Chapter 21-27

Summary

Seon-Hee Seo

 → Modified by S.H. Seo

21 Summary

Electric Charge

- The strength of a particle's electrical interaction with objects around it depends on its electric charge, which can be either positive or negative.

Conductors and Insulators

- Conductors are materials in which a significant number of electrons are free to move. The charged particles in nonconductors (insulators) are not free to move.

Conservation of Charge

- The net electric charge of any isolated system is always conserved.

Coulomb's Law

- The magnitude of the electrical force between two charged particles is proportional to the product of their charges and inversely proportional to the square of their separation distance.

$$\boxed{F = \frac{1}{4\pi\varepsilon_0}\frac{|q_1|\,|q_2|}{r^2}}$$

Eq. 21-4

The Elementary Charge

- Electric charge is quantized (restricted to certain values).
- *e* is the elementary charge

$$\boxed{e = 1.602 \times 10^{-19}\ \mathrm{C.}}$$

Eq. 21-12

22 Summary

WILEY

Definition of Electric Field

- The electric field at any point

$$\vec{E} = \frac{\vec{F}}{q_0}. \quad \text{Eq. 22-1}$$

Electric Field Lines

- provide a means for visualizing the directions and the magnitudes of electric fields

Field due to a Point Charge

- The magnitude of the electric field ***E*** set up by a point charge *q* at a distance *r* from the charge is

$$E = \frac{1}{4\pi\varepsilon_0}\frac{|q|}{r^2}. \quad \text{Eq. 22-3}$$

Field due to an Electric Dipole

- The magnitude of the electric field set up by the dipole at a distant point on the dipole axis is

$$E = \frac{1}{2\pi\varepsilon_0}\frac{p}{z^3} \quad \text{Eq. 22-9}$$

Field due to a Charged Disk

- The electric field magnitude at a point on the central axis through a uniformly charged disk is given by

$$E = \frac{\sigma}{2\varepsilon_0}\left(1 - \frac{z}{\sqrt{z^2 + R^2}}\right) \quad \text{Eq. 22-26}$$

22 Summary

WILEY

Force on a Point Charge in an Electric Field

- When a point charge *q* is placed in an external electric field ***E***

$$\boxed{\vec{F} = q\vec{E}.}$$ **Eq. 22-28**

Dipole in an Electric Field

- The electric field exerts a torque on a dipole

$$\boxed{\vec{\tau} = \vec{p} \times \vec{E}.}$$ **Eq. 22-34**

- The dipole has a potential energy *U* associated with its orientation in the field

$$\boxed{U = -\vec{p} \cdot \vec{E}.}$$ **Eq. 22-38**

23 Summary

WILEY

Gauss' Law

- Gauss' law is

$$\boxed{\varepsilon_0 \Phi = q_{enc}}$$

Eq. 23-6

- the net flux of the electric field through the surface:

$$\boxed{\Phi = \oint \vec{E} \cdot d\vec{A}}$$

Eq. 23-6

Applications of Gauss' Law

- surface of a charged conductor

$$\boxed{E = \frac{\sigma}{\varepsilon_0}}$$

Eq. 23-11

- Within the surface *E=0.*
- line of charge

$$\boxed{E = \frac{\lambda}{2\pi\varepsilon_0 r}}$$

Eq. 23-12

- Infinite non-conducting sheet

$$\boxed{E = \frac{\sigma}{2\varepsilon_0}}$$

Eq. 23-13

- Outside a spherical shell of charge

$$\boxed{E = \frac{1}{4\pi\varepsilon_0} \frac{q}{r^2}}$$

Eq. 23-15

- Inside a uniform spherical shell

$$\boxed{E = 0}$$

Eq. 23-16

- Inside a uniform sphere of charge

$$\boxed{E = \left(\frac{q}{4\pi\varepsilon_0 R^3}\right) r.}$$

Eq. 23-20

WILEY

24 Summary (I)

Electric Potential

- The electric potential V at point P in the electric field of a charged object:

$$\boxed{V = \frac{-W_\infty}{q_0} = \frac{U}{q_0},}$$ **Eq. 24-2**

Electric Potential Energy

- Electric potential energy U of the particle-object system:

$$\boxed{U = qV.}$$ **Eq. 24-3**

- If the particle moves through potential ΔV:

$$\boxed{\Delta U = q\,\Delta V = q(V_f - V_i).}$$ **Eq. 24-4**

Mechanical Energy

- Applying the conservation of mechanical energy gives the change in kinetic energy:

$$\boxed{\Delta K = -q\,\Delta V.}$$ **Eq. 24-9**

- In case of an applied force in a particle

$$\boxed{\Delta K = -q\,\Delta V + W_{\text{app}}.}$$ **Eq. 24-11**

- In a special case when *ΔK=0:*

$$\boxed{W_{\text{app}} = q\,\Delta V \quad (\text{for } K_i = K_f).}$$ **Eq. 24-12**

Finding V from *E*

- The electric potential difference between two point *I* and *f* is:

$$\boxed{V_f - V_i = -\int_i^f \vec{E} \cdot d\vec{s},}$$ **Eq. 24-18**

24 Summary (II)

WILEY

Potential due to a Charged Particle

- due to a single charged particle at a distance r from that particle :

$$V = \frac{1}{4\pi\varepsilon_0}\frac{q}{r}$$

Eq. 24-26

- due to a collection of charged particles

$$V = \sum_{i=1}^{n} V_i = \frac{1}{4\pi\varepsilon_0}\sum_{i=1}^{n}\frac{q_i}{r_i}.$$

