Spring 2023

CSE250 - Circuits and Electronics

Basics of Electricity

BRAC UNIVERSITY
Inspiring Excellence

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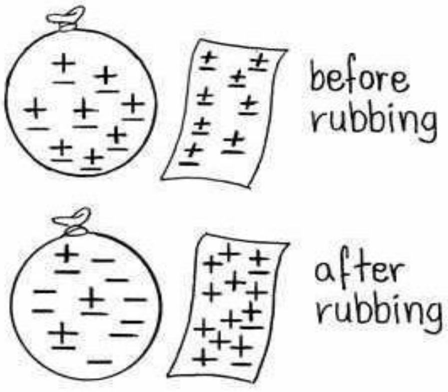
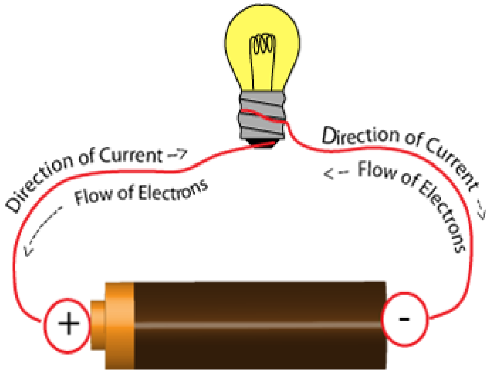
Electricity

- *Electricity* is the set of physical phenomena associated with the presence and motion of matter that has a property of <u>electric charge</u>. Electricity can be divided into two categories based on how the charge behaves. <u>Static</u> and <u>current electricity</u>.

- *Static electricity* is electricity in which the charges remain at rest on the surface of a material. These “static charges” don’t go away unless they’re grounded or released. It induces because of the movement of the negative charges from one object to another.

- *Current electricity* Current electricity is the electricity that is generated as a result of the movement of electrons. It can only form on materials with unbound electrons. It develops only in the conductor.

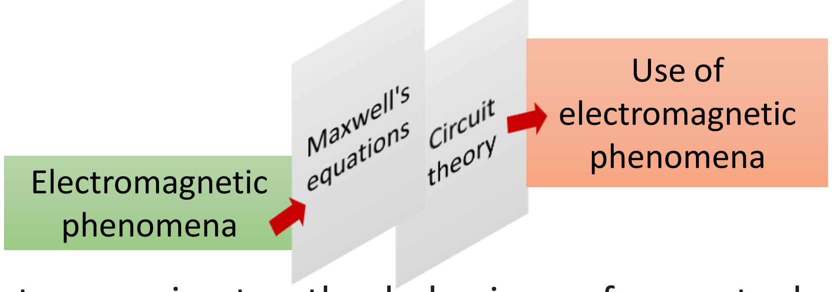




Static vs Current Electricity

Static electricity	Current electricity
The electricity which is built up on the surface of the substance is known as static electricity.	The current electricity is because of the flow of electrons.
It induces because of the movement of the negative charges from one object to another	The current electricity is because of the continuous movement of the electrons.
The static electricity develops both in the conductor and insulator.	The current electricity develops only in the conductor.
Does not induce magnetic field.	It induces a magnetic field.
Lightning strikes, it develops by rubbing the balloons on hair, etc.	The current electricity is used for running the fan, light, T. V., etc.

Circuit Theory

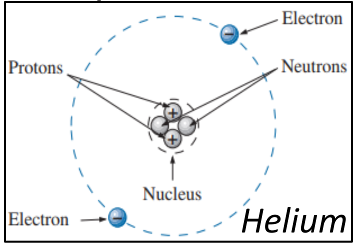


- An *electric circuit* is a mathematical model that approximates the behaviour of an actual electrical system. The term *electric circuit* is commonly used to refer to an actual electrical system as well as to the model that represents it.
- *Circuit theory* is a special case of electromagnetic field theory: the study of static and moving electric charges. It is a set of *abstraction layers* developed by engineers to circumvent the time-consuming application and complicated mathematics required for applying Maxwell's equations to analyse electrical circuits in particular.
- Three basic assumptions permit us to use circuit theory, rather than electromagnetic field theory, to study a physical system represented by an electric circuit.

