ECE113: Basic Electronics

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Electrical quantities

- Charge: unit - Coulomb
- Current: unit - Ampere
- Voltage: unit - Volt
- Power: unit – Watt
- Resistance: unit - Ohm

SI units

Charge

- A physical property of matter which interacts with electromagnetic field
  - Experiences a force due to a electromagnetic field
  - Responsible for creating electric field
- The force can be calculated using Coulomb's Law:

$$\boxed{F = \frac{Kq_1q_2}{d^2}}$$

$$F \propto \frac{q_1 q_2}{d^2}$$

- Two types of charges: +ve and –ve
- Same types of charges repel and unlike types attract
- Convention: charge of a proton is +ve and that of an electron is –ve
- The unit of charge is the coulomb (C),
- One coulomb is one ampere second (1 coulomb = 6.24×1018 electrons).
- The coulomb is defined as the quantity of electricity which flows past a given point in an electric circuit when a current of one **ampere** is maintained for one second

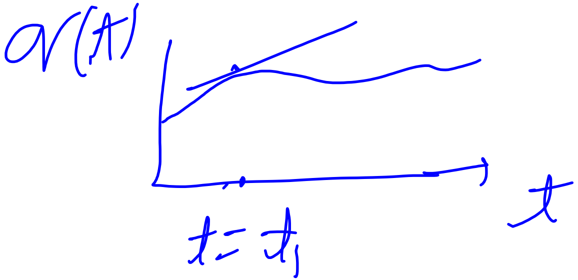
Current

- Electric/ electronic circuits' function depends on flow of charge
- Current is defined as the instantaneous rate at which net positive charge move past a specific point/ cross-section at a specific direction:

$$i = \frac{dq}{dt}$$

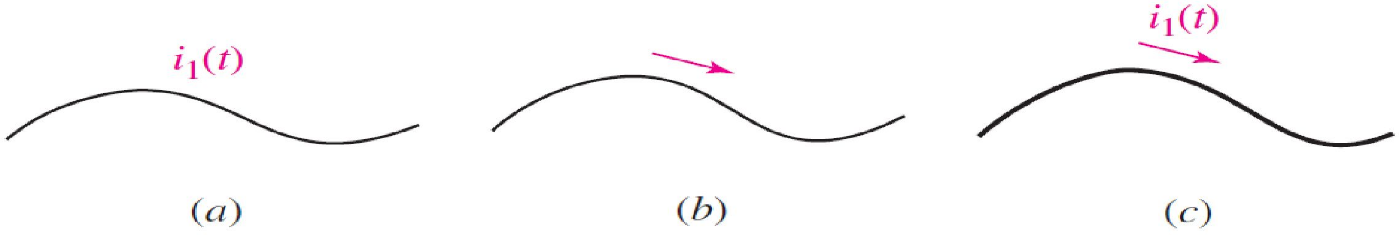
- Unit: Ampere (A): 1 C/s
- Can vary with time (unless DC, in ideal case)
- A current of 5 A flows for 2 minutes in a circuit, find the quantity of electricity transferred.

- Quantity of electricity $Q=It$ coulombs
- I =5 A, t =2×60=120 s
- Hence Q=5×120=**600** C



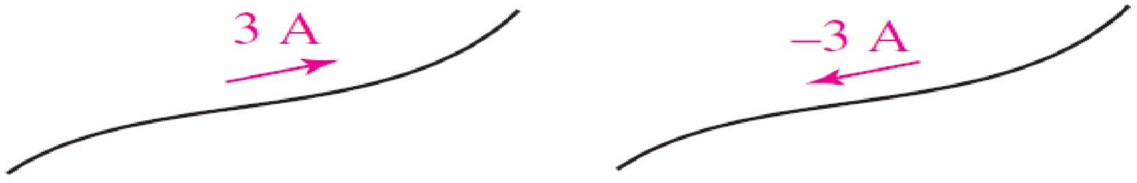
Current representation

- Direction is important



c) Is the correct representation

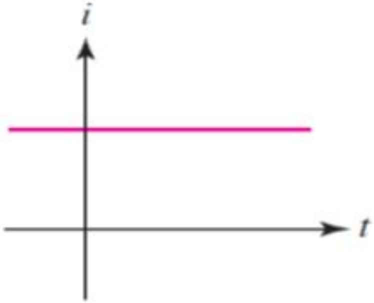
Current representation



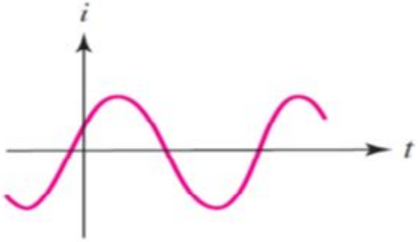
(a) (b)

Both are same

Types of current/voltage waveforms

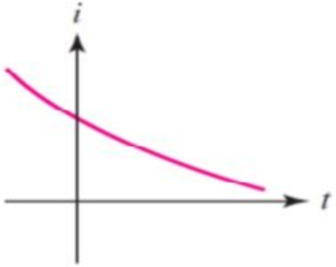


Direct Current (DC)

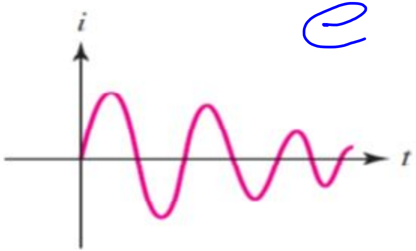


Sinusoidal Current

$e^{-\sigma t} \sin \omega t$



Exponential Current



Damped Sinusoidal Current

Voltage

The unit of electric potential is the volt (V), where one volt is one joule per coulomb. One volt is defined as the difference in potential between two points in a conductor which, when carrying a current of one ampere, dissipates a power of one watt, i.e.

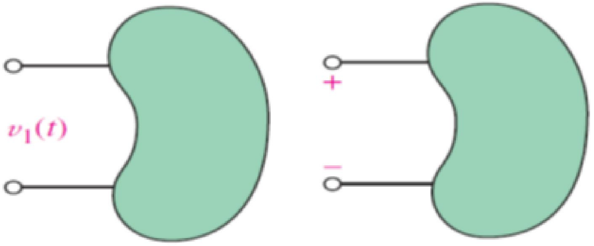
$$\text{volts} = \frac{\boldsymbol{Watt}}{\boldsymbol{amperes}} = \frac{\frac{\boldsymbol{joules}}{\boldsymbol{second}}}{\boldsymbol{ampere}}$$

$$= \frac{\boldsymbol{joules}}{\boldsymbol{amperes\ secomds}} = \frac{\boldsymbol{joules}}{\boldsymbol{coulombs}}$$

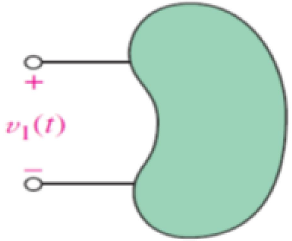
A change in electric potential between two points in an electric circuit is called a potential difference and its unit is Volt.

The electromotive force (e.m.f.) provided by a source of energy such as a battery or a generator is measured in volts.

