Electrical Materials & Fields

1st semester:
- Electro-statics
- 5% course-work: 1/11
- 25% in class test: 7/1

2nd semester:
- Electro-Dynamics (ED)
- Oscillations & Waves (O&W)
- 50% exam (10% ED, 40% O&W)

Laboratories
- 10% generic labs
- 10% specific labs (ferromagnetism, motors)

Lectures:
- Monday 2x
- Walk-in session: Thursdays 8.30am-10.00am room 53/3011

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Electrical Materials & Fields


- Electro-magnetism:
  - Ch. 21-24 Electric Charge, Electric Field, Gauss Law, Potential
    - Week 1-5
    - Coursework 5%: Thursday 1/11 (“tutorial questions” Ch23/24)
  - Ch. 25-28 Capacitors, Resistors, Circuits, Magnetic Fields
    - Week 6-11
    - Class test 25%: Monday 7/1 (“exam question” Ch21-28)
  - Ch. 29-32 Ferromagnetism, Solenoids, Inductors
    - Semester 2: week 1,2
    - Exam question 10%: May/June (Ch29, 30 only)
- Electromagnetic waves........
Electric Charge & Coulomb’s Law

- Charge
  - Quantization
  - Origin
  - Conservation

- Electro-magnetic Force
  - Coulomb’s Law
    - Properties
    - SI Units
    - Principle of Superposition
    - Some calculations
Charge Quantization

- quantized
  - Millikan experiment (1910)
  - no fractional charge
  - $Q = ne$
  - $e = 1.602 \times 10^{-19}$ Coulomb

1 Ampere = Coulomb/second

$A = C/\text{s}$
Origin of Charge

- atom
  - Nucleus
    - radius: 0.00001 nm=10fm
    - proton: positive charge
    - neutrons: neutral charge
    - $1.6724 \times 10^{-27} \text{ kg /particle}$
  - Electrons
    - negative electric charge
    - orbiting radius (0.1 nm)
    - $9.1083 \times 10^{-31} \text{ kg /electron}$
- Proton and electrons have equal and opposite charge
- $e=1.602 \times 10^{-19} \text{ C}$
Charge Conservation

- charge is conserved......
  - we cannot create or destroy a single electron
    - but we can create combinations of positive and negative:
    - radio-active decay:
      \[ n \rightarrow p + e \]
      \[ ^{14}C(6p, 8n, 6e) \rightarrow N(7p, 7n, 7e) \]
  - if we put a positive charge somewhere, we have automatically put a negative charge somewhere else
    - and created a capacitor by doing so!
how much is a Coulomb?

- 2 table tennis balls charged to 1 Coulomb 50 cm apart
  - 60 Watt lamp for 4 seconds
- same charges repel 2nd ball upwards
- gravitational force needed to compensate?

<table>
<thead>
<tr>
<th>A: force of ball 2.5g</th>
<th>C: midsize car 1000kg</th>
</tr>
</thead>
<tbody>
<tr>
<td>B: 3 pints of beer 2kg</td>
<td>D: Eiffel tower 10kton</td>
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</tbody>
</table>

E: 10 empire state buildings 3.60Mton
Coulomb’s law

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

- Charles Coulomb 1785
- \( q \) = charge of a “particle”
- \( r \) = distance between particles
- \( k \) = electrostatic constant

(a) Repulsion
(b) Repulsion
(c) Attraction
Analogies with gravitation

- Proportional to charge/mass
- Proportional to inverse of distance squared
- Force parallel to the line joining charges

\[
F = k \frac{q_1 q_2}{r^2} \quad F = G \frac{m_1 m_2}{r^2}
\]

- Coulomb: attractive or repulsive
- Coulomb: all shapes (not only spheres!)
SI units (systeme internationale)

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

- cgs electrostatic units [cm, gram, s]
  - F [dyne], q [esu], r [cm], k=1
- SI units [m, kg, s]
  - F [Newton], q [C], r [m], k = \(8.99 \times 10^9\) Nm\(^2\)C\(^{-2}\)
  - \(k = \frac{1}{4\pi\varepsilon_0}\) with \(\varepsilon_0\) : permittivity of vacuum
  - \(\varepsilon_0 = 8.85 \times 10^{-12}\) N\(^{-1}\)m\(^{-2}\)C\(^2\)
- dimensional analysis!
Superposition of point charges

- resultant force on a charge equals the sum of the individual forces exerted by all other charges
- vector algebra

\[ \vec{F}_0 = \vec{F}_{01} + \vec{F}_{02} + \vec{F}_{03} + \vec{F}_{0n} \]

- forces might also be due to gravitation
Example 1

- Three positive charges lie along the same line, find the force on charge $Q_2$.

- According to Coulomb’s law, the force on $Q_2$ from left to right is given by

$$F = \frac{Q_1 Q_2}{4\pi\varepsilon_0 a^2} - \frac{Q_3 Q_2}{4\pi\varepsilon_0 b^2} = \frac{Q_2}{4\pi\varepsilon_0} \left( \frac{Q_1}{a^2} - \frac{Q_3}{b^2} \right)$$
Example 2

- Three equal charges locate at the corners of a triangle. Find the force on the charge $Q$ at $A$

- There are two forces on $A$ with magnitude:

$$ F = \frac{Q^2}{4\pi \varepsilon_0 a^2} $$

- The forces in the x-direction cancel out, and those in the y-direction add up:

$$ F = 2 \cos 30^0 \frac{Q^2}{4\pi \varepsilon_0 a^2} = \frac{\sqrt{3} Q^2}{4\pi \varepsilon_0 a^2} $$
Tutorial

- For next lecture
- Problems
  - 21.2 charge transfer
  - 21.13 point of no force
  - 21.33 charge in substance (water)
Identical isolated conducting spheres 1 and 2 have equal charges and are separated by a distance that is large compared with their diameters (Fig. 21-21a). The electrostatic force acting on sphere 2 due to sphere 1 is $\vec{F}$. Suppose now that a third identical sphere 3, having an insulating handle and initially neutral, is touched first to sphere 1 (Fig. 21-21b), then to sphere 2 (Fig. 21-21c), and finally removed (Fig. 21-21d). The electrostatic force that now acts on sphere 2 has magnitude $F'$. What is the ratio $F'/F$?

Fig. 21-21  Problem 2.
13 In Fig. 21-25, particle 1 of charge +1.0 \( \mu \text{C} \) and particle 2 of charge \(-3.0 \mu \text{C} \) are held at separation \( L = 10.0 \) cm on an \( x \) axis. If particle 3 of unknown charge \( q_3 \) is to be located such that the net electrostatic force on it from particles 1 and 2 is zero, what must be the (a) \( x \) and (b) \( y \) coordinates of particle 3?

33 Calculate the number of coulombs of positive charge in 250 \( \text{cm}^3 \) of (neutral) water. (Hint: A hydrogen atom contains one proton; an oxygen atom contains eight protons.)