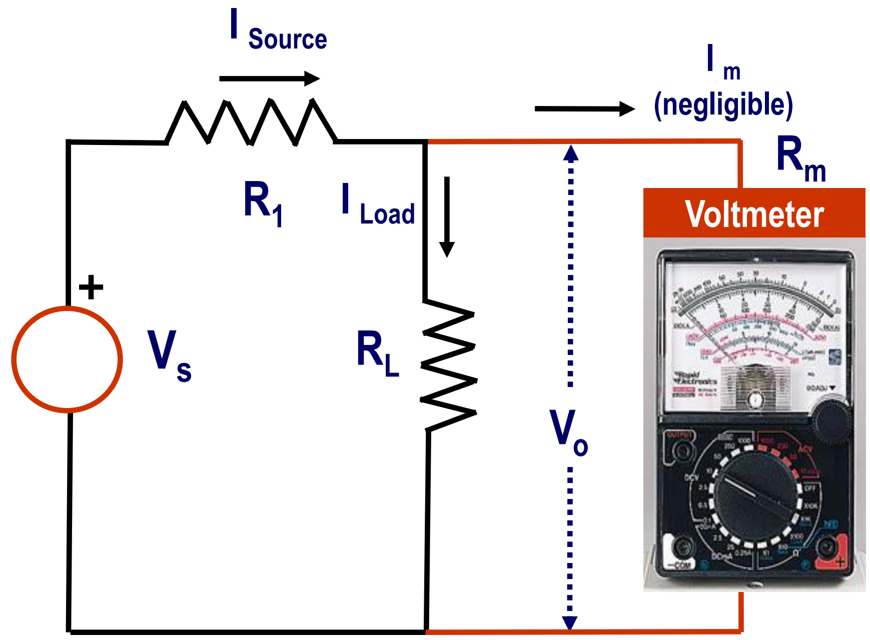
Definition

An ideal voltmeter is the one with infinite internal resistance (Open circuit)

An ideal voltmeter has a very large resistance, $R_m \cong \infty$. i.e. it behaves as an open circuit, so that the the measured circuit is not influenced

However, no voltmeter can ever be ideal, and therefore all voltmeters draw some current

A real voltmeter has a certain internal resistance so that it passes a certain current



Ideal Voltmeter

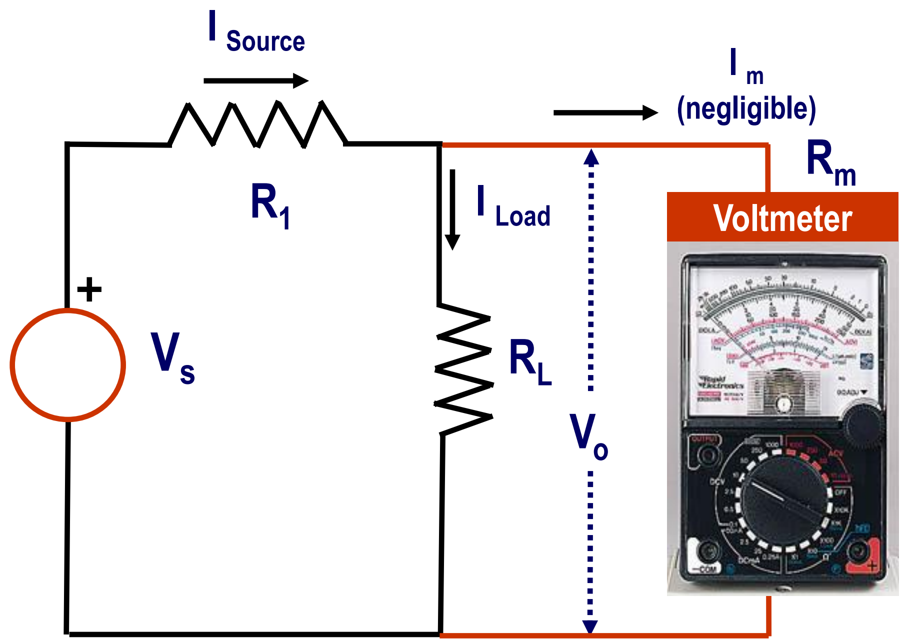
No voltmeter can ever be ideal, and therefore all voltmeters draw some current.