Voltage representation



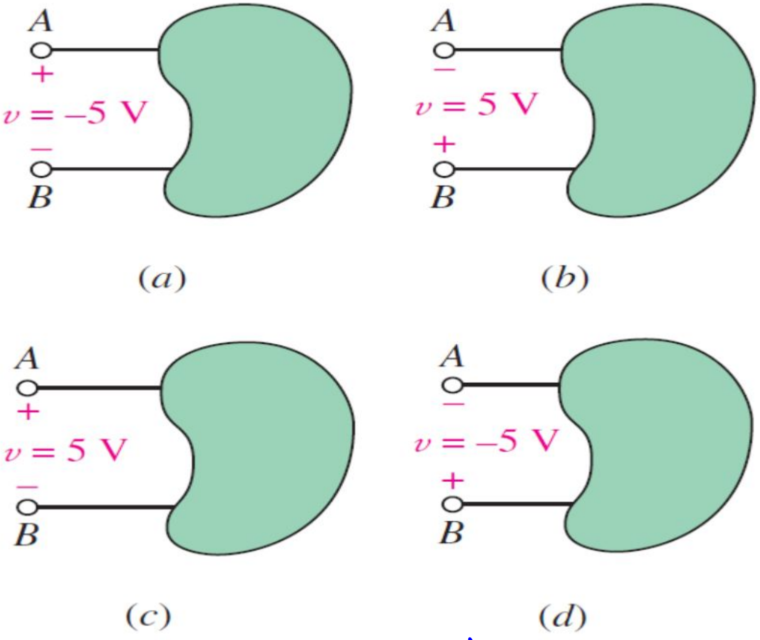
Incorrect representation



✓

Correct representation

$a = b$



$c = d$

Electric Power

- When a direct current of I amperes is flowing in an electric circuit and the voltage across the circuit is V volts, then

power in watts $P = VI$

Unit: Watt = 1 J/s

Electrical energy = Power × time

= $V\,I\,X\,t$ joules

$E = P \cdot t$

- Although the unit of energy is the joule, when dealing with large amounts of energy the unit used is the **kilowatt hour (kWh)**

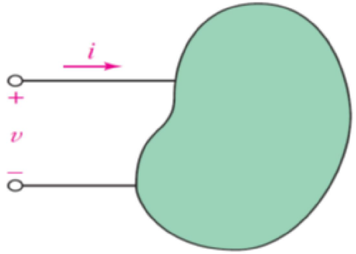
where 1kWh = 1000 watt hour

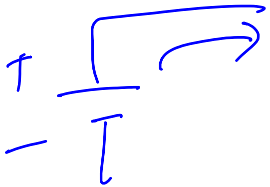
= 1000×3600 watt seconds (joules) = 3600 000 J

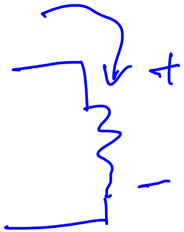
$P = \frac{dE}{dt}$

Passive sign convention

Power absorbed by the element $p = v\,i$
We can also be say that element
generates or supplies a power of $-v\,i$







- When the current arrow is directed into the element at the plus-marked terminal, we satisfy the passive sign convention.
- If the current arrow is directed into the "+" marked terminal of an element, then $p = vi$ yields the *absorbed* power. A negative value indicates that power is actually being generated by the element.
- If the current arrow is directed out of the "+" terminal of an element, then $p = vi$ yields the *supplied* power. A negative value in this case indicates that power is being absorbed.

- If a current of 5 A flows for 2 minutes, find the quantity of electricity transferred.

$Q = I \times t = 5 \times 2 \times 60 = 600\ C$

- An e.m.f. of 250 V is connected across a resistance and the current flowing through the resistance is 4 A. What is the power developed?

- 450 J of energy are converted into heat in 1 minute. What power is dissipated?

- A current of 10 A flows through a conductor and 10 W is dissipated. What p.d. exists across the ends of the conductor?

- A battery of e.m.f. 12 V supplies a current of 5 A for 2 minutes. How much energy is supplied in this time?

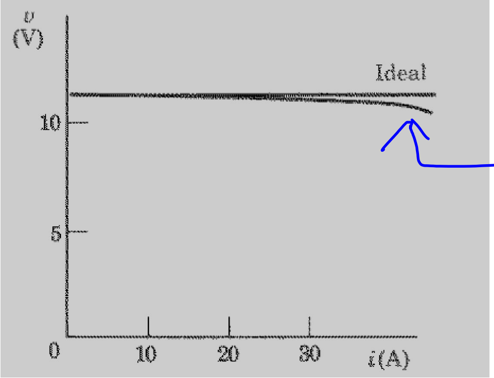
- A d.c. electric motor consumes 36 MJ when connected to a 250 V supply for 1 hour. Find the power rating of the motor and the current taken from the supply.

Energy Sources

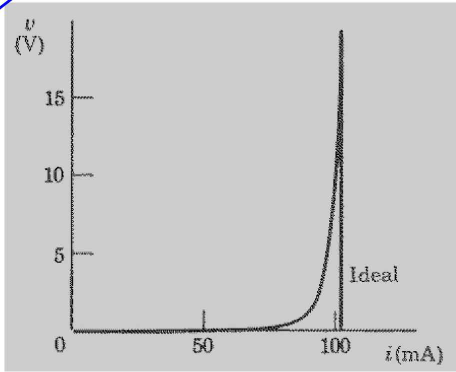
Although every generator supplies both voltage and current, it is desirable to distinguish between two general classes of devices.

If the voltage output is relatively independent of the circuit to which it is connected (as in the battery of Fig. 1), the device is called a "voltage source."

If over wide ranges the output current tends to be independent of the connected circuit (as in the transistor of Fig. 2), it is treated as a "current source."



voltage
source
Fig. 1



current
source
Fig. 2

Energy Sources

Ideal voltage source: the output voltage is completely independent of current.

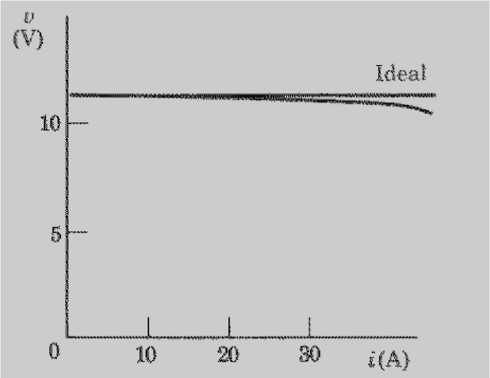
An ideal constant-voltage generator is one with zero internal resistance so that it supplies the same voltage to all loads.

Output voltage is function of time and the voltage is unaffected by changes in circuit configuration. Examples : DC battery, DC power supply

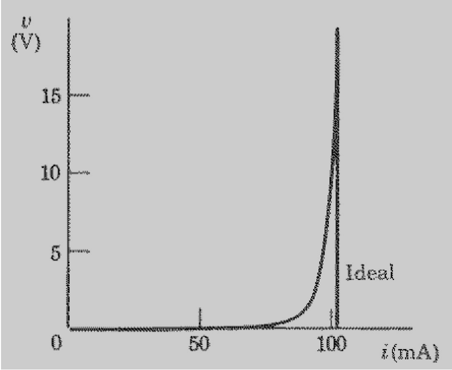
Ideal current source: the output current is completely independent of voltage.

