Chapter 3:

a. Electric current
b. Ohm's law and Joule's law
c. Electric circuits
d. Thévenin's and Norton's theorems

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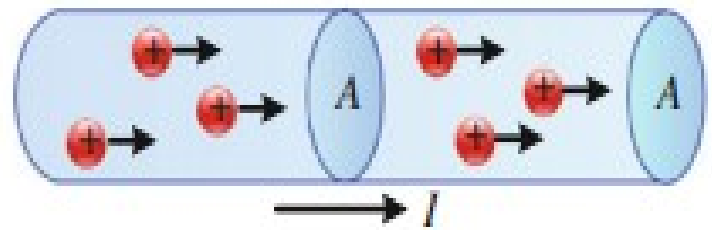
Electric Current

When there is a net flow of charge across any area, we say there is an electric current (or simply current) across that area

To define the current, we consider positive charges moving perpendicularly onto a surface area A as shown in Fig.



Thus, if a net charge ΔQ flows across an area A in a time Δ t, the average current I_{av} across the area is:

$$I_{av} = \frac{\Delta Q}{\Delta t}$$

When the rate of flow varies with time, we define the instantaneous current (or the current) I as:

$$I = \frac{dQ}{dt}$$

The SI unit of the current is ampere (abbreviated by A). That is:

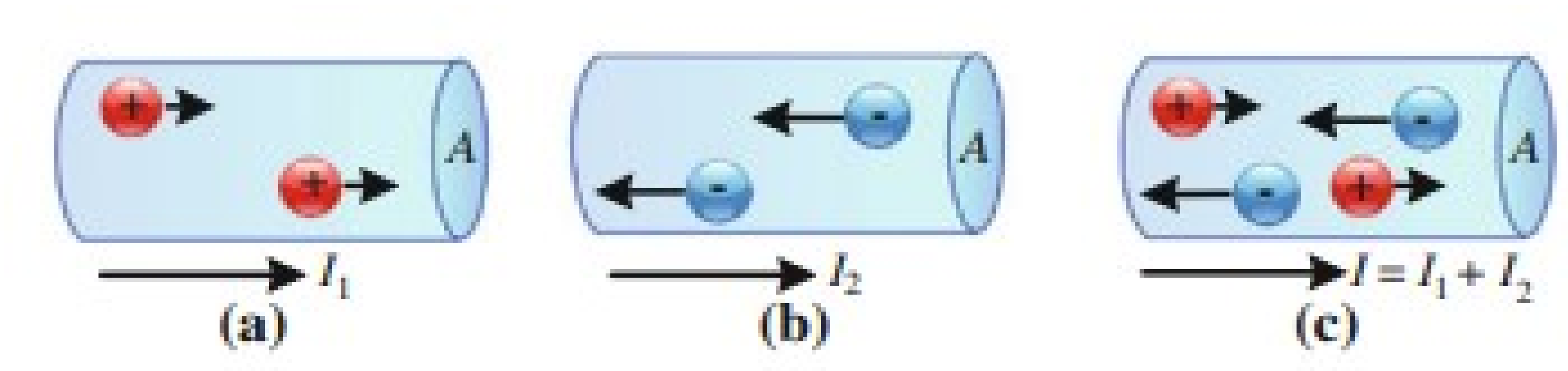
$$1\ A = \frac{1\ C}{1\ S}$$

Thus, 1 A is equivalent to 1 C of charge passing through the surface area in 1 s

Direction of Electric Current

Currents can be due to positive charges, or negative charges, or both. In conductors, the current is due to the motion of only negatively charged free electrons (called conduction electrons).

By convention, the direction of the current is **the direction of the flow of positive charges**. Therefore, the direction of the current is **opposite to the direction of the flow of electrons**, see Fig. A moving charge, positive or negative, is **usually referred to as a mobile charge carrier.**



Direction of current due to (a) positive charges, (b) negative charges, and (c) both positive and negative charges

The current density

The current density i is defined as the current per unit area

$$i = \frac{I}{A}$$

I → Current (A)

A → Area(m^2)

Since the current is a flow of electric charge, we can describe it using the density and velocity of electric charge. Suppose that particles of electric charge q and density n move with velocity v. The current density is then given by

$$i = n|q|v$$

vector is defined as

$$\vec{i} = nq\vec{v}$$

The free-electron density n

$$n = \frac{N_A \times d}{M}$$

N_A (Avogadro's number)

M (Molar mass)

d (Density)

[Hint: Assume that each metal atom contributes one free conduction electron to the current.]