$R_m \cong \infty$ i.e. $R_m >> R_L$

$I_m << I_{Load}$

$I_{Source} = I_{Load} + I_m \cong I_{Load}$

$$V_o = R_L (I_{source} - I_m)$$
$$= R_L I_{Source} - \underbrace{R_L I_m}_{\text{Negligible}}$$
$$\cong R_L I_{Source}$$



Example

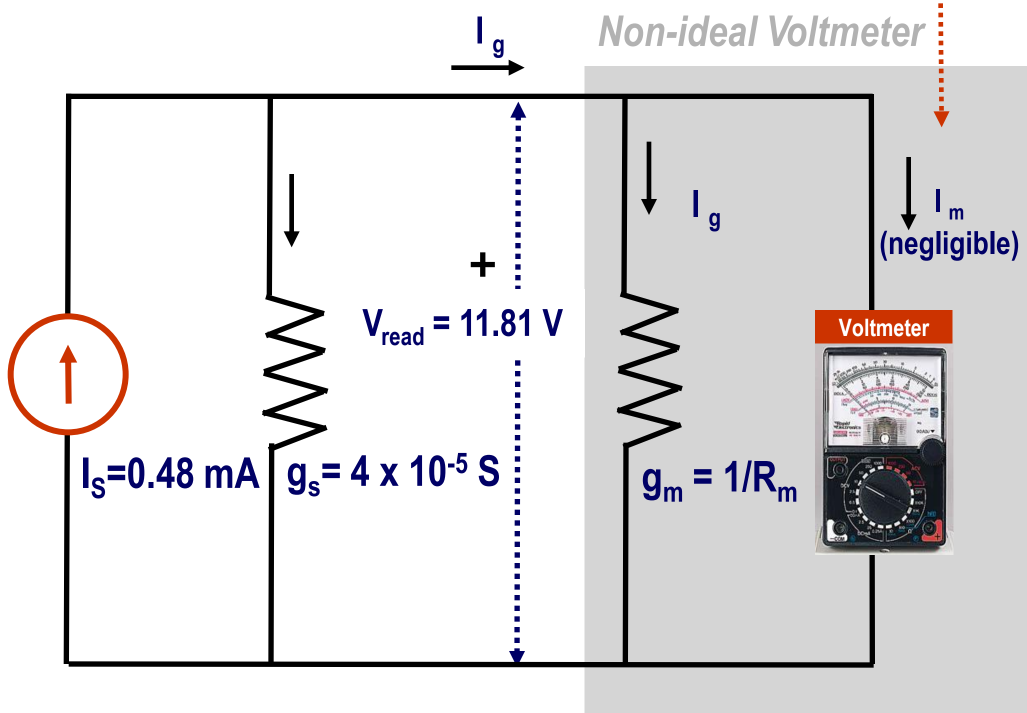
Problem

Calculate the internal admittance g_m of a voltmeter, if it reads 11.81 Volts when connected to a 0.48 mA current source with an internal admittance of
$g_s = 4 \times 10^{-5}$ Siemens

