Chapter 28 Direct Current Circuits

The discussion is restricted to direct currents (dc) that flows only in one direction. We first study a steady state case and then go on to a time-varying condition.

When a current flows through a resistors, electrical energy is dissipated. A circuit cannot consist solely of **passive devices**; there must also be some source of electrical energy (**active devices**). Such a device is called a source of ***electromotive force***, abbreviated **emf**.

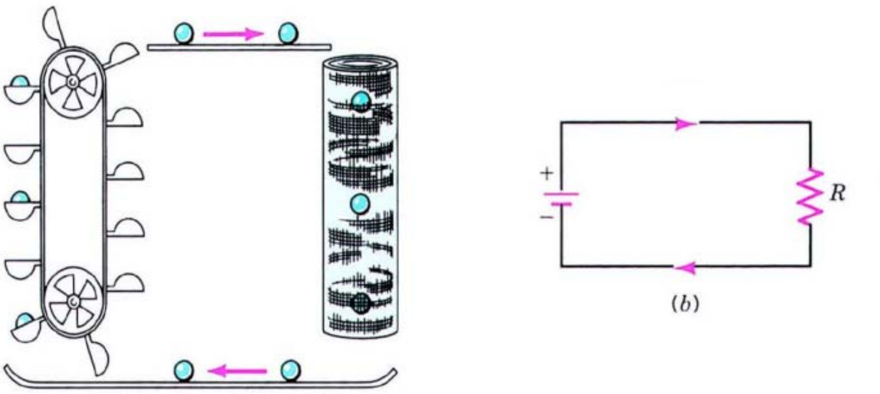
Why don't we use a direct current circuit to transmit electric power? (*extra bonus*)

28.1 Electromotive Force

An emf is the work per unit charge done by the source of emf in moving the charge around *a closed loop*.

$$\mathcal{E} = \frac{W_{ne}}{q}$$

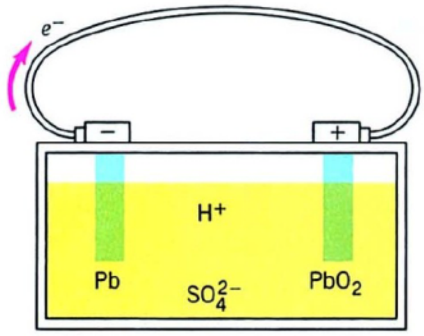
The subscript "ne" emphasizes that the work is done by some nonelectrostatic agent, such as a battery or an electrical generator.



What is the difference between emf and potential difference?

28.1 Electromotive Force:
Production of a current

What is the function of the acid solution in the voltaic pile?



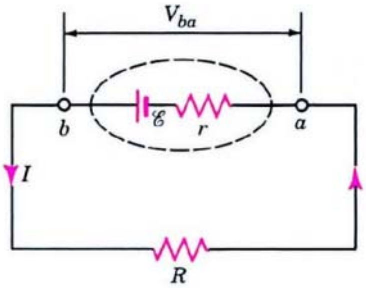
$$\mathrm{Pb} + \mathrm{SO}_4^- \rightarrow \mathrm{PbSO}_4 + 2\mathrm{e}^-$$

$$\mathrm{PbO}_2 + 4\mathrm{H}^+ + \mathrm{SO}_4^- + 2\mathrm{e}^- \rightarrow \mathrm{PbSO}_4 + 2\mathrm{H}_2\mathrm{O}$$

Note that for every electron that leaves the Pb plate, another enters the PbO_2 plate.

28.1 Electromotive Force:
Terminal Potential Difference

A real source of emf, such as a battery, has *internal resistance*.



$$V_{ba} = V_b - V_a = \mathcal{E} - Ir$$

The change in potential is called the **terminal potential difference**.

Unlike the emf, which is a fixed property of the source, the terminal potential difference depends on the current flowing through it.

As a battery ages its internal resistance increases, and so, for a given output current, the terminal potential difference falls.

