Ankara University
Engineering Faculty
Department of Engineering Physics

PEN207

Circuit Design and Analysis

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Chapter-1

Electric Circuits and Circuit Elements (1/2)

Chapter-1: Electric Circuit and Circuit Elements

- Electric Charge
- Current
- Potential Difference
- Electrical Energy, Work and Power
- Power Sources and Circuits Elements
- Resistance: Ohm’s Law
- Inductance
- Capacitance
- Fundamental Circuit Laws: Kirchhoff’s Laws

Chapter-1: Part One

- Electric Charge
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- Resistance: Ohm’s Law
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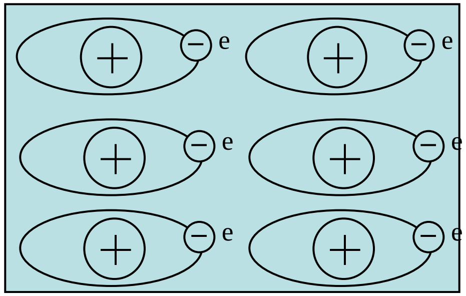
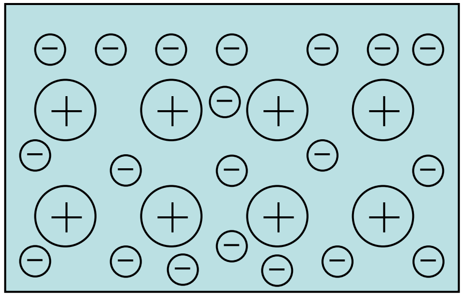
- Fundamental Circuit Laws: Kirchhoff’s Laws

Conductor and Insulators





Dielectrics(Insulators)

Free carrier density (n): **0** cm^{-3}

q=0, **I=0**

No net charge, no free carriers!

Glass
Ceramics
Plastic

Metal (Conductors)

Free carrier density (n): $\mathbf{10^{23}}$ cm^{-3}

q=0, **I≠0**

No net charge, but free carriers

Aluminium
Copper
Gold

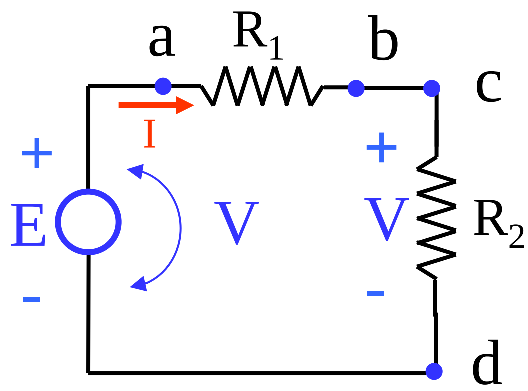
Conductivity: $\sigma = nq\mu$

Resistivity: $\rho = \frac{1}{\sigma} = \frac{1}{nq\mu}$

n: Free carrier density
q: electron's charge
μ: mobility

Definition: Current and Voltage

Current and Potential Difference (or Potential or Voltage)

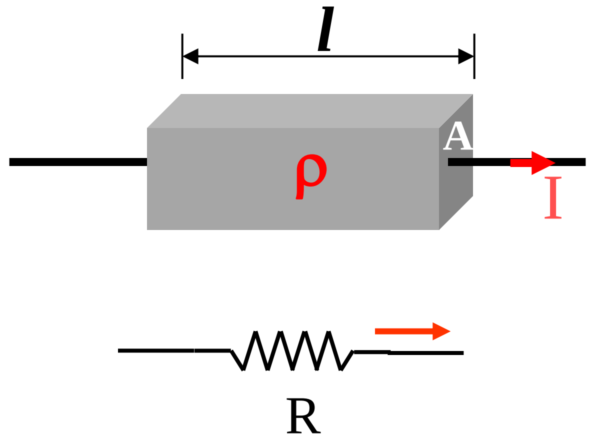


I: Current (unit Ampere)
E: Electromotor Force (Power Supply) - (unit Volt)
V: Potentil Difference (Measured btw two points in circuit) - (unit Volt)

Color Code used in this class :
Current (I)
Potential Difference (E,V)

Uppercase letters: For constant current (I) and Potential (E, V)
Lowercase letters: For current (i(t)) and potential (e(t), v(t)) changing in time

Definitions



Resistivity:

$$\rho = \frac{1}{\sigma} = \frac{1}{nq\mu}$$

l= Length

A=Cross Sectional Area

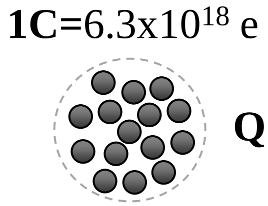
Resistivity is resistance of a specific material (specific electrical resistance, or volume **resistivity**)

Physics		**Circuit**
Resistivity (**ρ**)	$R = \rho\left(\frac{l}{A}\right)$	Resistance (**R**)
Electric Field (**E**)	$V=El$	Potential (**V**)
Current Density (**J**)	$I=JA$	Current (**I**)

Electric Charge

Current is the movement of electric charges so we have to define charge first

Unit of charge (symbol Q) is **Coulomb** (C)



Charge of an electron= -1.6×10^{-19} C

In order to have **1 Coulomb** charge we have to bring 6.3×10^{18} electrons together

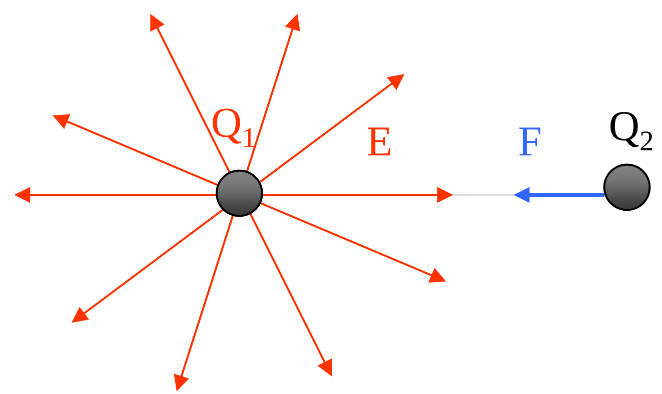
Force between charges (F)

Coulomb's Law $$F = k\frac{Q_1.Q_2}{d^2}$$

In physics forces can be expressed in terms of field:

$$F = \left(k\frac{Q_1}{d^2}\right).Q_2 = E.Q_2$$

Electric Field (E) $$E = k\frac{Q_1}{d^2}$$



Current

In engineering we interest in charges in motion because only moving charges transmit energy.

Current, is the flow of charges

Let’s consider charge (Q) passing through a wire with a constant rate;

Capital letter I used for current from the French word **intensitie**

Current can be defined: $I = \frac{Q}{t}$

If the number of charges chances with time then we can define *instantaneous current i(t):*

Instantaneous current: $i(t) = \frac{dq}{dt}$

Number of charges: $q = \int i(t)dt$

Notation
I, Q (Constant rate)
i, q (changing with time) i(t), q(t)

Current

Unit of electric current in SI unit system is ***ampere*** (symbol A)

[one ampere is the flow of electric charge at the rate of one coulomb per second]

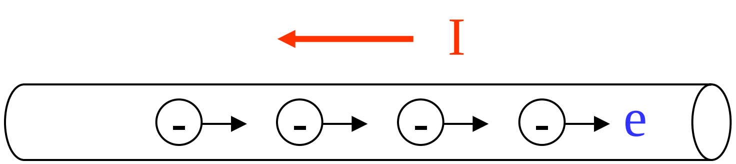
$$[amper] = \frac{[coulomb]}{[s]} \qquad 1A = \frac{1C}{1s}$$

Homework-1.1:
If the current passing through a wire is 1 µA how many electrons are flowing in 4 sec?

