PHYSICS NYB-10/11 Winter 2007

Lecture 2: Coulomb's law

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Review

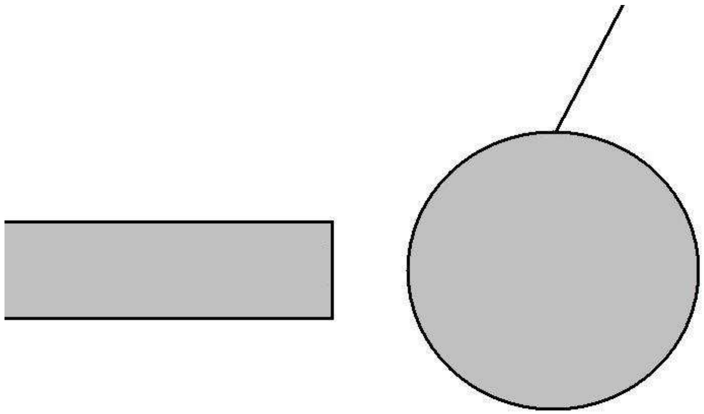
Important points from last lecture:

- There are two kinds of electric charge: positive and negative
- Electric charge is always conserved
- Electric charge comes in units of $e = 1.602 \times 10^{-19}$ C
- Opposite charges attract, like charges repel
- In conductors, some electrons or ions are free to move around
- In insulators, all electrons are tightly bound to a nucleus and there are no ions that can move
- We can charge objects by rubbing them
- We can charge objects through **induction**

Review: Using the charge model

Let's now go over the experiments we tried, and use the charge model to explain what's really happening.

The first thing we did was rub a rubber rod with fur, and we saw that it attracted a pith ball.

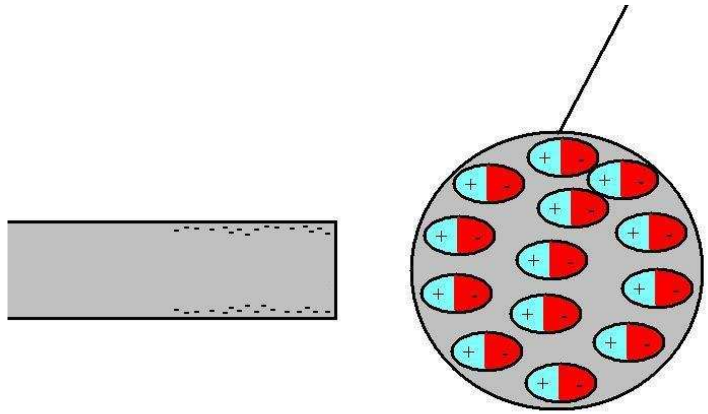


What was going on here?

Review: Using the charge model

Let’s now go over the experiments we tried, and use the charge model to explain what’s really happening.

The first thing we did was rub a rubber rod with fur, and we saw that it attracted a pith ball.

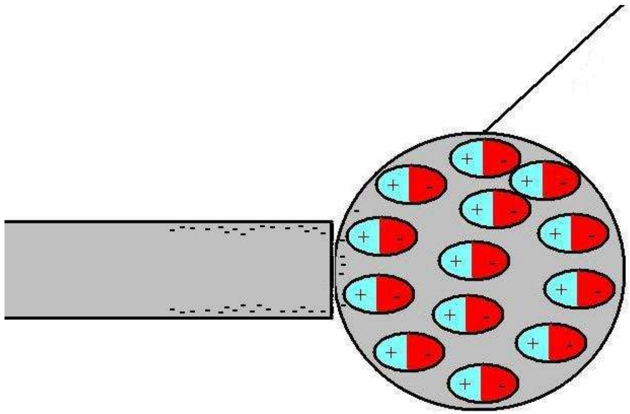


The rod had negative charges *on the surface* (because it’s an insulator), and the pith ball is also an insulator, so charges were *polarised* inside it. This leads to attraction between the mostly positive side of the ball and the negative rod.

Review: Using the charge model

Let's now go over the experiments we tried, and use the charge model to explain what's really happening.

The ball then made contact with the rod.

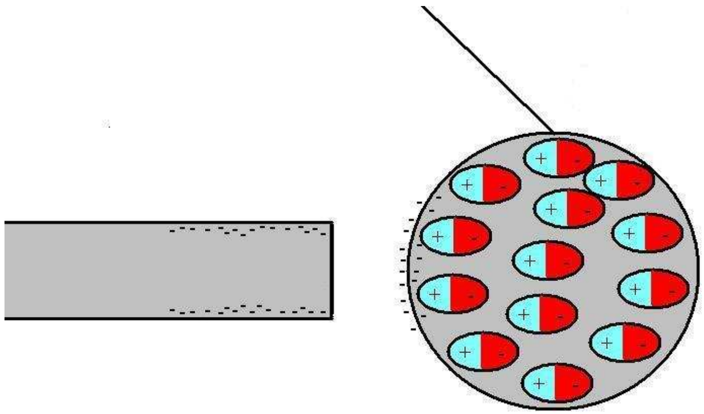


When this happens, some negative charges got transferred from the rod to the ball.

Review: Using the charge model

Let's now go over the experiments we tried, and use the charge model to explain what's really happening.

The ball now has negative charge, located where contact was made with the rod.