Ohm's Law

(Ohm's law)

$$\vec{E} = \rho \vec{i}$$

As a result of maintaining a potential difference V across a conductor, an electric field and a current density are established in the conductor. For materials with electrical properties that are the same in all directions (isotropic materials), the electric field is found to be proportional to the current density. That is

ρ is resistivity and the SI unit of **ρ** is (Ω.m)

Recall that for uniform electric fields we have:

$$\Delta V = E \times L \Leftrightarrow E = \frac{\Delta V}{L} = \rho i$$

Also, using i = I/A, the potential difference ΔV can be written as:

$$\frac{\Delta V}{L} = \rho \frac{I}{A} \Leftrightarrow \Delta V = \left(\frac{\rho L}{A}\right) I$$

we note that the direction of the current is in the direction of decreasing potential.

The quantity in brackets is called the electrical resistance (or simply resistance) of the conductor and is denoted by the symbol R; that is:

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

We can define the resistance R as a proportionality constant to the relation V ∝ I and write the equivalent Ohm's law as

$$\Delta V = RI$$

The SI unit of resistance is ohm (abbreviated by Ω)

The inverse of resistivity is called the conductivity σ, thus:

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

where the SI unit of σ is $(\Omega.m)^{-1}$

The resistance of a conductor can also be written in terms of the conductivity as follows

$$R = \frac{L}{\sigma A}$$

Electric Power

Power is the rate at which electrical energy is supplied to a circuit or consumed by a load.

Electric Power (Watts): 3 different ways

$$P = V\,I$$

$$P = V\,I \;\downarrow\; \text{From Ohm's Law } V = I\,R \;\downarrow\; P = I\,R\,I \;\downarrow\; P = I^2\,R$$

$$P = V\,I \;\downarrow\; I = \frac{V}{R} \;\downarrow\; P = V\,\frac{V}{R} \;\downarrow\; P = \frac{V^2}{R}$$

Remember:

1 W = 1 J/s

Electrical Energy and Joule's law

If a current I flows through a conductor kept across a potential difference V for a time t, the work done or the electric potential energy spent is $W = VIt$

In the absence of any other external effect, this energy is spent in heating the conductor. The amount of heat (H) produced is $H = VIt$

For a resistance R, $H = I^2Rt$

This relation was experimentally verified by Joule and is known as joule's law of heating. It states that the heat developed in an electrical circuit due to the flow of current varies directly as

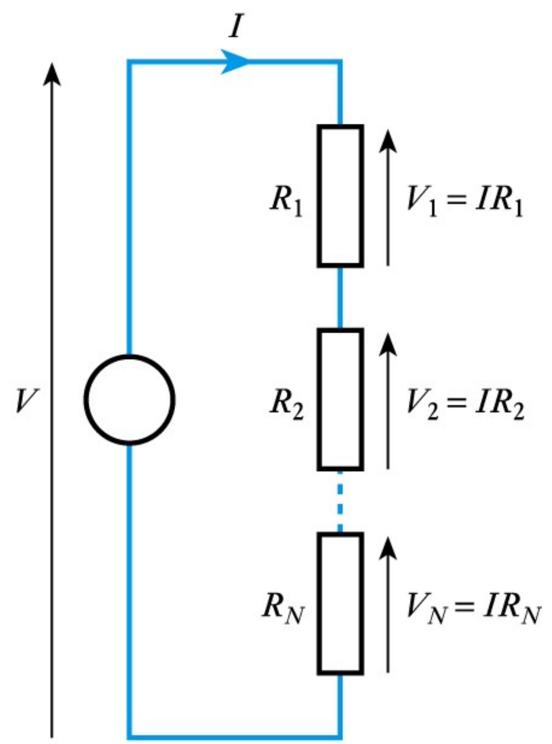
- **The square of the current**
- **The resistance of the circuit.**
- **The time of flow**

