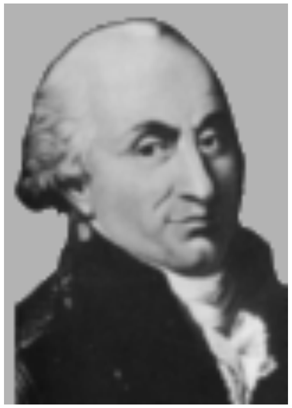
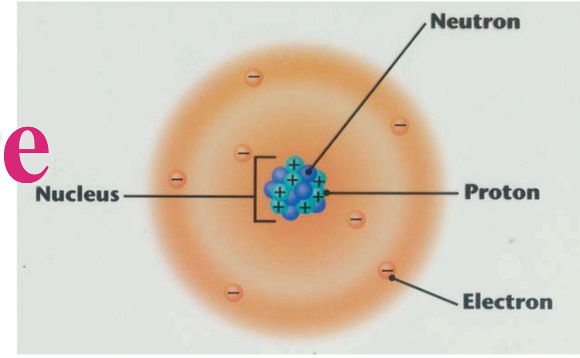
Physics 2102

Introduction to Electricity, Magnetism and Optics

Charles-Augustin de Coulomb (1736-1806)



Atomic structure



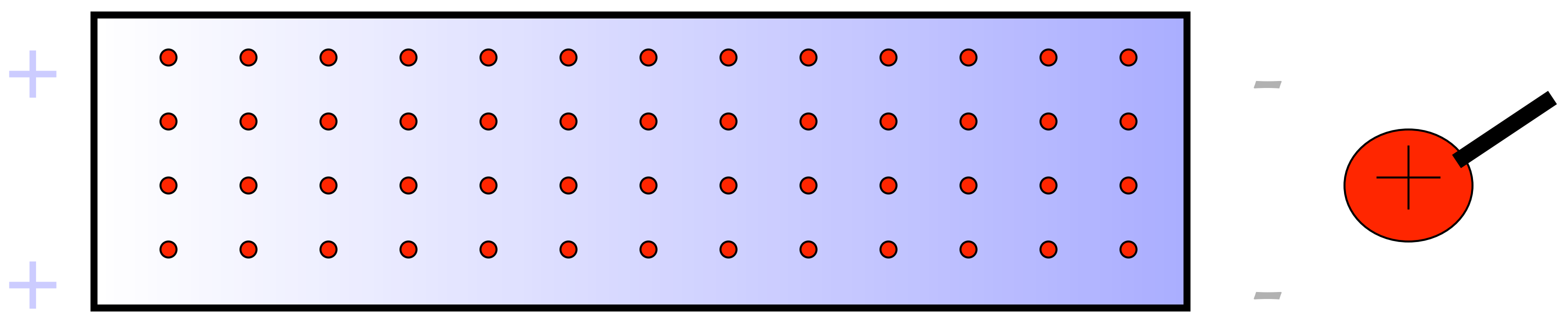
- negative electron *cloud*
- nucleus of positive protons, uncharged neutrons
- Z = atomic number = # of protons = # of electrons in a neutral atom
- A = mass number = # of protons (Z) + # of neutrons (N)
- electron charge = e = −1.6 x 10^{-19} Coulombs = − proton charge
- electron mass = 9.10938188 × 10^{-31} kilograms
- proton mass = 1.67262158 × 10^{-27} kilograms = neutron mass

Charges in solids

- In a conductor, electrons move around freely, forming a "sea" of electrons. This is why metals conduct electricity.
- Charges can be "induced" (moved around) in conductors.