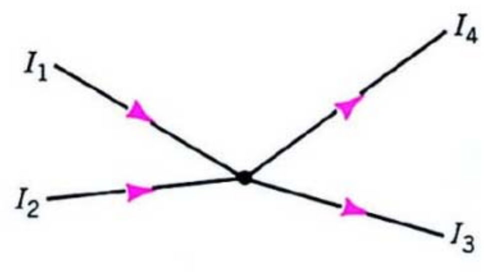
28.2 Kirchhoff's Rules

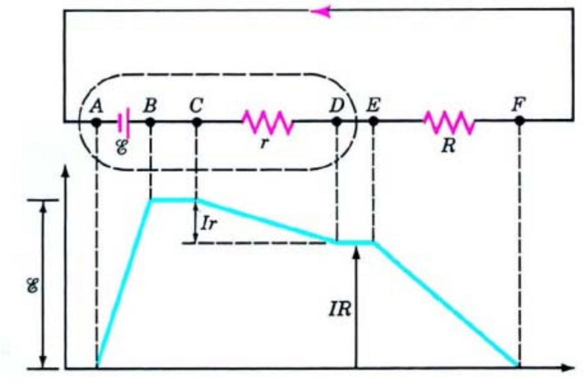
Kirchhoff's junction rule: the conservation of charge

The algebraic sum of the currents enter or leaving a junction is zero. $\Sigma I=0$

Kirchhoff's loop rule: the conservation of energy

The algebraic sum of the changes in potential around a closed loop is zero. $\Sigma V=0$



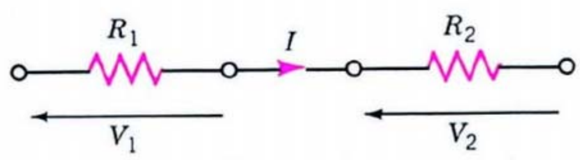


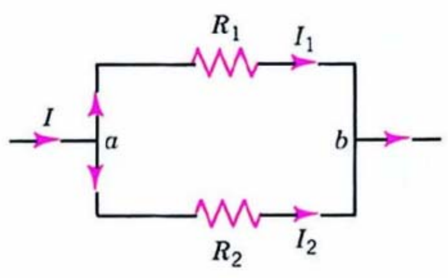
28.3 Series and Parallel Connection

Resistors, like capacitors, can be connected in series and in parallel.

(Series) $$R_{eq} = R_1 + R_2 + R_3 + \cdots + R_N$$

(Parallel) $$\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \cdots + \frac{1}{R_N}$$

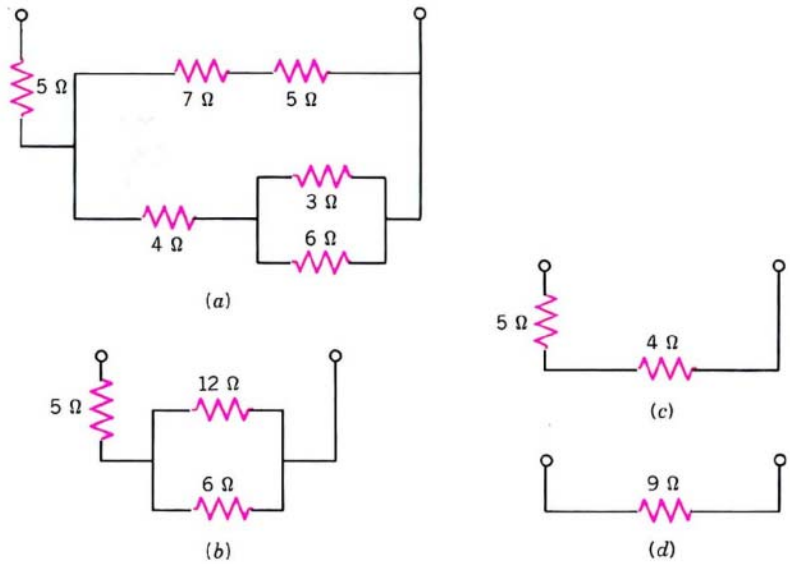




Example 28.1

Find the equivalent resistance of the combination of resistors shown in Fig. 28.10a.