An ideal constant-current generator is one with Infinite internal resistance so that it supplies the same current to all loads.

Output current is also function of time and the current is unaffected by changes in circuit configuration.



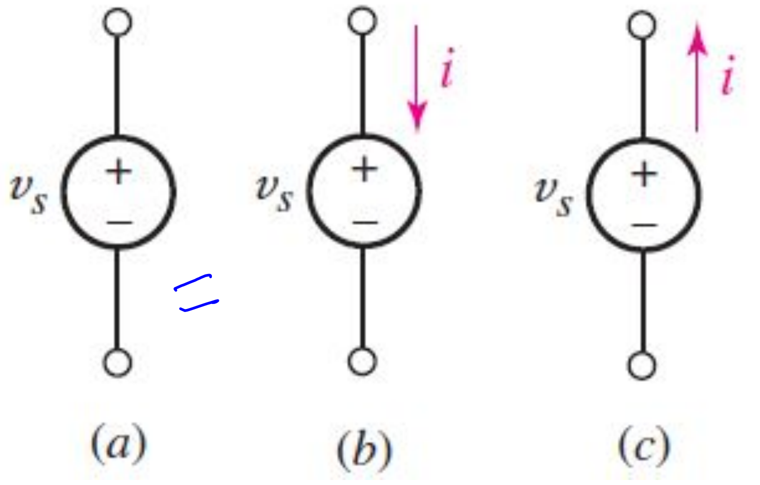
voltage source
Fig. 1



current source
Fig. 2

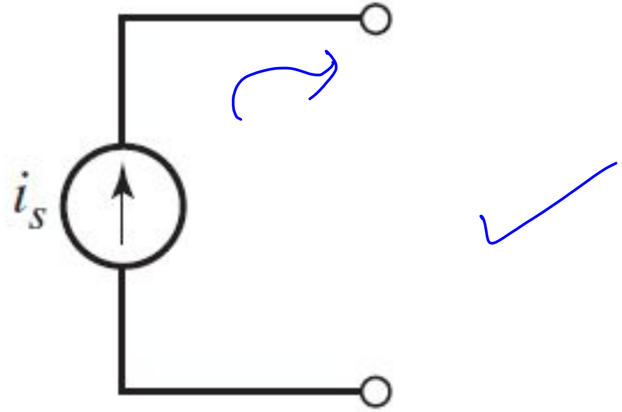
Independent Voltage Source

- Terminal voltage is completely independent of the current
- + sign is a reference, does not necessarily mean that upper terminal is numerically +ve
- This is a theoretical notion, a mathematical model that can be used for further analysis



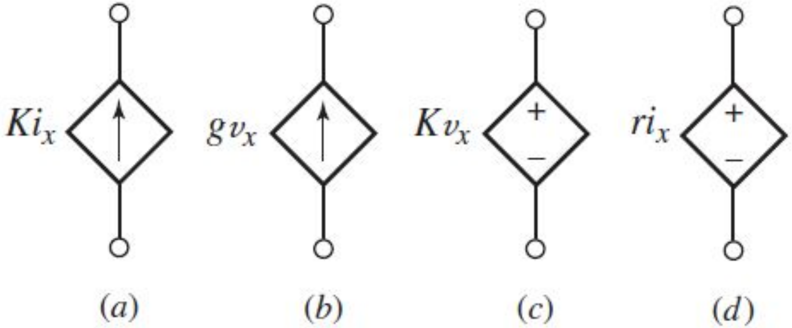
Independent Current Source

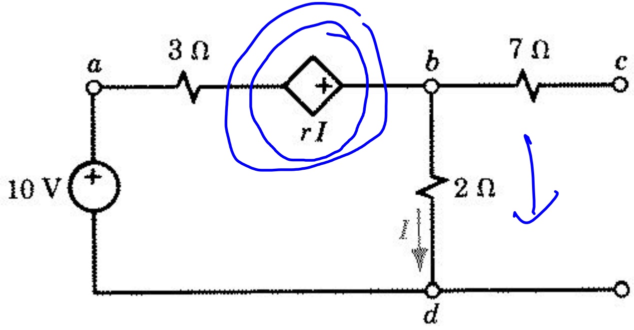
- Current is completely independent of the terminal voltage
- Arrow denotes the direction
- Does not necessarily mean that terminal voltage difference will be 0
- Direction: +ve to –ve is +
- Direction: -ve to +ve is -



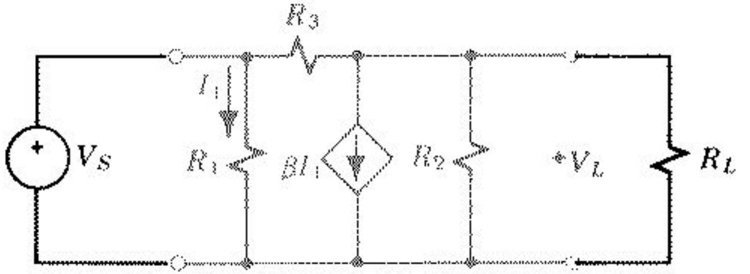
Dependent Voltage or Current Sources

- These are also ideal sources
- Dependent on current or voltage at some other area of the circuit
- Again independent of terminal voltage/current