  1. *Electrical effects happen instantaneously (near the speed of light) throughout a system.*
  2. *The NET charge on every component in the system is always zero.*
  3. *There is no magnetic coupling between the components in a system.*

Charge

- *Charge* is an electrical property of the atomic particles of which matter consists, measured in coulombs (C).
- All matter is made of fundamental building blocks known as atoms and that each atom consists of electrons, protons, and neutrons. The presence of equal numbers of protons and electrons leaves an atom neutrally charged.



- The charge e on an electron = -1.602×10^{-19} C
- The charge q on a proton = $+1.602 \times 10^{-19}$ C
- The *law of conservation of charge* states that charge can neither be created nor destroyed, only transferred. Thus, the algebraic sum of the electric charges in a system does not change.
- *Charge quantization* is the principle that the charge of any object is an integer multiple of the elementary charge. $[0.5e, 3.7q, 1.2e\ \textit{etc. charges don't exist}]$

Problem 1

(i) How many electrons are there in 1C of charge?

(ii) How much charge is represented by these number of electrons?

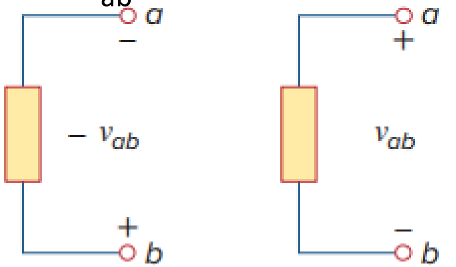
(a) 1.24×10^{18}
(b) 2.46×10^{19}

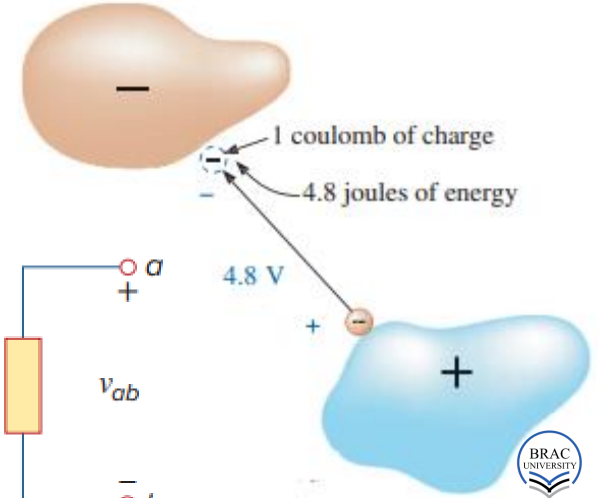
Ans: $(i)\ \mathbf{6.25\ \times\ 10^{16}\ \boldsymbol{electrons}}.$
$(ii)\ (a)\ -\ \mathbf{198.65\ \boldsymbol{mC}}, (b)\ -\ \mathbf{3.941\ \boldsymbol{C}}$

Voltage

- *Electric potential or potential difference or voltage* is the energy required per unit charge to move a charge from a reference point to another point of interest.
- The voltage V_{ab} between two points $\boldsymbol{a}$ and $\boldsymbol{b}$ in an electric circuit is the energy (or work) needed to move a unit charge from $\boldsymbol{b}$ to $\boldsymbol{a}$; mathematically,
- $V_{ab} = \frac{W}{Q} \quad (\frac{Joule}{Coulomb} = Volts)$
- The V_{ab} can be represented in two ways: (1) Point a is at a potential of V_{ab} volts higher than point b, or (2) the potential at point a with respect to point b is V_{ab}
- Logically, $V_{ab} = -V_{ba}$
- Is there anything like V_a or V_b?

Let's find on the next slide!