Remember:

$1\ J = 1\ N \cdot m = 1\ kg \cdot m^2/s^2$

Resistors in Series

- **Series**

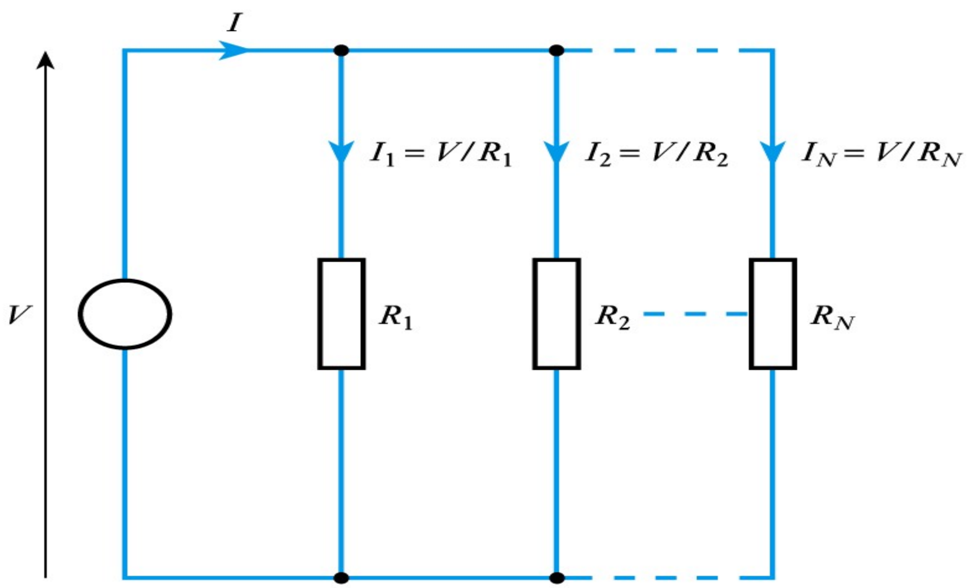


$$R = R_1 + R_2 + R_3$$

$$V_T = V_1 + V_2 + V_3$$

$$I_T = I_1 = I_2 = I_3$$

Resistors in Parallel



$$\frac{1}{R_t} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$

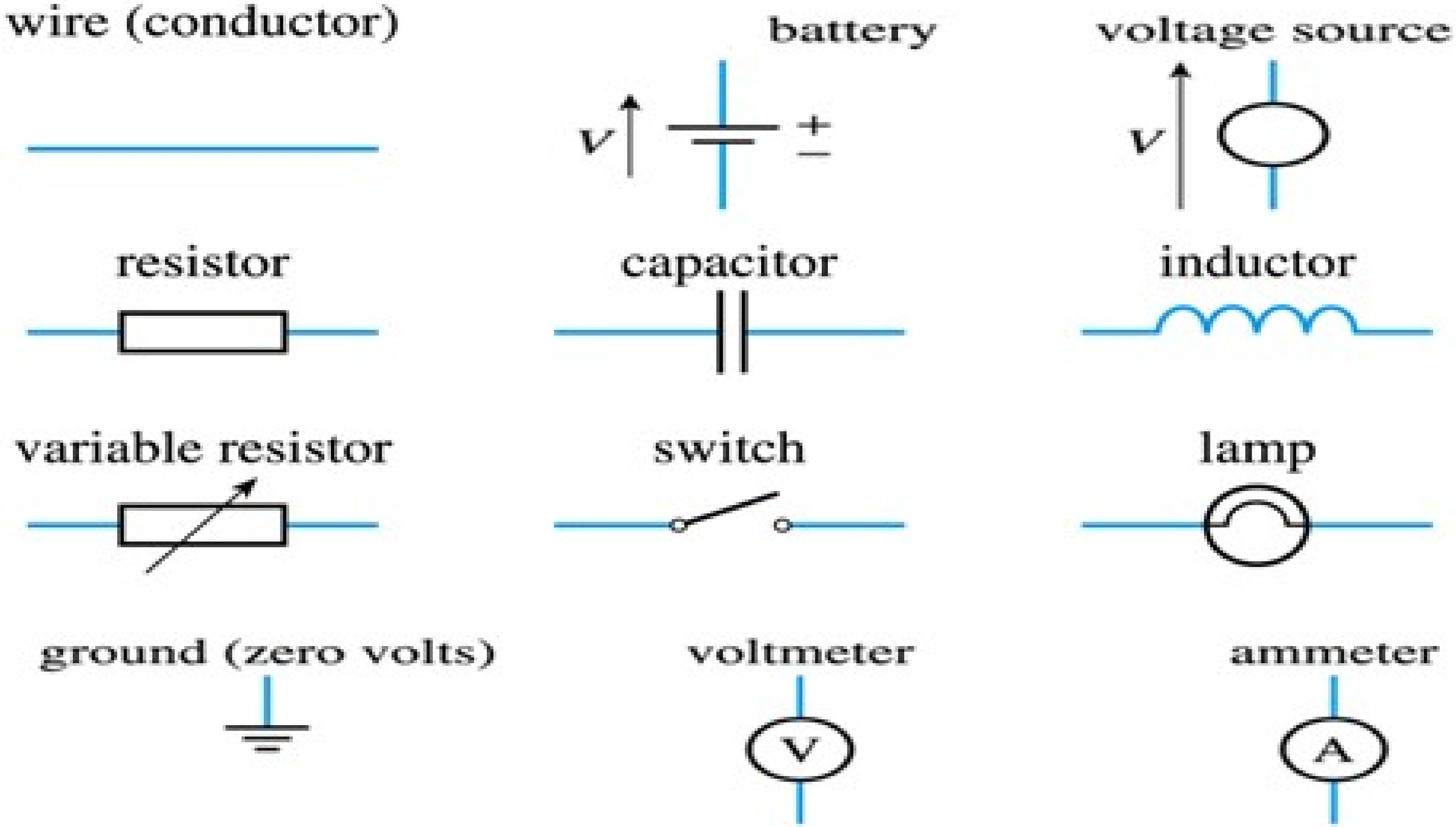
$$I_T = I_1 + I_2 + I_3$$

$$V_T = V_1 = V_2 = V_3$$