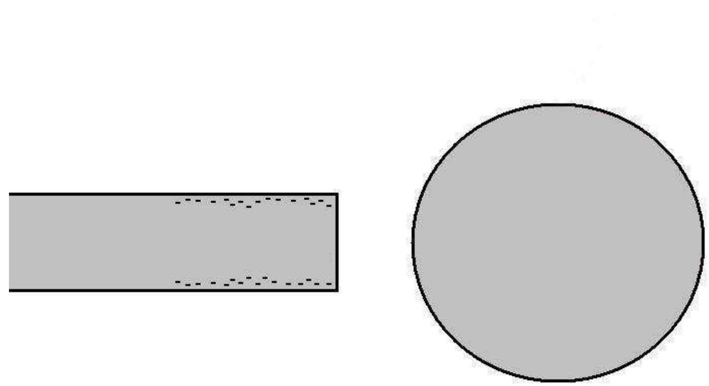


These negative charges now repel with the negative rod, which is why we had repulsion after the ball and rod made contact.

Review: Using the charge model

Another thing we did was to use the charged rod to deposit charge on a conducting metal sphere.

First, we approach the rod.

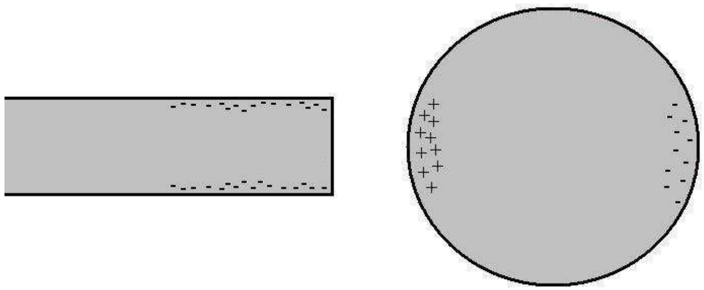


Is the sphere charged at this point?

Review: Using the charge model

Another thing we did was to use the charged rod to deposit charge on a conducting metal sphere.

First, we approach the rod.

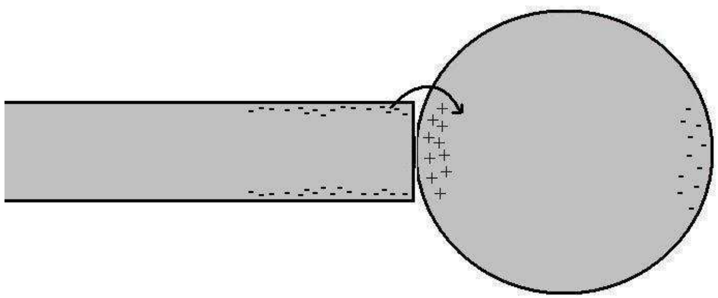


No! The negative rod causes negative electrons to move to the far end of the sphere, leaving the close end with more positive charges, and the far end with more negative charges. But the net charge on the sphere is still zero!

Review: Using the charge model

Another thing we did was to use the charged rod to deposit charge on a conducting metal sphere.

Then the rod made contact with the sphere.

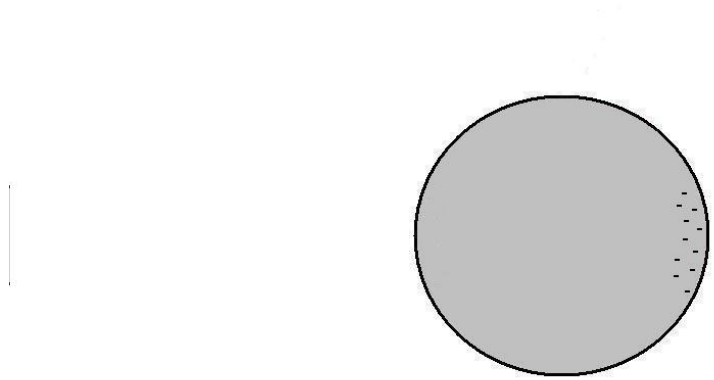


At this point, negative charge from the rod is attracted onto the sphere by the positive charge on the close end. From this point on, there are more negative charges than positive charges on the sphere, so it now has net negative charge.

Review: Using the charge model

Another thing we did was to use the charged rod to deposit charge on a conducting metal sphere.

Then the rod was taken away.

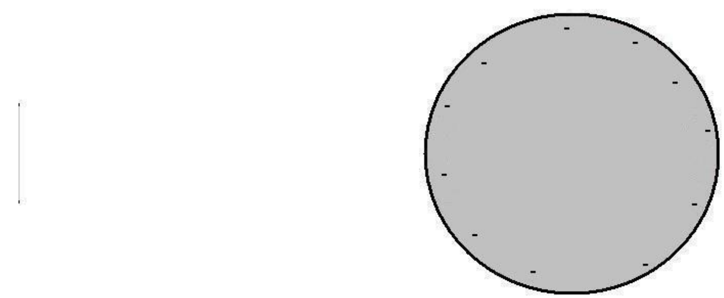


What happens to the charge on the sphere then?

Review: Using the charge model

Another thing we did was to use the charged rod to deposit charge on a conducting metal sphere.

Then the rod was taken away.



It spreads out over the surface.