Absolute Potential

- The concept of *absolute potential* is based on the reality that *there is no such thing as absolute potential!* Let's reiterate the definition of potential difference.
- *Potential difference or voltage* is the energy required per unit charge to move a charge from a reference point to another point of interest.
- We consider the potential of the point of interest to be the absolute potential if the reference point is at an infinite distance. Where the potential is considered to be 0 at infinite. Mathematically,
- $V_a - V_\infty = V_a - 0 = V_a; \quad where, V_\infty = 0$

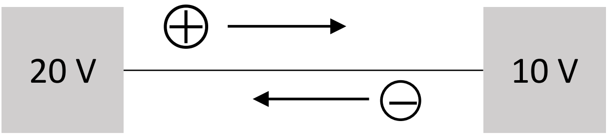
$$W = qV$$

- Work done to move a charge q from point A to point B is thus, $\boxed{W = q(V_B - V_A)}$

V_{Final} $V_{Initial}$

- Note that, W depends only on the potentials of the initial and final points, not on the path of the charge being moved

Sign convention



- Consider the scenario where two bodies at potentials 10 V and 20 V are connected by a conducting wire. In which direction the charges will move?

$\Rightarrow$ *Every system tends to reside in its lower energy state. For a –ve charge, the lower energy is toward the higher potential and vice versa for a +ve charge. So, –ve charges will move from the body at 10 V toward the body at 20 V and +ve charges will move in the opposite direction until the two bodies are at equal potential of 15 V. We say, this is the natural flow of charges. In this case, charges do the required work.*

- If we are to move the charges in opposite to their natural direction, external work must be done. 'W' is +ve if external work is done and –ve if the work is done by the charge itself. This signing convention is in accordance with that of moving object vertically. Lifting an object in opposite to the gravitational force increases its potential energy (+ve U).

$$W = q(V_B - V_A)$$

$+$ If external work is done

$-$ If work is done by charge itself

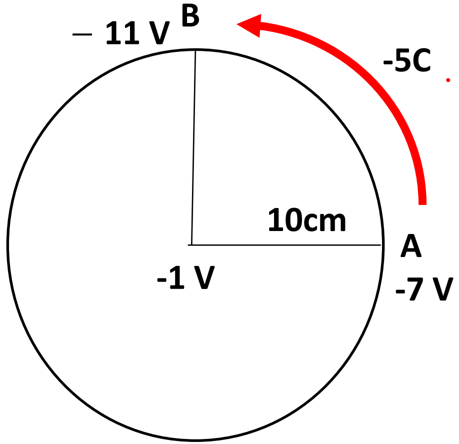
(for $+ve$ charge) $+$

$-$ (for $-ve$ charge)

Problem 2

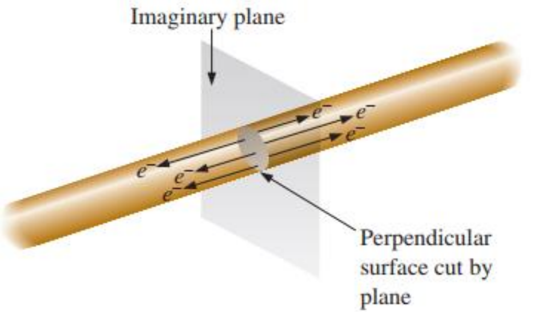
(i) At point **A**, there's a voltage of $V_A = 22\,V$. If a charge with $q = -2\,C$ moves from point A to another point B and while moving it does a work of $W = 10\,J$, what's the voltage of point **B**?

(ii) How much work must be done to transport the $-5\,C$ charge from point **A** to point **B** around the circle depicted in the diagram?



