Chapter 22 Electric Field

Electricity Charge

- *Conservation of Electric Charge* says that the total electric charge in an isolated system never changes, **electric charges cannot be created and cannot disappear from no where**
- But charges can be transferred from one object to the other, the *final sum will still be the same as the initial sum*
- *Positive charge* are possessed by **protons**
- *Negative charge* are possessed by **electrons**
- Charges of **same sign repel**, and charges with **opposite signs attract**

Conservation of Electric Charges

- When we rub a glass rod with silk cloth, electron are transferred from the glass to the silk cloth
- Each electron adds a negative charge to the silk cloth
- And an equal positive charge is left on the rod, this process is called electrification by friction

Quantization of Electric Charges

- The electric charge q is said to be quantized
  - $q = Ne$
  - e is the fundamental quantity of charge
  - $|e| = 1.602 \times 10^{-19}\,C$ (Coulomb)
  - Electron: $q : -e(-1.602 \times 10^{-19} C)$
  - Proton: $q : +e(-1.602 \times 10^{-19} C)$
  - N is an integer

Insulators

- Electrical insulators are materials in which all of the **electrons are bound to atoms**
- These electrons cannot move relatively freely through the material of insulators (rubber and wood)
- When a good insulator is charged (by rubbing it very hard) in a small region, the charge is unable to move to other regions of the material

Conductors

- Electrical conductors are materials in which **some of the electrons are free electrons**
- Free electrons are not bound to the atoms
- Can move relatively freely through the material of conductors (copper and aluminum)
- When a good conductor is charged in a small region, the charge readily distributes itself over the entire surface of the material

Point Charge

- The term **point charge** refers to a particle of close-to-zero size that carries an measurable electric charge

Coulomb's Law

- $F = k\frac{|q_1||q_2|}{r^2}$
- The electrostatic force between two stationary charged particles is parameterized by **Coulomb's Law**
- The force $\propto$ product of the charges q_1 and q_2
- The force is *inversely* $\propto\ r^2$, and directed along the line joining them
- The force is attractive if the charges are of opposite sign
- The force is a conservative force
- $k = 8.9875 \times 10^9\,M \cdot \frac{m^2}{C^2} = \frac{1}{4\pi\varepsilon_0}$ is the **coulomb constant**
- $\varepsilon_0 = 8.8542 \times 10^{-12}\,C^2 N \cdot m^2$ is the **electric permittivity of free space** (*capability of a vacuum to permit electric fields*)
- $1C = 6.24 \times 10^{18}$ protons or electrons
- Charges are usually in the μC range
- The force between the charges is a *vector* quantity

Superposition Principle

- The resultant force on any one charge equals the vector sum of the forces exerted by the other individual charges that are present

Electric Field

- An *electric field* exist in the region of space around a charged object (**source charge**)
  - When another charged object (**test charge**) enters this electric field, an electrostatic force acts on it
- The electric field vector, E at a point in space is defined as the electrostatic force F acting on a unit of the positive test charge q_0 place at that point
  - $E = \frac{F}{q_0} = k\frac{q}{r^2}\hat{r}$
  - $F = q_0 E$
- E is the field produced by some charge or charge distribution (**source charge**), and is separated from the *test charge* q_0
- The quantity of *test charge* should be small so that it will not significantly affect the field produced by the **source charge**
- The direction of E is the direction of the force on a *positive test charge*
- SI unit of E are N/C
- Electric field is a vector
- At any point P, the total electric field due to a group of source charges equals the *vector sum* of electric fields of all the charges in its proximity

Here's a summary for an Obsidian note on *Electric Field – Continuous Charge Distribution* with LaTeX for equations:

Electric Field – Continuous Charge Distribution

- If charges in a system are very close to each other compared to their distance from a point of interest, they can be approximated as a continuous charge distribution.
- This approach simplifies calculations by treating the total charge as if it's distributed along a line, across a surface, or within a volume.

Procedure for Calculating Electric Field from Continuous Charge Distribution

1. **Divide the charge distribution** into small elements, each containing a small charge, Δq.
2. **Calculate the small electric field**, ΔE, due to each element Δq at the point of interest P.
3. **Sum the contributions** of all the elements to get the total electric field at P:

$$E = \sum \Delta E$$

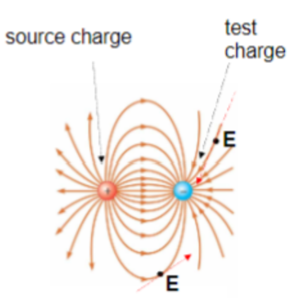
This approach uses integration for precise calculations when the distribution is truly continuous.

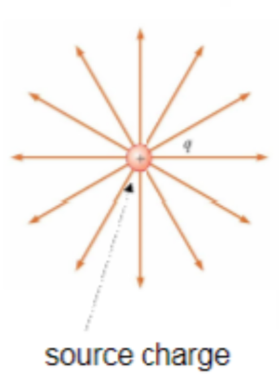
Charge Densities

- **Volume charge density** ρ: Charge distributed throughout a volume V.
  - $\rho = \frac{Q}{V}$, i.e., $dQ = \rho, dV$
- **Surface charge density** σ: Charge distributed over a surface area A.
  - $\sigma = \frac{Q}{A}$, i.e., $dQ = \sigma, dA$
- **Linear charge density** λ: Charge distributed along a line of length ℓ.
  - $\lambda = \frac{Q}{\ell}$, i.e., $dQ = \lambda, d\ell$

Here's a continuation of the notes, integrating information from the document, and specifying image pages for relevant sections.

