Chapter 22 : The Electrostatic Force

see sections 1-6 of text.

The remaider of this semester will be spend studying electricity & magnitism: (E&M), electrical and magnetic phenomena

we begin with the electrostatic force = force exerted among charged particles.

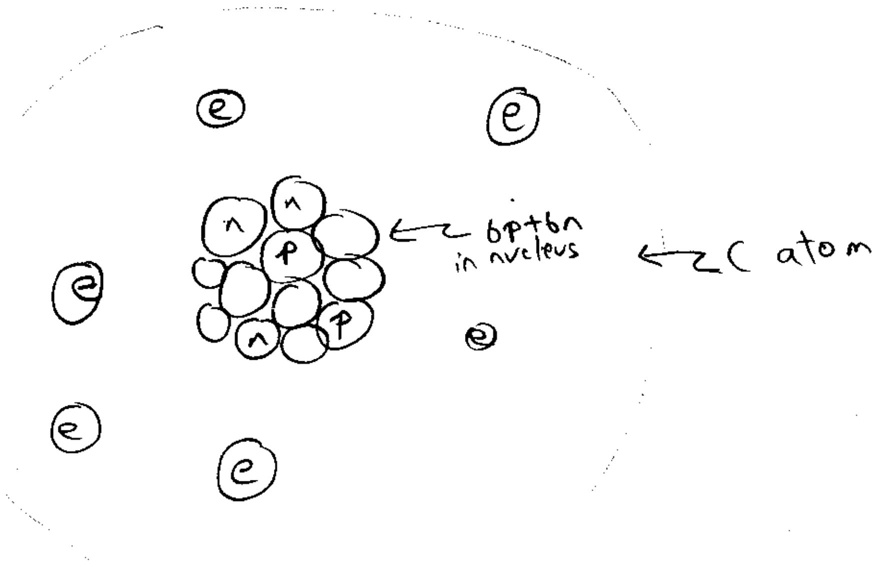
All matter is composed of tiny particles: electrons (e), protons (p), and neutrons (n), all of which carry electric charge ← which is an intrinsic property of the particle (eg., like mass).

example: (see back cover of text)

	mass m (kg)	charge q (C)
1e	$m_e = 9.1 \times 10^{-31}$	$-e = -1.6 \times 10^{-19}$
1p	$m_p = 1.67 \times 10^{-27}$	$e = +1.6 \times 10^{-19}$
1n	$m_n = 1.68 \times 10^{-27}$	?

p's, n's, and e's combine to form <u>atoms</u>.

For example, The typical carbon atom is composed of 6p + 6n in a nucleus that is surrounded by a cloud of 6e:



What is the net charge on this atom?

Suppose 1e gets knocked off this atom; we say the atom is ionized.

What is the net charge on this ion?

static electricity refers to the charging That occurs as you drag your feet on a carpet on a dry day.

