Electric Circuits

7-1

* Electric current

In a such a substance electric charge can be transferred from one point to another by a general drift of the charged particles within it. Such a movement of electric charge is called an "electric current".

Current in solids

* Materials through which an electric current will pass are known as (Conductors). These materials have free electrons.

** Materials in which there are no charged particles that are free to move are known as (Non-conductors) or (Insulators). There are no free electrons.

* Semi-conductors - in the semi-conductors only a very small proportion of the (valence-electrons) are free to move through materials.
Elements of electric circuits

1. Power supply (Dynamo, cell)
2. Wires
3. Loads
4. Switches

* The direction of the current

- When there is an electric current in a circuit, two physical effects are observed:
  1. A heating effect.
  2. A magnetic effect.
العزم الكهربائي يعتمد على الكمية السريعة للتيار، قانون أمبير ينص على ذلك.

الطريقة يمكن رؤية ذلك من خلال هذا الحرف:

\[ Q = qN \]

وانه عدد البلدات المتصلة

\[ I = \frac{Q}{t} \]

حيث:

- \( I \) هو التيار في الأمبير
- \( Q \) هو العزم الكهربائي
- \( t \) هو الوقت في الأصل

لدينا أيضاً تجربة عديدة، والتي تسمى النهائي، حيث يمكننا إضافة التيار من خلال:

\[ \text{Instantaneous current} \]

يجعل التيار أسرع

\[ I = \frac{dQ}{dt} \]

في الكيلومترات لكلثوبي، ونسبة

\[ \text{Coulomb} \]

\[ \text{Ampere} \]

العالم.

هو عزم التيار الكهربائي الذي يتم حسابه كثوبي.
Kirchhoff's First Law

At any junction-point in a circuit (such as B in figure) the rate at which charge enters the junction \((E_1 + I_2)\) is equal to the rate at which charge leaves it \((I_3)\).

This result is sometimes known as Kirchhoff's first law of electric circuits.
Currents in liquids

Electron flow

Anode

Cathode

Electrodes

\[ \text{Cu(H}_2\text{O)}_{4}^{2+} \]

Copper dissolved

\[ \text{Cu(H}_2\text{O)}_{4}^{2+} \]

Copper deposited
Specific Change.

Each ion carries a definite charge and has a definite mass, so that the mass liberated or deposited at the surface of an electrode is proportional to the total charge passed.

This is called [Faraday's first law of electrolysis]

\[
\text{specific charge} = \frac{Q_i}{m_i} = \frac{\text{total charge passed}}{\text{total mass deposited}}
\]

\[
Q = \frac{It}{M}
\]
7-4 Electrical Energy

If the charge separated is \( (Q) \) and the electrical potential energy produced is \( W \), then we define the e.m.f. \( (E) \) by

\[
\text{e.m.f. } E = \frac{W}{Q}
\]

Example: A small electric cell in a torch can maintain a current of \( (0.2 \, \text{A}) \) for about 2 hours. Estimate the total energy converted in the torch in this time, when the e.m.f. is \( 1.5 \times 8 \, \text{V} \).

\[
Q = It
= 0.2 \times (2 \times 3600)
= 1440 \, \text{C}
\]

\[
W = EQ
= 1.5 \times \frac{1440}{2}
= 9.18 \times 16 \, \text{kgf}
\]
Potential difference

The potential difference (P.D.) between two points in a circuit is an indication of the strength of the electric field acting to drive electric charge from one point to another.

\[ V = \frac{E \cdot q}{q} \]

\[ V = \frac{\int \mathbf{E} \cdot d\mathbf{l}}{q} \]

\[ E = \frac{V}{d} \]

\[ W = E_{P_1} - E_{P_2} = q \left( V_1 - V_2 \right) \]
Kirchhoff's second law of electric circuits:

The sum of the p.d.'s round any closed loop must always be zero.

\[ \text{P.d. between B and A} = 0.5 \, V \]
\[ \text{P.d. between D and C} = -0.9 \, V \]

Sum \[ \text{Zero} \]

Similarly for the loop ABEFA

\[ \text{P.d. between B and A} = 0.9 \, V \]
\[ \text{E and B} = +0.3 \, V \]
\[ \text{F and E} = -1.2 \, V \]

Sum \[ \text{Zero} \]
Electric Field Strength

If we have a current in an conductor of constant cross-section, the potential decreases uniformly along its length from its positive end to its negative end.