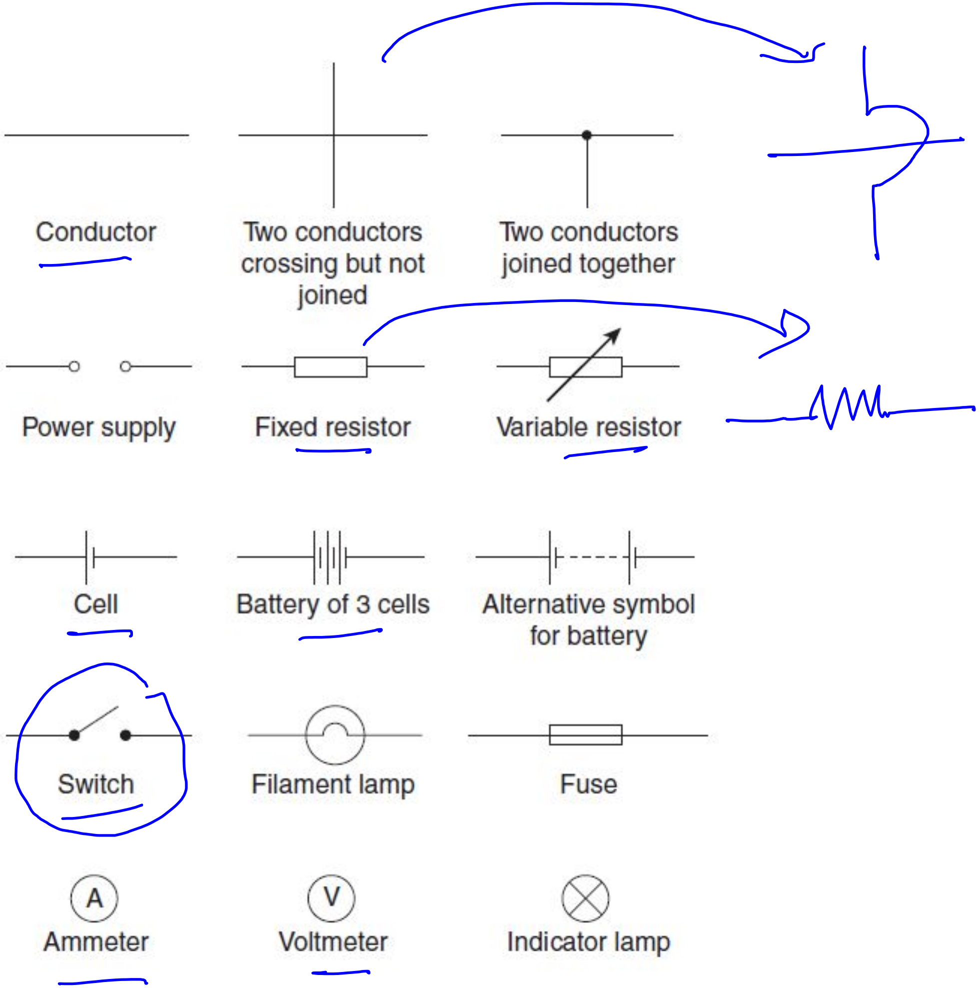


Dependent Voltage Source



Dependent Current Sources

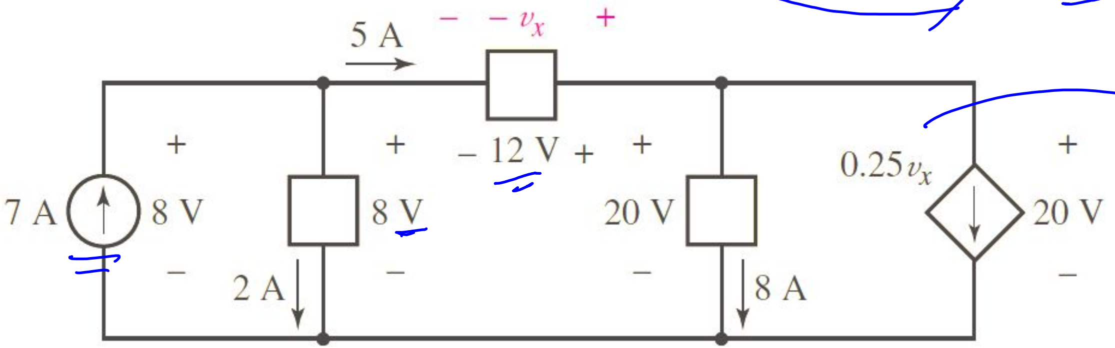
Standard symbol for electrical components



Example problem

Find the power *absorbed* by each element in the circuit in Fig

$-v_x = 12$



$= -3A$

Ans: (left to right) –56 W; 16 W; –60 W; 160 W; –60 W.

Resistance

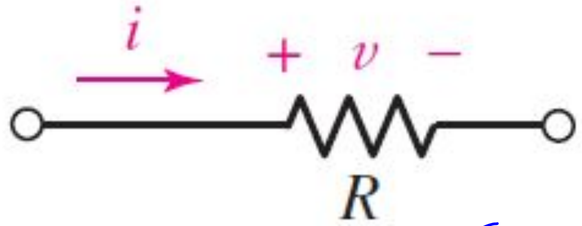
- The flow of electric current is subject to friction. This friction, or opposition, is called **resistance**, ***R***, and is the property of a conductor that limits current.
- The unit of resistance is the **ohm**; 1 ohm is defined as the resistance which will have a current of 1 ampere flowing through it when 1 volt is connected across it.

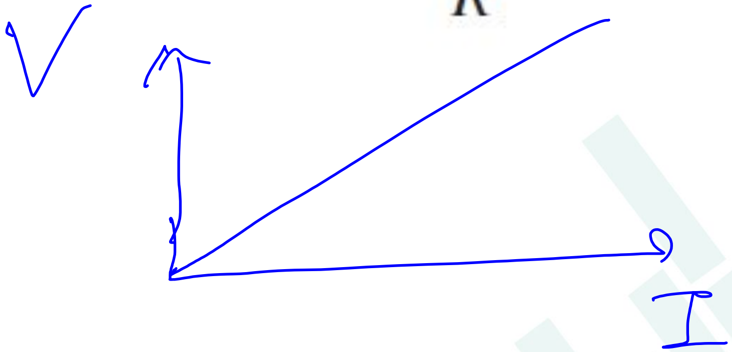
$$\textbf{resistance } R = \frac{potential\ difference}{current}$$

- **Ohm's law** states that the current I flowing in a circuit is directly proportional to the applied voltage V and inversely proportional to the resistance R, provided the temperature remains constant. Thus

$$i = \frac{v}{R} \quad \text{or} \quad v = I \cdot R \quad \text{or} \quad R = \frac{v}{i}$$

- Symbol of resistance is shown un figure





Resistance

Electric Power

- **Power *P*** in an electrical circuit is given by the product of potential difference *V* and current *I*
- The unit of power is the **watt**, **W**.

$$P = V \times I \text{ watts}$$

From Ohm's law $V = IR$, thus

$$P = I^2 R \text{ watts}$$

This is also equivalent to $P = \frac{V^2}{R}$ watts

$P = VI = I^2R$

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

- A 100 W electric light bulb is connected to a 250 V supply. Determine (a) the current flowing in the bulb, and (b) the resistance of the bulb

Current $I = P / V = 100/250 = 0.4$ amp

Resistance $R = V/I = 250/0.4 = 625\ \Omega$

$R = \varepsilon$

$\varepsilon \to 0$

Resistance and resistivity

The resistance of an electrical conductor depends on

- the length of the conductor
- the cross-sectional area of the conductor
- the type of material and
- the temperature of the material.

Resistance, R,

- directly proportional to length, l, of a conductor, i.e.$R \propto l$.
- inversely proportional to cross-sectional area, a, of a conductor, i.e. $R \propto 1/a$.

Thus resistance $R \propto l/a$

By inserting a constant of proportionality into this relationship the type of material used may be taken into account.

The constant of proportionality is known as the **resistivity** of the material and is given the symbol ρ (Greek rho). Thus

Resistance $R = \frac{\rho l}{A}$ ohms

Unit of ρ is ohm meter.