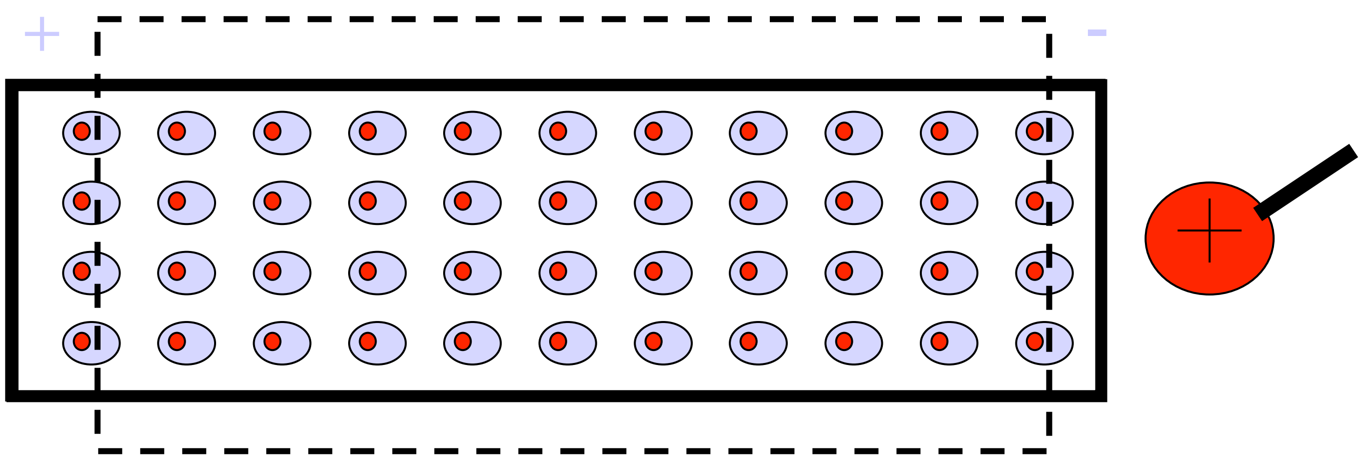
Blue background = mobile electrons

Red circles = static positive charge (nuclei)



Insulating solids

- In an insulator, each electron cloud is tightly bound to the protons in a nucleus. Wood, glass, rubber.
- Note that the electrons are not free to move throughout the lattice, but the electron cloud can “distort” locally.



How to charge an object

- An object can be given some “excess” charge: giving electrons to it (we give it negative charge) or
taking electrons away (we “give” it positive charge).

- How do we do charge an object? Usually, moving charges from one surface to another by adhesion (helped by friction), or by contact with other charged objects.

- If a conductor, the whole electron sea redistributes itself.

- If an insulator, the electrons stay where they are put.

Summary

• **Electric charges** come with two signs: **positive and negative**.

• Like charges repel, opposite charges attract, with a magnitude calculated from **Coulomb's law**: $F=kq_1q_2/r^2$

• **Atoms** have a positive nucleus and a negative "cloud".

• Electron clouds can combine and flow freely in **conductors**; are stuck to the nucleus in **insulators**.

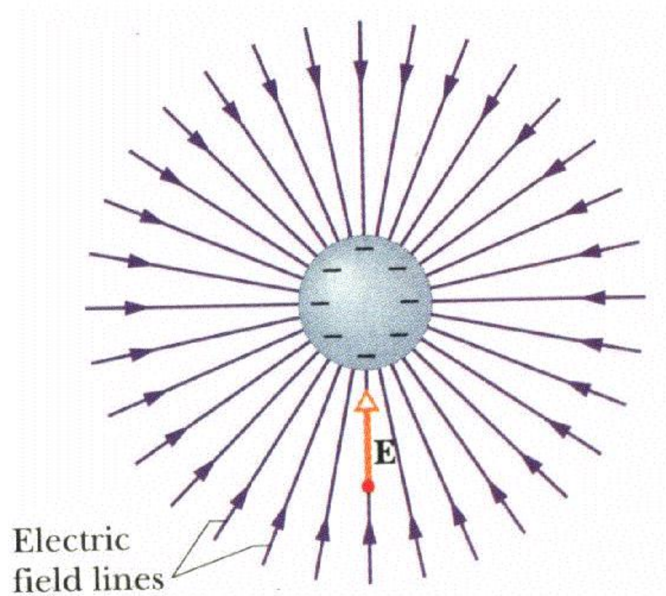
•We can **charge objects** by transferring charge, or by induction.

• Electrical charge is **conserved**, and **quantized**.

