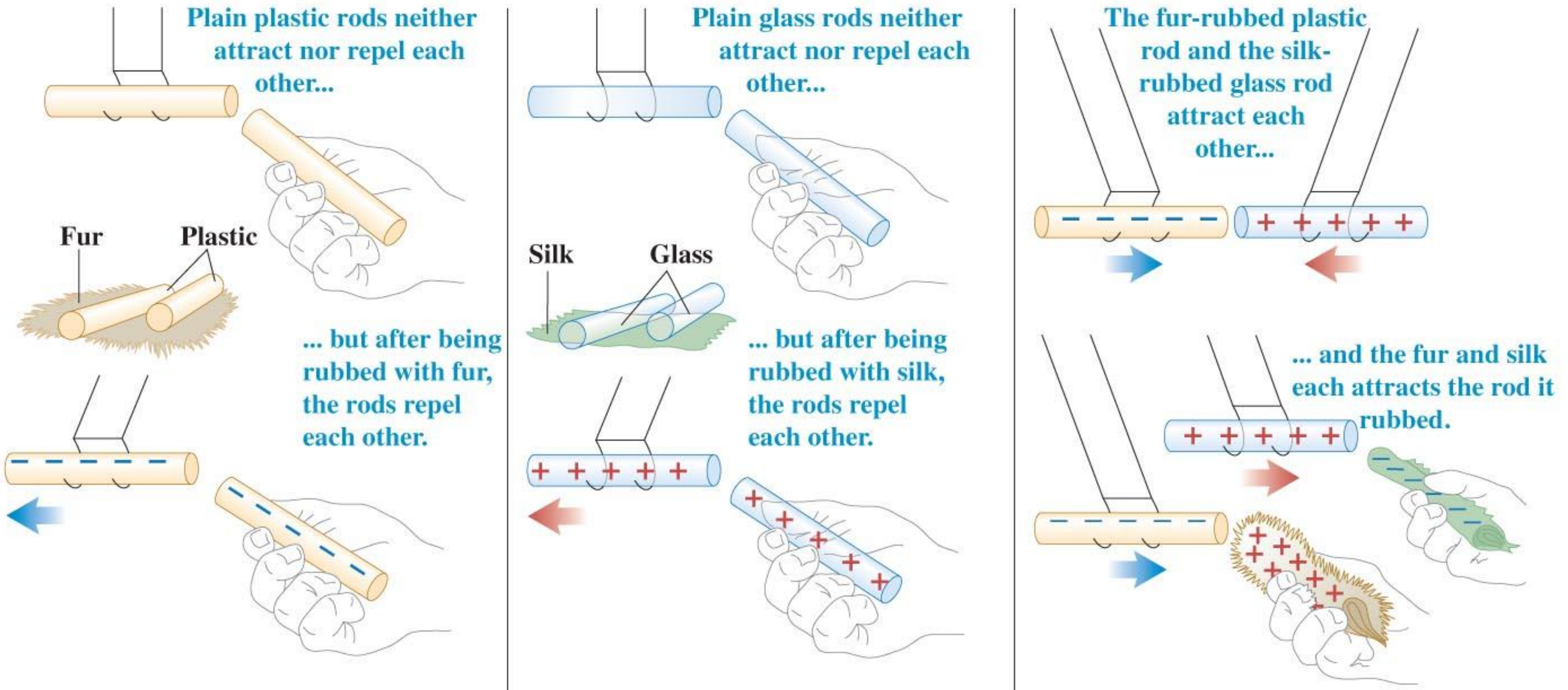
Chapter 16

Electric Charge and Electric Field

Electric Charge: Why Important

- Many natural phenomena (static shock, lightning,…)
- Huge application in the distribution and use of electricity (not really electrostatic)
- Ultimately responsible for the interactions between matter (other than gravity)