We have to also define the direction of current as well as its magnitude.

The direction of <u>positive</u> charges is assumed the **direction of current**.

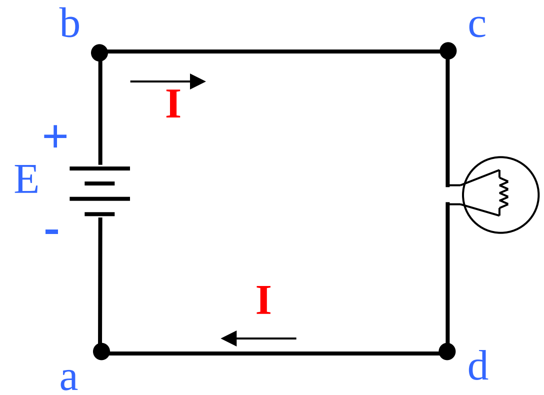
In fact in metals (or conductors) moving charges are negatively charged electrons, so current direction is the opposite direction of free carriers.



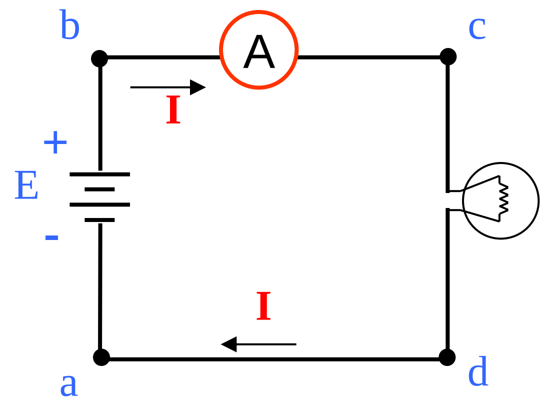
Measurement of Current

Current through a branch of a circuit does not change. Measuring instrument called **Ammeter** is used to measure current in a circuit.

Ammeters are connected **in series with the circuit**. The **resistance of an Ammeter is zero (ideally)**.



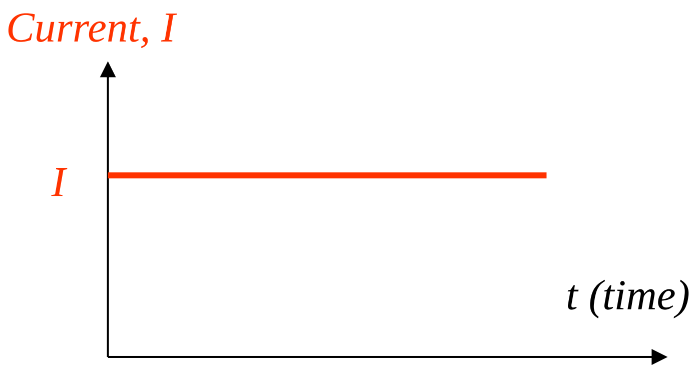
$I_{ab} = I_{bc} = I_{cd} = I_{da} = I$



Measurement of current

Different Forms of Current

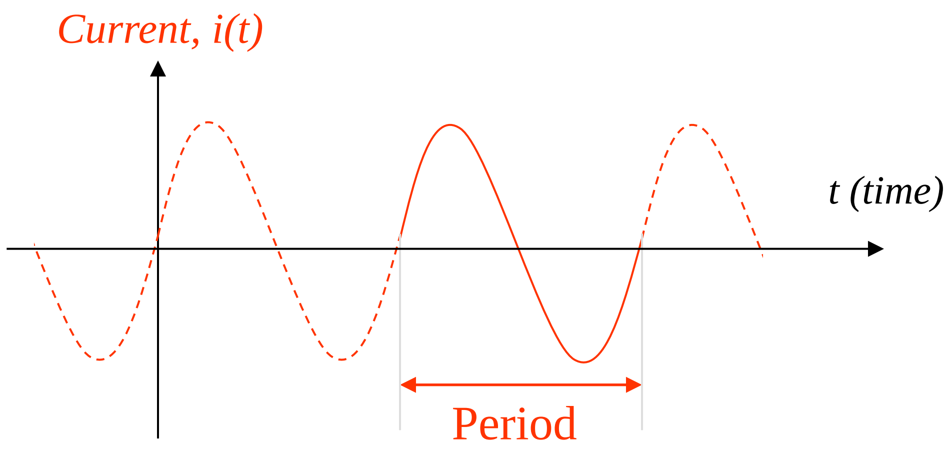
Direct Current (DC)



Direct current, flow of charges are in one direction number of charges does not change

Battery and accumulator are example of DC current

Alternating Current (AC)



Alternating Current , current that direction and value is changing periodically

period=1/frequency

Unit:

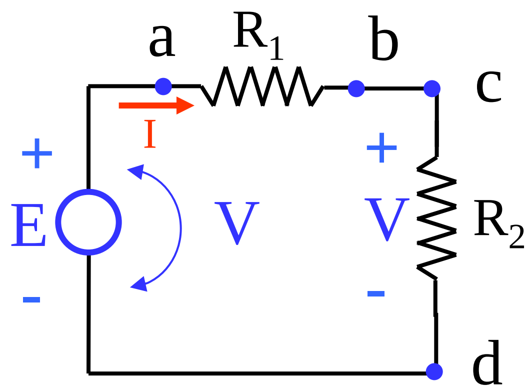
periyod [time]=second

frequency [1/time]=1 /second= hertz (Hz)

In Turkey mains voltage (grid power voltage) is 220V and frequency is 50 Hz

Definition of Potential Difference or Voltage

Potential Difference (or Potential or Voltage)

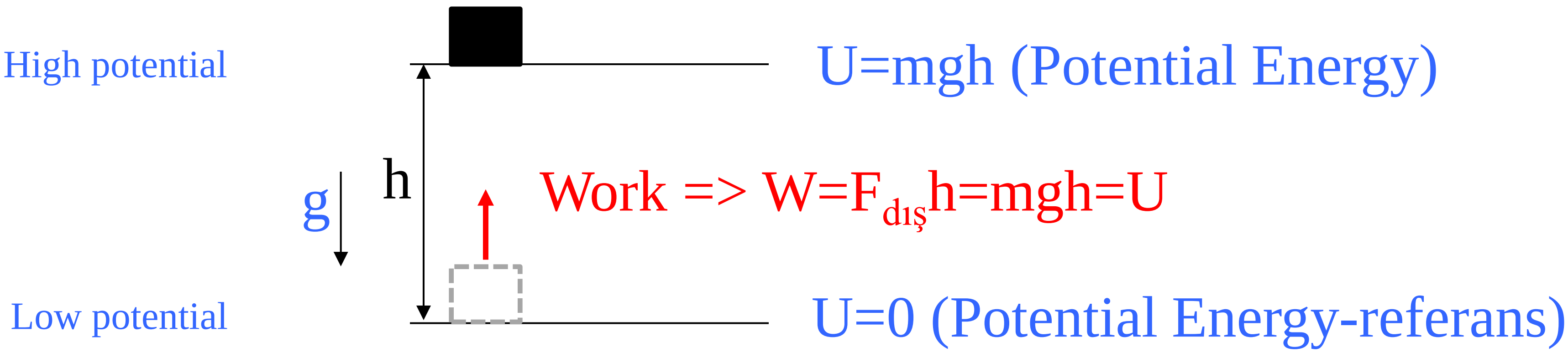


E: Electromotor Force (Power Supply) - (unit V)
V: Potentil Difference (Measured btw two points in circuit) - (unit V)