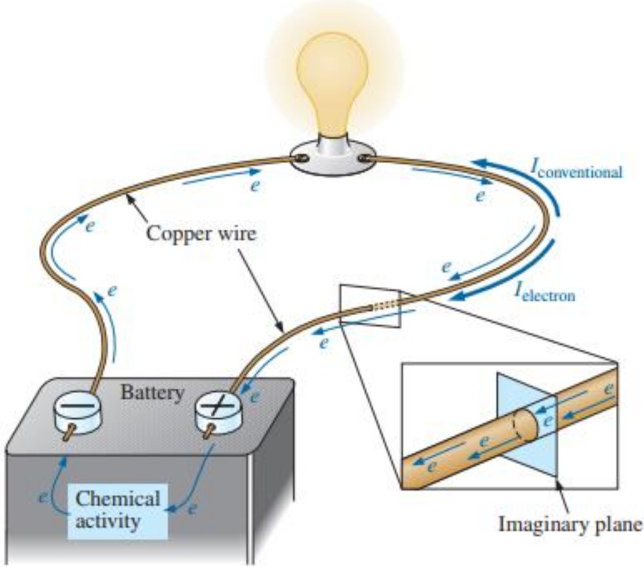
Ans: (i) $\boldsymbol{V_B = 27\,V}$
(ii) $\boldsymbol{W = +20\,J}$

Current



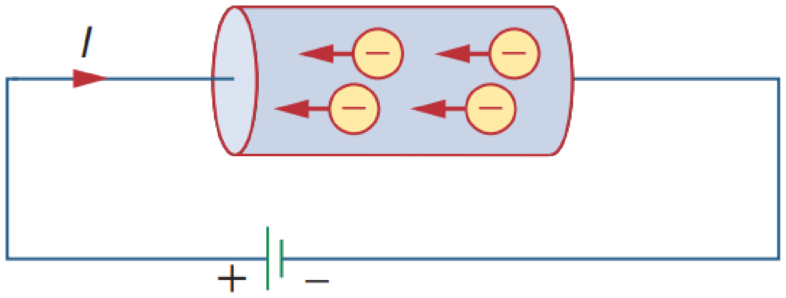
Isolated Cu wire with zero net flow of charge in any particular direction

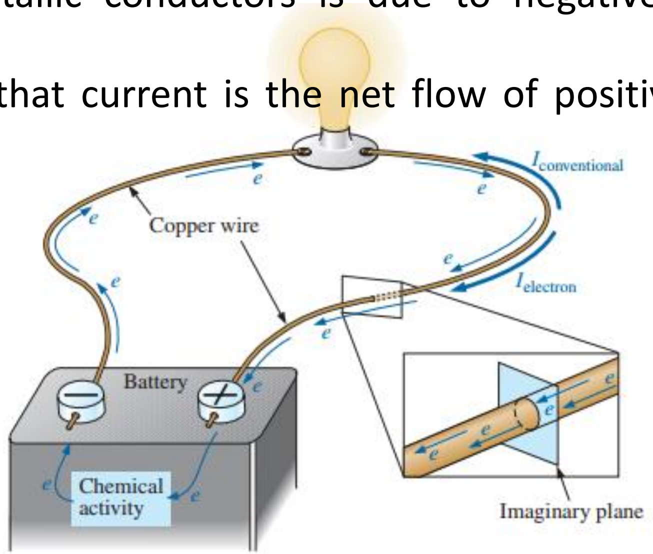
- *Electric current* is the time rate of change of charge, measured in amperes (A).
- Mathematically, the relationship between current i, charge q, and time t is,
- $i = \frac{dq}{dt}$ (coulomb/sec = Ampere)
- Free electrons generated at room temperature in a conductor are in constant motion in random directions, however, the net flow in any one direction is zero (current is zero).
- To make this electron flow do work for us, we need to give it a direction and be able to control its magnitude. This is accomplished by simply applying a voltage (driving force) across the wire to force the electrons to move toward the positive terminal of the battery.