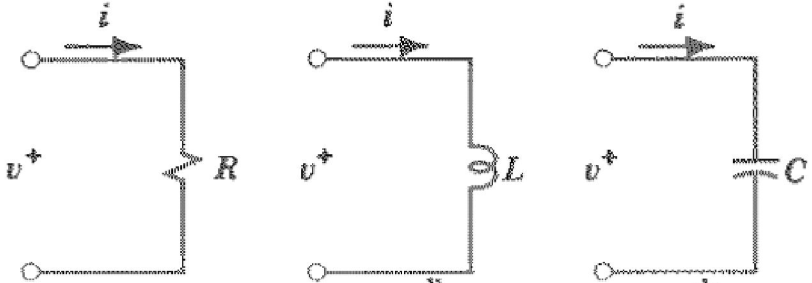
$$R = \frac{\rho l}{A}$$

Problems

- A piece of wire of cross-sectional area 2 mm^2 has a resistance of 300 Ω. Find (a) the resistance of a wire of the same length and material if the cross-sectional area is 5 mm^2, (b) the cross-sectional area of a wire of the same length and material of resistance 750 Ω.
- Calculate the resistance of a 2 km length of aluminium overhead power cable if the cross-sectional area of the cable is 100 mm^2. Take the resistivity of aluminium to be 0.03×10^{-6} Ωm.
- Some wire of cross-sectional area 1 mm^2 has a resistance of 20 Ω . Determine (a) the resistance of a wire of the same length and material if the cross-sectional area is 4 mm^2, and (b) the cross- sectional area of a wire of the same length and material if the resistance is 32 Ω.

$$\frac{R_1}{R_2} = \frac{A_2}{A_1} \Big\} \; l \qquad \frac{R_1}{R_2} = \frac{l_1}{l_2} \Big\} \; A$$

Circuit Elements



$$v = Ri \qquad\qquad v = L\frac{di}{dt} \qquad\qquad i = C\frac{dv}{dt}$$

$$i = \frac{v}{R} = Gv \qquad\qquad i = \frac{1}{L}\int_{-\infty}^{t} v\,dt \qquad\qquad v = \frac{1}{C}\int_{-\infty}^{t} i\,dt$$

Resistance Inductance Capacitance

Capacitor

A capacitor is an electrical device that is used to store electrical energy.

Next to the resistor, the capacitor is the most commonly encountered component in electrical circuits.

Capacitors are used extensively in electrical and electronic circuits.

For example, capacitors are used to smooth rectified a.c. outputs, they are used in telecommunication equipment – such as radio receivers – for tuning to the required frequency, they are used in time delay circuits, in electrical filters, in oscillator circuits and in magnetic resonance imaging (MRI) in medical body scanners, to name but a few practical applications.

Every system of electrical conductors possesses capacitance.

For example, there is capacitance between the conductors of overhead transmission lines and also between the wires of a telephone cable.

In these examples the capacitance is undesirable but has to be accepted, minimized or compensated for.

There are other situations where capacitance is a desirable property. Devices specially constructed to possess capacitance are called capacitors (or condensers, as they used to be called). In its simplest form a capacitor consists of two plates which are separated by an insulating material known as a dielectric. A capacitor has the ability to store a quantity of static electricity.

Capacitor

Figure 1(a) shows two parallel conducting plates separated from each other by air. They are connected to opposite terminals of a battery of voltage V volts.

Static electric fields arise from electric charges, electric field lines beginning and ending on electric charges. Thus the presence of the field indicates the presence of equal positive and negative electric charges on the two plates of Figure 1. Let the charge be +Q coulombs on one plate and −Q coulombs on the other. If the voltage is disconnected, the charge persists on capacitor.

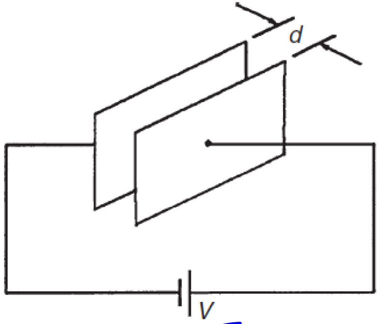


Figure 1(a)

The property of this pair of plates which determines how much charge corresponds to a given p.d. between the plates is called their capacitance:

$$C = \frac{Q}{V} \text{ Farad or } Q = C\,V$$

$Q = CV$

Symbol of capacitor is shown in Figure 1(b)

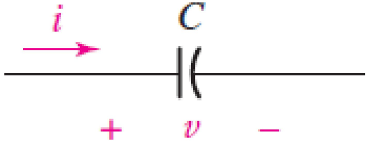


Figure 1(b)

If voltage V is constant, no current flows through capacitor. If V is changing with time, there is a current flow through the capacitor and it is given by

$$\boxed{i \cong C\frac{dv}{dt}}$$

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

Capacitor

$i = C \frac{dv}{dt}$

Current-voltage relationship

We have $C = Q/V$ or $V = Q.C$

Thus for a current $i(t)$, the voltage $v(t)$ across the capacitor is given as

$$v(t) = \frac{1}{C}\int_{t_0}^{t} i(t')\,dt' + v(t_0)$$

where $v(t_0)$ is initial charg

- Find the capacitor voltage that is associated with the current shown graphically in Figure 3. The value of capacitor is 5 μF.

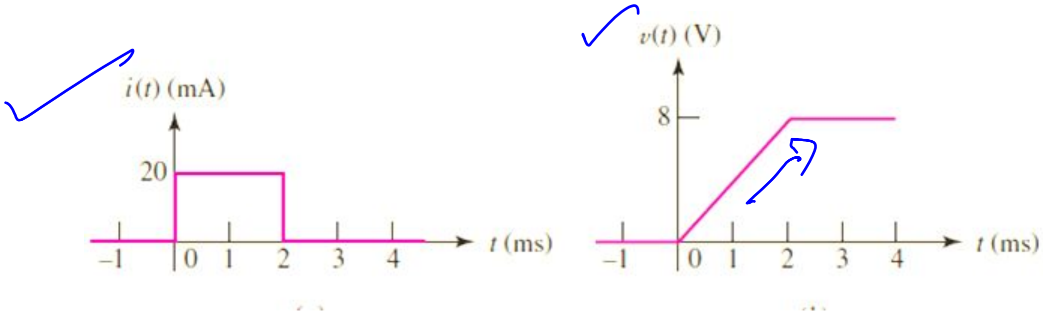


Figure 3

Capacitor

The power across the capacitor is given as

$$\text{Power: } p = vi = vC\frac{dv}{dt}$$

Stored energy can be calculated by integrating power considering zero initial voltage:

$$w_C(t) = \frac{1}{2}Cv(t)^2$$

$$E = \int P\,dt = \int_0^t V\,I\,dt$$

$$= \int_0^t V \cdot C\frac{dV}{\cancel{dt}} \cdot \cancel{dt}$$

$$= \int_0^{V(t)} V\,C\,dV = \frac{1}{2}C\,V(t)^2$$

Inductor

$\phi = LI$

If a conductor is wound as a coil as shown in Figure 5, the coil behaves as an inductance.

Voltage across the coils is approximately proportion to rate of change of current and it is given by following relation:

Induced voltage (v) = $L\frac{di}{dt}$ volts.

L is constant of proportionality and is measured in henrys.

This relationship can be derived from our knowledge of magnetic fields.

If a magnetic flux (Φ) is obtained by passing a current i, the Inductance (L) is $L = \frac{\Phi}{i}$

(Faraday's Law of induction) and we get,

$$v = \frac{d\Phi}{dt} = L\frac{di}{dt}$$

Given the waveform of the current as shown in Figure 6(a). Plot the voltage waveform.