If the p.d. between the ends of the conductor is \( V \) and its length \( l \) we have:

\[
\text{Potential gradient } E = \frac{V}{l} = \frac{[V]}{[m]} = \text{V/m}
\]

\[
\text{Electric Cells (Battery)} \ 1 \ 2 \ 3 \ 4 \ 5
\]

\[ E_1 Q + E_2 Q + E_3 Q \]

\[ Q = \text{charge} \]

the total e.m.f. \( f = \frac{\text{total energy}}{Q} \)

\[
E_1 Q + E_2 Q + E_3 Q = \frac{Q(E_1 + E_2 + E_3)}{Q} = E_1 + E_2 + E_3
\]
Thermocouples

If we form a circuit of two different metals A and B, a small e.m.f. $E$ is found to act in it when the junctions of the metals are at different temperatures.

$$e.m.f = E = E_1 - E_2$$

A thermocouple is a form of heat engine converting internal energy to electrical energy.
7-6 Electrical Power

The rate at which energy is converted from one form to another in some mechanical or electrical device is called its "power."

\[ W = Pt \]

\( \text{The unit of power is the J s}^{-1} = \text{watt (w)} \quad (P = \frac{W}{s}) \)

\[ P = VI \]

\( \text{current: I} \) \hspace{2cm} \( P \text{.d. : V} \)

\( \text{e.m.f. : E} \)

\( (P, \text{التي} \text{هي} \text{مثبطة}) \) \hspace{2cm} \text{سرير Arduino}
7-3

\[ I_1 = I_2 + I_3 \]

\[ I_1 = 2I' + I'' \]

\[ I_1 = 3I' \]

\[ I' = 0.39 \]

\[ 2I'' = 0.39 \]

\[ I'' = 0.39 \]

\[ I'' = 2 \times 0.39 = 0.78 \]

7-4

\[ 0.2 - 0.15 = 0.5 \text{ A in D} \]

B, C is full brightness

\( I \) current in B and C = 0.2 A
\[ I = \frac{\Phi}{t} \quad \implies \quad \Phi = It \]

\[ = 0.25 \times (12 \times 60) \]

\[ = 180 \text{ C} \]

The total amount of charge passed

\[ N = \frac{\Phi}{e} = \frac{180}{1.6 \times 10^{-19}} = 1.1 \times 10^{21} \]

no. of electrons

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**7-8**

\[ I = 1.5 \text{ mA} \]

\[ = 1.5 \times 10^{-3} \text{ A} \]

\[ N = \frac{I}{e} = \frac{1.5 \times 10^{-3}}{1.6 \times 10^{-19}} = 9.3 \times 10^6 \]

\[ = 9.3 \times 10^{15} - 6 \times 10^{15} \]

\[ = 3.3 \times 10^{15} \text{ s}^{-1} \]

no. of hydrogen ions.
7.9 \[ V = \frac{S}{t} \Rightarrow t = \frac{S}{V} = \frac{0.5}{8 \times 10^{-3}} = 0.0625 \times 10^{-7} \]

\[ I = \frac{Q}{t} \Rightarrow Q = tI = 2 \times 10^{-3} \times 0.0625 \times 10^{-7} = 0.12 \times 10^{-10} \]

\[ N = \frac{Q}{t} = \frac{0.12 \times 10^{-10}}{0.0625 \times 10^{-7}} = 0.075 \times 10^9 \]

7.10 \[ \text{no. of drops} = 10 \times 60 \times 12 = 7200 \]

\[ V = 7200 \times 5 \times 10^{-8} = 2.16 \times 10^{-6} \text{ the volume of the water} \]

\[ Q = 4 \times 10^{-15} \times 7200 = 2.88 \times 10^{-13} \text{ total charge} \]

\[ I = \frac{Q}{t} = \frac{2.88 \times 10^{-13}}{10 \times 60} = 0.48 \times 10^{-13} \]
7-11 \[ V = \frac{I}{e_{nA}} = \frac{I}{\Phi} - \frac{I}{e_n} \]
\[ = 1.9 \times 10^6 - \frac{1}{1.6 \times 10^{-19} \times 10^{19}} \]
\[ = 0.75 \times 10^{-3} \text{ m.s}^{-1} \]

7-13 \[ V = \frac{I}{e_{nA}} \Rightarrow n = \frac{I}{e_{nA}} \]
\[ = \frac{1.2 \times 10^{-3} A}{1.6 \times 10^{-19} \times 4 \times 9 \times 10^{-6}} \]
\[ = 0.07 \times 10^{-1} \]

**Note:** The text is in English, but some parts are written in Arabic.
8.1 Ohm's Law

An electric current $I$ is produced in a conductor by applying a potential difference $V$ across it. The relationship between these two quantities for metal conductors is "Ohm's Law" when all these were kept constant.