Electric circuits

Before you begin to understand circuits you need to be able to draw what they look like using a set of standard symbols understood anywhere in the world

Circuit Symbols

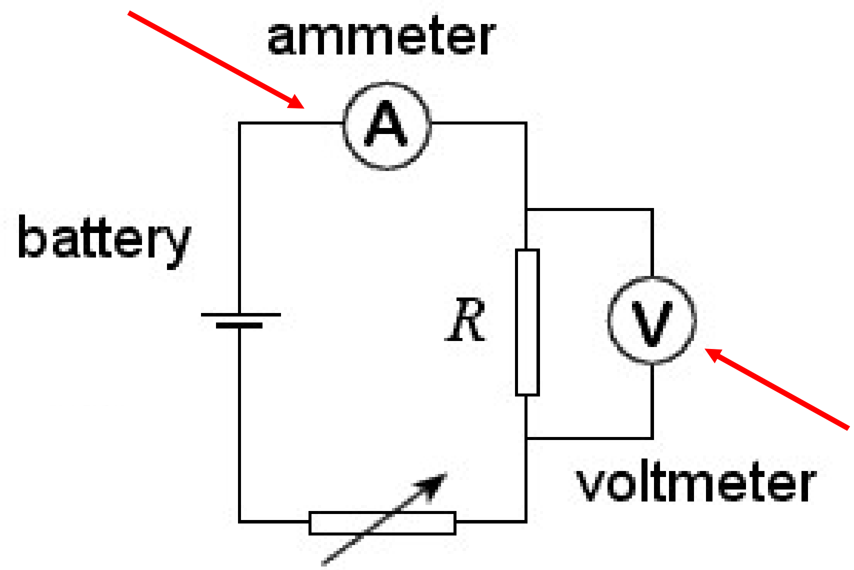


Electric circuits

The Voltmeter and Ammeter

The voltmeter and ammeter cannot be just placed anywhere in the circuit. They must be used according to their DEFINITION.