Siemens = 1/ Ω

Ideal Voltmeter

$I_m \cong 0$



Basic Principles of Electricity

Example

Problem

$R_s = 1 / g_s = 1 / (4 \times 10^{-5})$ *Siemens*

$= 10^5 / 4 = 25\ k\Omega$

$I_s \times R_{eq} = V_{read} = 11.81$ *Volts*

Hence,

$R_{eq} = V_{read} / I_s = 11.81 / (0.48 \times 10^{-3})$

$= 24607.17\ \Omega$

$R_{eq} = R_s \,//\, R_m$

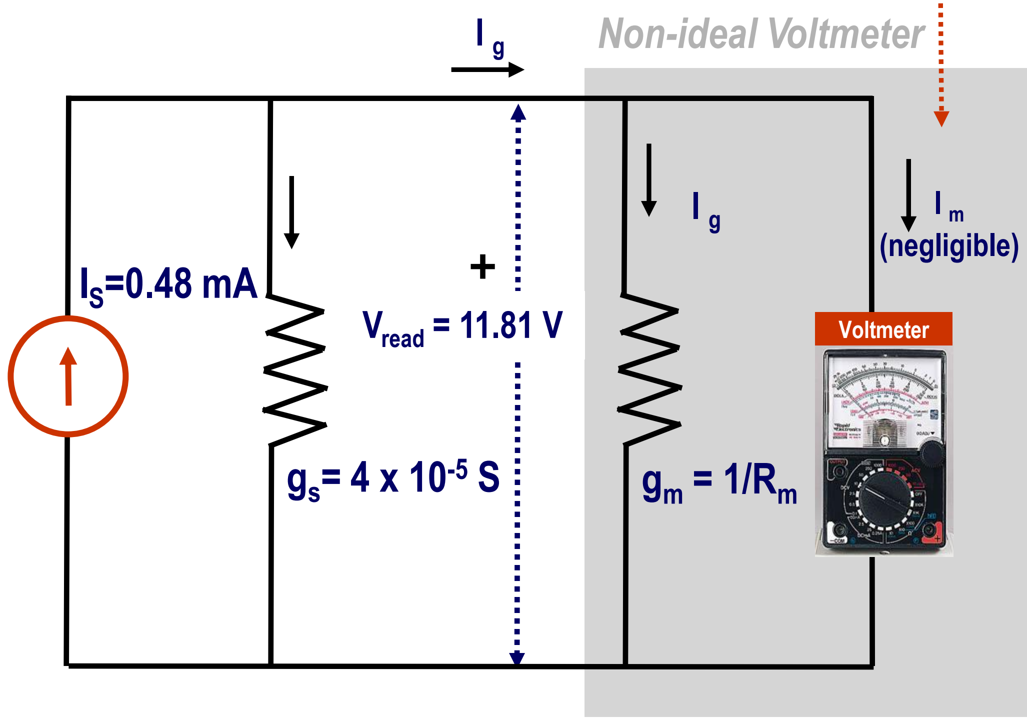
Hence,

$R_{eq} = (R_s \times R_m) / (R_s + R_m) = 24607.17\ \Omega$

$Rm = 155.39\ M\ \Omega$

Ideal Voltmeter

$I_m \cong 0$

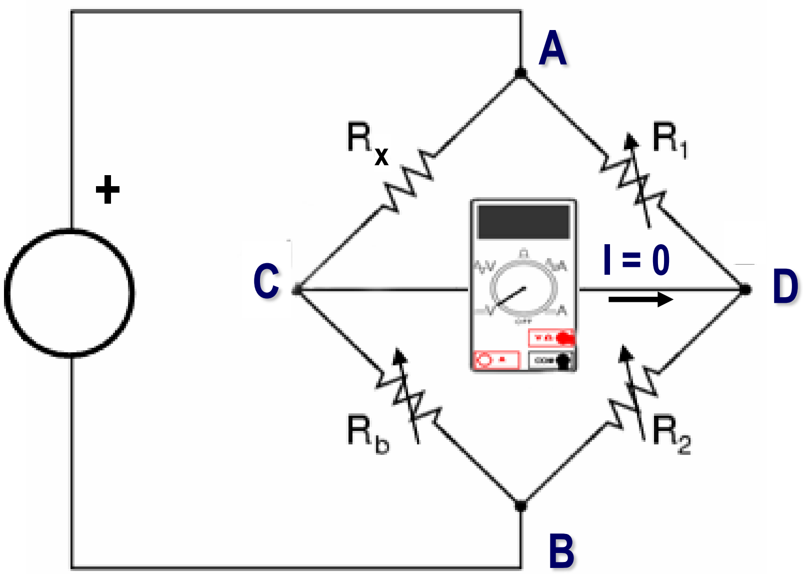


Advanced Measuring Devices

Power Quality Analyzer

Wheatstone Bridge

The Wheatstone Bridge is an electrical circuit used to determine an unknown resistance R_x by adjusting the values of known resistances, so that the current measured in the line connecting the terminals C and D is zero



Wheatstone Bridge

Principle

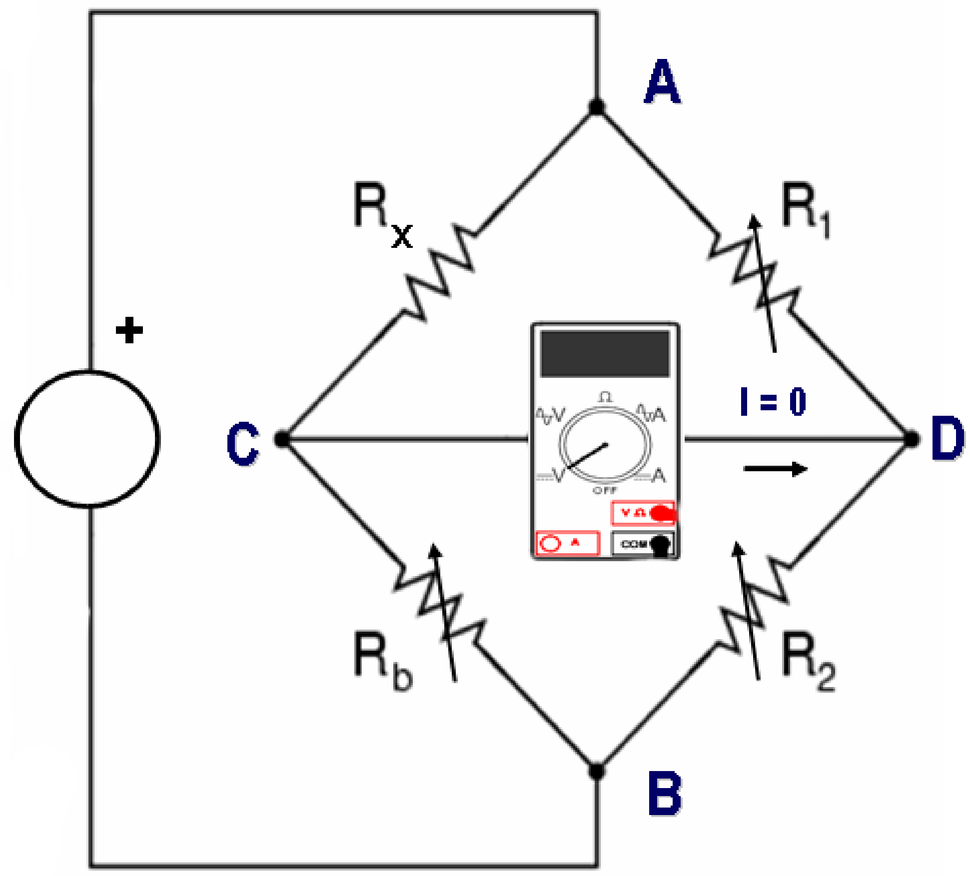
Adjust the resistances R_1, R_2 and R_b such that the ammeter connected between the terminals C and D reads zero current