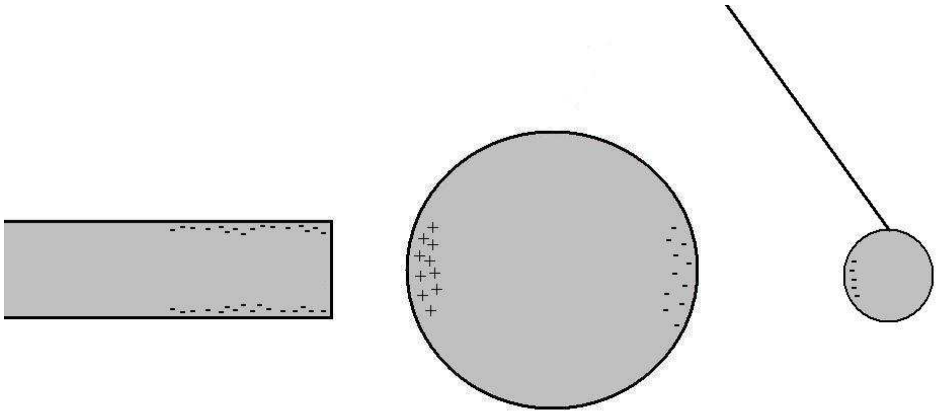
Review: Using the charge model

We also showed repulsion of a pith ball by a neutral metal sphere.

We charged a pith ball, and a rod with the same sign charge. Even though the rod is held too far from the ball to have an effect on its own, when the metal sphere is brought between them, the ball is repelled. How does this work?

Review: Using the charge model

We also showed repulsion of a pith ball by a neutral metal sphere.

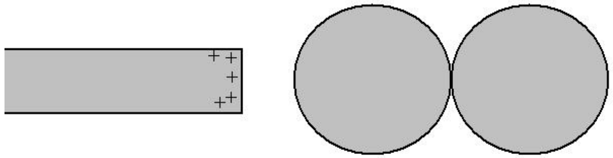


The presence of the rod near the sphere leads charges to separate in the sphere. One side is negative, the other positive. Since the negative ball is close to the negative side, it feels a repulsive force.

Review: Using the charge model

Now let's try something we *didn't* do.

First, we bring a charged rod close to two metal spheres making contact.

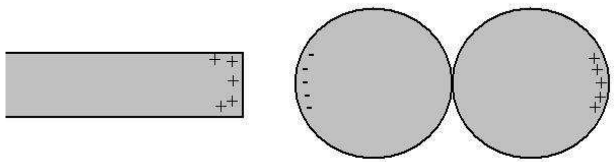


What happens in the spheres?

Review: Using the charge model

Now let's try something we *didn't* do.

First, we bring a charged rod close to two metal spheres making contact.

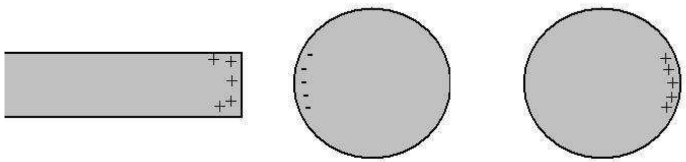


The charges separate under the influence of the rod. Are the spheres charged overall? Is each sphere charged?

Review: Using the charge model

Now let's try something we *didn't* do.

First, we bring a charged rod close to two metal spheres making contact.



The overall charge of both spheres is zero, but one of them is positive, and the other negative. So if we separate them, we now have two spheres with equal but opposite charge.

Review: Using the charge model

Now let's try something we *didn't* do.

Now we take away the rod and move the spheres apart.

What happens to the charges in the spheres?

Review: Using the charge model

Now let's try something we *didn't* do.

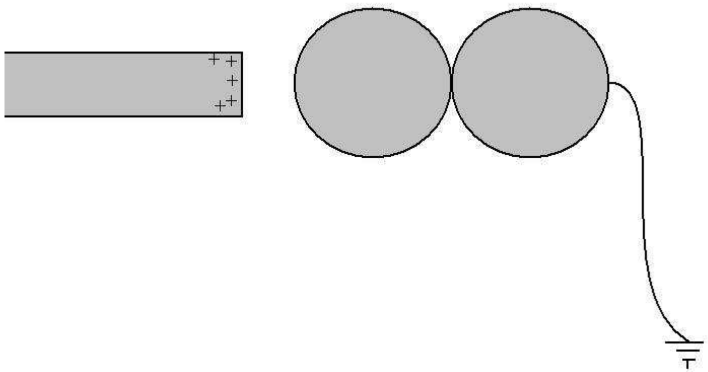
Now we take away the rod and move the spheres apart.

They spread out over the surface.

Review: Using the charge model

Now let’s try something *else* we didn’t do.

First, we bring a charged rod close to two metal spheres making contact, and *grounded*.

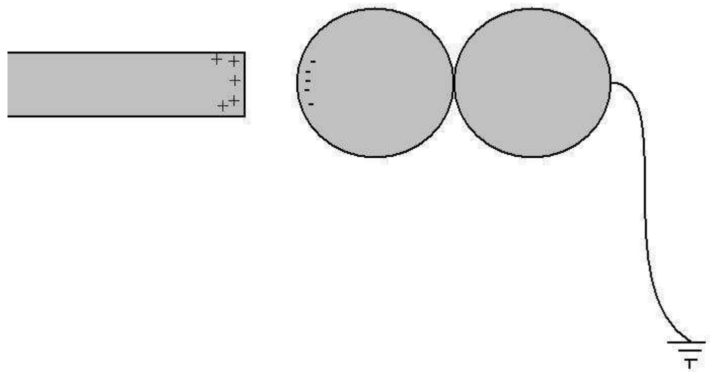


What happens in the spheres?

Review: Using the charge model

Now let's try something *else* we didn't do.