Solution:



Example 28.3

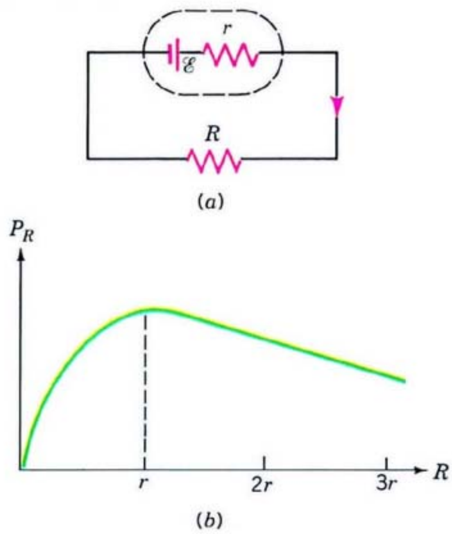
Whenever a real source of emf supplies power to an external load, some power is also dissipated in the internal resistance. A load resistance R is connected to a source of emf whose internal resistance is r, as in Fig.28.11a. For what value of R will the power supplied to the load be a maximum?

Solution:

$$P = I^2 R = \frac{\mathcal{E}^2 R}{(R+r)^2}$$

$$\frac{dP}{dR} = \mathcal{E}^2 \left(\frac{1}{(R+r)^2} - \frac{2R}{(R+r)^3} \right)$$

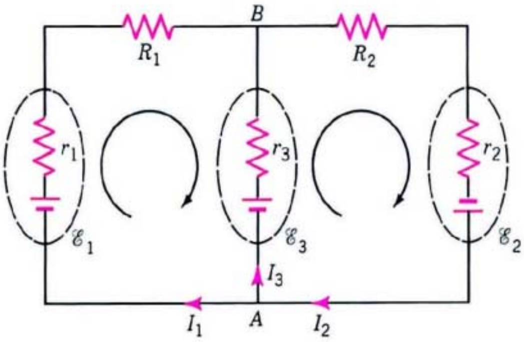
$$\frac{dP}{dR} = 0 \quad \Rightarrow \quad R = r$$



Example 28.5

The circuit in Fig. 28.14 has two loops and three sources of emf. (a) determine the currents given that r1=r2=2 ohm, r3=1 ohm, R1=4 ohm, R2=4 ohm, E1=15V, E2=6V, and E3=4V. (b) What is the change in potential Va-Vb?

Solution:



$$\text{Left loop} \qquad 15-2I_1-4I_1+I_3-4=0$$

$$\text{right loop} \qquad 4-I_3-3I_2+6-2I_2=0$$

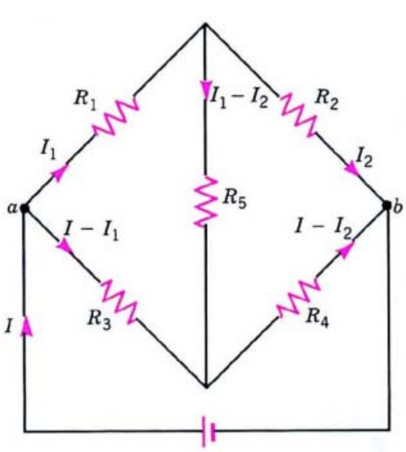
$$\text{junction rule} \quad I_1-I_2+I_3=0$$

When analyzing a circuit, the currents may be drawn in arbitrary directions.

Example 28.6

Five resistors are connected as shown in Fig. 28.15. What is the equivalent resistance between points a and b?