Eq. 24-27

Potential due to an Electric Dipole

- The electric potential of the dipole is

$$V = \frac{1}{4\pi\varepsilon_0}\frac{p\cos\theta}{r^2}$$

Eq. 24-30

Potential due to a Continuous Charge Distribution

- For a continuous distribution of charge:

$$V = \frac{1}{4\pi\varepsilon_0}\int\frac{dq}{r}$$

Eq. 24-32

Calculating *E* from V

- The component of ***E*** in any direction is:

$$E_s = -\frac{\partial V}{\partial s}.$$

Eq. 24-40

Electric Potential Energy of a System of Charged Particle

- For two particles at separation *r*:

$$U = W = \frac{1}{4\pi\varepsilon_0}\frac{q_1 q_2}{r}.$$

Eq. 24-46

WILEY

25 Summary

Capacitor and Capacitance

- The capacitance of a capacitor is defined as:

$$\boxed{q = CV}$$ **Eq. 25-1**

Determining Capacitance

- Parallel-plate capacitor:

$$\boxed{C = \frac{\varepsilon_0 A}{d}.}$$ **Eq. 25-9**

- Cylindrical Capacitor:

$$\boxed{C = 2\pi\varepsilon_0 \frac{L}{\ln(b/a)}.}$$ **Eq. 25-14**

- Spherical Capacitor:

$$\boxed{C = 4\pi\varepsilon_0 \frac{ab}{b-a}.}$$ **Eq. 25-17**

- Isolated sphere:

$$\boxed{C = 4\pi\varepsilon_0 R.}$$ **Eq. 25-18**

Capacitor in parallel and series

- In parallel:

$$\boxed{C_{eq} = \sum_{j=1}^{n} C_j}$$ **Eq. 25-19**

- In series

$$\boxed{\frac{1}{C_{eq}} = \sum_{j=1}^{n} \frac{1}{C_j}}$$ **Eq. 25-20**

Potential Energy and Energy Density

- Electric Potential Energy (U):

$$\boxed{U = \frac{q^2}{2C} = \frac{1}{2}CV^2}$$ **Eq. 25-21&22**

- Energy density (*u*)

$$\boxed{u = \frac{1}{2}\varepsilon_0 E^2.}$$ **Eq. 25-25**

25 Summary

Capacitance with a Dielectric

- If the space between the plates of a capacitor is completely filled with a dielectric material, the capacitance C is increased by a factor κ, called the dielectric constant, which is characteristic of the material.

Gauss' Law with a Dielectric

- When a dielectric is present, Gauss' law may be generalized to

$$\boxed{\varepsilon_0 \oint \kappa \vec{E} \cdot d\vec{A} = q.} \qquad \textbf{Eq. 25-36}$$

26 Summary

Current

- The electric current *i* in a conductor is defined by

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

Eq. 26-1

Current Density

- Current is related to current density by

$$i = \int \vec{J} \cdot d\vec{A},$$

Eq. 26-4

Drift Speed of the Charge Carriers

- Drift speed of the charge carriers in an applied electric field is related to current density by

$$\vec{J} = (ne)\vec{v}_d$$

Eq. 26-7

Resistance of a Conductor

- Resistance *R* of a conductor is defined by

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

Eq. 26-8

- Similarly the resistivity and conductivity of a material is defined by

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

Eq. 26-10&12

- Resistance of a conducting wire of length *L* and uniform cross section is

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

Eq. 26-16

Change of ρ with Temperature

- The resistivity of most material changes with temperature and is given as

$$\rho - \rho_0 = \rho_0 \alpha (T - T_0).$$

Eq. 26-17

26 Summary

Ohm's Law

- A given device (conductor, resistor, or any other electrical device) obeys Ohm's law if its resistance R (defined by **Eq. 26-8** as *V/i*) is independent of the applied potential difference *V.*

Resistivity of a Metal

- By assuming that the conduction electrons in a metal are free to move like the molecules of a gas, it is possible to derive an expression for the resistivity of a metal:

$$\boxed{\rho = \frac{m}{e^2 n \tau}.}$$

Power

- The power P, or rate of energy transfer, in an electrical device across which a potential difference V is maintained is

$$\boxed{P = iV} \qquad \textbf{Eq. 26-26}$$

- If the device is a resistor, we can write

$$\boxed{P = i^2 R = \frac{V^2}{R}} \qquad \textbf{Eq. 26-27\&28}$$

WILEY

27 Summary

Emf

- The **emf** (work per unit charge) of the device is

$$\mathscr{E} = \frac{dW}{dq} \quad \text{(definition of } \mathscr{E}\text{)}.$$ Eq. 27-1

Single-Loop Circuits

- Current in a single-loop circuit:

$$i = \frac{\mathscr{E}}{R + r},$$ Eq. 27-4

Power

- The rate P of energy transfer to the charge carriers is $P = iV.$ Eq. 27-14

- The rate P_r at which energy is dissipated as thermal energy in the battery is $P_r = i^2 r.$ Eq. 27-16

- The rate P_{emf} at which the chemical energy in the battery changes is $P_{\text{emf}} = i\mathscr{E}.$ Eq. 27-17

Series Resistance

- When resistances are in series

$$R_{\text{eq}} = \sum_{j=1}^{n} R_j$$ Eq. 27-7

Parallel Resistance

- When resistances are in parallel

$$\frac{1}{R_{\text{eq}}} = \sum_{j=1}^{n} \frac{1}{R_j}$$ Eq. 27-24

RC Circuits

- The charge on the capacitor increases according to

$$q = C\mathscr{E}(1 - e^{-t/RC})$$ Eq. 27-33

- During the charging, the current is

$$i = \frac{dq}{dt} = \left(\frac{\mathscr{E}}{R}\right)e^{-t/RC}$$ Eq. 27-34

- During the discharging, the current is

$$i = \frac{dq}{dt} = -\left(\frac{q_0}{RC}\right)e^{-t/RC}$$ Eq. 27-40