Current: direction controversy

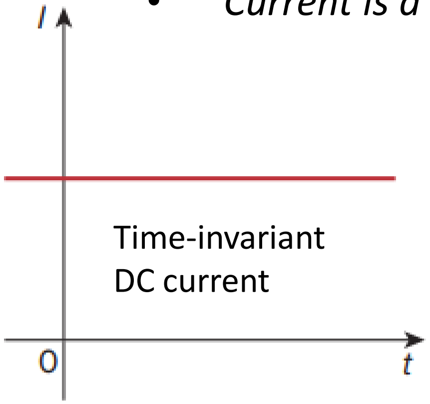
- There are two directions of charge flow: positive charges move in one direction while negative charges move in the opposite direction.
- The controversy in the direction of current is a result of an assumption made at the time electricity was discovered that the positive charge was the moving particle in metallic conductors although we know that current in metallic conductors is due to negatively charged electrons.
- We will follow the universally accepted convention that current is the net flow of positive charges.

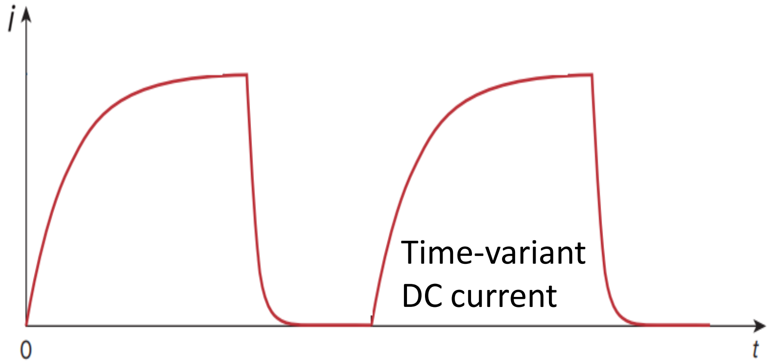


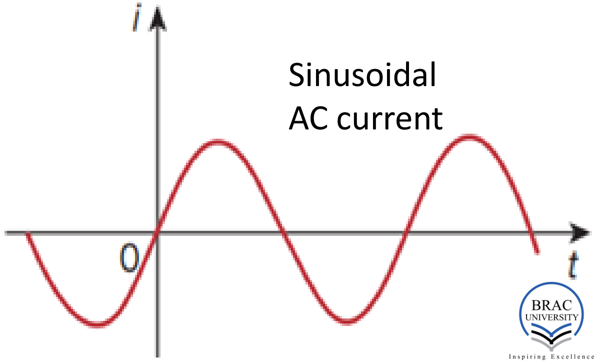


Current: types

- $i = \frac{dq}{dt}$ or $q = \int_{t_0}^{t} i\,dt$ suggests that current need not be a constant-valued function. It can vary in several ways. But there are two ways that current can flow. It can only flow in one direction or in both directions simultaneously.
- A *direct current (dc)* flows only in one direction and can be constant or time varying.
- An *alternating current (ac)* is a current that changes direction with respect to time. So, ac current is always time-varying. We will explore ac current more in detail later.
- "*Current is a scalar quantity in spite of having magnitude and direction*",----- think why!







Power

- *Power* is the time rate of expending or absorbing energy, measured in watts (W).

- $p = \frac{dw}{dt}$, where p is power in watts (W), w is energy in joules (J), and t is time in seconds (s).

$$\Rightarrow p = \frac{dw}{dt} = \frac{dw}{dq} \cdot \frac{dq}{dt} = vi$$

$$\Rightarrow \boxed{p = vi}$$ [1 Watt = 1 Joule/sec] [746 Watt = 1 horse-power (hp)]

$$\Rightarrow w = \int_{t_0}^{t} p\, dt = \int_{t_0}^{t} vi\, dt$$

- The power p is a time-varying quantity and is called the *instantaneous power*.

- Power is a signed quantity as voltage and current are signed quantities. So, what does positive power and negative power mean? Let's find in the next slide.