What are we going to learn?
A road map

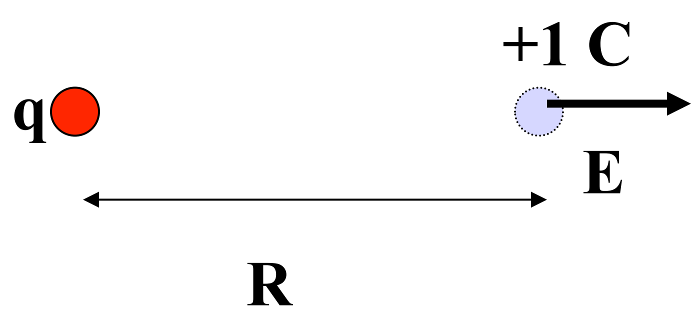
- Electric *charge*
    - Electric *force* on other electric charges
    - Electric *field*, and electric *potential*
- Moving electric charges : current
- Electronic circuit components: batteries, resistors, capacitors
- Electric currents
    - Magnetic field
    - Magnetic force on moving charges
- Time-varying magnetic field
    - Electric Field
- More circuit components: inductors
- All together: Maxwell's equations
- Electromagnetic waves
- Optical images
- Matter waves

Electric Fields



Electric field of a point charge

- **Electric field E at some point in space is defined as the force experienced by an *imaginary* point charge of +1 C, divided by 1 C.**
- **Note that E is a VECTOR.**
- **Since E is the force per unit charge, it is measured in units of N/C.**
- **We *measure* the electric field using very small "test charges", and dividing the measured force by the magnitude of the charge.**



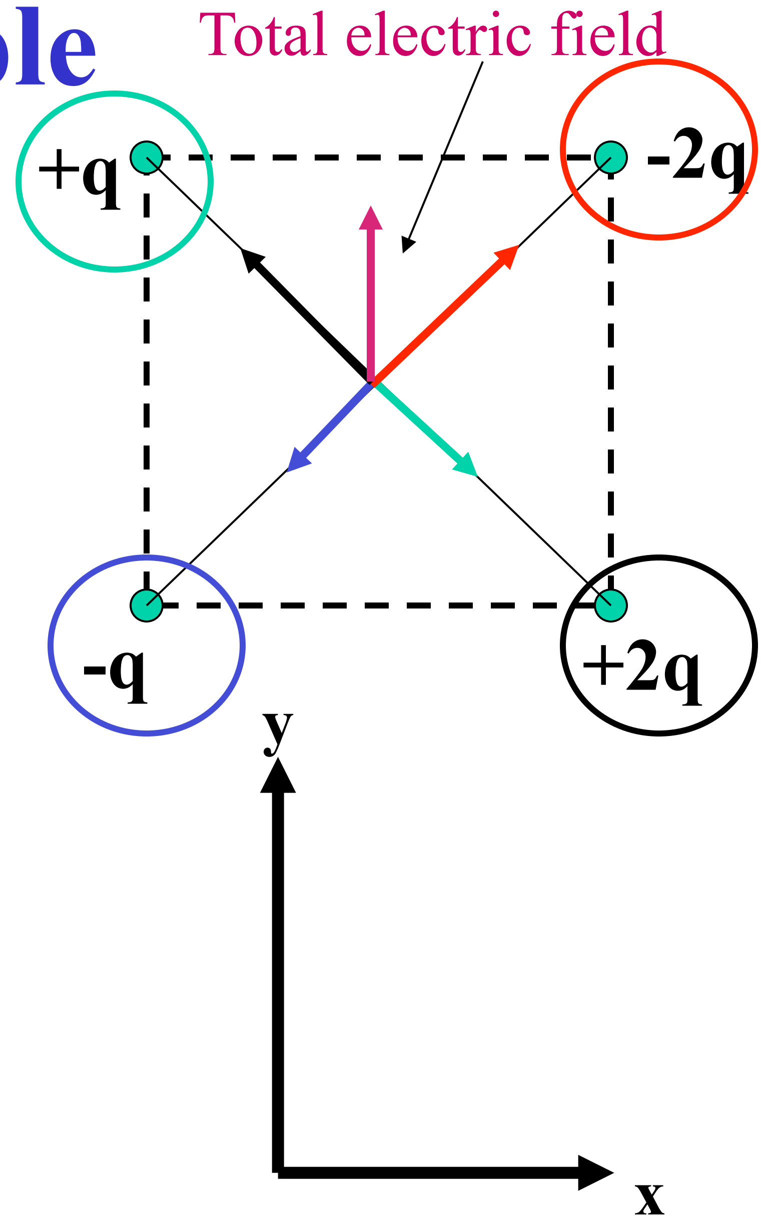
$$|E| = \frac{k\,|q|}{R^2}$$

Superposition

- **Question**: How do we figure out the field due to several point charges?
- **Answer**: consider one charge at a time, calculate the field (a vector!) produced by each charge, and then add all the vectors! ("superposition")
- Useful to look out for SYMMETRY to simplify calculations!