Hence, the voltage difference between the terminals C and D is zero

$$\Delta V_{CD} = 0$$

or

$$V_C = V_D$$



Wheatstone Bridge

Principle

$$V_C = V_D$$

$$V_C = V_s\, R_b / (R_x + R_b)$$

$$V_D = V_s\, R_2 / (R_1 + R_2)$$

$$V_s\, R_b / (R_x + R_b) = V_s\, R_2 / (R_1 + R_2)$$

or

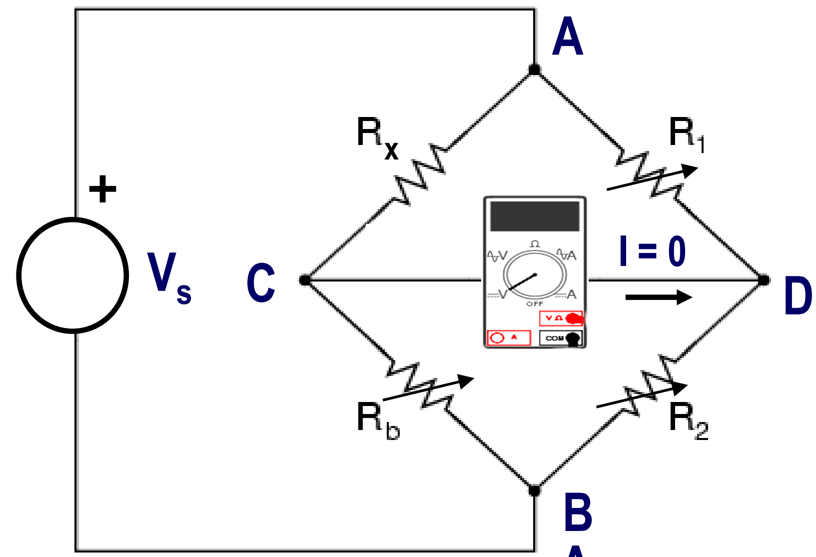
$$R_b / (R_x + R_b) = R_2 / (R_1 + R_2)$$