⇒ evidently, rubbing things can transmit charge between objects

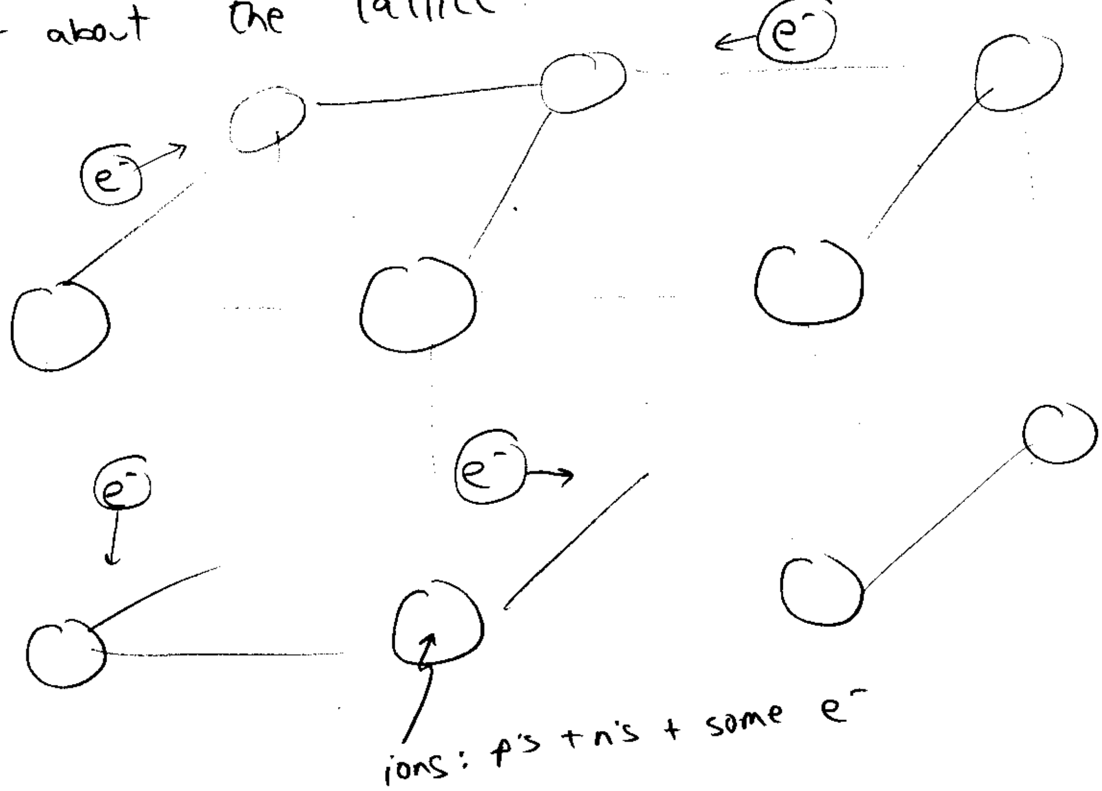
Example: petting your dog causes you to gain or lose electrons to the dog. To 'neutralize' these charges, touch the dog on his wet nose...

See 'Pith Ball' Demo - what is happening here?

In solid substances, The electrons are the mobile charge carriers, while the protons are stationary.

Conductors & Insulators

a conductor is a lattice of ions = atoms that have 'donated' one or more free electrons that wander about the lattice:



conduction electrons = The mobile electrons in a conductor.

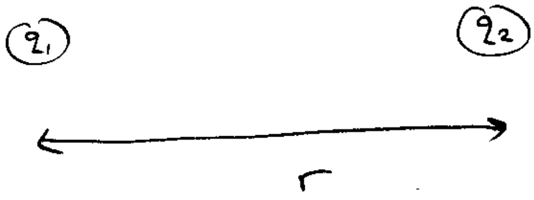
What is the net charge on a grounded, isolated conductor?

Are there any conduction charges in an insulator?

Coulomb's Law = electrostatic force exerted by charge q_1 on charge q_2:

$$F_{12} = \frac{|q_1|\,|q_2|}{4\pi \varepsilon_0 r^2}$$

= force on charge q_1 due to q_2



where q_i = charge on particle i in units of coulombs (C)

(example: 1 electron has a charge $|q| = e = 1.60\times10^{-19}$ C)

e = absolute value of charge on an electron.

r = separation,

$\varepsilon_0 = 8.85\times10^{-12}\ C^2/N\cdot m^2$

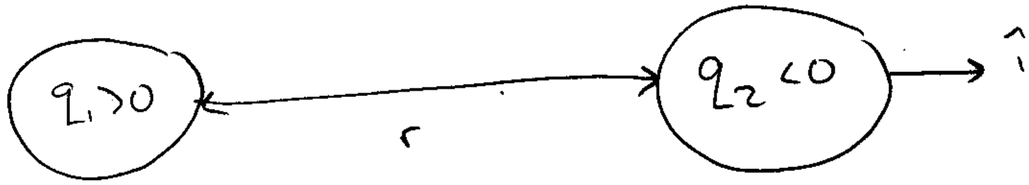
= permittivity constant

The direction of this force is along the line connecting q_1 & q_2.

Is this an attractive force law? or repulsive?

Remember - opposites attract.