Example

- 4 charges are placed at the corners of a square as shown.
- What is the direction of the electric field at the center of the square?



(a) Field is zero

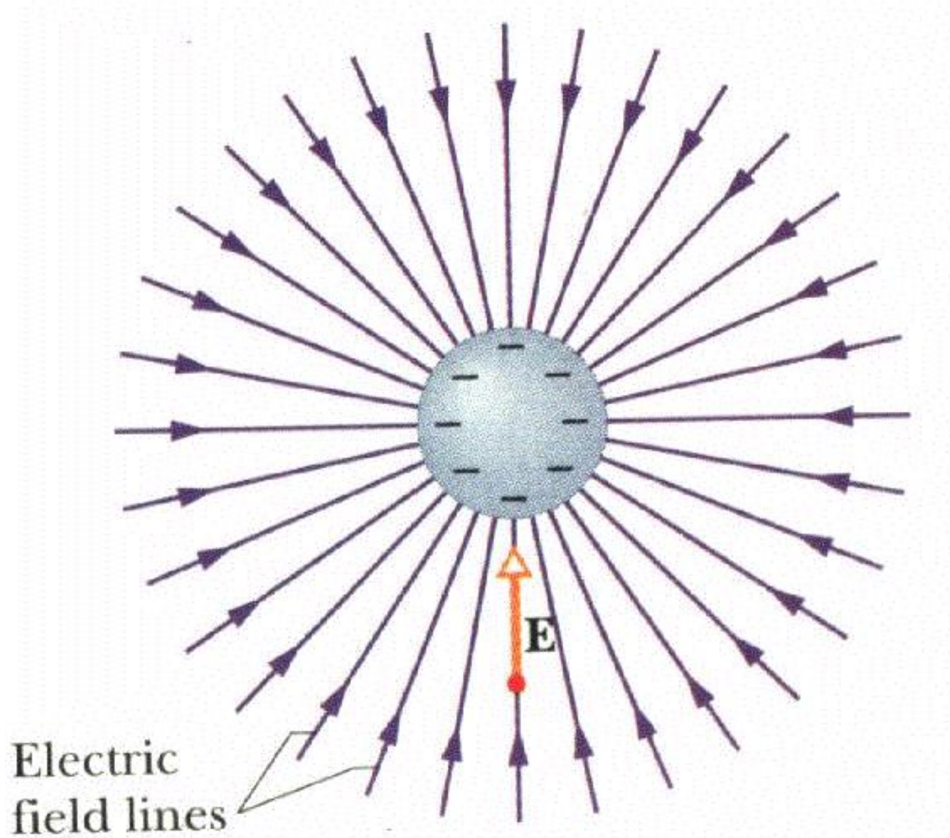
(b) Along +y ↑

(c) Along +x →

Electric Field Lines

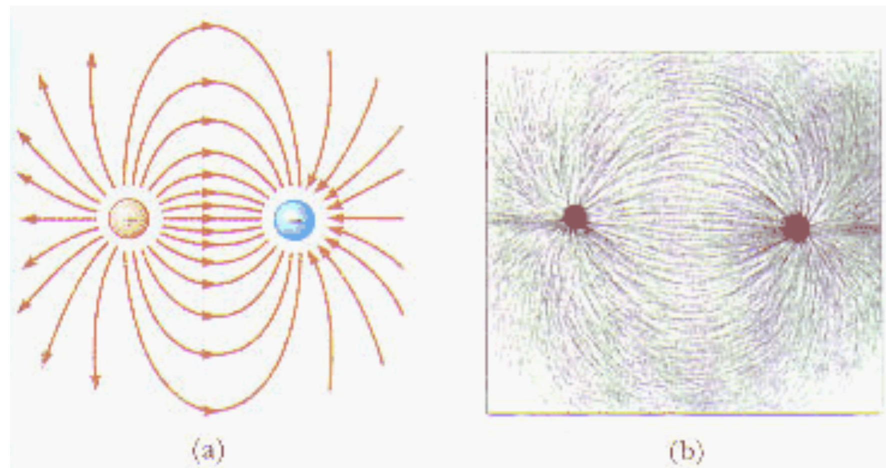
- **Field lines: useful way to visualize electric field E**
- **Field lines start at a positive charge, end at negative charge**
- **E at any point in space is tangential to field line**
- **Field lines are closer where E is stronger**