The voltage output is 3 di/dt and voltage waveform is plotted in

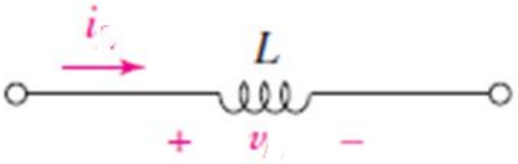
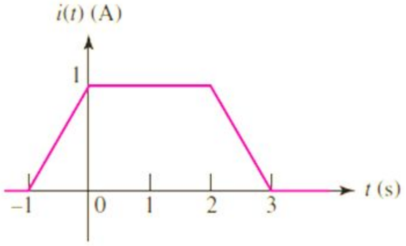
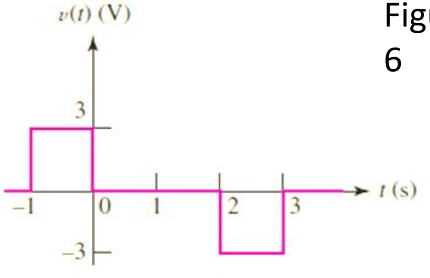


Figure 5



(a)

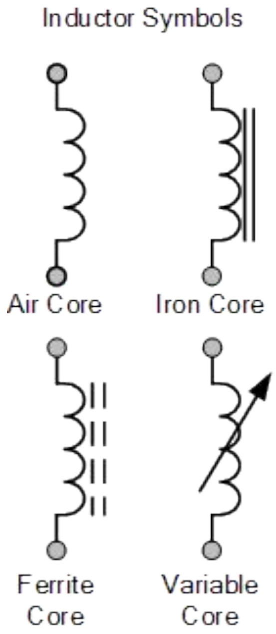


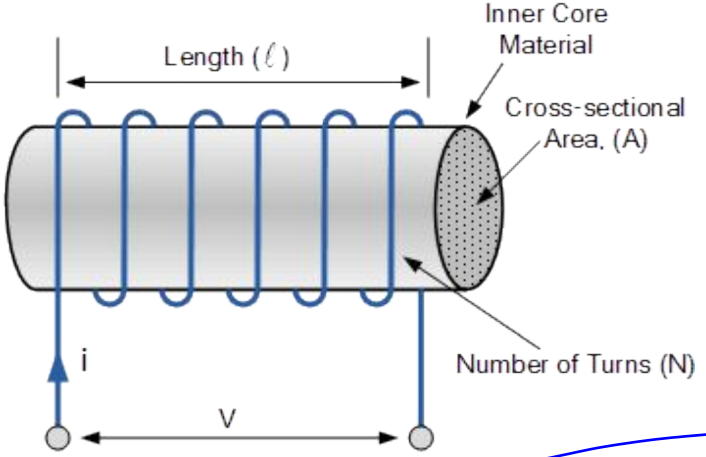
(b)

Figure 6

Inductor

$V(t)$ $V \neq \infty$ $I(t)$





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

μ is the permeability of the core

$I \neq \infty$

Capacitors

$I(t)$ $= V(t)$

Inductor

- The Voltage-current relationship is given as

$$i(t) = \frac{1}{L}\int_{t_0}^{t} v\,dt' + i(t_0)$$

Power $p = vi = Li\frac{di}{dt}$

Energy with zero initial current: $w_L(t) = \frac{1}{2}Li(t)^2$

$$E = \int P\,dt = \int V I\,dt$$

$$= \int L I \cdot \frac{dI}{\cancel{dt}} \cdot \cancel{dt}$$

$$= \frac{1}{2}LI^2$$

Energy stored in linear elements

If the *v-i* characteristics of a device is known, energy = $\int v\, i\, dt$

Inductance

We know v = $L\, di/dt$ volts and I = 0 at t = 0,

and

This equation t

$$w_L = \int_0^T L \frac{di}{dt}\, i\, dt = \int_0^I Li\, di = \tfrac{1}{2} LI^2$$

nd it is not dissipated like resistance.

Capacitance

In capacitance, we know $i = C\, dv/dt$ and v across the capacitor is zero at $t = 0$.

and

In capacitance also

$$w_C = \int_0^T vC \frac{dv}{dt}\, dt = \int_0^V Cv\, dv = \tfrac{1}{2} CV^2$$

Resistance

In resistance, we have v = R i and I = 0 at t = 0 and

$$w_R = \int_0^T Ri\, i\, dt = \int_0^T Ri^2\, dt = Ri^2 T$$

Capacitor and Inductor

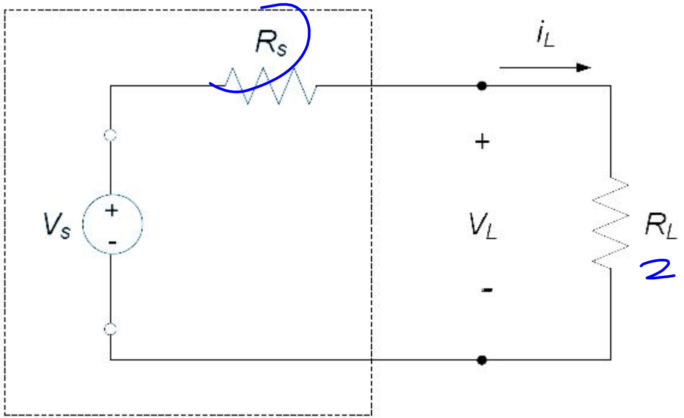
- These elements store and deliver finite amount of energy
- Passive linear circuit elements
- The current-voltage relationships for these new elements are time dependent
- Ideal Capacitors and Inductors can neither generate nor dissipate energy

Applicability of KCL and KVL

- L and C are linear elements
- Kirchhoff's laws can be applied (are not restricted to only resistance)

Non-ideal Voltage Source

trade-off

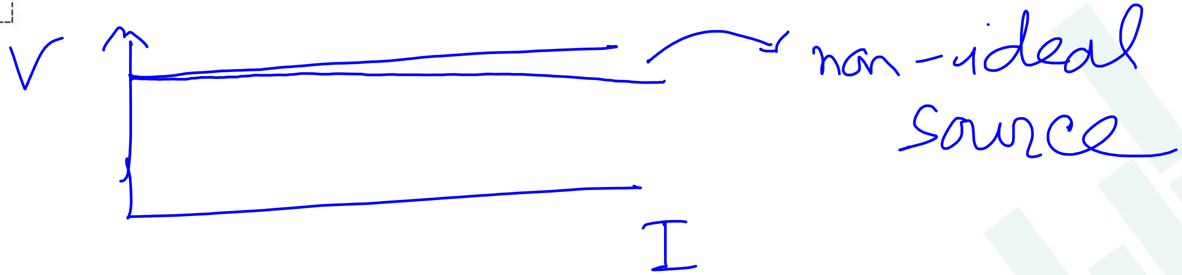


- Modelled as an ideal voltage source Vs and internal resistance Rs
- When load resistance RL draws large current, supply voltage Vs decreases and the converse
- It does not provide infinite power
- Ideal voltage source has zero internal resistance Rs

Problem:

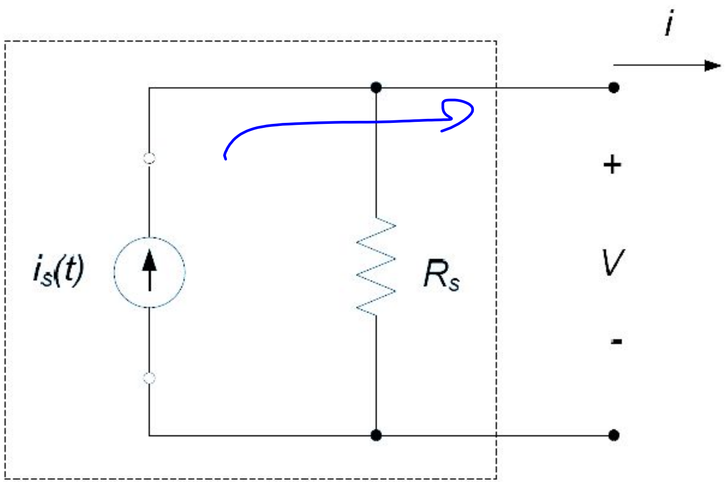
- The no load or open circuit voltage of voltage source is 16 Volts. When a load resistance of 10 ohm is applied, the output voltage VL is 8 Volts. Find the source resistance Rs.
- Twelve cells, each with an internal resistance of 0.24 and an e.m.f. of 1.5 V are connected (a) in series, (b) in parallel. Determine the e.m.f. and internal resistance of the batteries so formed.