As usual, these forces add vectorially:



$$\vec{F}_{12} = \frac{|q_1 q_2|}{4\pi\varepsilon_0 r^2}\,\hat{i} = |\vec{F}_{12}|\,\hat{i}$$ = force on charge 1 due to charge 2

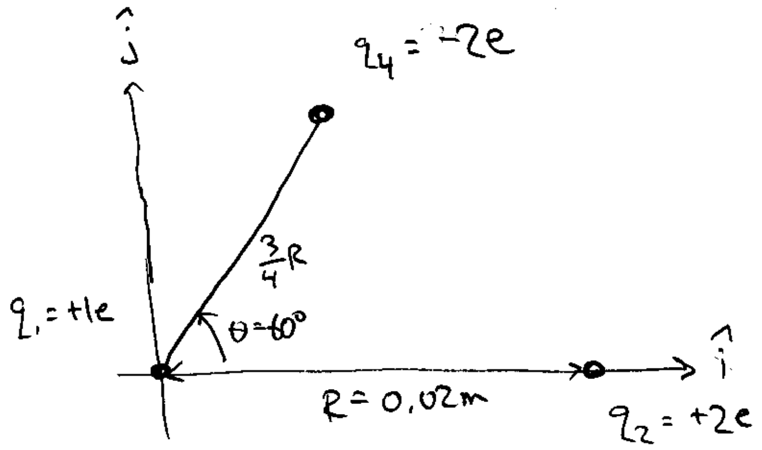
↑ sign OK?

What does Newton's Third law say about

$\vec{F}_{21}$ = force on 2 due to 1?

$$\vec{F}_{21} = -\vec{F}_{12} = -|F_{12}|\,\hat{i}$$

Sample Problem 22-1, part c):



where $e = |\text{charge on 1 electron}| = 1.6 \times 10^{-19} C$ ← absolute value

so $\vec{F}_1 = \vec{F}_{12} + \vec{F}_{14}$

where $\vec{F}_{12} = -\frac{|q_1 q_2|}{4\pi\varepsilon_0 R^2}\hat{i}$ = force on 1 due to 2

↑ sign OK?

so $\vec{F}_{12} = \frac{-2e^2}{4\pi\varepsilon_0 R^2}\hat{i} = -\frac{2(1.6\times10^{-19} C)^2}{4\pi(8.85\times10^{-12} C^2/N\cdot m^2)(0.02 m)^2}\hat{i}$

$= -1.15\times10^{-24} N\ \hat{i}$

Likewise,

$$|F_{14}| = \frac{2e^2}{4\pi\varepsilon_0 (3R/4)^2} = 2.05 \times 10^{-24}\ N$$

while
$$\vec{F_{14}} = |F_{14}| \left(\cos\theta\ \hat{\imath} + \sin\theta\ \hat{\jmath}\right)$$
$$= |F_{14}| \left(\tfrac{1}{2}\hat{\imath} + \tfrac{\sqrt{3}}{2}\hat{\jmath}\right)$$ ← signs OK?

so
$$\vec{F_1} = \vec{F_{12}} + \vec{F_{14}} = \left(-|F_{12}| + \tfrac{1}{2}|F_{14}|\right)\hat{\imath}$$
$$\tfrac{\sqrt{3}}{2}|F_{14}|\hat{\jmath}$$

$$= \left(-1.25 \times 10^{-25}\ \hat{\imath} + 1.78 \times 10^{-24}\ \hat{\jmath}\right) N$$

Shell Theorems :

The electrostatic force law is

$$F_{elec} = \frac{|q_1 q_2|}{4\pi \varepsilon_0 r^2}$$

what other force law resembles Coulomb's Law ?