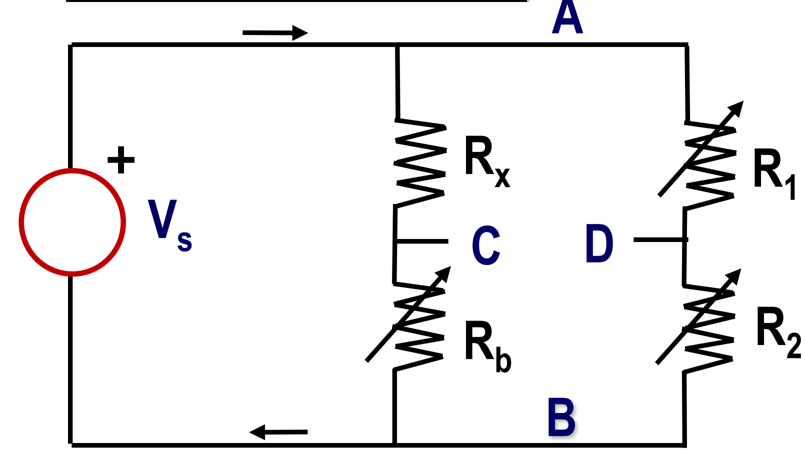
$$R_b (R_1 + R_2) = R_2 (R_x + R_b)$$

$$R_b R_1 + \cancel{R_b R_2} = R_2 R_x + \cancel{R_2 R_b}$$

or

$$R_x = R_b \times R_1 / R_2$$





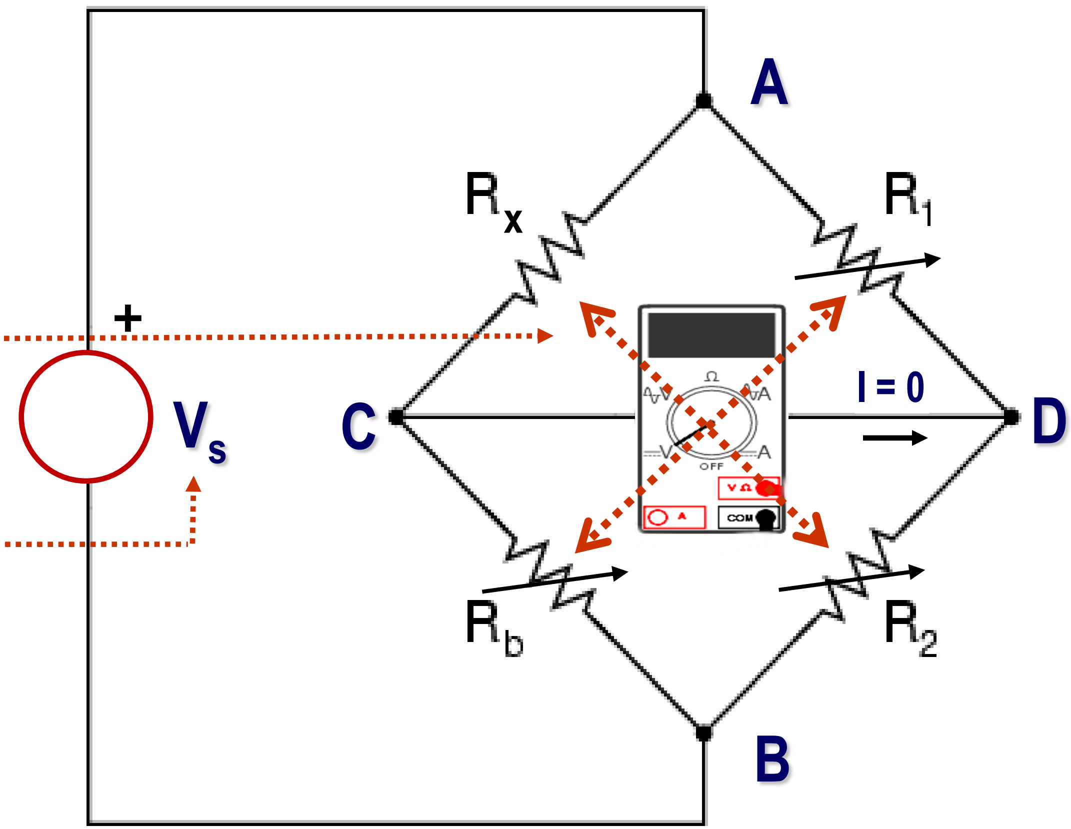
Wheatstone Bridge

Basic Rule

Cross multiplication branch resistances must be equal at balance condition

$$R_x \times R_2 = R_b \times R_1$$

Please note that voltage V_s is neither used, nor needed in the above equation, i.e. its value is arbitrary



Wheatstone Bridge

Example

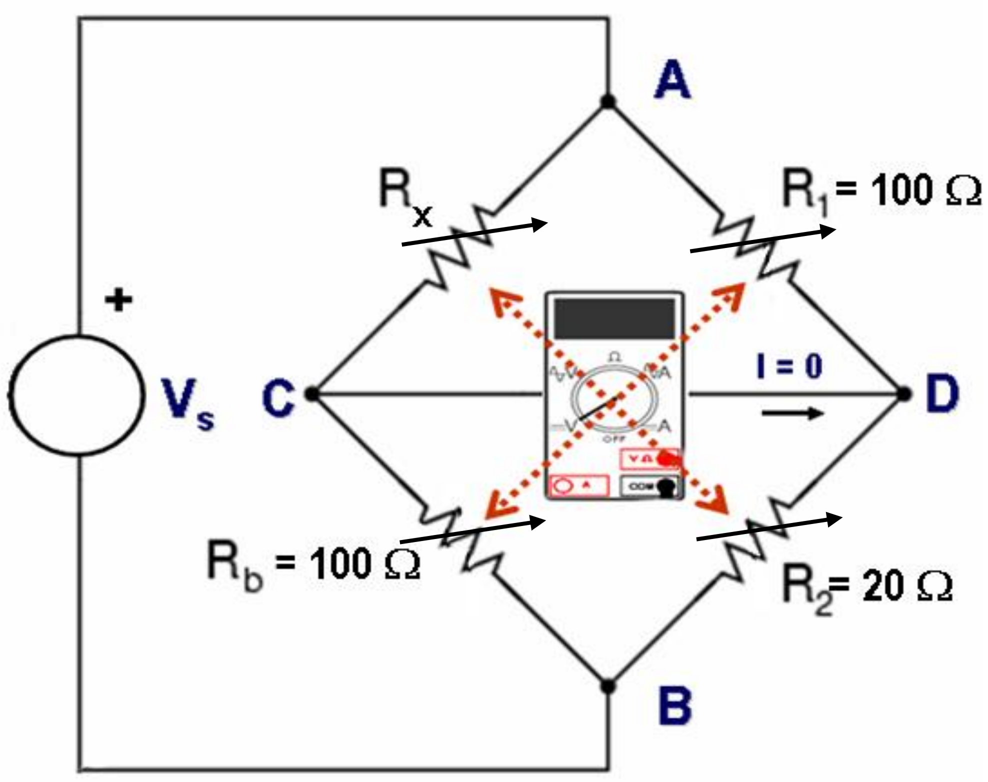
Calculate the value of unknown resistance R_x in the balanced Wheatstone Bridge shown on the RHS