$R_L >> R_s$



Non-ideal current source

- Modelled as an ideal current source I_S and internal resistance R_S in parallel
- Higher terminal voltage results in lower supply current
- Ideal current source means a source with infinite internal resistance

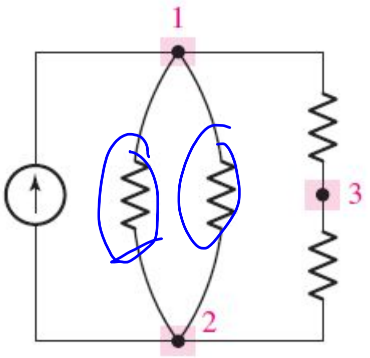


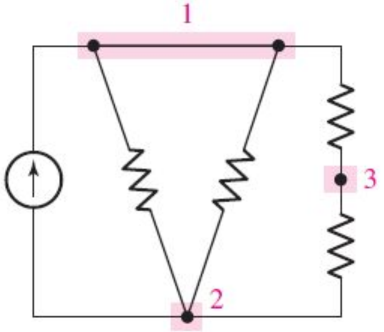
Ideal case ← $R_s \approx \infty$

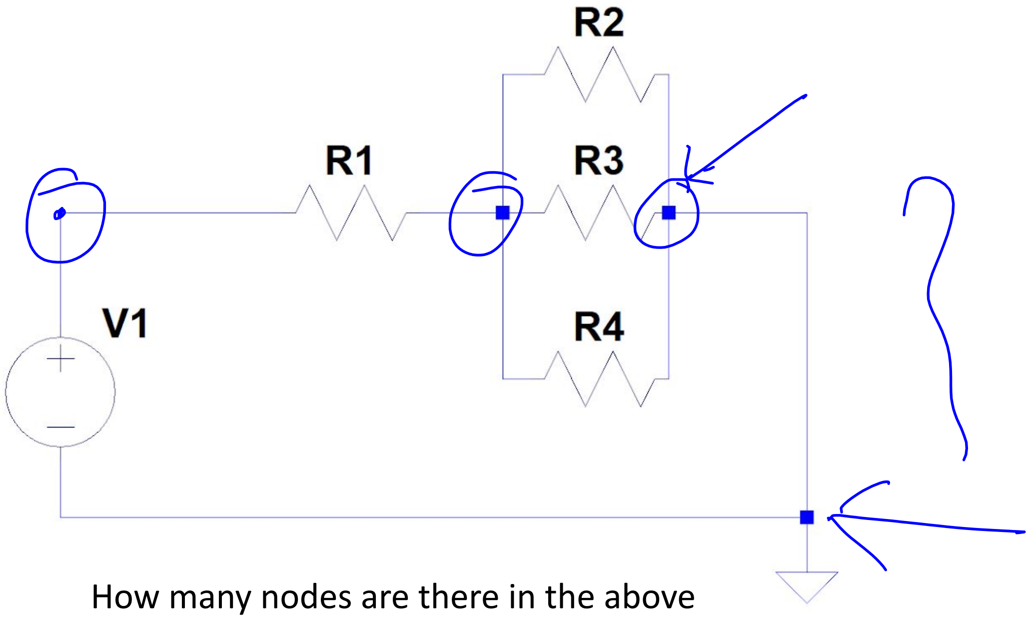
Nodes

branches

- Node: A point at which two or more circuit elements have a common connection.



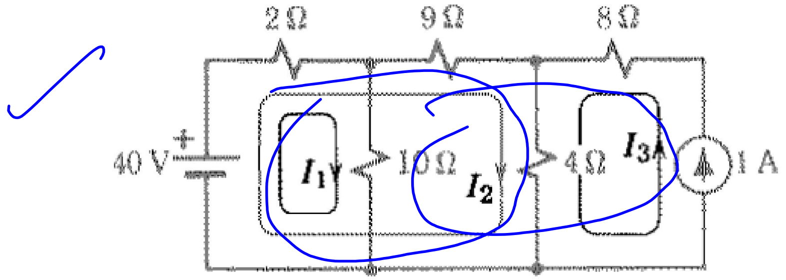


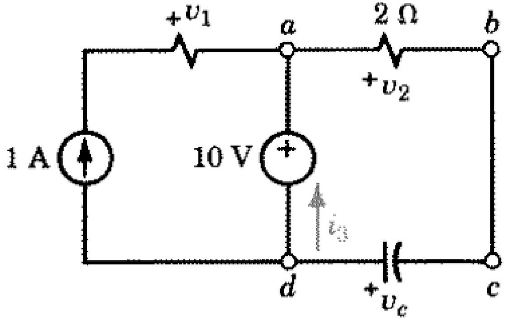


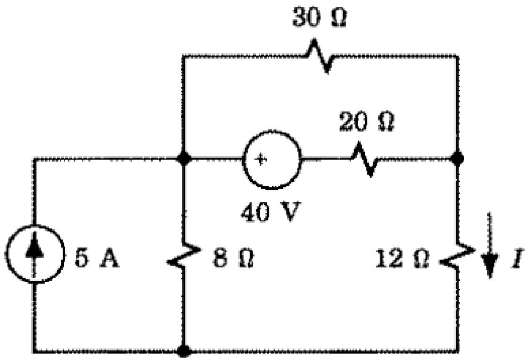
How many nodes are there in the above circuit?

Loops

- Loop: If a set of nodes and elements are traversed in such a way that no node is encountered more than once, then the set of nodes and elements are called a path. If the start and end point of a path is the same node, then it is called a loop.

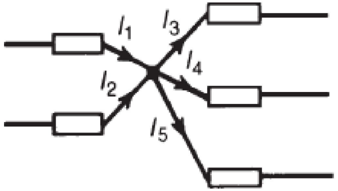






Kirchhoff's Laws

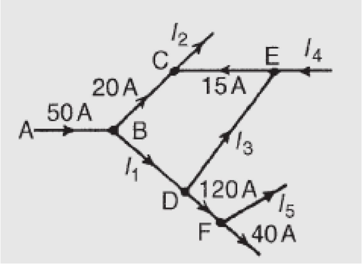
- Kirchhoff's Current Law (KCL):
- At any junction in an electric circuit the total current flowing towards that junction is equal to the total current flowing away from the junction, i.e. $\sum I = 0$
- Thus current entering a node is equal to the current exiting the node
- For the given example



$$I_1 + I_2 = I_3 + I_4 + I_5 \quad \text{or}$$

$$I_1 + I_2 - I_3 - I_4 - I_5 = 0$$

- Find the unknown currents marked in Figure



Kirchhoff's Laws - Examples

Use Kirchhoff's laws to determine the currents flowing in each branch of the network shown in Figure 1.