Solution:



Applying the junction rules

$$\text{Left loop} \qquad -I_1R_1-(I_1-I_2)R_5+(I-I_1)R_3=0$$

$$\text{right loop} \qquad +(I_1-I_2)R_5-I_2R_2+(I-I_2)R_4=0$$

$$I_1=\alpha_1 I, \qquad I_2=\alpha_2 I$$

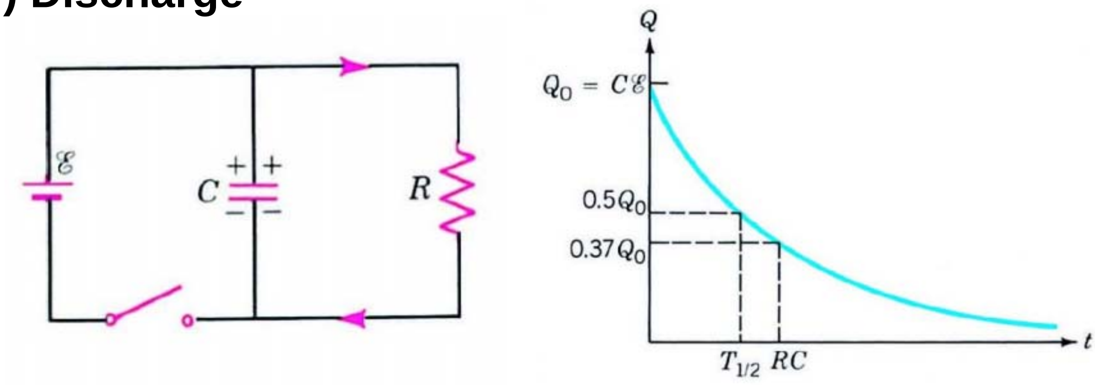
$$V_b-V_a=-I_1R_1-I_2R_2=-(\alpha_1R_1+\alpha_2R_2)I$$

28.4 RC Circuits: Charge and Discharge

When a capacitor is connected directly across the terminals of an ideal battery, the capacitor becomes ***charges*** instantaneously.

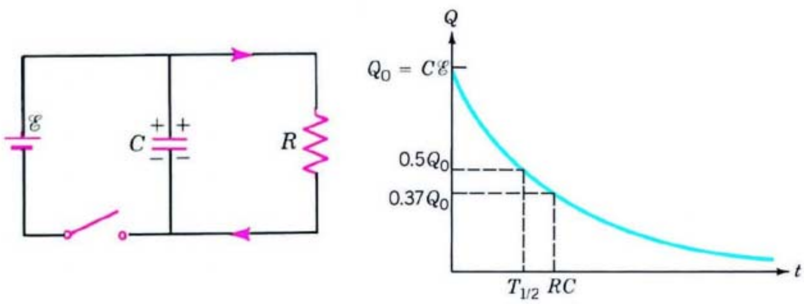
Similarly, if the terminals of a charges capacitor are connected by a wire, the capacitor is ***discharged*** instantaneously.

(i) Discharge



28.4 RC Circuits: Charge and Discharge

(i) Discharge



loop rule $\dfrac{Q}{C} - IR = 0$

The current I is equal to the rate at which the charge Q is decreasing; therefore, $I = -dQ/dt$, the loop rule becomes

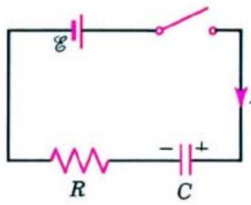
$$\frac{dQ}{dt} = -\frac{Q}{RC} \quad \Rightarrow \quad Q = Q_0 e^{-t/RC}$$