First, we bring a charged rod close to two metal spheres making contact, and *grounded*.

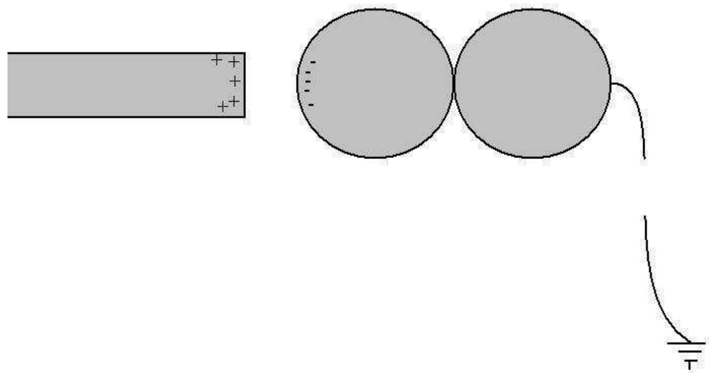


The charges separate under the influence of the rod. But since the spheres are grounded, charges don't accumulate in the second sphere. They rather go to the Earth, where we can now forget about them.

Review: Using the charge model

Now let's try something *else* we didn't do.

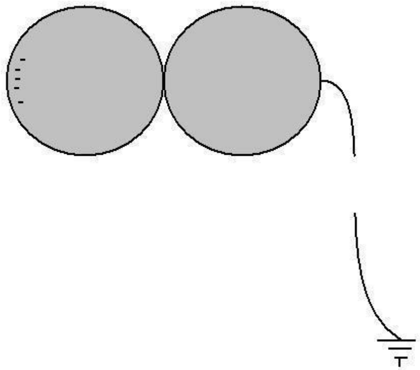
Now we cut the wire.



What does that do?

Review: Using the charge model

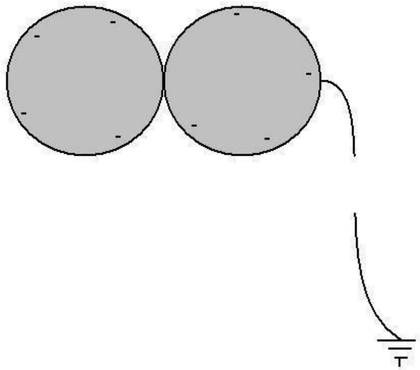
Now let's try something *else* we didn't do.



The charge is now stuck on the spheres. If we now take away the rod while the spheres are still touching...

Review: Using the charge model

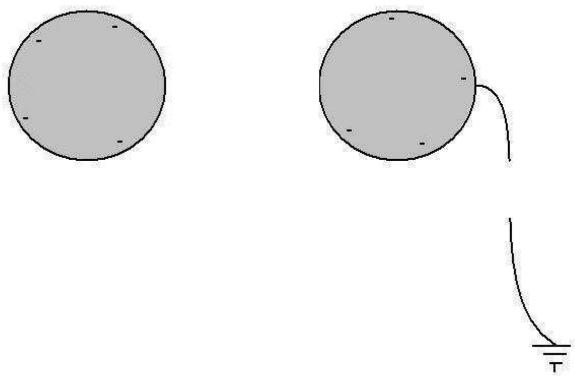
Now let's try something *else* we didn't do.



The charges spread over the surface of both spheres. What if we now separate the spheres?

Review: Using the charge model

Now let’s try something *else* we didn’t do.



We wind up with two spheres of equal and same sign charge.

Note that in both this and the previous example, no contact was made between the spheres and the charged rod. We charged the sphere by *induction*.

Review

<u>Question</u>: True or false: when rubbing a glass rod with silk, the glass rod picks up a charge but the silk remains neutral.

False. Since charge is conserved, the silk picks up a charge equal and opposite to the one picked up by the rod.
<u>Question</u>: Is this situation possible?

Two objects A and B are neutral. You charge object A by rubbing it with fur. When you approach object A and object B, they repel.

No! A charged object can only attract a neutral object, not repel it.

Review

Question: Three objects A, B and C behave in the following way: objects A and B repel; objects A and C attract. How do objects B and C behave?

A and B have the same charge, so if A attracts C, B also must attract C.

What can we say about object C's charge?

If it is charged, its charge is different from objects A and B, but we do not know their charge. Furthermore, object C could very well be neutral and still be attracted by A and B.

Review

Question: Objects A and B attract. Objects A and C attract. Can objects B and C attract? Can they repel? Can they have no effect on each other?

Yes, yes and yes. B and C can attract, for example, if they have opposite charges. (The fact that they both attract A can be explained if A is neutral.) B and C can repel if they have the same charge. (In which case A either is oppositely charged or neutral.) B and C have no effect on each other if they are both neutral. (In which case A is necessarily charged).