Static Electricity



(a) Interaction between plastic rods rubbed on fur

(b) Interaction between glass rods rubbed on silk

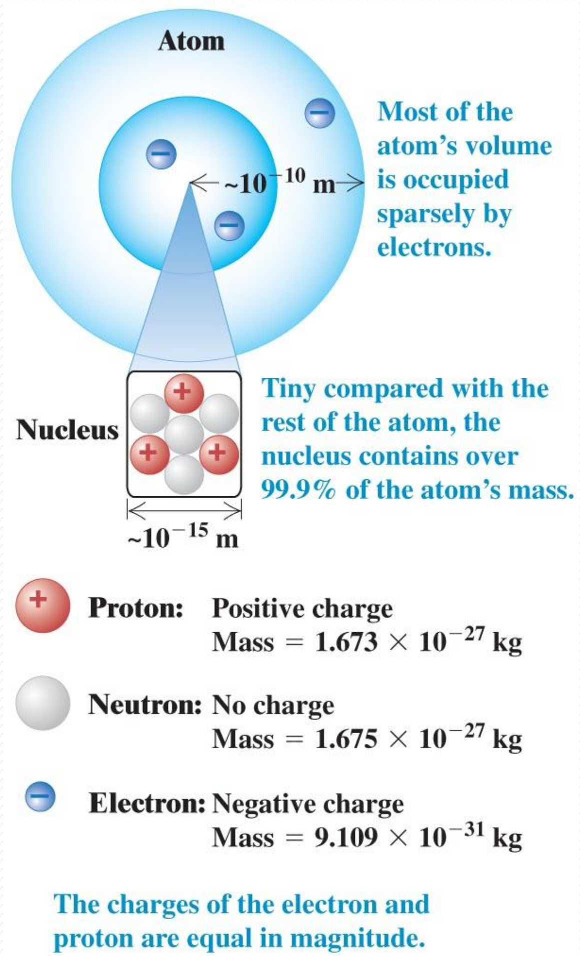
(c) Interaction between objects with opposite charges

Properties of Electric Charges

- There are only two types of electric charge: positive and negative
  - like charges attract, opposite charges repel
- Charges are neither created nor destroyed – they are redistributed
  - the net amount of electric charge produced in any process is zero

Electric Charge in the Atom

- Electron: −e
- Proton: +e
- Neutron: no charge
- Atoms: nucleus of protons/neutrons surrounded by electrons
- Atoms are neutral, so the number of protons = the number of electrons



Elementary Charge

- Electrons and protons have charge $e = 1.602 \times 10^{-19}$ C
  - by convention, the charge of the electron is negative
- Electric charge is quantized
  - any amount of charge must be a multiple of e (unless we want to discuss quarks, that is)
- A neutral particle can decay into charged particles ($n \rightarrow p + e$) and two particles can annihilate their charges ($e^+ + e^- \rightarrow \gamma\gamma$), but the total amount of charge in the system never changes

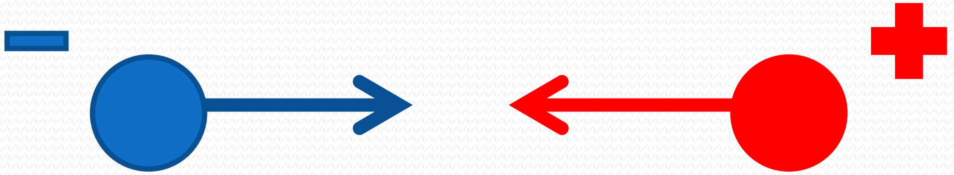
Insulators and Conductors

- Some materials allow charges to move freely within them → conductors
  - examples: metals, salt water
  - in metals, electrons are nearly free and can easily move from one atom to another
  - in salt water, molecules of salt (NaCl) are dissolved into charged ions which move freely in the liquid
- In other materials, charges cannot move or can only move with great difficulty → insulators
  - examples: glass, pure water
- There are semiconductors, too

Coulomb's Law

$$F = k\frac{Q_1 Q_2}{r^2}$$

2.0000000000000000...