Color Code used in this class :
Potential Difference (E,V)

Uppercase letters: For constant Potential (E, V)
Lowercase letters: For potential (e(t), v(t)) changing in time

Potential Energy and Potential Difference (Mech)



Potential Energy (U): $U=mgh$

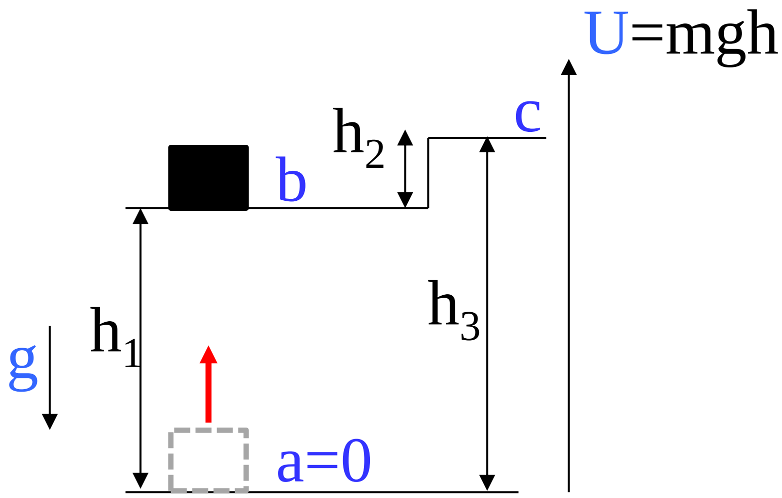
Potential (V): $V=U/m$ => $V=U/m=mgh/m=gh$

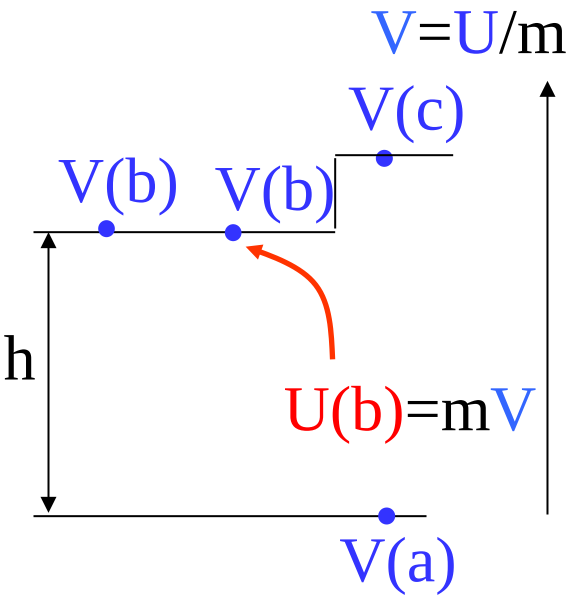
(Potential energy per unit mass)

$V=gh$ **Potential is proportional with height.**

Relation btw **Potential Energy & Potential difference** $U=mV$

Potential Energy and Potential Difference





Potential Energy (U): $U=mgh$

Potential (V): $V=U/m$ =>

(Potential energy per unit mass)

$$V=U/m=mgh/m=gh$$

Potential difference is a measure of the potential energy independent of mass

$$U(h)=mV(h)$$

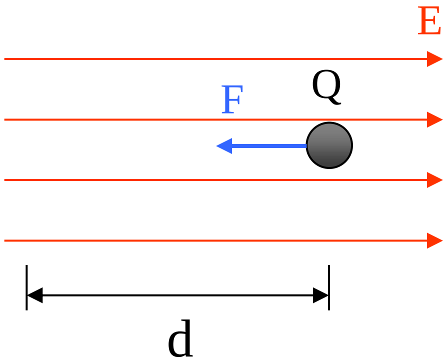
Potential Energy & Potential Difference (Elec)

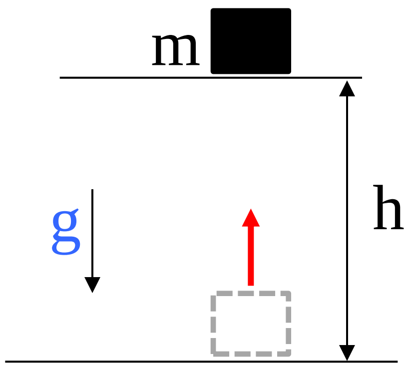
Force acting on a charge Q in an electric field E

Coulomb Law: $F = k\frac{Q_1.Q_2}{d^2}$

Electric Field: $E = k\frac{Q_1}{d^2}$

$F = E.Q$





Work: (Potential Energy) $W = U = \vec{F}.\vec{d} = \left(k\frac{Q_1.Q_2}{d^2}\right).d = (E.Q).d = (E.d)Q$

$W = U = mg.h$

Potential: $V \equiv \frac{U}{Q} = Ed$

$V = \frac{U}{m} = gh$

$U = mV$

Relation between **Potential Energy** and **Potential Difference**: $U = QV$

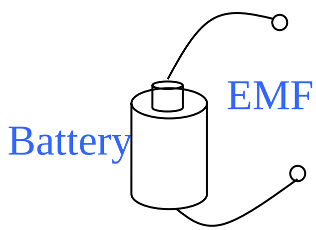
Potential Difference

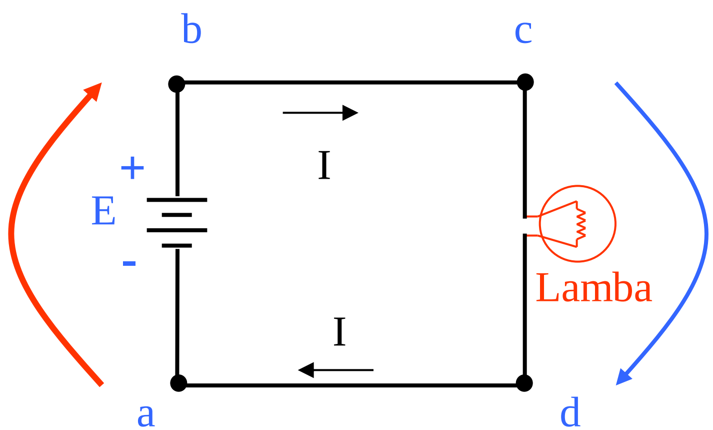
In a circuit, work done to move a unit positive charge between two points is called *Potential Difference* or *Voltage*. In other words ***Potential difference*** or **Volt** is the work (energy) done per unit charge.

[If work done on a **1 Coulomb** charge to bring charge from point A to point B is **1 Joule** then the potential difference between these wto points is one volt (symbol V)]

$$[volt]=\frac{[joule]}{[coulomb]} \qquad 1\,V=\frac{1J}{1C}$$

If the potential diffenence is the difference of power supply or battery it is commonly called *elektromotor force* or shortly *EMF* and potential diffenence is shown by symbol E.