Current goes THROUGH the ammeter



Since a voltmeter measures voltage or POTENTIAL DIFFERENCE it must be placed **ACROSS** the device you want to measure. That way you can measure the CHANGE on either side of the device.

Voltmeter is drawn ACROSS the resistor

Since the ammeter measures the current or FLOW it must be placed in such a way as the charges go **THROUGH** the device.

Direct Current and Alternating Current

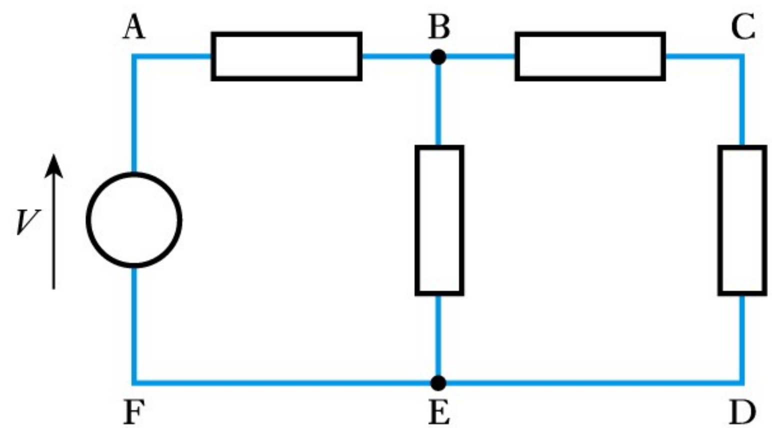
- Currents in electrical circuits may be constant or may vary with time
- When currents vary with time they may be **unidirectional** or **alternating** (**AC**)
- When the current flowing in a conductor always flows in the same direction this is **direct current** (**DC**)

Resistors, Capacitors and Inductors

- **Resistors** provide resistance
  - they oppose the flow of electricity
  - measured in Ohms (Ω)
- **Capacitors** provide capacitance
  - they store energy in an electric field
  - measured in Farads (F)
- **Inductors** provide inductance
  - they store energy in a magnetic field
  - measured in Henry (H)

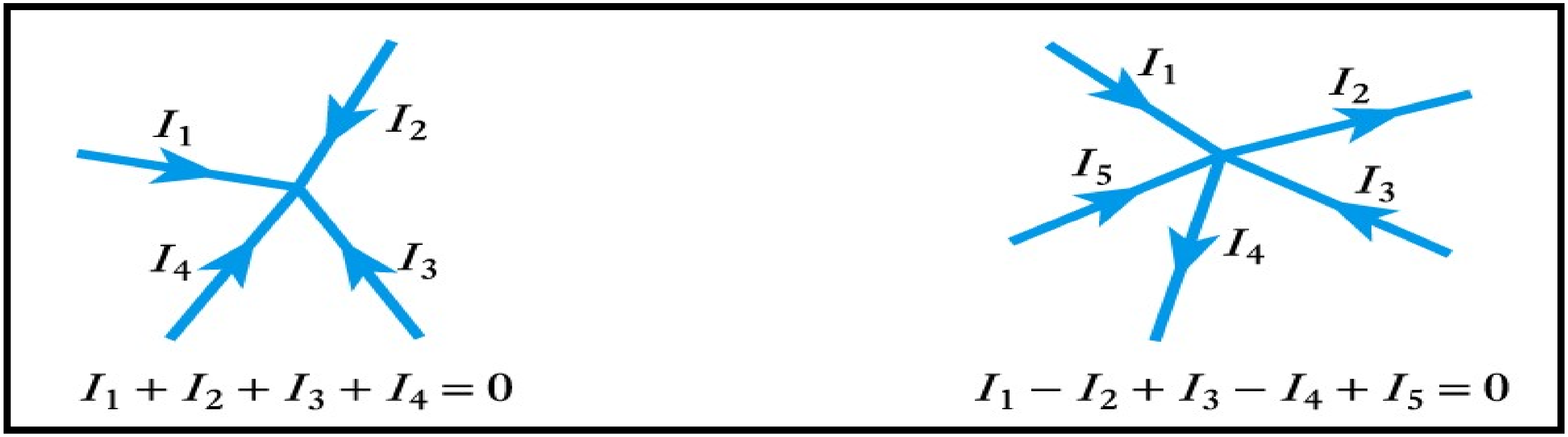
Kirchhoff's Laws

- **Node or Junction**
  - a point in a circuit where three or more wires meet.
- **Loop**
  - any closed path that passes through no node more than once
- **Examples:**
  - B and E are *nodes*
  - the paths ABEFA, BCDEB and ABCDEFA are *loops*
  - ABEFA and BCDEB are *meshes*