$$k = 8.988 \times 10^9\ \mathrm{N \cdot m^2/C^2}$$

$$k = \frac{1}{4\pi\varepsilon_0}$$

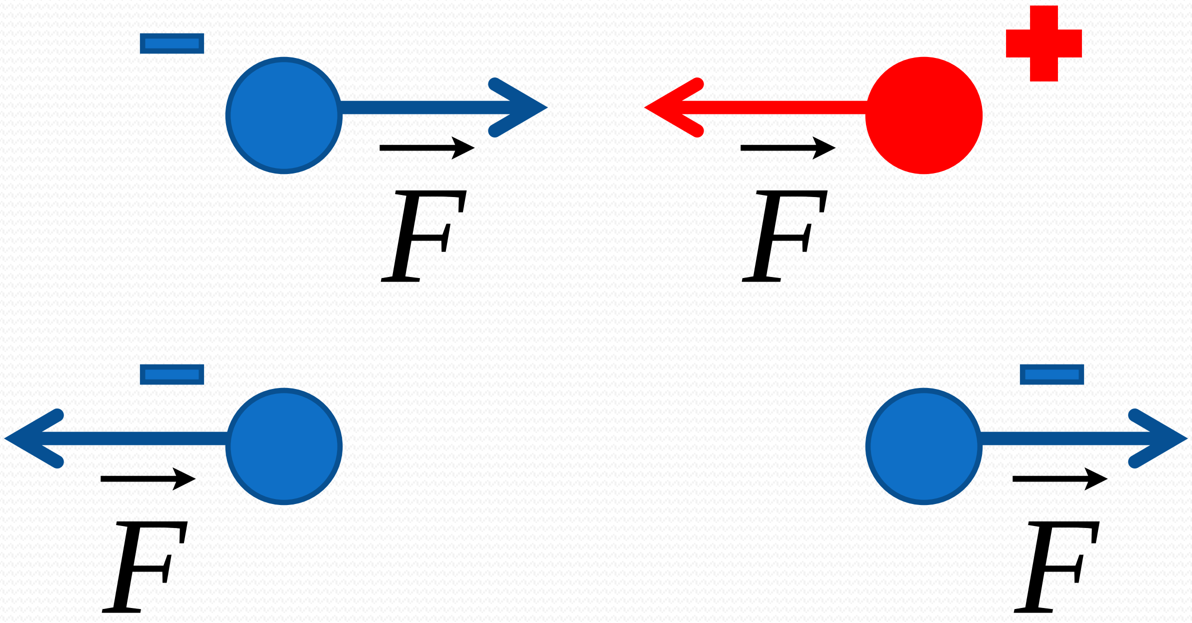
$$\varepsilon_0 = 8.85 \times 10^{-12}\ \mathrm{C^2/N \cdot m^2}$$

"permittivity of free space"

denominator!