Review

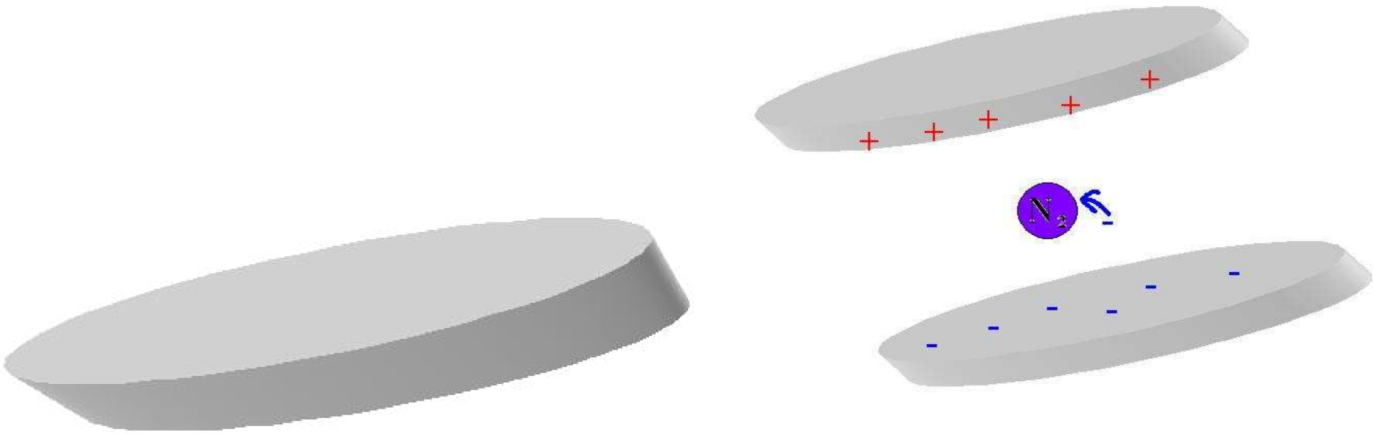
Question: Two metal spheres A and B have charges of -50e and $+20e$ respectively and are indentical in size. If the spheres touch, what is the resulting charge of sphere A? Sphere B?

The total charge of both spheres is $-30e$. Since the two objects are conductors and identical in shape, the charge will spread uniformly across both spheres when they are brought into contact. They will therefore each have a charge of $-15e$.

The physics of candy

DO try this at home!

Buy a packet of Wint-O-Green Life Savers. Close all lights, and wait about 15 minutes for your eyes to become acclimatized. Have a friend bite down on a Life Saver. Enjoy the show!

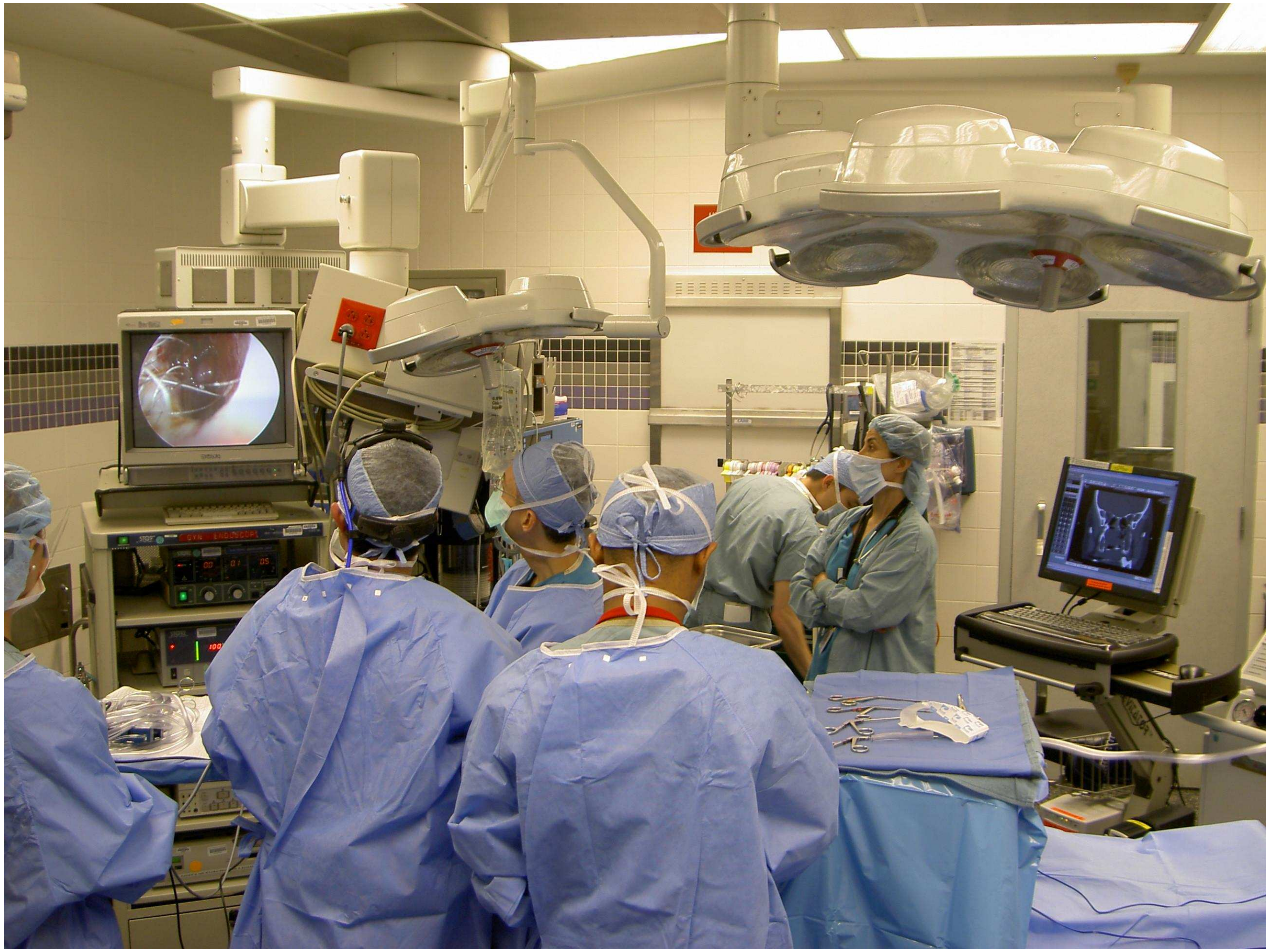


The physics of candy

When the Life Saver cracks, one side of the candy is positively charged while the other is negatively charged. This creates a strong electric force on electrons that are on the negative side. Some of these electrons actually leave their atoms and jump across the gap.