Passive sign convention

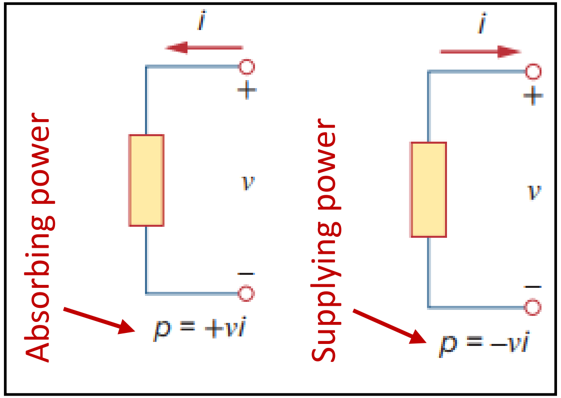
- The universal standard is that, if the power has a + sign, power is being delivered to or absorbed by the element. If, on the other hand, the power has a − sign, power is being supplied by the element. But how do we know when the power has a negative or a positive sign? *Current direction and voltage polarity determines the sign of power.*

- *Passive sign convention* is satisfied when the current enters through the positive terminal of an element and $p = +vi$. If the current enters through the negative terminal, $p = -vi$.

- In an electric circuit, $+Power\ absorbed = -Power\ supplied$

- The *law of conservation of energy* requires that, $\sum p = 0$

☞ Determine first, by looking at the polarity of the voltage and the direction of the current, whether it is absorbing or supplying power. Then use $p = +vi\ or\ p = -vi$ accordingly.

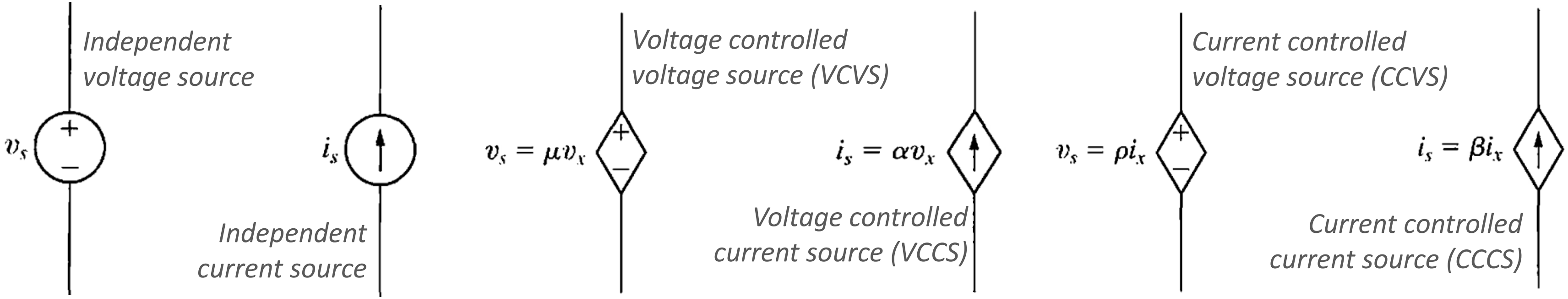


Circuit elements

- **Active element**
  - An *active element* is capable of generating energy.
  - In other words, an element is said to be active if it can add some gain (in terms of voltage or current) to a circuit.
  - Active elements can absorb energy if they are forced to do so by other active elements.
  - Examples: *Voltage/current sources, generators, transistors, operational amplifiers.*
- **Passive element**
  - *Passive elements* cannot supply energy. They can only consume/dissipate/store energy.
  - Examples: *Resistors, capacitors, inductors, transformers.*
  - Transformers change the voltage or current levels, but the power is unchanged. This is why transformers are passive element.

Electrical sources

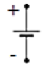
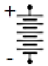
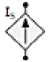
- An *electrical source* is a device that is capable of converting nonelectric energy to electric energy and vice versa. They can either deliver or absorb electric power, generally maintaining either voltage or current.
- *Ideal voltage sources* maintain a set voltage across their terminals regardless of current flow. *Ideal current sources* maintain a defined current via their terminals regardless of voltage.
- They can be further described as either independent sources or dependent sources.
- A *dependent source* or *controlled source* establishes a voltage or current whose value depends on the value of a voltage or current elsewhere in the circuit.