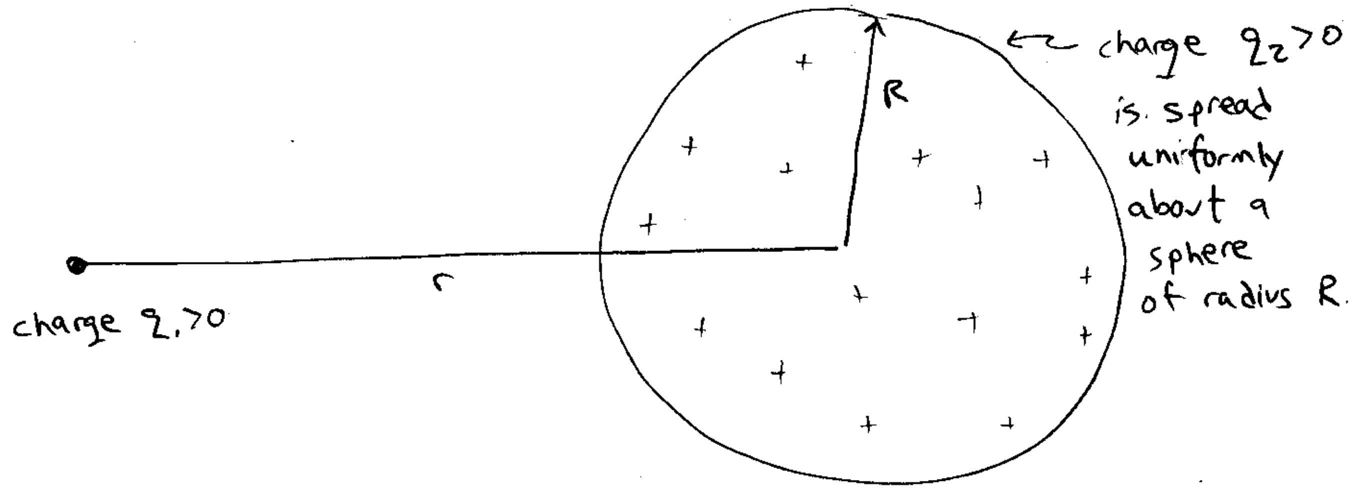
Gravity: $F_{grav} = \frac{G m_1 m_2}{r^2}$

$\rightarrow F_{elec}$ as $m_1 \rightarrow q_1$,

$m_2 \rightarrow q_2$,

$G \rightarrow \frac{1}{4\pi \varepsilon_0{}^2}$

$\Rightarrow$ many of the results you obtained in your earlier study of gravity also apply to electrostatics.



What is the force that the sphere exerts on q_1?

$$F_1 = \frac{|q_1 q_2|}{4\pi\varepsilon_0 r^2}$$ by the outside shell theorem

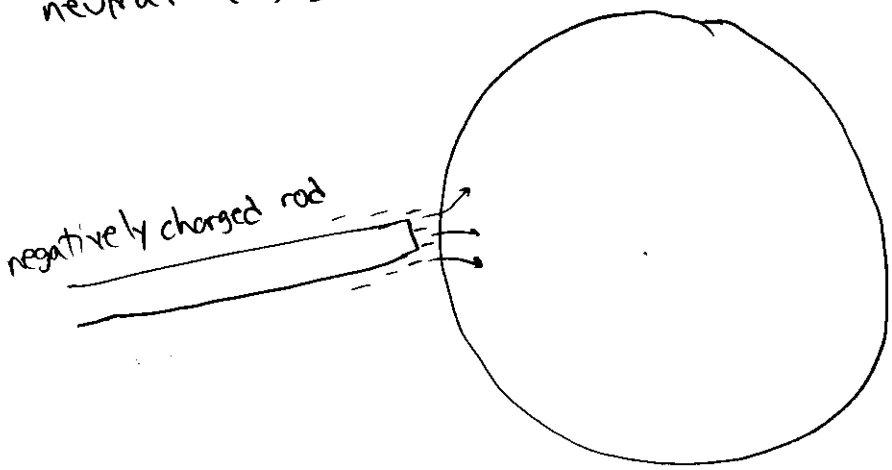
what is Direction of force?

what if q_1 where inside shell q_2?