In the gap, there is air, which consists mostly of nitrogen, N_2. When an electron collides with a nitrogen molecule, it causes it to emit ultraviolet radiation, which you can't see. However, the ultraviolet light is then absorbed by the wintergreen molecules on the surface of the candy, and the wintergreen molecules can then emit *blue* light (remember NYC!!!), which you *can* see.

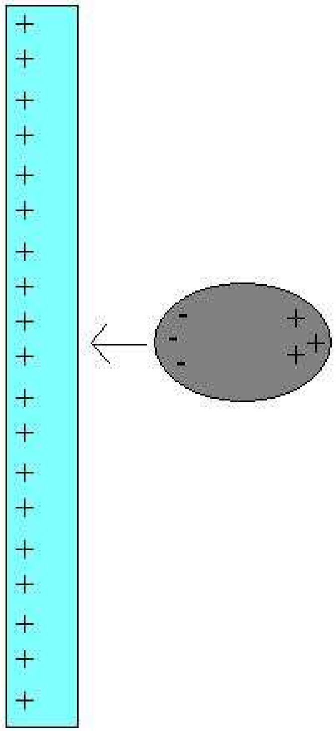
Bacterial contamination



Why should surgeons keep their hands a fair distance away from television screens in the operating room?

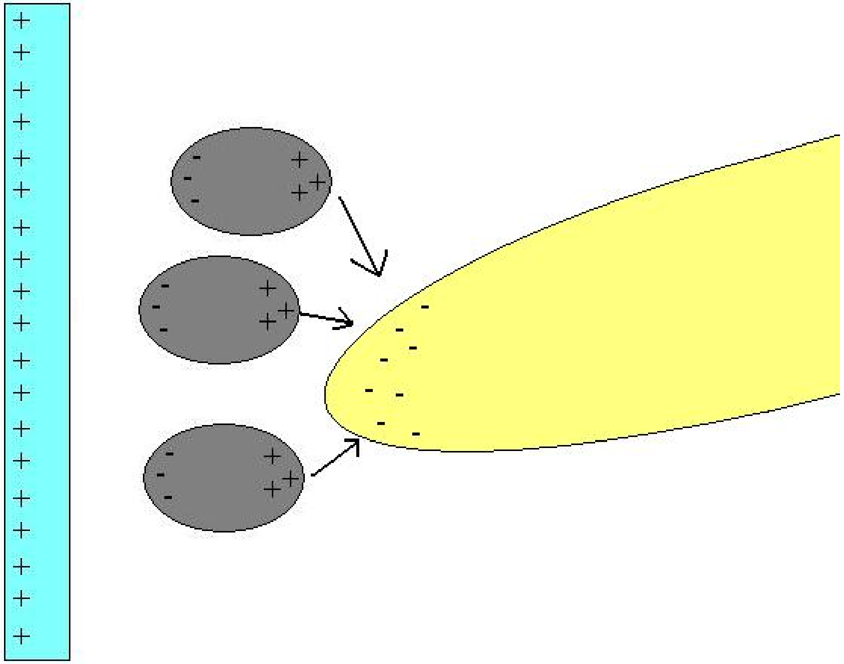
Bacterial contamination

A television fires electrons from the back of the screen to the screen to produce an image. To attract the electrons, the screen is given a positive charge. The screen can also attract dust particles, which can carry bacteria.



Bacterial contamination

When a surgeon puts his finger close to the screen, the positive screen attracts electrons towards the fingertip, so the tip is now negatively charged. This negative charge on the fingertips can then attract some of the dust particles towards the finger. The finger is now contaminated, and touching the patient can now spread infection...



Coulomb's law

Qualitatively: opposite charges attract, like charges repel.

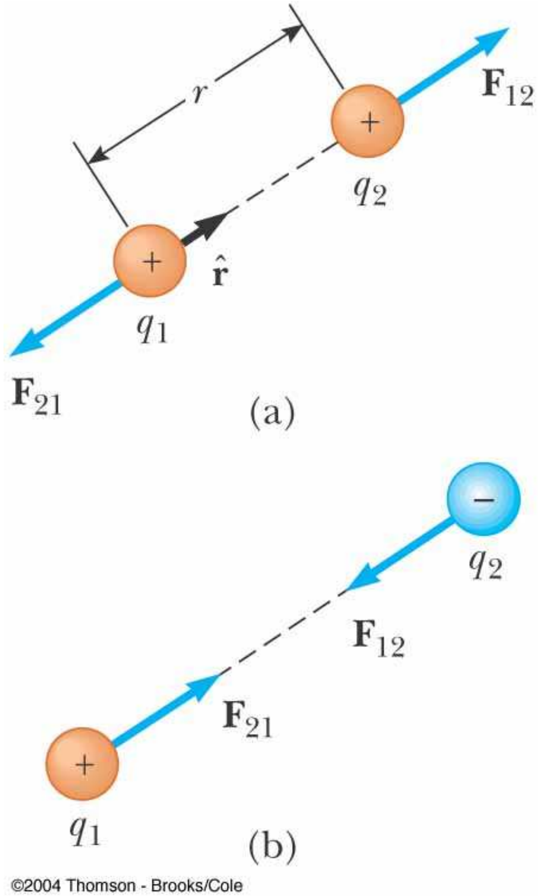
Quantitatively: we'd like to know *how strongly*, and in what *direction* the force acts, as a function of the charges q_1 and q_2 involved and their separation r.