Electric Force is a Vector

… like any other force



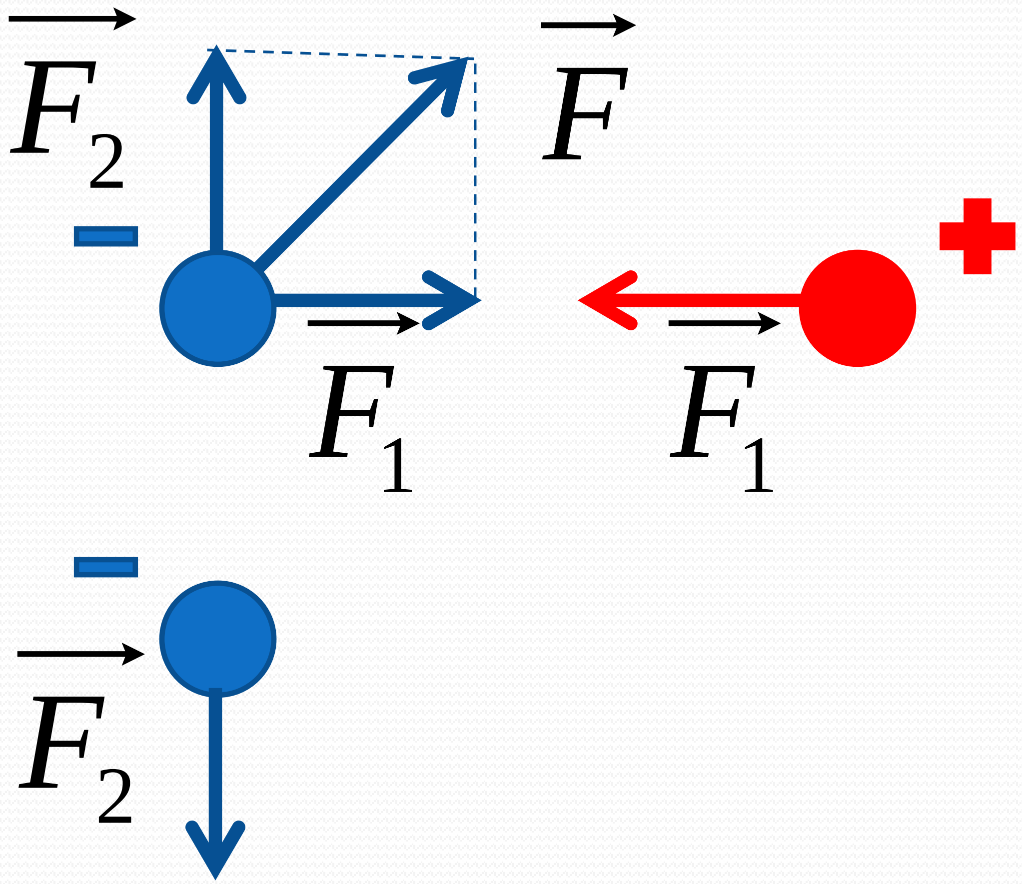
trivial if there are two charges

what if there are more than two?

Adding Electric Forces

- Everybody is affected by everybody else
  - if there are n charges, there are (n-1) forces acting on each charge
- Like charges repel, opposite charges attract
- When solving a problem, first figure out the number of dimensions
- Remember: forces are vectors!
- Cross check: sum of all forces acting on all charges is zero

Vector Sum of Forces



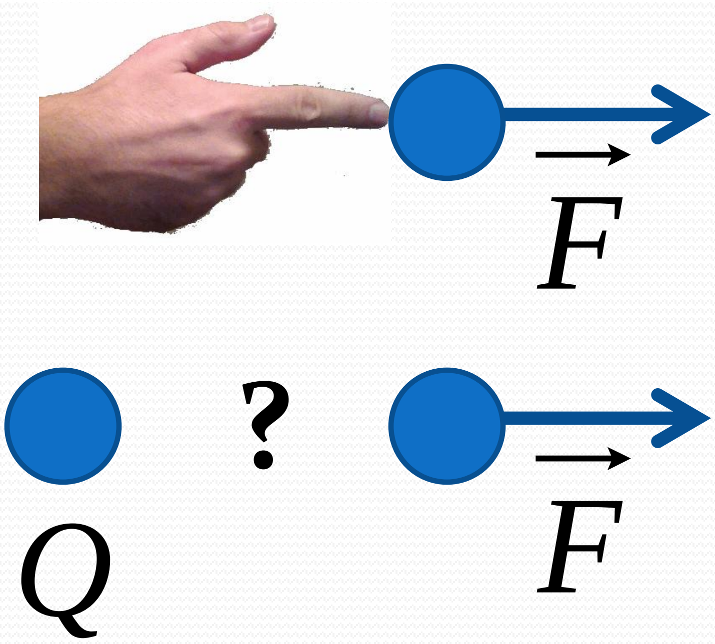
$$\vec{F} = \vec{F_1} + \vec{F_2}$$

$$F_x = F_{1x} + F_{2x}$$

$$F_y = F_{1y} + F_{2y}$$

Electric Field

- How come that one electric charge pushes (or pulls) another electric charge without touching it?



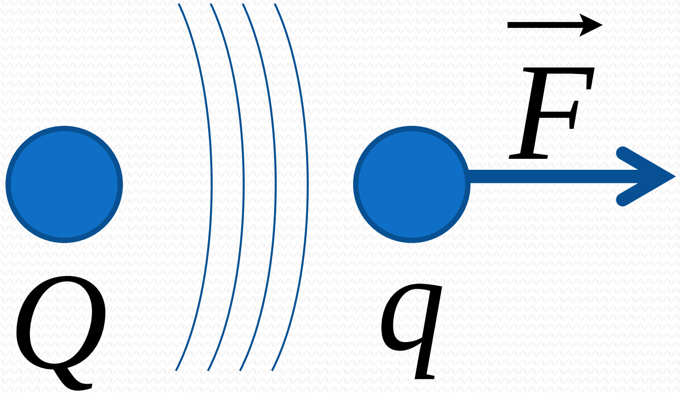
The answer (M. Faraday): there is **field**