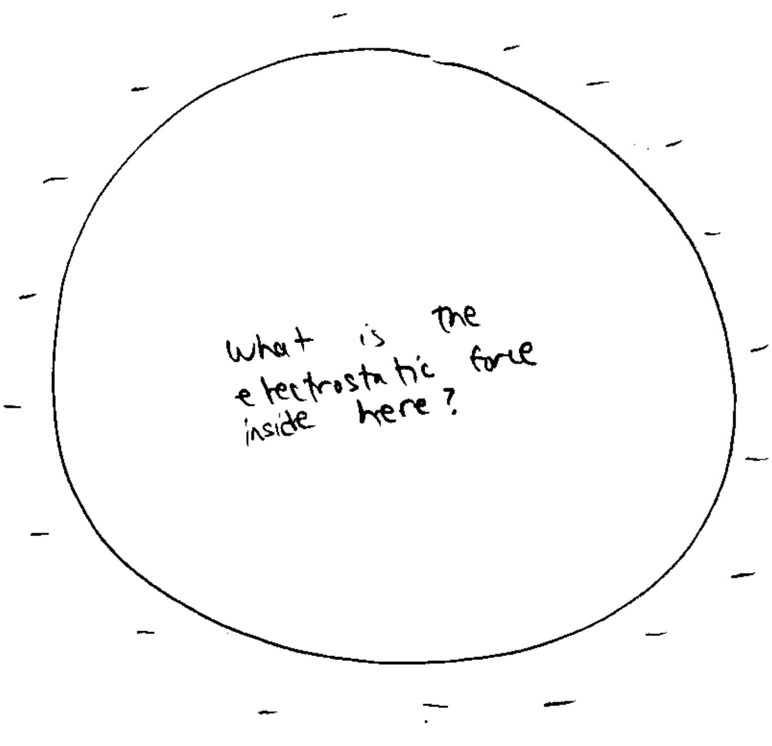
$F_1 = 0$ by the inside shell theorem

Spherical conductors

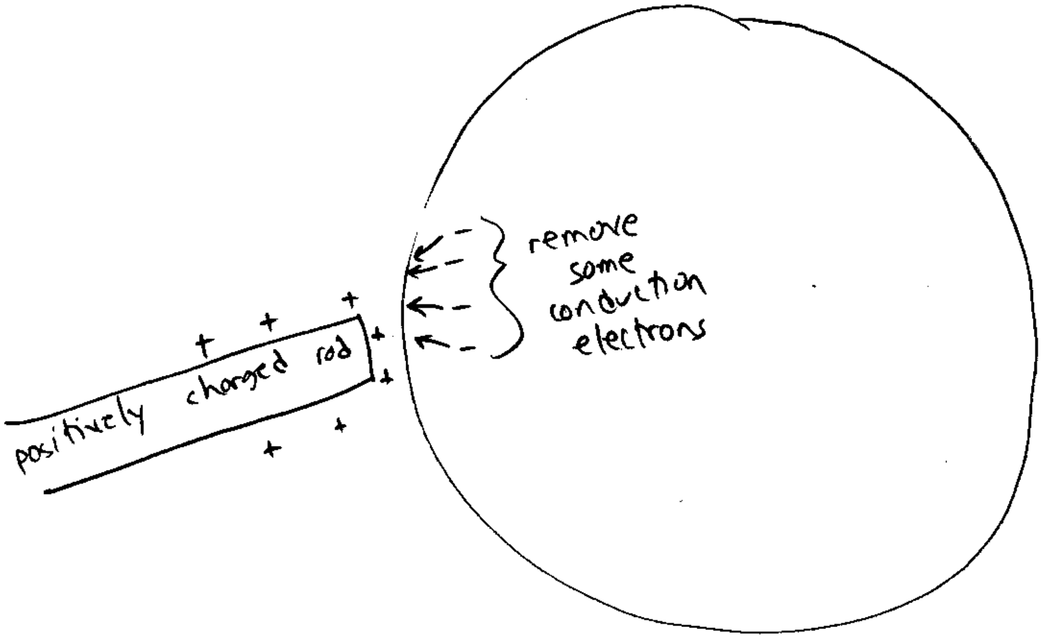
add electrons to a thin spherical shell of conducting material that is initially neutral (ie, $q=0$)



