Chapter 22: The Electric Field

Read Chapter 22

- **Do Ch. 22 Questions 3, 5, 7, 9**
- **Do Ch. 22 Problems 5, 19, 24**
- **Do WileyPlus assignment**

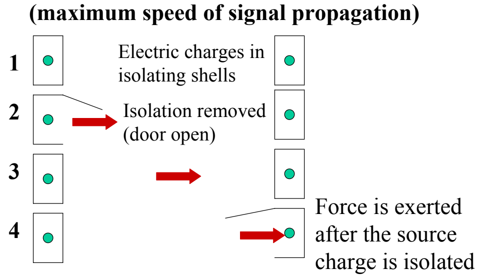
The Electric Field

- Replaces action-at-a-distance
- Instead of Q_1 exerting a force directly on Q_2 at a distance, we say:
- Q_1 creates a ***field*** $\vec{E}$ and then the ***field*** exerts a force on Q_2.
- NOTE: Since force is a vector then the electric field must be a ***vector field!***

$$\vec{F} = q\vec{E}$$

Does the field really exist?

It exists due to the finite speed of light (maximum speed of signal propagation)

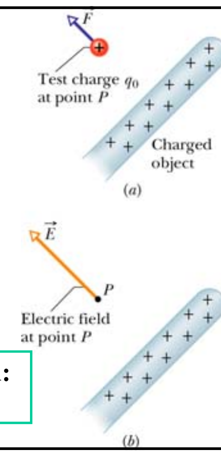


Interaction by the field rather than by charge

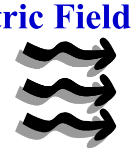
Field E is defined as the force that would be felt by a unit positive test charge

$$\vec{E} = \vec{F} / q_0$$

SI units for the electric field: newtons per coulomb.



Electric Field Lines

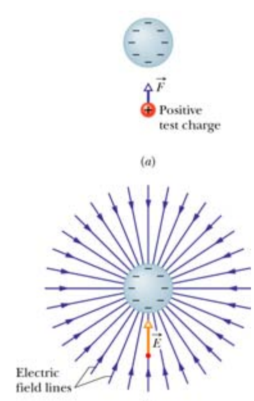


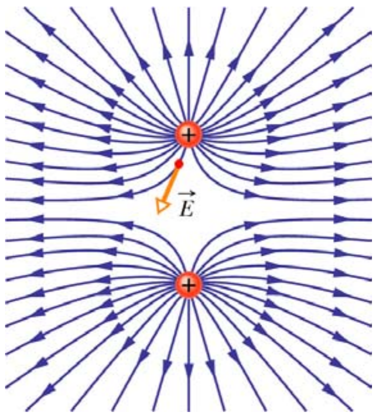
We **visualize** the field by drawing **field lines.**

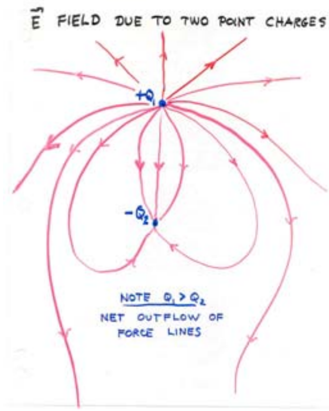
These are defined by **three properties:**

- Lines point in the **same direction** as the field.
- Density of lines gives the **magnitude** of the field.
- Lines begin on + charges; end on – charges.

Electric field created by a negatively charged metal sphere







Coulomb's Law for the Field

Coulomb's law for the force on *q* due to *Q*: $\vec{F} = k\dfrac{qQ}{r^2}\hat{r} = q\vec{E}$

Coulomb's law for the field *E* due to *Q*: $\vec{E} = k\dfrac{Q}{r^2}\hat{r}$

Example 1

What is the electric field strength at a distance of 10 cm from a charge of 2 μC?

$$E = \frac{kQ}{r^2} = \frac{(9\times10^9)(2\times10^{-6})}{(10\times10^{-2})}$$

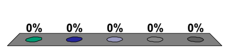
$$= \frac{18\times10^3}{10^{-1}} = 1.8\times10^5\ N/C$$

So a one-coulomb charge placed there would feel a force of 180,000 newtons.