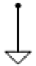
Circuit symbols

- Basic Electrical and Electronic Schematic Symbols (Click here for more circuit symbols)

Power Supply Schematic Symbols

Schematic Symbol	Symbol Identification	Description of Symbol
	Single Cell	A single DC battery cell of 0.5V
	DC Battery Supply	A collection of single cells forming a DC battery supply
	DC Voltage Source	A constant DC voltage supply of a fixed value
	DC Current Source	A constant DC current supply of a fixed value
	Controlled Voltage Source	A dependent voltage source controlled by an external voltage or current
	Controlled Current Source	A dependent current source controlled by an external voltage or current
	AC Voltage Source	A sinusoidal voltage source or generator

Electrical Grounding Schematic Symbols

Schematic Symbol	Symbol Identification	Description of Symbol
	Earth Ground	Earth ground referencing a common zero potential point
	Digital Ground	A common digital logic circuit ground line

Resistor Schematic Symbols

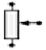
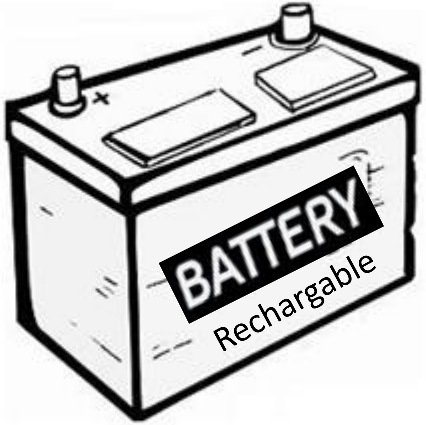
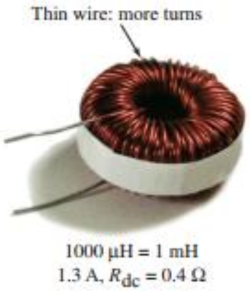
Schematic Symbol	Symbol Identification	Description of Symbol
	Fixed Resistor (IEEE Design)	A fixed value resistor whose resistive value is indicated next to its schematic symbol
	Fixed Resistor (IEC Design)	
	Potentiometer (IEEE Design)	Three terminal variable resistance whose resistive value is adjustable from zero to its maximum value
	Potentiometer (IEC Design)	
	Rheostat (IEEE Design)	Two terminal fully adjustable rheostat whose resistive value varies from zero to a maximum value
	Rheostat (IEC Design)	

Illustration of some basic circuit elements

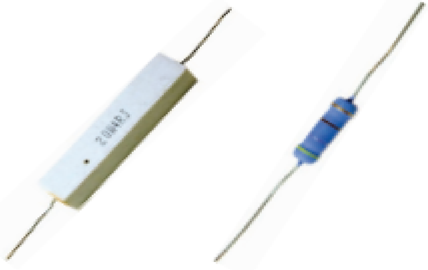


Function generator

Capacitor



Inductor

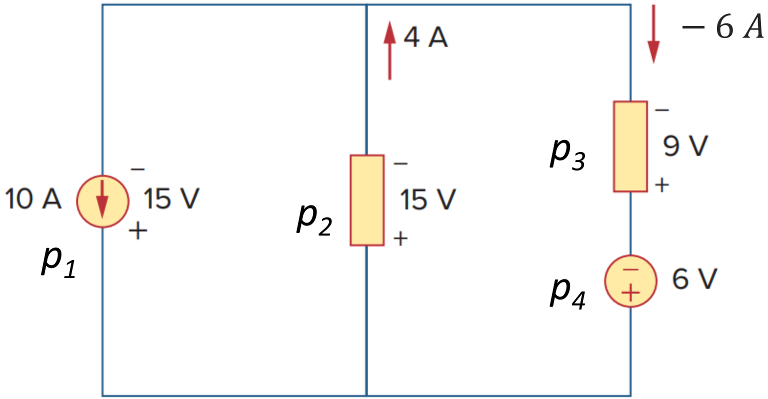


Fixed resistors

Variable resistors

Example 1

- Find power absorbed by each element in the network.