Cross multiplication of branch resistances must be equal at balance condition:

$$R_x \times R_2 = R_b \times R_1$$

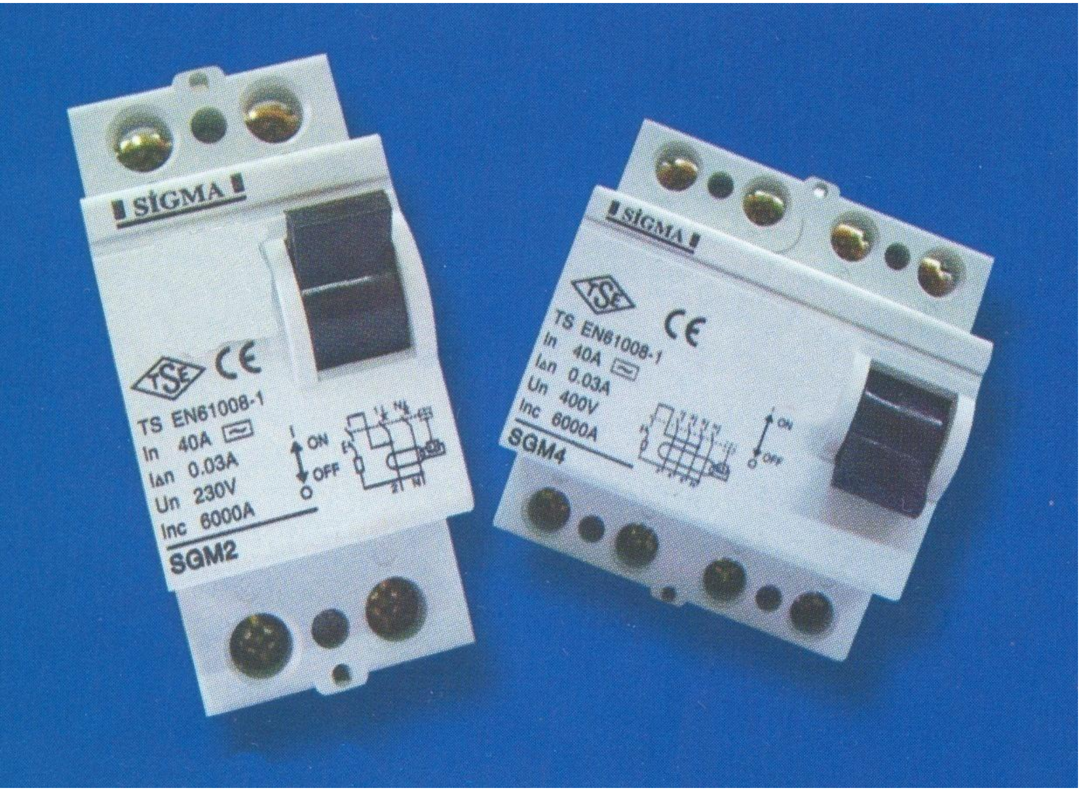
$$R_x = R_b \times R_1 / R_2$$

$$= 100 \times 100 / 20 = 500 \text{ Ohm}$$

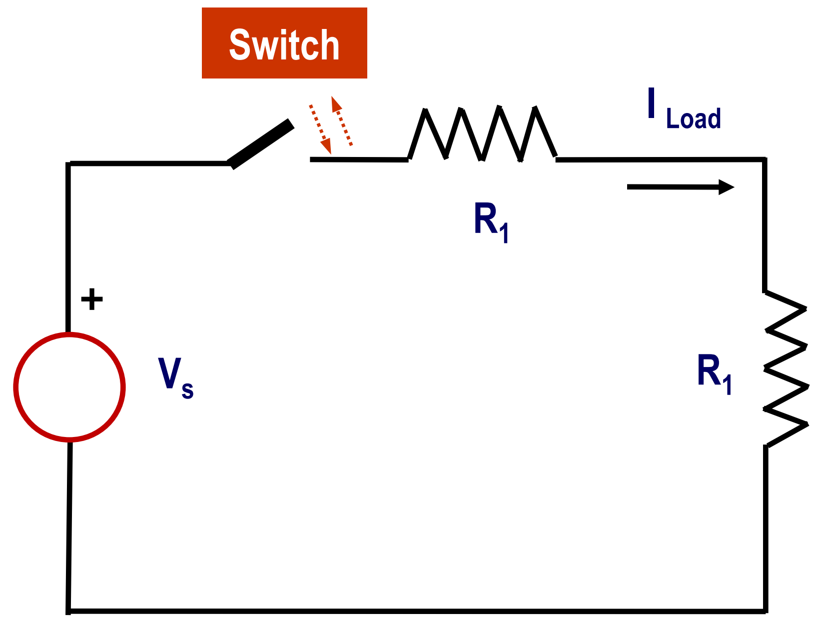


Switch - Circuit Breaker

Switch or Circuit Breaker