The quantity $V/I$ is a constant for a given metallic conductor under steady physical conditions. It is known as its resistance $R$. Thus

$$R = \frac{V}{I}$$

The unit of $R$ is therefore $\text{V/A}^{-1}$ (Ω).
* Fixed resistors

- Wire-wound type
- Carbon composition type
- Carbon film type

* Variable resistors

a. As a rheostat - for controlling the current in a low resistance device

b. As a potentiometer - for controlling the p.d. across some device
Energy Conversion in Resistors

The electrical power $P$ converted in a resistor is given by

$$P = VI$$

but $P_r = \frac{V}{I} \Rightarrow V = IR$

$$P = I^2 R$$

8-2 Combinations of Resistors

a - Resistors in Series

$$R_{\text{ser}} = \frac{V}{I}$$

$I_t = I_1 = I_2 = I_3$

$V_t = V_1 + V_2 + V_3$

$R_t = R_1 + R_2 + R_3$
b - Resistor in parallel

\[ V_t = V_1 = V_2 = V_3 \]

\[ I_t = I_1 + I_2 + I_3 \]

\[ \frac{1}{R_t} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} \]

\[
\begin{align*}
\frac{R_1}{R_2} &= \frac{R_3}{R_4} \\
\text{when the bridge is balanced} \quad & \text{no current in } R_5 \\
\text{there is the same current in } R_1 \text{ and } R_2 \ (I_1) \\
\text{and } R_3 \text{ and } R_4 \ (I_2) \quad & \frac{R_1}{R_2} = \frac{R_3}{R_4}
\end{align*}
\]

\[ \text{potential } R_1 \text{ and } R_3 \text{ are the same} \ (I_1 R_1 = I_2 R_3) \]

\[ \frac{R_1}{R_2} = \frac{R_3}{R_4} \]

\[ I_1 R_2 = I_2 R_4 \]
8-3 Battery resistance

When a current is taken from a cell (or any other source of e.m.f.), it is found that the p.d. across it falls.

\[ \text{Internal} \quad \text{external} \]
\[ R_{\text{int}} = \frac{E - V}{I} \]

\[ R_{\text{ext}} = \frac{V}{I} \]

\[ (R_{\text{ext}} + R_{\text{int}}) = \frac{E}{I} \]

\[ R_{\text{tot}} = \frac{E}{I} \]
8.4 Resistivity

The resistance of a conductor at given temperature depends on its length and cross-sectional area, and material.

\[ R = \frac{L}{A} \]

\[ \therefore f = \frac{RA}{L} = \frac{[S][m^2]}{[m]} = S \cdot m \]

The reciprocal of the resistivity of a material is known as its conductivity. 

\[ \sigma = \frac{1}{f} \]

\[ \sigma = \frac{L}{RA} \cdot [S^{-1} \cdot m^{-1}] \]
8-4 \( \text{p.d.?} \quad R = 10 \, \text{M} \Omega \quad I = 5 \, \text{mA} \)

\[
R = \frac{V}{I} \quad \Rightarrow \quad V = R \times I
\]

\[
\therefore \quad V = 10 \times 10^6 \times 5 \times 10^{-6} = 50 \, \text{volt} \quad \text{p.d.}
\]

8-6

\[ U_1 = U_1 + U_2 \quad \text{(b)} \]

\[ 6 = 3 + U_2 \quad \Rightarrow \quad U_2 = 3 \, \text{volt} \]

\[ R_2 = \frac{V}{I} \quad 20 = \frac{3}{I} \quad \therefore \quad I = 0.15 \, \text{A} \]

\[ R = \frac{V}{I} = \frac{3}{0.15 \times 10^{-3}} = 20 \, \text{k} \Omega \]

\[ U_1 = U_1 + U_2 \quad \text{b) } \]

\[ 6 = U_1 + 2 \]

\[ \therefore \quad U_1 = 4 \, \text{volt} \]

\[ \text{b) } \quad \text{R}_1 = \frac{V}{I} = 20 \, \text{k} \Omega \quad I = 0.2 \, \text{mA} \]

\[ R_2 = \frac{V}{I} \]

\[ \text{Output:} \text{ } 7 \]
8-31 \[ P_e = \frac{F \cdot l}{A} = \frac{4.8 \times 10^{-7} \cdot 4}{1 \times 10^{-6}} \]

\[ = 1.92 \, \Omega \]

\[ R \cdot q = \frac{V}{l} = \frac{0.96}{4} = 0.24 \, \text{V/m} \]

\[ R = \frac{V}{I}, \quad 1.92 = \frac{V}{0.5} \Rightarrow V = 0.96 \, \text{V} \]