Increasing potential (voltage jump)

E_{ab}=+120 V

Decreasing Potential (voltage drop)

E_{bc}= - 2,5 V

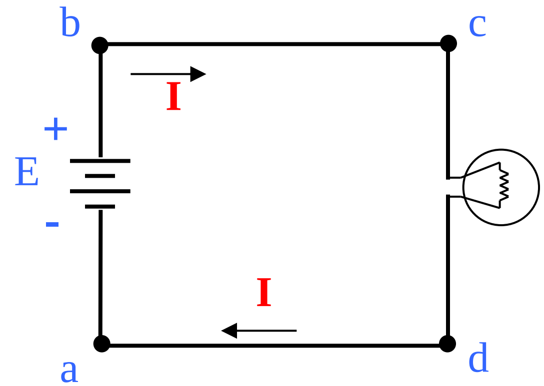
E_{cd}= - 115 V

E_{da}= - 2,5 V

The sign of voltage sign shows increase (+) or decrease (-).

Measurement of Voltage

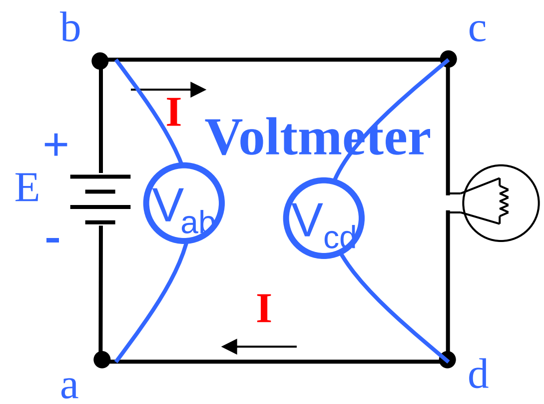
Potential difference in a circuit is measured with a measurement instrument called **Voltmeter**



V_{ab}=?

V_{cd}=?

Voltmeters are connected **in paralel with the circuit**. So the resistance of **an voltmeter is infinity**.

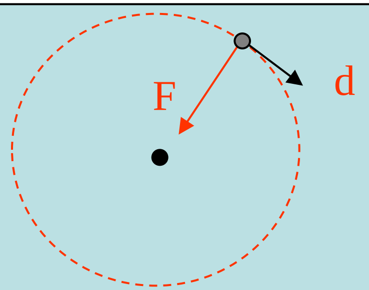


Potential Difference Measurement

$V_{bc}=V_{da}=0$

$V_{ab}= V_{cd}$

Energy, Work and Power



In circular motion force (F) and displacement (d) is always perpendicular to each other so no work is done

Work=(Force).(Displacement)   W=F.d

Unit of work is (in SI unit system) Joule (J)
[joule]=[newton].[meter]

Energy is the ability to do work

Power = Work / Time   P=W/t

Measured in Watt (W) (in SI)
[watt]=[joule] / [second]

Power is the rate at which work is done

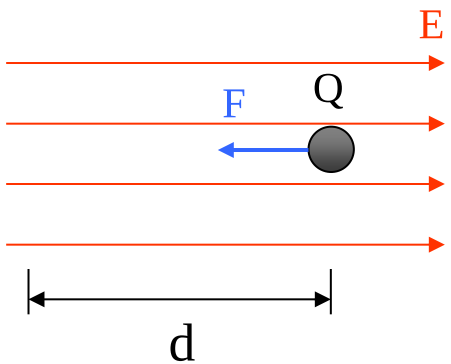
Since there is close relation between power and energy sometime energy unit is given in terms of power unit:

For example energy (joule), can be given as watt-sec or kilowatt-hour ($1000 \times 3600 = 3.6 \times 10^6$ watt-sec)

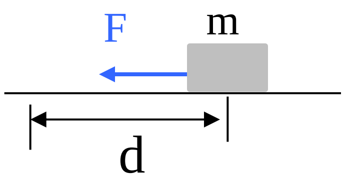
Work, Energy and Power in Circuits

Force acting on a charge (Q) in electric field (E),

$$F = E.Q$$



In Mechanics



$$W = \vec{F}.\vec{d}$$

Work: $$W = \vec{F}.\vec{d} = (E.Q).d = (E.d)Q = V.Q = U(Potential energy)$$

We define potential: $$V \equiv \frac{U}{Q} \equiv E.d = \left(k\frac{Q}{d^2}\right).d = k\frac{Q}{d}$$

Power: $$P = \frac{W}{t} = \frac{V.Q}{t} = V\left(\frac{Q}{t}\right) = V.I$$

$$P = F.v$$

Electrical Energy and Power

How can we express energy and power in terms of electrical quantitie current and voltage?

Electrical energy can be given below in terms of , Voltage (V) and charge (Q)

Electric Energy: $W = (E.d).Q = V.Q$

İş, sabit bir hızda yapılırsa ve toplam Q yükü, t saniyede E voltluk bir gerilim altında hareket ederse, güç:

Electric Power: $P = \frac{W}{t} = \frac{V.Q}{t}$

Uygulamada, yükten ziyade akım ile ilgilendiğimizden güç ifadesi:

$P = V.I$ Power

Bu güç, uçlarındaki gerilim (V), üstünden geçen akım I olan devre elemanının birim zamanda soğurduğu veya dışarıya verdiği enerjidir.

If both current and voltage are changing with time *p(t);*

$p(t) = v(t).i(t)$ Instantenous Power

Example 1.1: Electrical energy is stored at a constant speed by transmitting it to a battery and converting it to 400W chemical energy. During the process, 20% of the power transmitted to the battery is lost in heat. If the cost of kW-hour of electricity is 1.25TL, find the energy value and cost spent to charge the battery for 10 hours.

Solution:

If the total power transmitted to the battery is P_b then:

$400W+0.2P_b=P_b \Rightarrow P_b=500W$

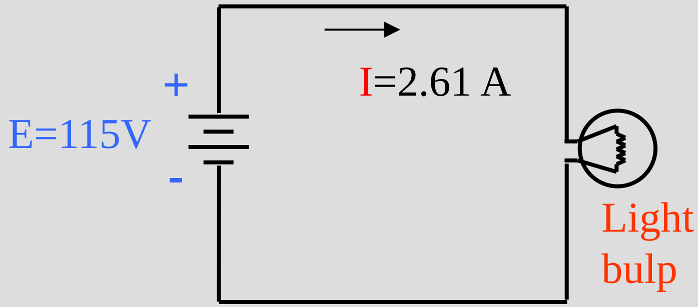
Total energy in 10 hours W_b=(500W)x(10 hours)=5000W-hour=5 kW-hour

Cost of consumed energy= (5kW-hour)x(1.25TL / (kW-hour))=6.25TL

Efficiency %80 (loss %20)

Energy, Work and Power

Example-1.2: In the circuit below there is voltage supply of 115V. The current flowing in the curcuit is 2.61A. (a) What is the power dissipated on the light bulp if the cost of kW-hour energy is 1.25TL. (b) How much we should pay if we use the bulp 10 hours?