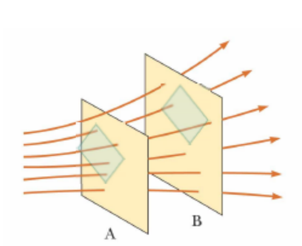
Electric Field Lines





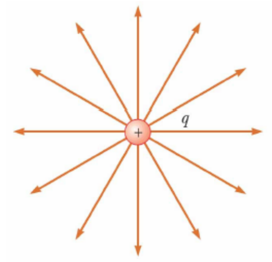
- Electric field lines provide a **visual representation** of the patterns of the electrostatic field.
- The electric field vector E is **tangent** to the electric field line at each point, with the line's direction matching the electric field vector.
- Lines are drawn **from positive charges** or **toward negative charges**.

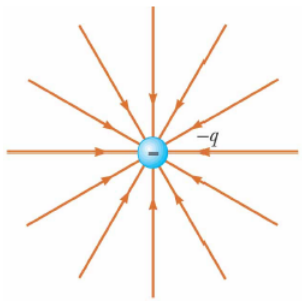
General Properties of Electric Field Lines



- The **number of lines per unit area** through a surface perpendicular to the lines correlates with the magnitude of the electric field.
- A **higher line density** indicates a stronger electric field in that region.
- Electric field lines point in different directions in non-uniform fields.

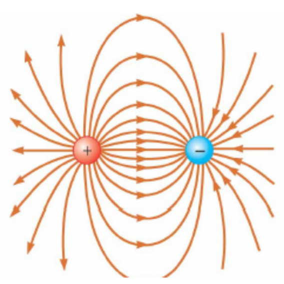
Electric Field Lines – Positive and Negative Point Charges





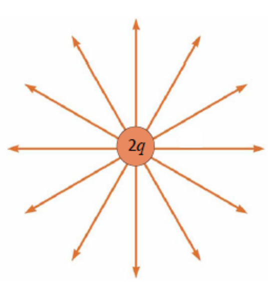
- For a **positive point charge**, field lines radiate outward in all directions.
  - A positive test charge would be repelled away from it.
- For a **negative point charge**, field lines converge inward from all directions.
  - A positive test charge would be attracted toward it.

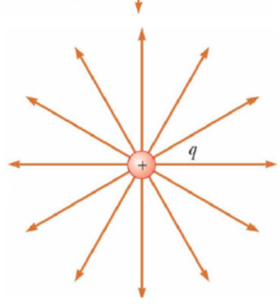
Electric Field Lines – Dipole



- A **dipole** consists of two equal but opposite charges.
- The number of lines leaving the positive charge equals the number of lines terminating on the negative charge.

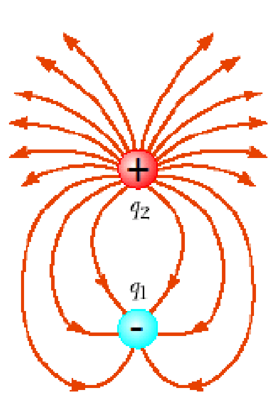
Electric Field Lines – Like and Unequal Charges





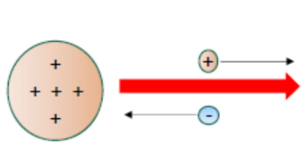
- **Like charges** (e.g., two positive charges) have lines repelling each other, and from a distance, resemble a single charge of double magnitude.
- For **unequal charges**, the electric field lines are drawn with a ratio indicating the relative magnitudes of the charges.

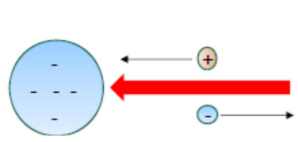
Rules for Drawing Electric Field Lines



- Lines must begin on positive charges and terminate on negative charges.
- The number of lines is proportional to the charge magnitude.
- No two field lines should cross, nor should they meet if they originate from like charges.

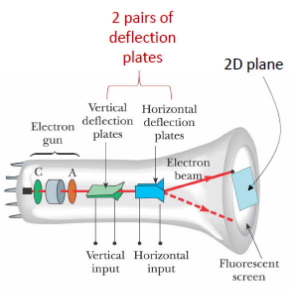
Motion of Charged Particles in an Electric Field





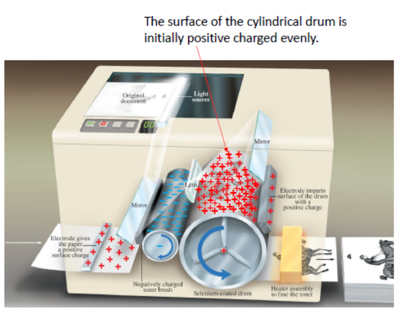
- A charged particle in an electric field experiences a **force** that causes it to accelerate.
- If the electric field E is uniform, acceleration a is constant.
  - **Positive charges** accelerate in the field's direction.
  - **Negative charges** accelerate in the opposite direction.
- This behavior is governed by **Newton's second law**: $F = qE = ma$.

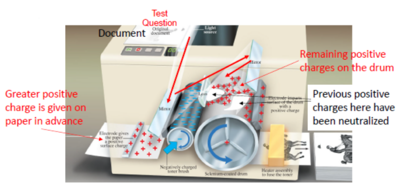
Cathode Ray Tube (CRT) Application



- A **CRT** is a vacuum tube where an electron beam is accelerated and deflected by electric fields.
- The electron gun produces electrons that are directed using deflection plates, allowing the beam to be manipulated on a 2D plane.

Photocopy Machine Application





- **Photocopy machines** use electrically charged toner particles that are attracted to certain regions of a cylindrical drum.
- The drum is initially positively charged, and the toner, given a negative charge, adheres to the positively charged areas that match the document's dark regions.