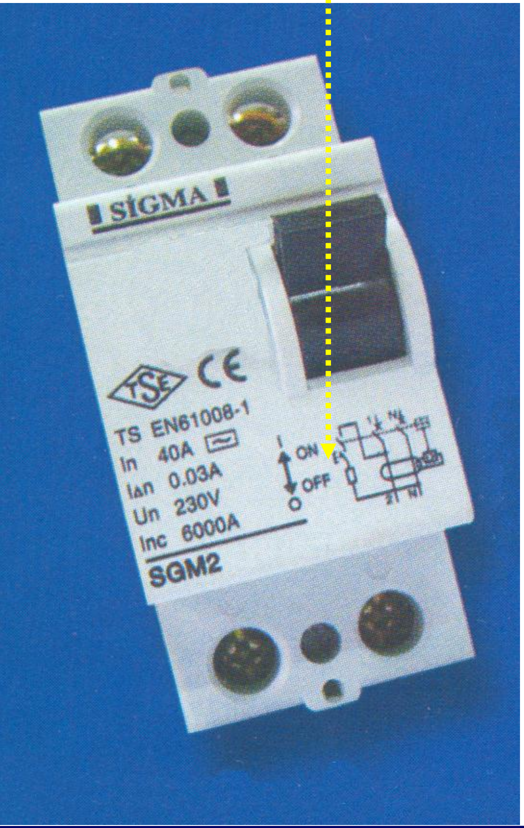
Switch or circuit breaker is a device used to open an electrical circuit manually or automatically by an electronic relay system

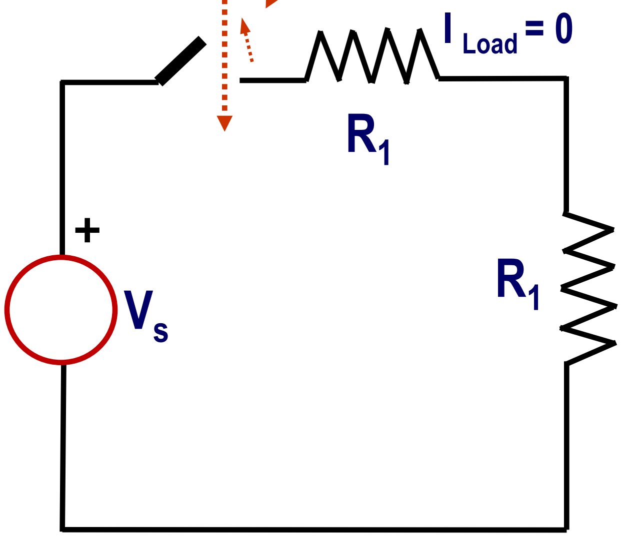


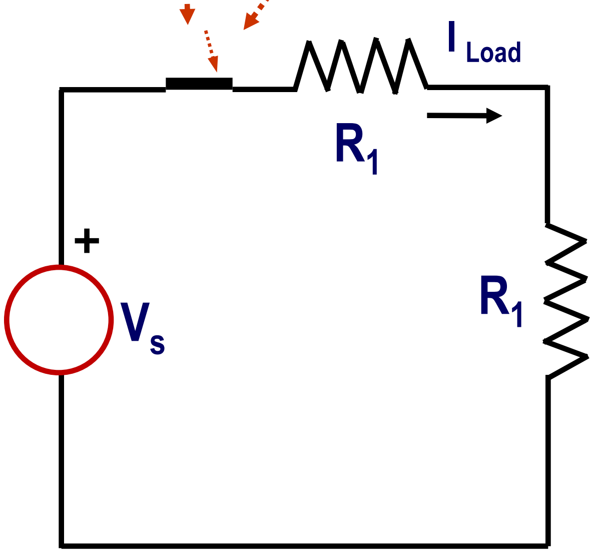
Basic Principles of Electricity

Meaning of "Open" and "Closed" (Highly Important)