8-37

\[ E = 1.5 \, \text{V} \]

\[ V = 1.3 \, \text{V} \]

\[ I = 0.4 \, \text{A} \]

\[ P_{\text{in}} = \frac{(E - V)}{I} = \frac{1.5 - 1.3}{0.4} \]

\[ = 0.5 \, \text{W} \]
Storing Electric Charge

Capacitors:
An arrangement of two conductors close together, but insulated from one another.

\[ Q \propto \frac{1}{d} \]

\[ Q = \epsilon_0 \varepsilon A \]

Calibration Constant

Charging

Discharging
Capacitance

\[ Q \times V \]

\[ Q = C \times V \]

\[ C = \frac{Q}{V} = \left[ \text{C. V}^{-1} \right] = \left[ \text{Farad} \right] \]

\[ \mu F = 10^{-6} \text{ F} \]

\[ \mu F = 10^{-12} \text{ F} \]
The charging current

\[ I = \frac{dQ}{dt} \]

\[ I = C \frac{dV}{dt} \]

\( I \) is the current in the wires joined to a pair of capacitor plates.

\[ Q = CV \]
Capacitors in Parallel

Where \( Q \) is the total charge on the capacitors, the sum of their separate charges.

\[
Q = Q_1 + Q_2 + Q_3 + \cdots + Q_n
\]

\[
\therefore Q = CV \quad \therefore \quad C = \frac{Q}{V}
\]

\[
Q_x = C_1 V_1 + C_2 V_2 + C_3 V_3
\]

\[
Q = V(C_1 + C_2 + C_3)
\]

\[
C_t = C_1 + C_2 + C_3 + \cdots + C_n
\]

Capacitors in Series

\[
V_t = V_1 + V_2 + V_3
\]

\[
\begin{aligned}
\sqrt{\frac{Q}{C}} &= \frac{Q}{C_1} + \frac{Q}{C_2} + \frac{Q}{C_3} \\
V &= \frac{Q}{C} \left( \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} \right) + Q
\end{aligned}
\]

\[
\frac{1}{C} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} + \cdots + \frac{1}{C_n}
\]
Alternating current in capacitors

If an alternating current supply is joined to the plates of a capacitor charge flows on and then off the plates as the potential difference between them oscillates; and there may be a larger alternating current in the connecting wires.

The magnitude of the alternating current $I$ in capacitor of capacitance $C$ may be calculated as follows:

$$I = C \frac{dU}{dt}$$

If a sinusoidal alternating p.d. at peak value $V_0$ and frequency $f$ is joined to the capacitor we have

$$V = V_0 \sin(2\pi ft)$$
The maximum current occurs at the moment when the p.d. $V$ is zero, when the p.d. is changing at the maximum rate. The peak value $I_0$ of the current is therefore given by

$$I_0 = C \frac{dV}{dt}$$

$$I = C (2\pi f V_0)$$

**Charging and discharging**

**Energy storage**

The total energy $W_E$ stored in the capacitor is:

$$W_E = \frac{1}{2} C V^2 = \frac{1}{2} \frac{Q^2}{C}$$

Since $Q = CV$.
14-6
\[ b = 1.3 \times 10^{-8} \text{ C/div} \]
\[ \text{e.m.f.} \, F = 6 \text{ volt} \]
\[ \theta = 22 \]
\[ Q = ? \]

\[ Q = b \theta = 1.3 \times 10^{-8} \times 22 \]
\[ = 28.6 \times 10^{-8} \]

\[ C = \frac{Q}{V} = \frac{28.6 \times 10^{-8}}{6} \]
\[ = 4.7 \times 10^{-8} \text{ F} \]