Solution:

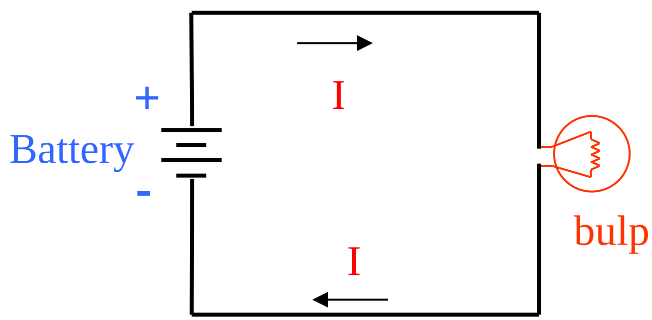
(a) P=E.I=(115 V).(2.61 A)= 300W

(b) W=E.I.t=(300 W).(10 hour)=3000 W-hour=3.0 kW-hour

Cost=(3.0 kW-hour).(1.25 TL/kW-hour)=3.75 TL

Definition of Closed, Open and Short Circuits

CLOSED circuit is a circuit where power source and other circuit elements (such as resistor) are connected by wires so there will be **flow of current** and **voltage**.



CLOSED CIRCUIT

In Closed Circuit

$R \neq \infty$

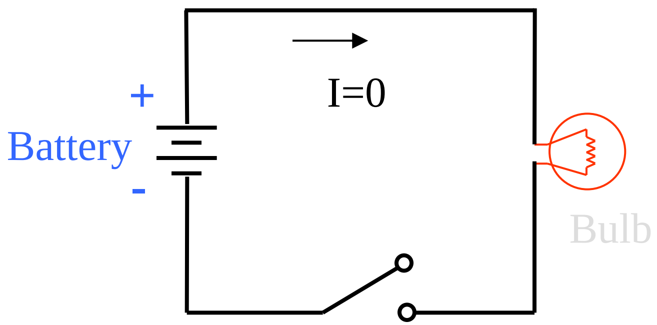
$\neq 0$ (Considerable resistance)

Current $\neq 0$ (no high current)

Voltage $\neq 0$

Open Circuit

In a circuit if wires are cut off so there will be no current flow, but there is **voltage**. Then, we have an **open circuit.**



OPEN CIRCUIT

In Open Circuit

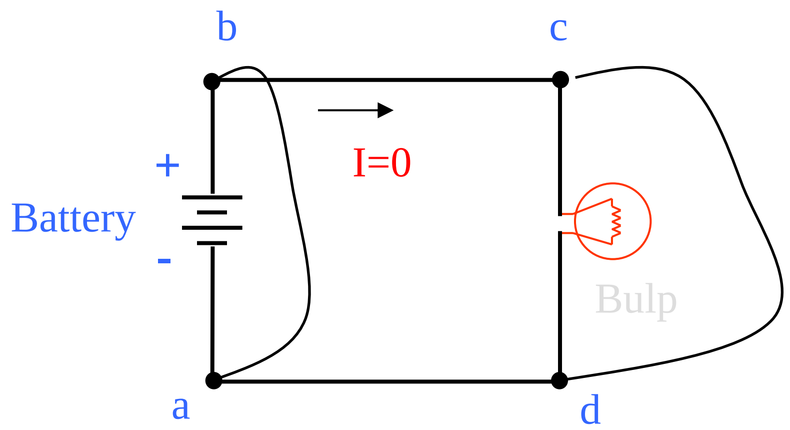
$R=\infty$

Current=0

Voltage$\neq$0

Short Circuit

In Short circuit the poles of battery or power supply is connected directly

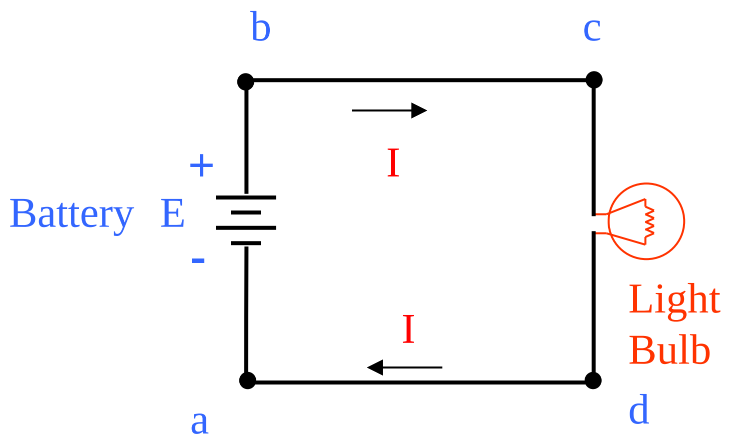


SHORT CIRCUIT

In Short Circuit
R=0
Current=Max (too high to damage the circuit)
Voltage=0 V (forced (by shorting) to be zero)

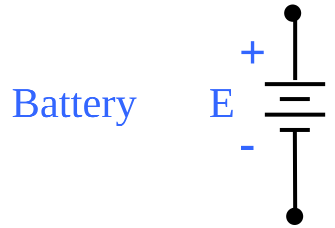
Battery

Consider a circuit below:



In order to keep current flowing through circuit an external electric energy must be supplied. The energy is suplied by the poer sourcees. Battery is an example of voltage sources.

Battery gives necessary energy to electrons to flow in circuit.



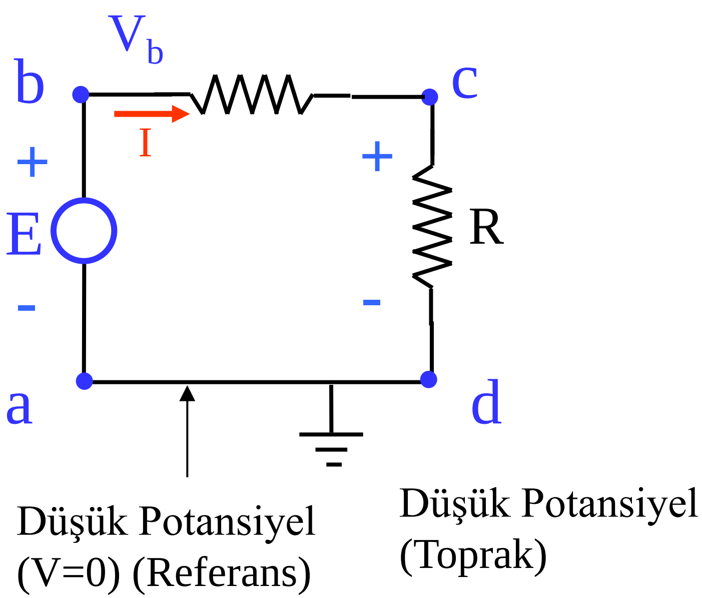
Symbol

Potansiyel (Referans)

Bir devrede en düşük nokta referans noktası olarak alınır ve '**toprak**' olarak adlandırılır.