Breaker	Open Circuit or Switch		Closed Circuit or Switch	
Open (On), Closed (Off)	Open Circuit	Open (Off) Switch	Closed Circuit	Closed (On) Switch



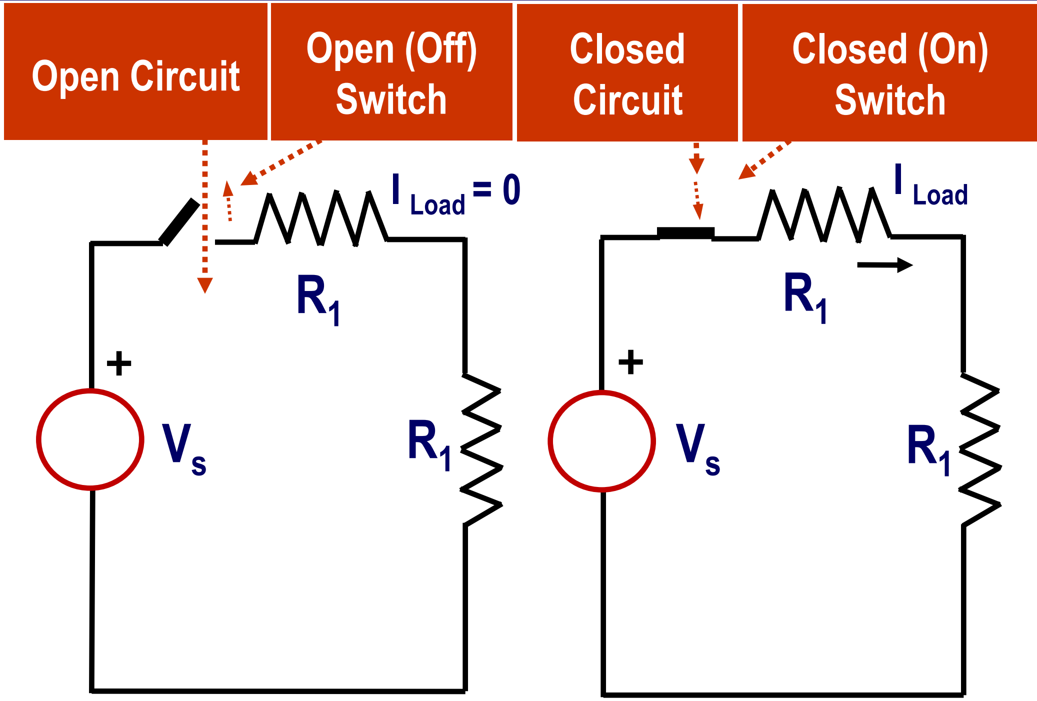




"Closed Switch (On)" does NOT mean that there is no voltage (current) in the circuit !

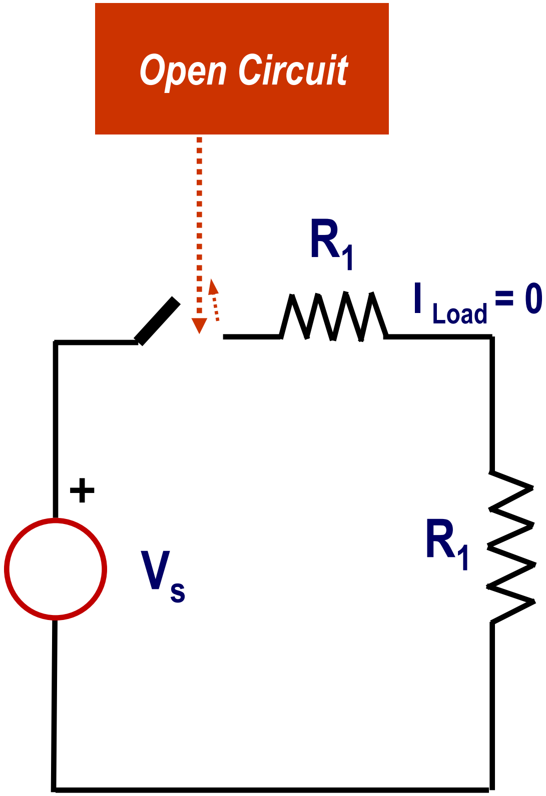
Thermal-Magnetic Circuit Breaker

220 Volt, 63 Amp. Thermal-Magnetic (Molded-Case) Breaker



"Closed Switch (On)" does NOT mean that there is no voltage (current) in the circuit !

Medium Voltage (36 kV) Vacuum Circuit Breaker



Vacuum tube enclosing breaker poles

Tripping buttons

Spring handle (taken off)

METU

Basic Principles of Electricity

Did everbody understand the Basic Principles of Electricity ?