- ➢ It extends outwards the charge and penetrates the whole space
- ➢ Fields from multiple charges add up (“superposition”)

Electric Field and Electric Force

- Electric field is a property of the charge that emits it, but does not depend on the probe charge

$$E = \frac{F}{q} = k\frac{Q}{r^2}$$



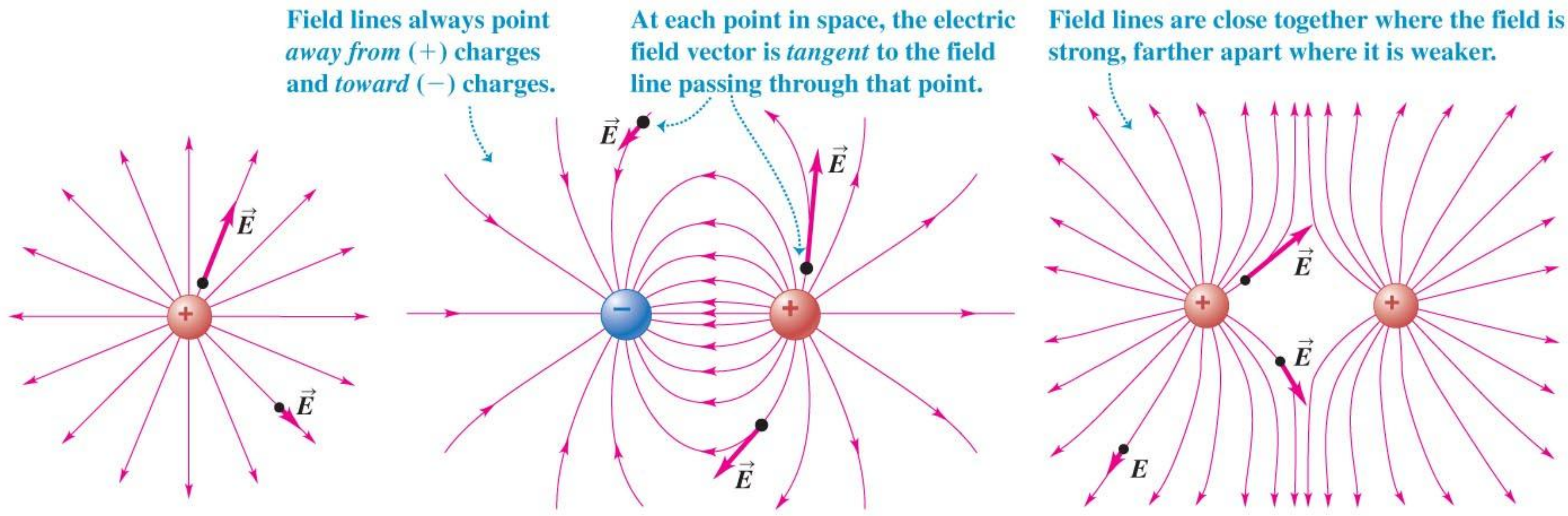
- Electric field is a vector

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

two similar types of problems:
➢ find the force acting on a charge
➢ find electric field at a given point
make sure you understand the question!

Field Lines

- Field lines are drawn so that they indicate the direction of the force on a positive probe charge
- More on them when we'll talk about potential



(a) A single positive charge **(b)** Two equal and opposite charges (a dipole) **(c)** Two equal positive charges

Electric Fields and Conductors

- In electrostatics, the electric field inside a conductor is zero
  - otherwise the charges would experience a force and move – not static anymore
- Outside the conductor, the electric field is always perpendicular to the conductor surface
  - otherwise the charges would move along the surface
- Electric field inside a hollow metal box is zero
  - a person inside such a box (e.g. in a car) is protected against a strong electric discharge (e.g. lightining)