Example: a negative point charge -- note spherical symmetry



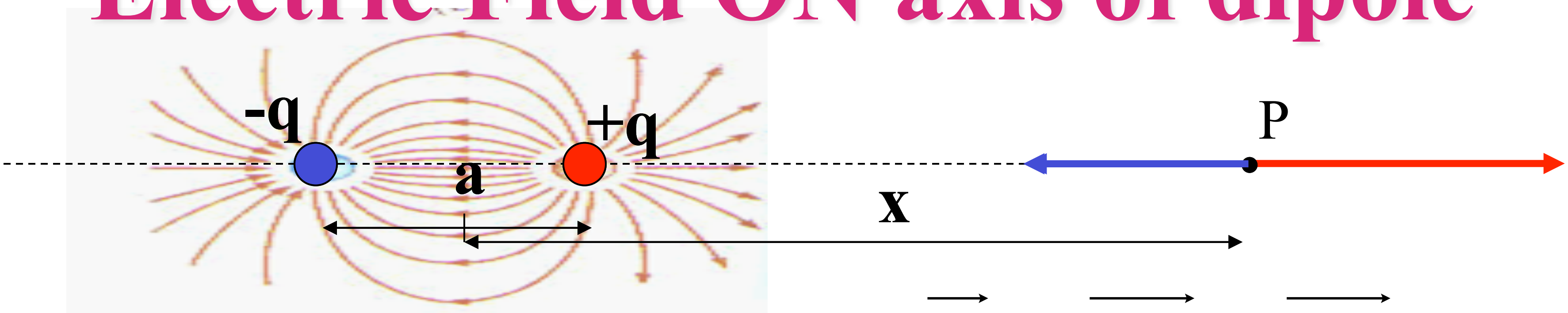
Electric Field of a Dipole

- **Electric dipole: two point charges +q and -q separated by a distance a**
- **Common arrangement in Nature: molecules, antennae, …**
- **Note axial or cylindrical symmetry**



Play hockey with electric charges and learn!
http://phet.colorado.edu/en/simulation/electric-hockey

Electric Field ON axis of dipole



Superposition : $\vec{E} = \vec{E}_+ + \vec{E}_-$

$$\vec{E}_+ = \frac{kq}{\left(x - \frac{a}{2}\right)^2}$$

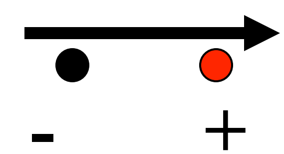
$$\vec{E}_- = -\frac{kq}{\left(x + \frac{a}{2}\right)^2}$$

$$\vec{E} = kq\left[\frac{1}{\left(x - \frac{a}{2}\right)^2} - \frac{1}{\left(x + \frac{a}{2}\right)^2}\right] = kq\frac{2xa}{\left(x^2 - \frac{a^2}{4}\right)^2}$$

Electric Field ON axis of dipole

$$E = kq\frac{2xa}{\left(x^2 - \frac{a^2}{4}\right)^2} = \frac{2kpx}{\left(x^2 - \frac{a^2}{4}\right)^2}$$

p = qa
"dipole moment"
-- VECTOR



What if x>> a? (i.e. very far away)

$$E \approx \frac{2kpx}{x^4} = \frac{2kp}{x^3} \quad \Rightarrow \quad \left|\vec{E}\right| \propto \frac{\left|\vec{p}\right|}{r^3}$$

E~p/r^3 is actually true for ANY point far from a dipole (not just on axis)

Summary

- Electric field is the electric force on an imaginary unit positive charge.
- Electric field lines start or end in electric charges.
- When fields are strong, electric field lines get closer.
- Electric field of a single charge is $|E|=kq/r^2$
- The "dipole moment" vector **p** has magnitude qa and direction from –ve to +ve charge.
- Far from a dipole, $|E|\sim kp/r^3$