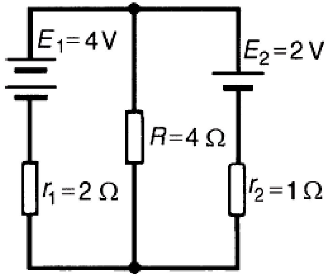


Fig. 1

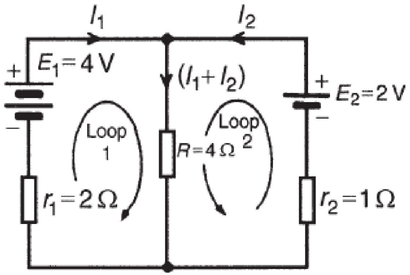


Fig. 2

Procedure Use Kirchhoff's current law and label current directions on the original circuit diagram. The directions chosen are arbitrary, but it is usual, as a starting point, to assume that current flows from the positive terminals of the batteries. This is shown in Figure 2, where the three branch currents are expressed in terms of $I1$ and $I2$ only, since the current through R is $I1+I2$.

Kirchhoff's Laws - Examples

- Divide the circuit into two loops and apply Kirchhoff's voltage law to each. From loop 1 of Figure 2, and moving in a clockwise direction as indicated (the direction chosen does not matter), gives

$$E_1 = I_1 r_1 + (I_1 + I_2)R, \text{ i.e. } 4 = 2I_1 + 4(I_1 + I_2)$$

$$\text{i.e. } 6I_1 + 4I_2 = 4 \qquad (1)$$

- From loop 2 of Figure 2, and moving in an anticlockwise direction as indicated (once again, the choice of direction does not matter; it does not have to be in the same direction as that chosen for the first loop), gives:

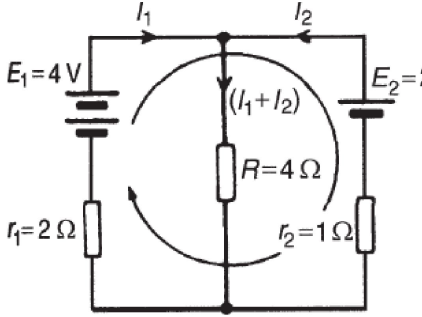
$$E_2 = I_2 r_2 + (I_1 + I_2)R, \text{ i.e. } 2 = I_2 + 4(I_1 + I_2)$$

$$\text{i.e. } 4I_1 + 5I_2 = 2 \qquad (2)$$

- From equ. 1 and 2, we get

  I1 = 0.867 A and I2 = -0.286 A and I1 + I2 = 0.571 A

- Note that a third loop is possible, as shown in Figure 3, giving a third equation which can be used as a check. How?



Kirchhoff's Laws - Examples

For the bridge network shown in Figure 4 determine the currents in each of the resistors.
Let the current in the 2 resistor be $i1$, then by Kirchhoff's current law, the current in the 14 resistor is (i –$i1$). Let the current in the 32 resistor be $i2$ as shown in Figure 5. Then the current in the 11 resistor is ($i1$–$i2$) and that in the 3 resistor is (i –$i1$+$i2$). Applying Kirchhoff's voltage law to loop 1 and moving in a clockwise direction as shown in Figure 5 gives:

$$13\ i1 - 11\ i2 = 54 \qquad (1)$$

Applying Kirchhoff's voltage law to loop 2 and moving in an anticlockwise direction as shown in Figure 5 gives:

$$16\ i1 + 32\ i2 = 112 \qquad (2)$$

Using equ. (1) and (2), find all currents.

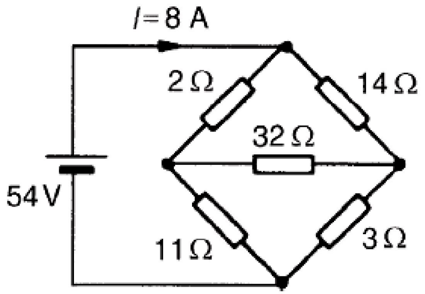
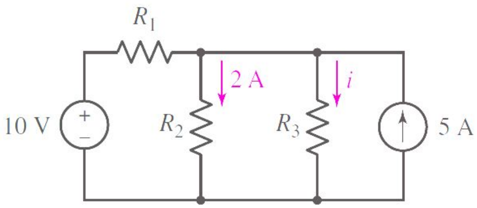


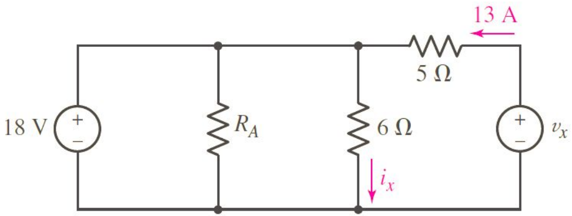
Fig. 4

Problems

For the circuit in the Fig, compute the current through resistor R3 if it is known that the voltage source supplies a current of 3 A.



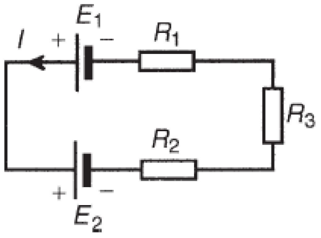
If ix = 3 A and the 18 V source delivers 8 A of current, what is the value of RA?



Kirchhoff's Laws

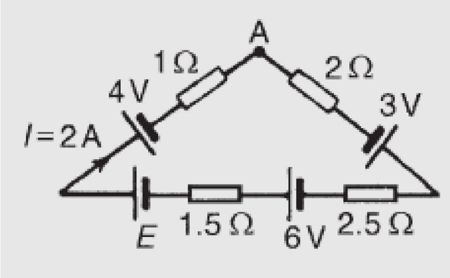
Kirchhoff's Voltage Law (KVL):

In any closed loop in a network, the algebraic sum of the voltage drops (i.e. products of current and resistance) taken around the loop is equal to the resultant e.m.f. acting in that loop.



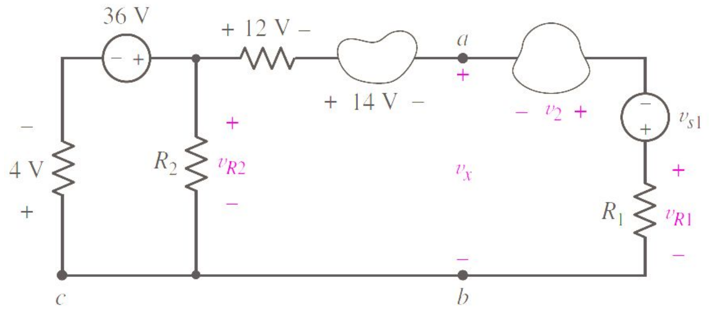
Thus $E_1 - E_2 = IR_1 + IR_2 + IR_3$

Determine the value of e.m.f. E in Figure



Problems

Find v_{R2} (the voltage across R2) and the voltage labeled v_x.



Determine v_x