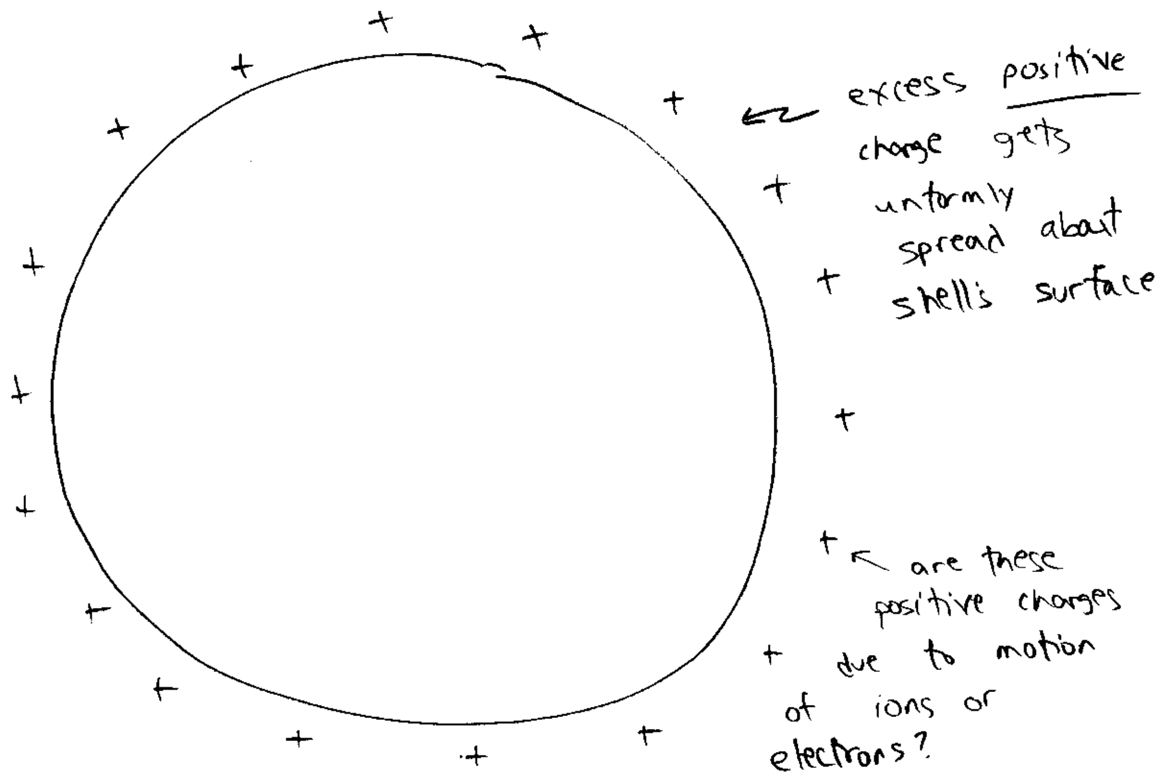
How will the electrons arrange themselves about the shell?



what if we had instead removed some conduction electrons from a neutral shell?

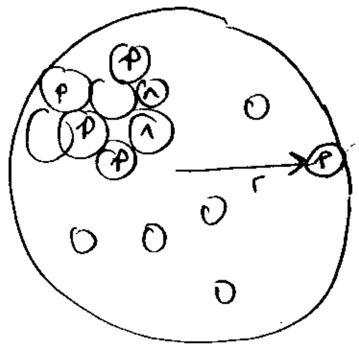


How are the charges arranged on the shell?



Sample Problem 22-4

An iron atom has a radius of $r = 4 \times 10^{-15}$ m containing 26 protons + 30 neutrons.



Use shell theorem to calculate the electrostatic force that the nucleus exerts on an outer proton.

what is q_1 & q_2 for this problem?

$$F = \frac{26e^2}{4\pi\varepsilon r^2} = 374 \text{ N}$$

The proton mass is $m_p = 1.7 \times 10^{-27}$ kg.

If there were no other binding forces, that proton would experience an outward acceleration of

$$a = \frac{F}{m_p} = 2 \times 10^{29} \text{ m/sec}^2 \; !$$

Could gravity bind the protons in a nucleus?

1 proton ↓ ; ← 55 other ptn

$$F_{grav} = \frac{G m_p (55 m_p)}{r^2}$$

$$\sim 10^{-33} \text{ N}$$

no... too small by 35 orders of magnitude!

So, what binds a nucleus together? Please ask Dr Austin during mini-symposium...

Also, please read Sections 22-5: charge is quantized

22-6: charge is conserved.