Coulomb's law:

$$|\vec{F}_e| = k_e \frac{|q_1||q_2|}{r^2}$$

along the line joining the two *point* charges, where $k_e = 8.987\,5 \times 10^9 \text{Nm}^2/\text{C}^2$ is *Coulomb's constant*.

Coulomb's law



Note that the force of 1 on 2 is equal and opposite to the force of 2 on 1. (Which law does that correspond to?)

Coulomb's law

Note that you will sometimes see Coulomb's constant written as

$$k_e = \frac{1}{4\pi\epsilon_0}$$

where ϵ_0 is called the *permittivity of free space*.

Question: what is the value and what are the units of ϵ_0?

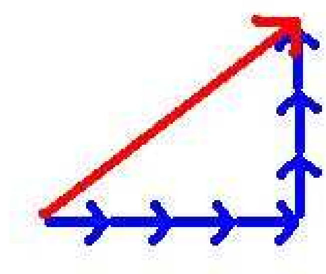
$$\epsilon_0 = 8.854\ 2 \times 10^{-12} \text{C}^2/\text{Nm}^2$$

Remember vectors?

Question: What is a vector?

- A vector is something that has a *magnitude* and a *direction*.
- We can represent them using arrows.
- Mathematically, we use *components* to represent vectors, $\vec{A} = A_x\hat{i} + A_y\hat{j} + A_z\hat{k}$

$$\vec{\mathbf{A}} = 4\,\hat{\mathbf{i}} + 3\,\hat{\mathbf{j}}$$



Vectors: magnitude and angle

The *magnitude* of a vector is its length.

We represent this as $|\vec{A}|$.

The magnitude of the component vectors are called the *components*

$$A_x = |\vec{A}_x| \qquad A_y = |\vec{A}_y| \qquad A_z = |\vec{A}_z|$$

Using Pythagoras, we see the the magnitude of a vector is

$$|\vec{A}| = \sqrt{A_x^2 + A_y^2 + A_z^2}$$

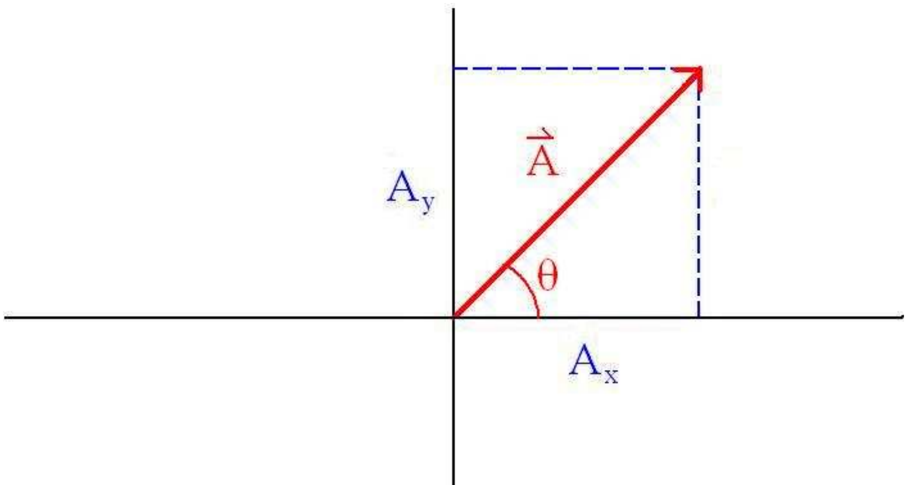
Vectors: magnitude and angle

For two dimensional vectors, the magnitude simplifies to

$$|\vec{A}| = \sqrt{A_x^2 + A_y^2}$$

and we can find the angle the vector makes with the x-axis **through**

$$\theta = \arctan \frac{A_y}{A_x}$$



Coulomb's law

<u>Question</u>: Objects A and B have respective charges of +2μC and +6μC. Which statements are true?