V_b dediğimiz zaman anlamamız gereken V_{ba}

Bu slide üzerinde
biraz daha çalış



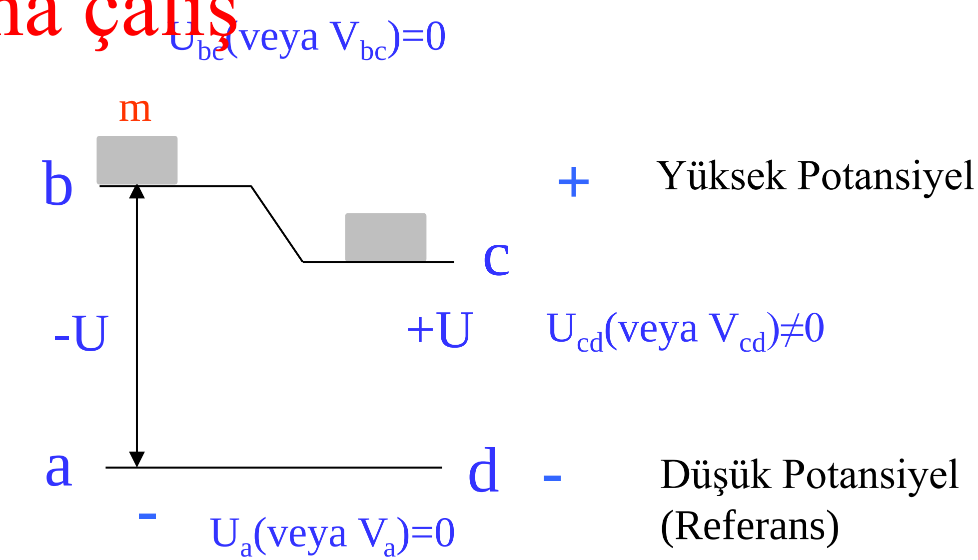


Table-Electrical Quantities and Mechanical Equivalences

Electric	Symbol	Unit (SI)	Equation	Mechanical Equivalence
Charge	q, Q	Coulomb (C)	-	Displacement
Curent	i, I	Amper (A)	i=dq/dt	Velocity
Potential Difference or Voltage	e, E or v, V	Volt (V)	e=dw/dq	Force
Power Energy (Work)	p, P w, W	Watt (W) Joule (J)	p=vi $w = \int v dq$ $w = \int vi dt$	Power Energy (Work)

Some Metric Prefixes Used in Physics

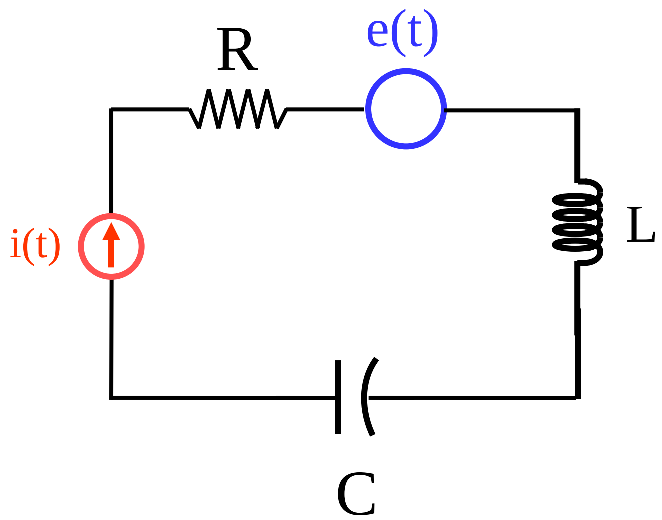
Large quantities		Small quantities	
Kilo (k)	10^{3}	Mili (m)	10^{-3}
Mega (M)	10^{6}	Micro (μ)	10^{-6}
Giga (G)	10^{9}	Nano (n)	10^{-9}
Tera (T)	10^{12}	Pico (p)	10^{-12}

Power Sources & Circuit Elements

Electric Circuit is consist of **electrical power sources** (voltage and current) and other **circuit elements (Receivers)** that absorb or store energy.

Sources

- Current
- Voltage

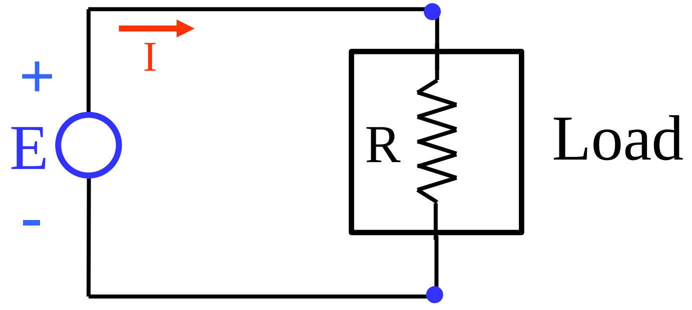


Receivers or Absorbers

- Resistor (R)
- Inductor (L)
- Capacitor (C)

Before we start to analyse circuits we have to know each individual circuit elements' voltage-current behaviour.

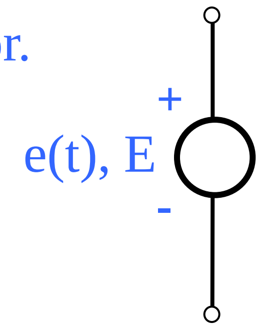
Definition of Load



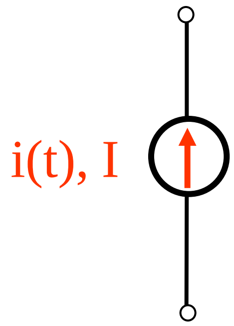
Load can be resistors or any other combination of mix circuit elements

Ideal Power Sources-Independent

Ideal sources supply constant voltage (Voltage Source) or constant current (Current Source) ; the current and voltage values at the source terminal **does not changes** with the load (external resistor) it will always stay the same. Also ideal sources have no internal resistor.



Ideal Voltage Source



Ideal Current Source

Voltage value of **an ideal voltage source** does not change with the load (external resistor) Voltage at the terminal is always constant! (But the drawn current can be changed)

Current value of **an ideal current source** does not change with the load (external resistor) Current is always constant! (But the voltage at the terminal can be changed)

In reality no source is ideal and we will look at real sources in **Chapter-2**

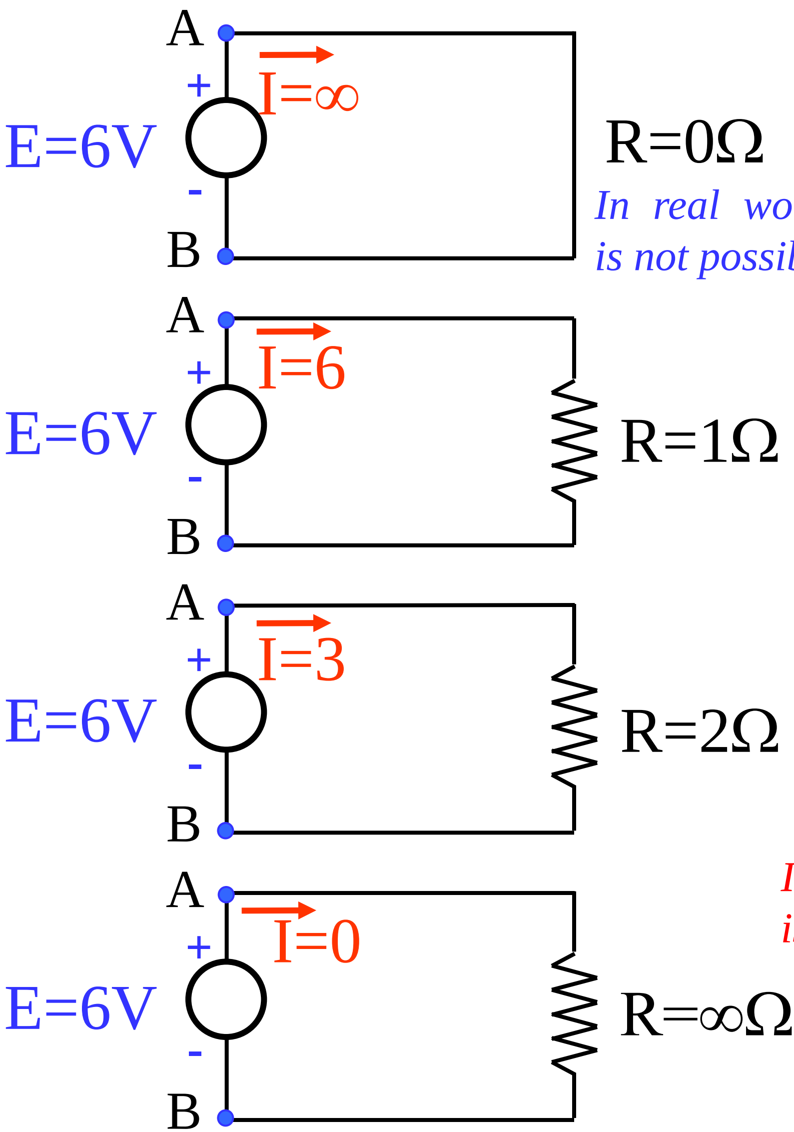
Notation:

Uppercase letters: For constant current (I) and Potential (E) sources

Lowercase letters: For current (i(t)) and potential (e(t), v(t)) sources changing in time

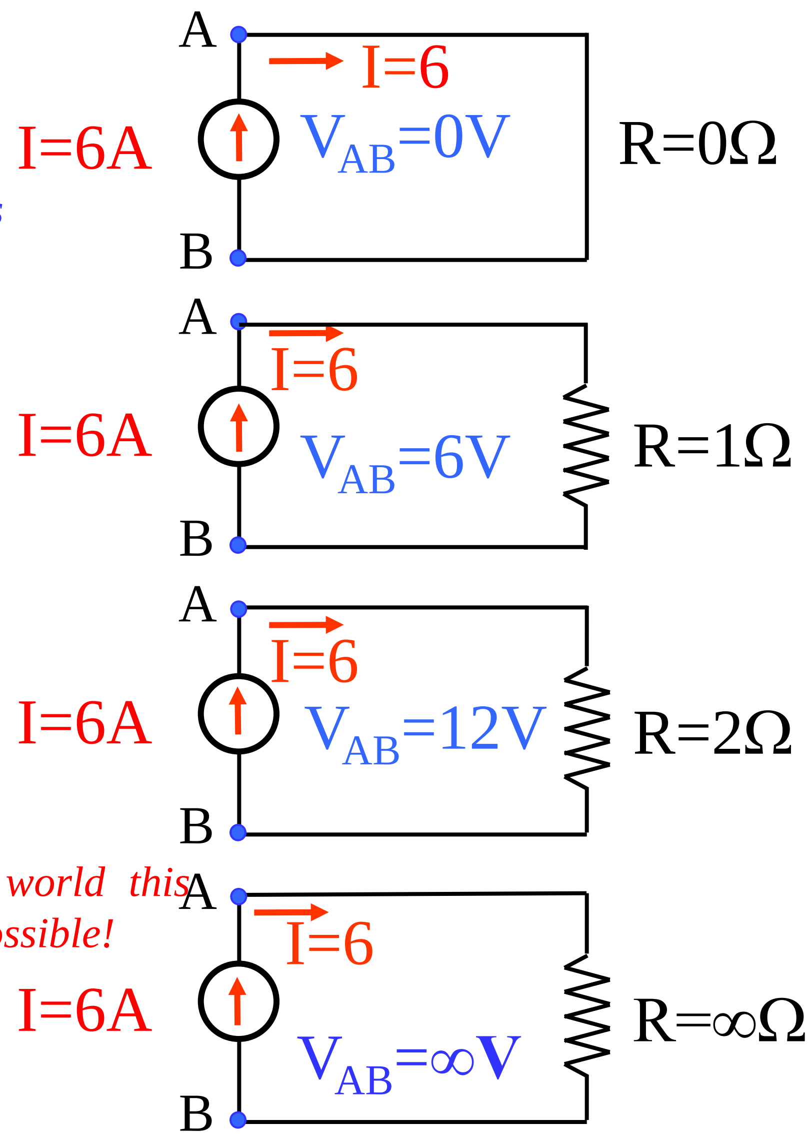
Ideal Sources

Ideal Voltage Source



In real world this is not possible!

Ideal Current Source

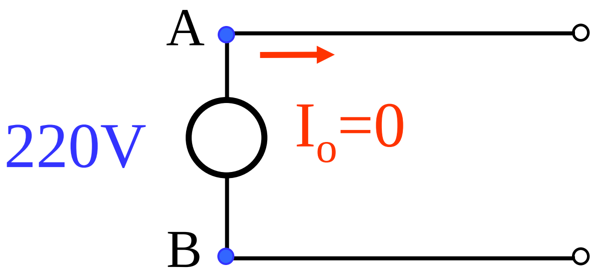


In real world this is not possible!

Voltage value of **an ideal voltage source** does not change with the load (external resistor) it is always constant! (But drawn current can be changed.

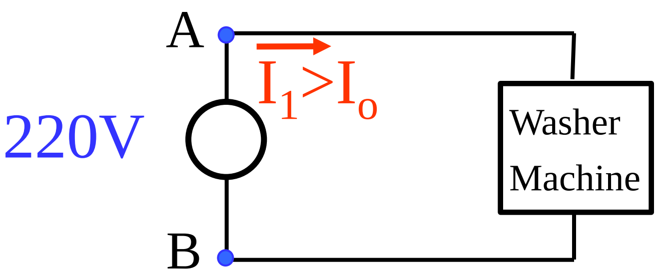
Current value of **an ideal current source** does not change with the load (external resistor) it is always constant! (But drawn current can be changed.