Q.22-1

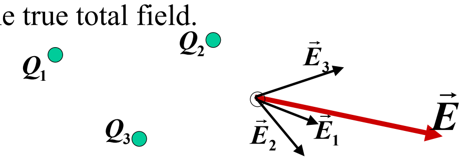
A point charge Q is far from all other charges. At a distance of 2 m from Q, the electric field is 20 N/C. What is the electric field at a distance of 4m from Q?

1. 5 N/C
2. 10 N/C
3. 20 N/C
4. 40 N/C
5. 80 N/C



Adding fields

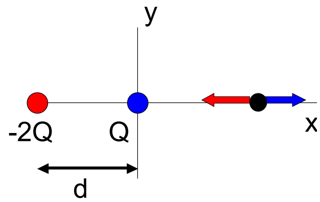
- Principle of superposition
- Electric fields due to different sources combine vector addition to form the one true total field.



$$\vec{E} = \vec{E}_1 + \vec{E}_2 + \vec{E}_3 + \cdots$$

Example 2

1. Find the electric field on the x axis.



$$E_y = 0$$

$$E_x = E_1 - E_2 = \frac{kQ}{x^2} - \frac{2kQ}{(x+d)^2}$$

2. Where will the field be zero? $x + d = \sqrt{2}x$ $\quad$ $x = 2.4d$

The shell theorems for E

In Chapter 13 we had the shell theorems for gravity

In Chapter 21 (p. 567) the shell theorems for electrostatics were stated.

In Chapter 23 (p. 618) they will be proven.

But we can easily understand them now from our knowledge of electric field lines.

The shell theorems for gravity

Given a **uniform spherical shell** of mass:

(1) The field outside is the same as if all the mass were concentrated at the center.

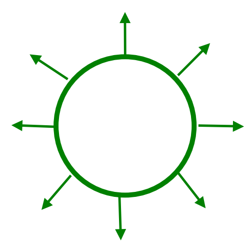
(2) The field inside the shell is zero.

(These theorems for gravity are given in Chapter 14.)

(Newton's headache!)

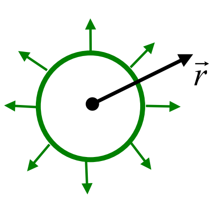
Prove true also for electric field

Use our knowledge of electric field lines to draw the field due to a spherical shell of charge:

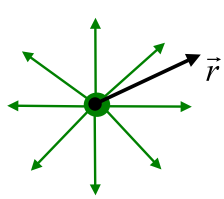


There is no other way to draw lines which satisfy all 3 properties of electric field lines, **and are also spherically symmetric**. **Notice that both shell theorems are obviously satisfied.**

Fields at $\vec{r}$ are the same!



Q spread over shell

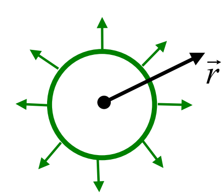


point Q at center

PROOF: **(1)** Spherical symmetry

(2) Fields far away must be equal

Useful result for spherical symmetry

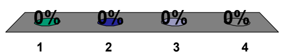


Field outside a sphere of total charge Q is radially outward with magnitude

$$E = \frac{kQ}{r^2}$$

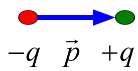
Q.22-2 **A shell of uniform charge attracts or repels a charged particle that is outside the shell as if all the shell's charge were . . .**

1. **Concentrated at the center.**
2. **Concentrated at the point closest to the particle.**
3. **Concentrated at the point opposite the particle.**
4. **Zero.**

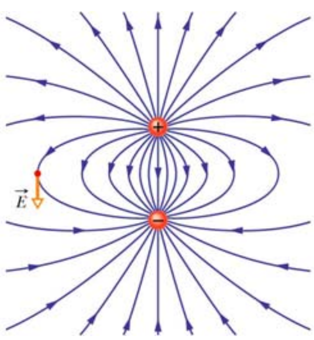


Electric Dipole

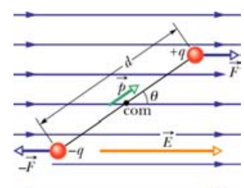
- The combination of two charges of equal but opposite sign is called a dipole.
- If the charges +q and –q are separated by a distance d, then the ***dipole moment*** $\vec{p}$ is defined as a vector pointing from –q to +q of magnitude $p = qd$.



Electric Field Due to a Dipole



Torque on a Dipole in a Field



$$\tau = 2 \times F \times (\frac{d}{2} \sin\theta) = qE \times d \sin\theta = pE \sin\theta$$

$$\vec{\tau} = \vec{p} \times \vec{E}$$