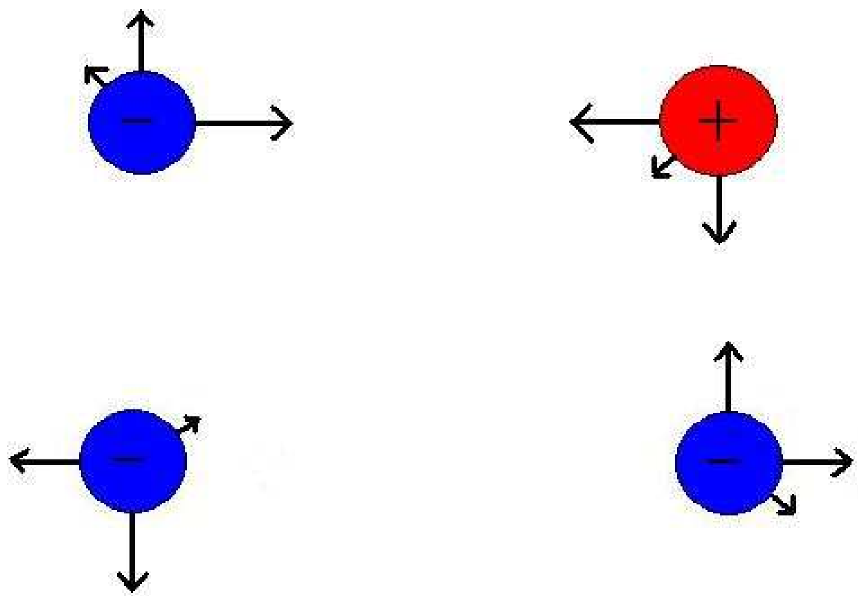
$\vec{F}_{AB} = -3\vec{F}_{BA}$, $F_{AB} = -3F_{BA}$, $\vec{F}_{AB} = -\vec{F}_{BA}$, $F_{AB} = -F_{BA}$, $3\vec{F}_{AB} = -\vec{F}_{BA}$, $3F_{AB} = -F_{BA}$, $\vec{F}_{AB} = 3\vec{F}_{BA}$, $\vec{F}_{AB} = \vec{F}_{BA}$, $F_{AB} = 3F_{BA}$, $F_{AB} = F_{BA}$, $3F_{AB} = F_{BA}$, $3\vec{F}_{AB} = \vec{F}_{BA}$.

Would the answer change if object A's charge was negative?

No!

Superposition

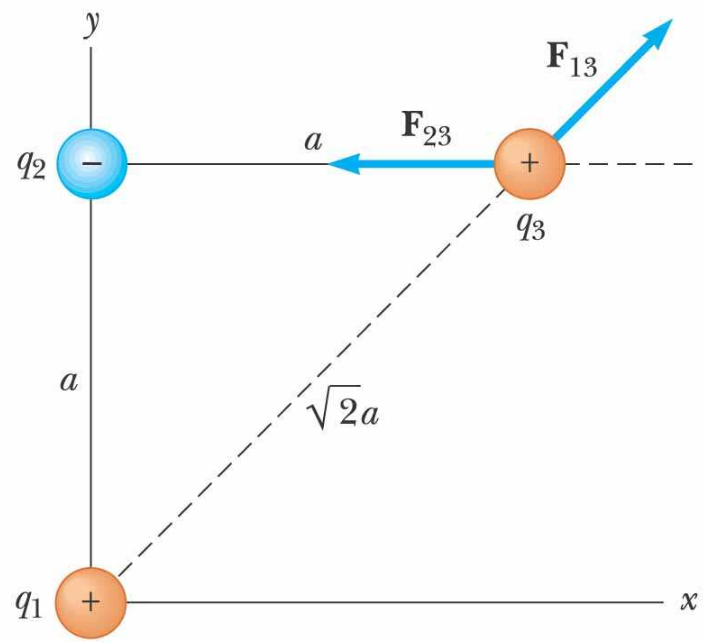
Coulomb's law applies to two charged *point particles*. What happens when there are more than two charges present???



We simply add up the mutual effects of all charges on each other.

Example

If $q_1 = 10\mu$C, $q_3 = 5.0\mu$C, $q_2 = -2.0\mu$C and $a = 0.10$ m, what is the net force on q_2? Where could we place q_2 in order for the net force on it to vanish?



Example

$$\begin{aligned}
\vec{F}_{3\ on\ 2} &= k_e \frac{|q_3||q_2|}{a^2}\hat{i} \\
&= 8.99 \times 10^9 \frac{5.0 \times 10^{-6} \times 2.0 \times 10^{-6}}{(0.1)^2}\hat{i} \\
&= (8.99\hat{i})\ \text{N} \\
\vec{F}_{1\ on\ 2} &= -k_e \frac{|q_1||q_2|}{a^2}\hat{j} \\
&= 8.99 \times 10^9 \frac{10.0 \times 10^{-6} \times 2.0 \times 10^{-6}}{(0.1)^2}\hat{i} \\
&= (-17.98\hat{j})\ \text{N} \\
\Rightarrow \vec{F}_{net\ on\ 2} &= (8.99\hat{i} - 17.98\hat{j})\ \text{N}
\end{aligned}$$

Example

For the forces on q_2 to cancel, they must point in opposite directions, which means we have to put q_2 in between q_1 and q_3. Also the magnitudes of the forces must be equal, so

$$
\begin{aligned}
k_e \frac{|q_1||q_2|}{d^2} &= k_e \frac{|q_3||q_2|}{(\sqrt{2}a - d)^2} \\
\left(1 - \frac{q_3}{q_1}\right) d^2 - 2\sqrt{2}ad + 2a^2 &= 0 \\
\frac{1}{2}d^2 - 2\sqrt{2}ad + 2a^2 &= 0 \\
d = \frac{2\sqrt{2}a \pm \sqrt{8a^2 - 4a^2}}{1} &= 2a(\sqrt{2} \pm 1) = \sqrt{2}a(2 \pm \sqrt{2})
\end{aligned}
$$

We know that $d < \sqrt{2}a$, so we must choose $d = \sqrt{2}a(2 - \sqrt{2})$.

Assignment 1

- Chapter 23, problems 4, 6, 7, 10, 50, 66

What to read for next lecture

- 23.4