ELECTROSTATICS

ELECTRIC CHARGE

- Electric charge is a property of atomic particles, the electron and the proton, which make up atoms (together with neutrons).
- The standard unit of charge is the Coulomb (C).
- Electric charge and mass of particles

<table>
<thead>
<tr>
<th>Particle</th>
<th>Electric Charge</th>
<th>Mass</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electron</td>
<td>(-e = -1.6 \cdot 10^{-19} \text{ C})</td>
<td>(m_e = 9.11 \cdot 10^{-31} \text{ kg})</td>
</tr>
<tr>
<td>Proton</td>
<td>(+e = 1.6 \cdot 10^{-19} \text{ C})</td>
<td>(m_p = 1.672 \cdot 10^{-27} \text{ kg})</td>
</tr>
<tr>
<td>Neutron</td>
<td>0</td>
<td>(m_n = 1.674 \cdot 10^{-27} \text{ kg})</td>
</tr>
</tbody>
</table>

- Law of charges: Like charges repel, and unlike charges attract.
- An electric charge \(q\) is a charge which is an integer multiple of the fundamental charge constant \(e = 1.6 \cdot 10^{-19} \text{ C}\), \(q = n e\). Electric charge is quantized.
- The net charge of an object is the difference between the number of protons and electrons in it times the elementary charge constant.
- Law of conservation of net charge: The net charge of an isolated system remains constant.
- Electric charge transfer is a transfer of electrons.
  
  Charging positively: Removal of electrons from an object  
  Charging negatively: Addition of electrons to an object

ELECTRIC FORCE

- The mutual electrostatic forces on two point charges are equal and opposite, pointing to (away from) the other particle for unlike (like) charges.
- Coulomb’s Law
  - The electrostatic force between two charges \(q_1\) and \(q_2\) separated by a distance \(r\) is:

    \[
    F = \frac{k q_1 q_2}{r^2}
    \]

    \[
    k = 8.99 \cdot 10^9 \text{ N m}^2/\text{C}^2
    \]

- Charges interact pairwise via Coulomb force. The superposition principle is valid:

  The net force acting on any charge is the vector sum of the forces due to each of the remaining charges in a given distribution.
ELECTRIC FIELD

- **Test charge** = charge which feels the force of other charges, but exerts no force on them. (mathematical construction)

- **Electric field**, \( \vec{E} \) = force per unit test charge: \( \vec{E} = \vec{F}/q_0 \).
  SI-unit of the \( \vec{E} \)-field: N/C.

- Electric field of a point charge:
  - Force between two point charges: \( F = kQq_0/r^2 \).
  - \( E \)-field felt by test charge \( q_0 \) at \( r \) due to the presence of \( Q \) is then: \( E = F/q_0 = kQ/r^2 \).
  - Direction of \( \vec{E} \) = direction of \( \vec{F} \).
  - Unit positive test charge would be attracted to a negative charge. \( \vec{E} \)-field points towards a negative point charge and away from a positive point charge.

- Superposition of electric fields: \( \vec{F} = \vec{F}_1 + \vec{F}_2 + \vec{F}_3 + ..., \quad \vec{E} = \vec{F}/q_0 \rightarrow \vec{E} = \vec{E}_1 + \vec{E}_2 + \vec{E}_3 + ... \)

- Rules for electrical field lines:
  - The lines are directed pointing away from the positive and towards the negative charges.
  - At any given point in space, the tangent to the line is the direction of the \( \vec{E} \)-field at that point.
  - The number of lines drawn to or from a charge is proportional to the magnitude of the charge.

- Consequences of these rules:
  - In the immediate vicinity of a point charge, field lines are radially directed.
  - Field lines do not intersect in a charge-free region.
  - Field lines do not begin or end in a charge-free region.

- Density of field lines (number of field lines per unit area) is proportional to the \( \vec{E} \)-field; and by convention, the total number of field lines is proportional to the charge \( q \).

ELECTRIC DIPOLE

- An arrangement of two equal but opposite charges \( q \) separated by a fixed distance \( d \) is called a dipole.
  In a uniform field \( E \), a fixed dipole is subject to a torque: \( \tau = qdE \sin \theta \). \( \theta \) is the angle between the dipole direction and the field. \( p = qd \) is the dipole moment.

- The field of a dipole along the dipole axis at large distances (\( z \gg d \)) is: \( E = 2kp/z^3 \)

- The field of a dipole along an axis perpendicular to the dipole axis at large distances (\( x \gg d \)) is: \( E = kp/x^3 \)

CONTINUOUS CHARGE DISTRIBUTIONS

- The linear charge density is defined as \( \lambda = Q/L \)
  The surface charge density is defined as \( \sigma = Q/A \)
  The volume charge density is defined as \( \rho = Q/V \)

- The electric field along the \( z \)-axis of a charged ring is: \( E = kqz/(z^2 + R^2)^{3/2} \)
- The electric field along the \( z \)-axis of a charged disk is: \( E = \sigma/2\epsilon_0(1 - z/\sqrt{z^2 + R^2}) \)