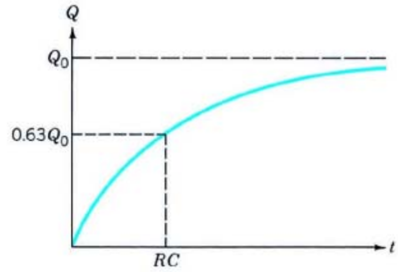
time constant $\tau = RC$ when $Q = Q_0 e^{-1}$

half - time $\mathrm{T}_{1/2} = RC \ln 2$ when $Q = \dfrac{1}{2} Q_0$

28.4 RC Circuits: Charge and Discharge

(iI) Charge





loop rule $\quad \varepsilon - IR - \dfrac{Q}{C} = 0$

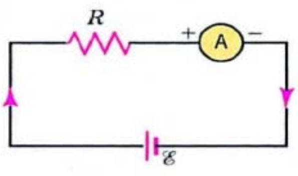
In this circuit, the current I increases the charge on the cpacitor, and therefore, $I = +dQ/dt$, the loop rule becomes

$$C\varepsilon - Q = \frac{dQ}{dt}RC \quad \Rightarrow \quad Q = Q_0(1 - e^{-t/RC})$$

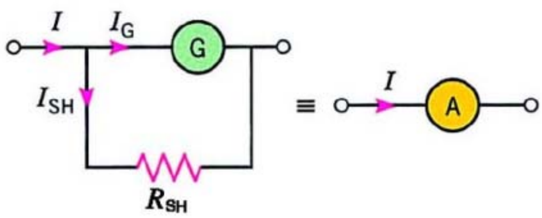
$$I = I_0 e^{-t/RC}$$

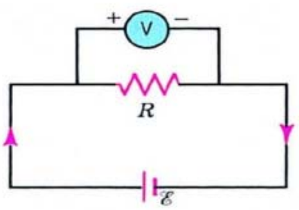
28.5 Direct Current Instruments

An instrument that measures current is called an **ammeter**, And one that measures potential difference is called a **voltmeter**. Many of these meters are based on the **galvanometer.** An **ohmmeter** is an instrument designed to measure resistance.
A commercial meter, which uses to measure current, voltage, resistance, and capacitance, is called **multimeter**.

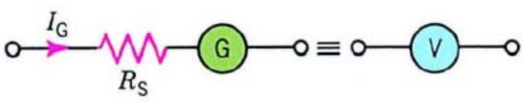


(a)



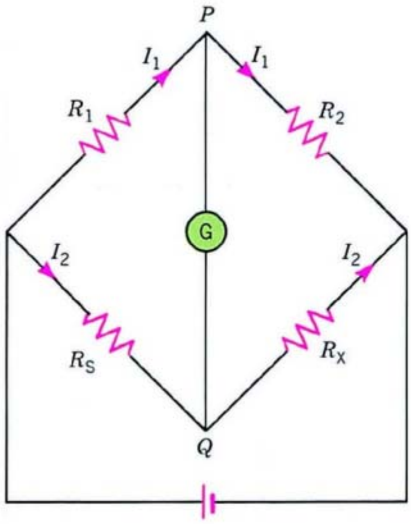


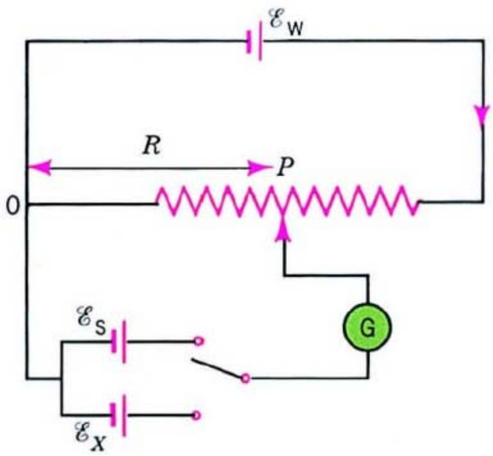
(b)



28.5 Direct Current Instruments (II)

Wheatstone Bridge & **Potentiometer**





Exercises and Problems

Ch.28:

Ex. 25, 42

Prob. 1, 2, 4, 7, 12, 13, 15