Element 1

Current is leaving the + terminal of the voltage. So, according to the passive sign convention, E1 is supplying power.

$$p_1 = -15 \times 10 = -150\ (W)$$

Element 2

Current is entering the + terminal of the voltage. So, according to the passive sign convention, E2 is absorbing power.

$$p_2 = +15 \times 4 = +60\ (W)$$

Element 3

Current (the arrow) is leaving the + terminal of the voltage. So, according to the passive sign convention, it seems that E2 is supplying power.

$$p_3 = -9 \times (-6) = +54\ (W)$$

However, as the final form of the calculation is $+ve$, it is actually absorbing.

Element 4

Current is leaving the + terminal of the voltage. So, according to the passive sign convention, it seems that E2 is supplying power.

$$p_4 = +6 \times 6 = +36\ (W)$$

However, as the final form of the calculation is $+ve$, it is actually absorbing.

Problem 3

- Find power absorbed by each element in the network.

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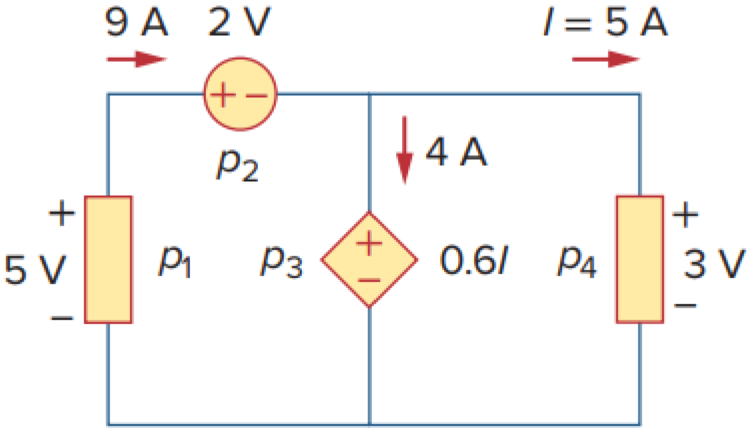
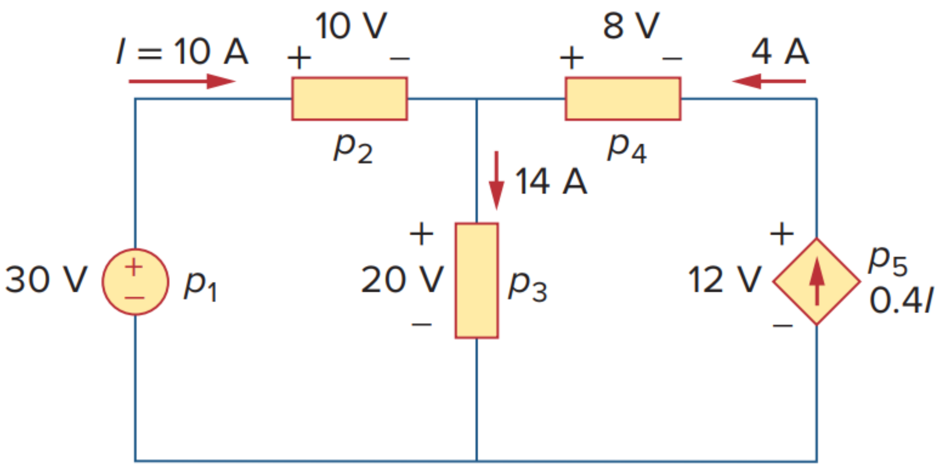


Ans: $p_1 = -45\ W, p_2 = 18\ W, p_3 = 12\ W, p_4 = 15\ W$

Problem 4

- Find power absorbed by each element in the network.



Ans: $p_1 = -300\ W, p_2 = 100\ W, p_3 = 280\ W, p_4 = -32\ W, p_5 = -48\ W$

Practice Problems

- Additional practice problems can be found here

Thank you for your attention