Ideal Voltage Source

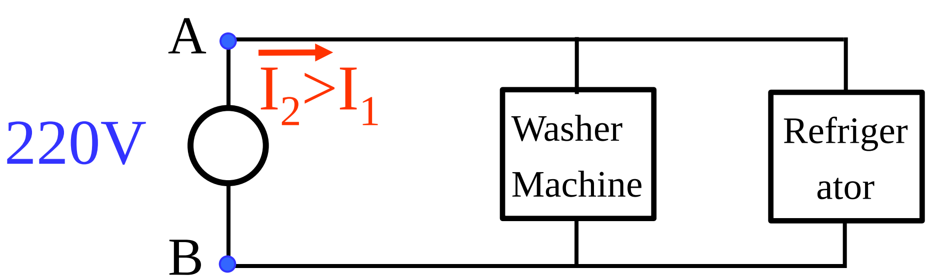


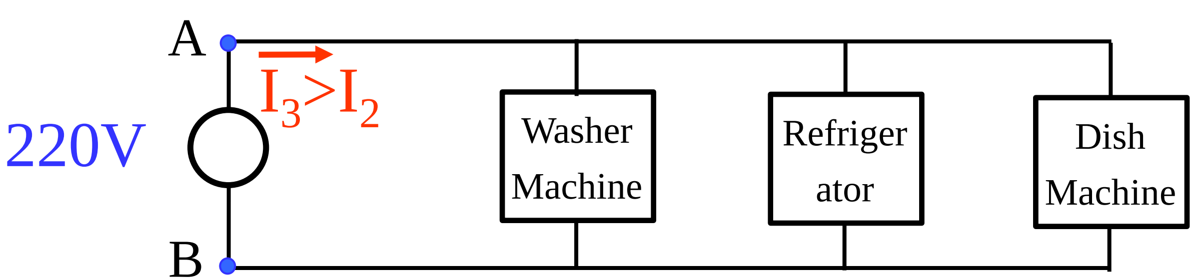
$R = \infty\ \Omega$

$V_{AB} = 220V$

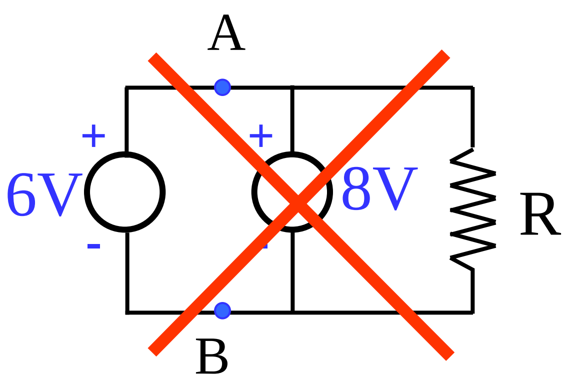


Outlets in our homes are example of **an ideal voltage source.** The potential difference (220V) does not change with the addition of appliance (load) (Note: *current of an ideal voltage source is not defined*)

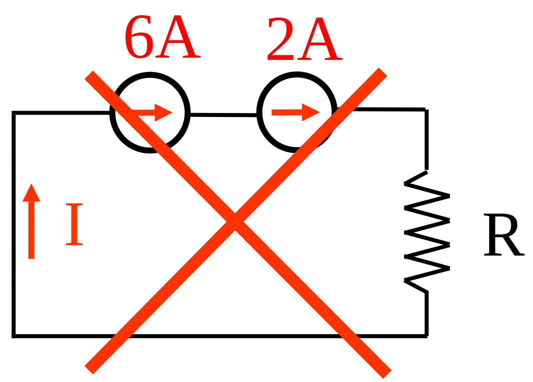




Ideal Power Sources



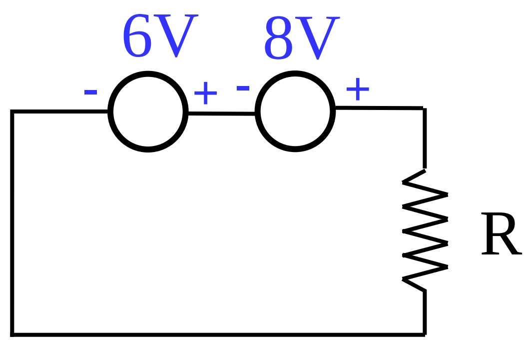
V_{AB}=?



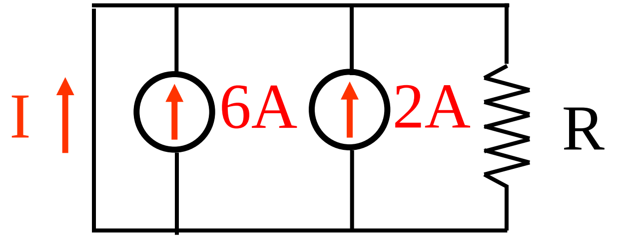
I=?

This configuration does not apply because the voltage between A and B will be single value and same!

This configuration is not valid because the current through a branch should be constant!



V_{AB}=14V

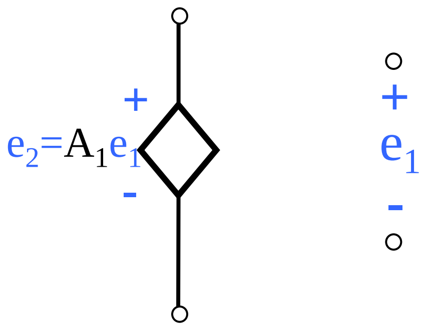


I=8A

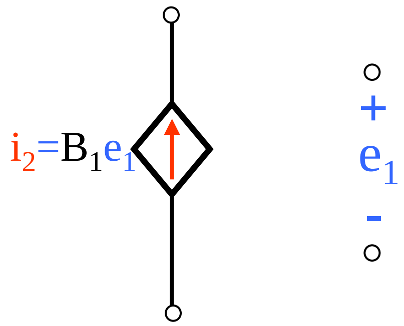
Dependent (Controlled) Source Types

In **Dependent Sources** the voltage or current at the terminals of the sources depends on the current or voltage value of any specific points at the circuit. Examples of such sources are transistors.

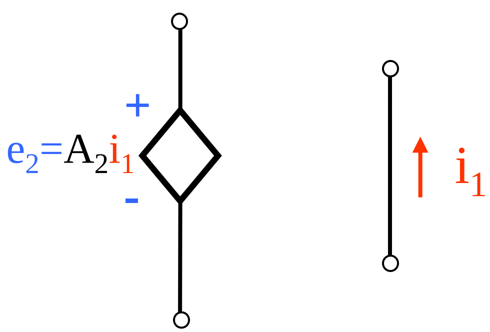
There are four possible case for the dependent sources



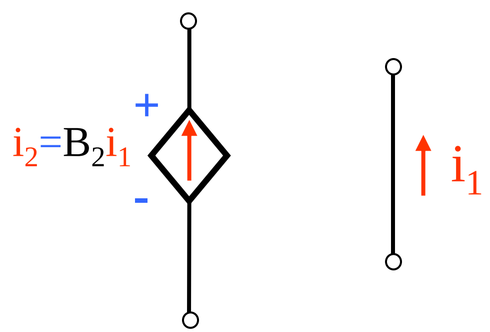
Voltage dependent **voltage source**



Voltage dependent **current source**



Current dependent **voltage source**



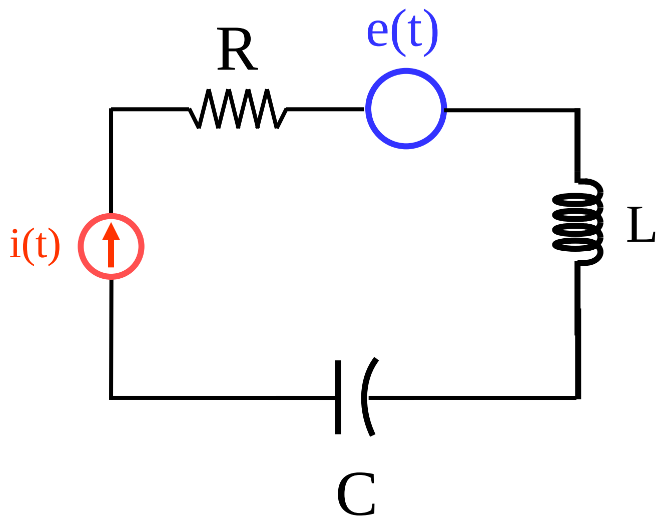
Current dependent **current source**

Power Sources & Circuit Elements

Electric Circuit is consist of **electrical power sources** (voltage and current) and other **circuit elements (Receivers)** that absorb or store energy.

Sources √

- Current
- Voltage



Receivers or Absorbers

- Resistor (R)
- Inductor (L)
- Capacitor (C)

Before we start to analyse circuits we have to know each individual circuit elements' voltage-current behaviour.