Important Concepts

1. Coulomb’s Law
2. Electric Fields
3. Electric Field Lines
4. Electric Fields in Conductors
5. Electric Flux
6. Gauss’s Law
7. Electric Potential Energy
8. Electrostatic Potential
9. Equipotential Lines
10. Capacitance
11. Resistance and Ohm’s Law (series & parallel)
12. Kirchhoff’s Laws
13. RC Circuits
14. Magnetic Force on Particle – RHR
15. Magnetic Force on Conductor
16. Sources of Magnetic Fields Law of Biot-Savart
17. Magnetic Flux – Ampere’s Law
18. Magnetic Flux – Induction (Faraday & Lenz)
19. Inductance
20. RL Circuits
21. RC Circuits
22. AC Circuits
Coulomb's Law

There is a force between any two charges.

- The force is directed along the line between the charges.
- The force is attractive if the charges are of different sign, repulsive if they are the same.
- The magnitude of the force is inversely proportional to the square of the distance between the charges.

The force is a vector.

The force is proportional to the product of the two charges (q_1 \times q_2).

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

Important - Force is a Vector

**Important - Force is a Vector**

- The force is in Newtons (N).
- Charge is in Coulombs (C).
- Distance is in Meters (m).

The constant k must have units of Newtons(meters)²(coulomb)².
Coulomb’s Law
Key Points

1. Force is a vector

2. Sign of the Force (attractive-repulsive)

3. Superposition of Forces (add vectors via components)
**Example 2.12** Two equal positive point charges in a plane

**IDENTIFY and SET UP:** As in Example 2.3, we have to consider the force each charge exerts on $\vec{q}$ and then find the vector sum of the forces.

**Solution**

The force on each charge is directed away from the positive charge. Since each charge is positive, a force away from a positive charge is attractive. Therefore, the force on $q$ due to charge $q$ is $\vec{F}_{12}$.

The force on $q$ due to charge $q$ is $\vec{F}_{21}$.

**EXECUTE:** Figure 2.12 shows the force on $q$ due to the upper positive charge.

**RESULT:** The forces are in the same magnitude but at different angles. The easiest way to do this is to use components of the forces.

**CHECK:** The directions of the forces are consistent with the direction of the total net force on $q$.
2. **The Electric Field**

We can calculate the Electric field from a collection of charges from:

\[ \vec{E} = \lim_{q \to 0} \frac{\vec{F}}{q} \]

\[ \vec{F} = q \sum_i \frac{1}{4 \pi \epsilon_0} \frac{q_i \hat{r}_i}{r_i^2} \]

Which Gives

\[ \vec{E} = \sum_i \frac{1}{4 \pi \epsilon_0} \frac{q_i \hat{r}_i}{r_i^2} \]

or for continuous charge distribution

\[ \vec{E} = \int_{all} \frac{1}{4 \pi \epsilon_0} \frac{\rho(\vec{r}) \hat{r}}{r^2} d\vec{r} \]

Electric Fields

Key Study Points

1. Electric Field is a vector

2. Direction of Vector (plus - minus)

3. Superposition of Fields (add vectors via components)
3. Electric Field Lines

The local direction of the Field Lines is the direction of the electric field at that point.

The “density” of electric field lines is proportional to the magnitude of the electric field at that point.

The direction of the electric field line give the direction of the force on a charge particle at that point. *It does not necessarily represent the direction of motion of a charged particle at that point!*

Electric Field Lines always point from the “+” charge to the “-” charge.
4. Electric Field Inside a Conductor

1. Charges can move freely inside a conductor
   (actually it is only the electrons that move)
2. Assume that there is an Electric Field Inside Conductor:

3. Since the Charges are free to move, they will be pushed towards the surface of the Conductor:

4. The field of these charges will tend to cancel the original Field.
5. They will continue to move until the field is zero

The Electric Field inside a Conductor is EXACTLY ZERO
5. Electric Flux

\[ \Phi_E = EA \cos \phi \]

\[ \Phi = E \cdot A \]

Direction of \( \vec{A} \) is \( \perp \) to the surface

Magnitude of \( \vec{A} \) is equal to area of surface

\( \vec{A} = A\hat{n} \)

Total Flux \( \Phi = \int E \cos \phi \, dA = \int E_{\perp} \, dA = \int \vec{E} \cdot d\vec{A} \)
6. GAUSS’S LAW

\[ \Phi_E = \oint_{\text{closed surface}} \vec{E} \cdot d\vec{A} = \frac{Q_{\text{enclosed}}}{\varepsilon_0} \]

The total electric flux through a closed Surface is equal to \(1/\varepsilon_0\) times the total (net) electric charge inside the surface.

Key Points in applying Gauss’s Law

- Pick a surface that goes through the place where you want to know the Electric field
- G’s law problems come in 3 flavors – spheres, cylinders or planes
- Pick a surface with an appropriate symmetry, this means you want electric filed to be either parallel or perpendicular to the surface and constant on the surface
- Use the properties of the scalar product to turn the surface integral into a simple integral
\[ E(x) = \frac{\text{charge}}{4\pi \varepsilon_0 \text{ inner sphere}} \]

\[ 4\pi \varepsilon_0 E(x) = \frac{\text{charge}}{\text{outer sphere}} \]

\[ \oint \mathbf{E} \cdot d\mathbf{S} = \frac{\varepsilon_0 }{c^2} \frac{d\mathbf{E}}{dt} \]

What is the radial component of the electric field \( E_x \) at a point located at radius \( r = 1.60 \text{ cm} \), i.e., between the two conductors?

Charge \( Q = -7.10 \text{ microcoulombs} \) is on the inner sphere and the outer spherical shell has net outer radius \( r = 2.40 \text{ cm} \). The inner sphere has net charge \( Q = 3.80 \text{ microcoulombs} \) and the outer spherical shell of inner radius \( r = 1.90 \text{ cm} \) is surrounded by a concentric spherical metal shell of radius \( a = 1.30 \text{ cm} \). A solid metal sphere of radius \( a = 1.30 \text{ cm} \) is surrounded by a concentric spherical metal shell of radius \( a = 1.30 \text{ cm} \).
What is the surface charge density, $\sigma$, on the inner surface of the outer spherical conductor?

A solid metal sphere of radius $a = 1.30$ cm is surrounded by a concentric spherical metal shell of inner radius $b = 1.90$ cm and outer radius $c = 2.40$ cm. The inner sphere has net charge $q_1 = 3.80 \ \mu$Coulombs, and the outer spherical shell has net charge $q_2 = -7.10 \ \mu$Coulombs.

Thus surface is inside a conductor so $\mathbf{E} = 0$.

So $\oint \mathbf{E} \cdot d\mathbf{l} = 0$

$\sigma$ (surface $b$) + $\sigma_1$ = 0

$\sigma = \frac{4\pi b^2}{2} - \sigma_1$

All charge must be on surface.
What is the surface charge of a solid metal sphere of radius 7.10 cm if the outer radius is 2.40 cm? 

Charge Q = -7.10 microC