14-7
\[ C = 100 \text{ nF} \]
\[ V = 200 \text{ V} \]
\[ t = 4.5 \]

\[ Q = CV = 100 \times 10^{-6} \times 200 \]
\[ = 2 \times 10^{-2} \text{ C} \]

\[ I = \frac{Q}{t} = \frac{2 \times 10^{-2}}{4} = 0.5 \times 10^{-2} \]
\[ = 5 \text{ mA} \]
14-8

\[ C = 33 \text{ mF} \]
\[ V = 4 \text{ V} \]
\[ t = 605 \text{ s} \]
\[ I = ? \]

\[ I = C \frac{dV}{dt} = 33 \times 10^{-6} \frac{6}{60} \]
\[ = 22 \times 10^{-6} \text{ AmP} \]

14-9

\[ I = 50 \text{ mA} \]
\[ V = 5 \text{ V} \]
\[ t = 205 \text{ s} \]
\[ C = ? \]

\[ I = C \frac{dV}{dt} \]

\[ 50 \times 10^{-6} = C \frac{5}{205} \Rightarrow C = 200 \times 10^{-6} \text{ F} = 200 \text{ mF} \]
14 - 14

\[ C = 180 \text{ PF} \]

\[ V = 12 \text{ V} \]

\[ R = 250 \Omega \quad \Rightarrow \quad t = \frac{1}{250} \]

\[ I = ? \]

\[ I = C \frac{dV}{dt} = 180 \times 10^{-12} \times \frac{12}{1/250} \]

\[ = 54 \times 10^{-8} \text{ Amp} \]

14 - 17

\[ C_1 = 2 \text{ MF} \]

\[ C_2 = 3 \text{ MF} \]

\[ C_3 = 6 \text{ MF} \]

\( \Rightarrow \) in parallel

\[ C_t = C_1 + C_2 + C_3 = 2 + 3 + 6 = 11 \text{ MF} \]

\( \Rightarrow \) in series

\[ \frac{1}{C_t} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} \]

\[ \frac{1}{C_t} = \frac{1}{2} + \frac{1}{3} + \frac{1}{6} \]

\[ \frac{1}{C_t} = 0.996 \]

\[ \therefore C_t = 1 \text{ MF} \]
14-18

\[ C_A = 3 \text{ mF} \]
\[ C_B = 1.5 \text{ mF} \]
\[ C_C = 4.5 \text{ mF} \]

\[ C_{CB} = C_B + C_C = 1.5 + 4.5 = 6 \text{ mF} \]

\[ \frac{1}{C} = \frac{1}{C_{CB}} + \frac{1}{C_A} = \frac{1}{6} + \frac{1}{3} \]
\[ \frac{1}{C} = 0.496 \]
\[ C = 2 \text{ mF} \]

\[ Q = \varepsilon CV = 2 \times 10^{-6} \times 9 = 18 \times 10^{-6} \text{ C} \]

\[ V = \frac{Q}{C} = \frac{18 \times 10^{-6}}{6 \times 10^{-6}} = 3 \text{ V} = C_{CB} \text{ V} \]

\[ V_A = 9 - 3 = 6 \text{ V} \]

\[ Q_C = 3 \times 4.5 \times 10^{-6} = 13.5 \times 10^{-6} \text{ C} \]

\[ Q_B = 3 \times 1.5 \times 10^{-6} = 4.5 \times 10^{-6} \text{ C} \]
\[ C_1 = 16 \, \mu F \quad C_2 = 8 \, \mu F \]
\[ V = 150 \, V \quad V = ? \]
\[ Q = ? \quad W_E = ? \]

\[ Q = C_1 V = 16 \times 10^{-6} \times 150 \]
\[ = 2.4 \times 10^{-3} \, C \quad \text{ Stored Energy} \]
\[ \frac{Q}{C_1} \]

\[ W_E = \frac{1}{2} Q V = \frac{1}{2} \times 2.4 \times 10^{-3} \times 150 \]
\[ = 18 \times 10^{-2} \, \text{Joul} \quad \text{Energy Stored} \]

\[ C_F = C_1 + C_2 = 16 + 8 \]
\[ = 24 \, \mu F \quad \text{Total Capacitance} \]

\[ V = \frac{Q}{C} = \frac{2.4 \times 10^{-3}}{24 \times 10^{-6}} = 100 \, V \quad \text{Voltage Across} \]

\[ W_E = \frac{1}{2} C V^2 = \frac{1}{2} \times 24 \times 10^{-6} \times (100)^2 \]
\[ = 12 \times 10^{-2} \, \text{Joul} \quad \text{Energy Stored} \]

\[ 18 \times 10^{-2} - 12 \times 10^{-2} = 6 \times 10^{-2} \, \text{Joul} \quad \text{Energy Transferred} \]