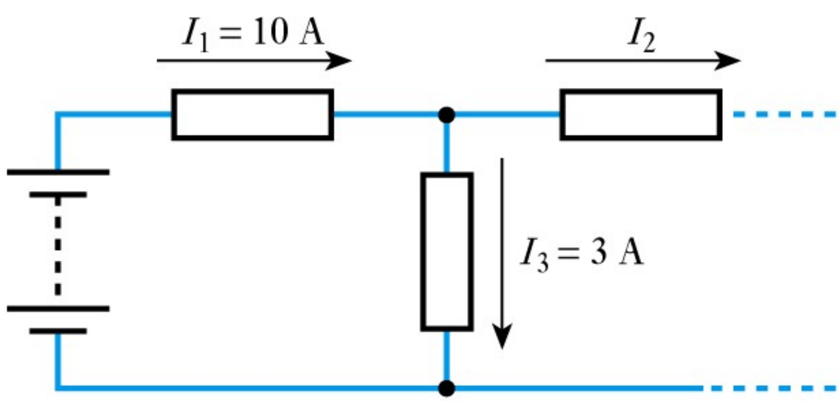


Kirchhoff's Current Law

At any instant, the algebraic sum of all the currents flowing into any node in a circuit is zero $\sum I = 0$
if currents flowing into the node are positive, currents flowing out of the node are negative, then



- **For example**



$$I_1 - I_2 - I_3 = 0$$

$$I_2 = I_1 - I_3 = 10 - 3 = 7\text{ A}$$

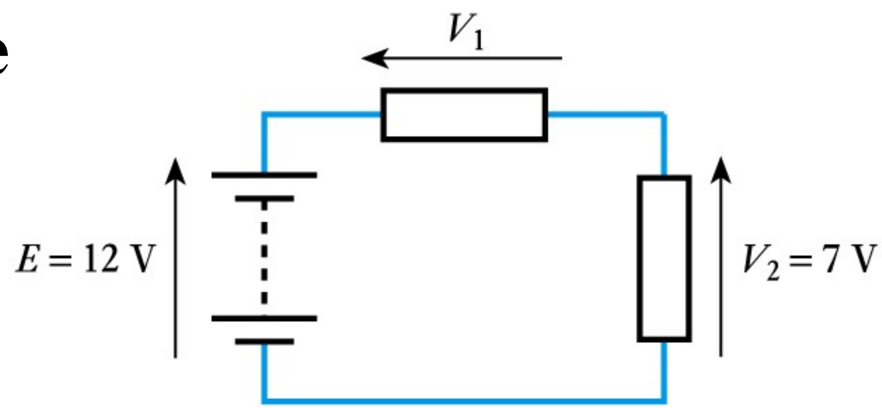
Kirchhoff's Voltage Law

At any instant the algebraic sum of all the voltages around any loop in a circuit is zero

$$\sum V = 0 \Leftrightarrow \sum RI = \sum E$$

- **If clockwise voltage arrows are positive and anticlockwise arrows are negative then**

For example



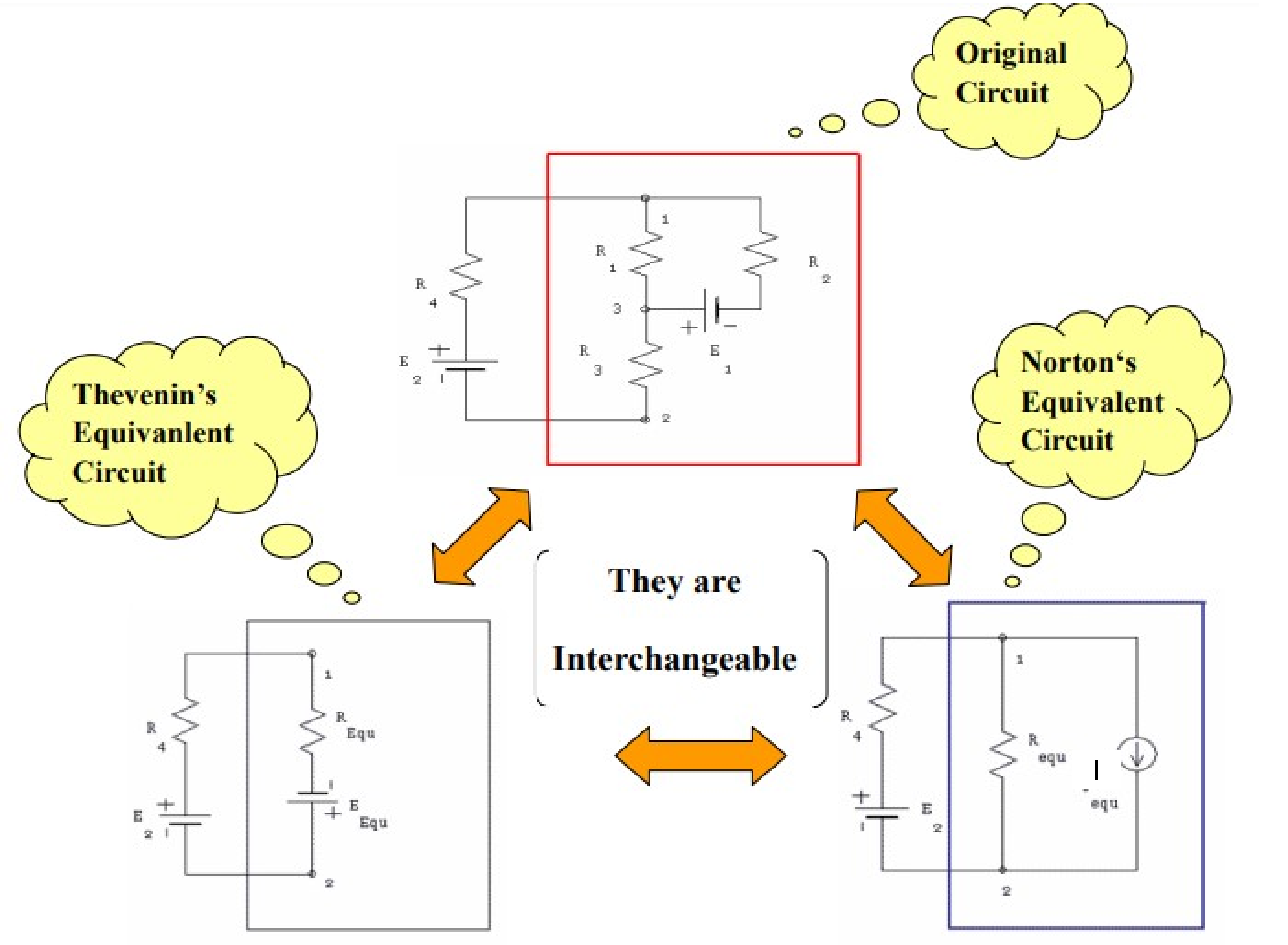
$$-V_1 - V_2 = E$$
$$V_1 = -E - V_2$$
$$= -12 - 7$$
$$= -19 \text{ V}$$

Thevenin’s and Norton’s Equivalent Circuit Tutorial

Thevenin’s and Norton’s Equivalent Circuit Tutorial

Thevenin's Theorem states that we can replace entire network by an equivalent circuit that contains only an independent voltage source in series with an impedance (resistor) such that the current-voltage relationship at the load is unchanged.

Norton's Thereom is identical to Thevenin's Theorem except that the equivalent circuit is an independent current source in parallel with an impedance (resistor).



Original Circuit
Thevenin's Equivanlent Circuit
Norton's Equivalent Circuit
They are Interchangeable