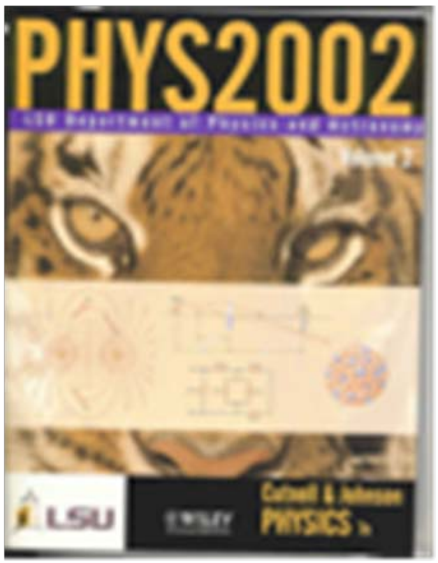
Algebra-based Physics II

Aug. 23, Chap. 18



Announcements:

- Who am I ?
- Why are you here?
- What are you suppose to learn here?

Who I am?

Jiandi Zhang, Professor of Physics
Office : 229A Nicholson Hall

jiandiz@lsu.edu
225-578-4103

http://www.phys.lsu.edu/~jzhang/

What I am doing? Experimental Condensed Matter Physics

http://www.lsu.edu/highlights/2009/06/NSF.shtml

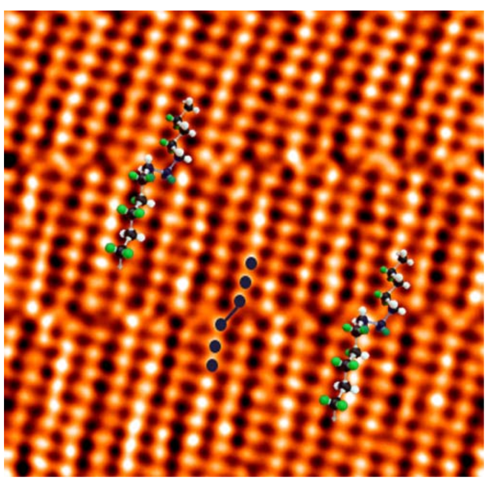
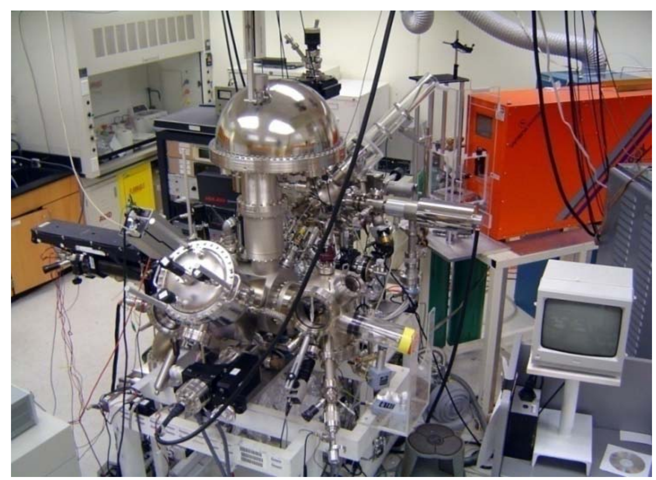


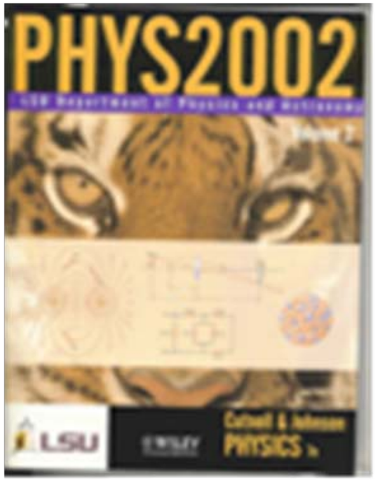
image of atomic scale manipulation

4.4 nm x 4.4 nm polymer film



experimental toys

Syllabus



- **Lectures:** MWF 9:30 – 10:30 AM, Room 130 Nicholson Hall
- **Office Hours:**
  Mondays/ Wednesdays/Fridays: 10:30am – Noon:
- **Text:** Physics, by Cutnell & Johnson, 7^{th} edition
  LSU customized version, Vol. 2
- **Class:** cover Chapter 18 through 32 of the text (except Chapter. 23 and 28)
- **Quizzes in class**
  You need a Clicker to answer in class (personal response system)
- **Homework:** http://www.masteringphysics.com
- **Tutoring:** Room 365 Nicholson Hall (check the schedule)

- **Test:**
  1. **There will be three 1-hour tests.**
  2. The tests will be computer based and will be administered by the Office of Assessment and Evaluation.
  3. You have a 3-day window within which to take each test. You will need to set up an appointment for taking your test. You can do this online with your PAWS ID at http://www.cae.lsu.edu/default.asp.
  4. You will need a scientific calculator.
  5. A hard copy of a formula sheet will be provided for you to use when taking the test.
  6. **Other notes, books, and resources are strictly forbidden.**

- **Final exam: Dec. 6-8**
  1. The final exam will have the same format as the 1-hour test, but with about twice as many questions and problems given in twice the time.
  2. The Final Exam will be cumulative with extra emphasis (approximately 1/3 of the questions and problems) on material since the last exam.

- **Grading:**
  - Homework -- 50 points total
  - Lecture clicker quizzes/participation -- 50 points total (from 200 raw points)
  - Three one-hour exams -- 100 points each (300 points total)
  - Final Exam -- 200 points
  - Your final grade will be based upon your percentage score out of 600 total points.
  - *If your percentage score on the Final Exam is higher than your lowest test score, your lowest test score will be replaced by your final exam score.*

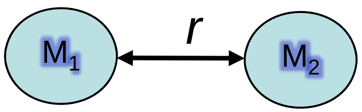
A: 100-90%
B: 89-80%
C: 79-60%
D: 59-50%
F: <49%

If your overall average is within these ranges, you are guaranteed the associated letter grade. In general, there will be **<u>no curving</u>** of individual exam grades. However, depending on class performance, the above scale may change slightly.

Welcome to PHYS2002!

Physics I – Done! We are now all experts in mechanics.

Mechanics → <u>Mass</u>



Interaction: $F = G\frac{m_1 m_2}{r^2}$ $G = 6.67\times10^{-11}\,Nm/kg^2$

We never said what mass is, only how it behaves.

New Semester

We are concerned with something called charge.

Electricity → <u>Charge</u>

***And just like in mechanics, E&M will not tell us what charge is, but only how it behaves.**

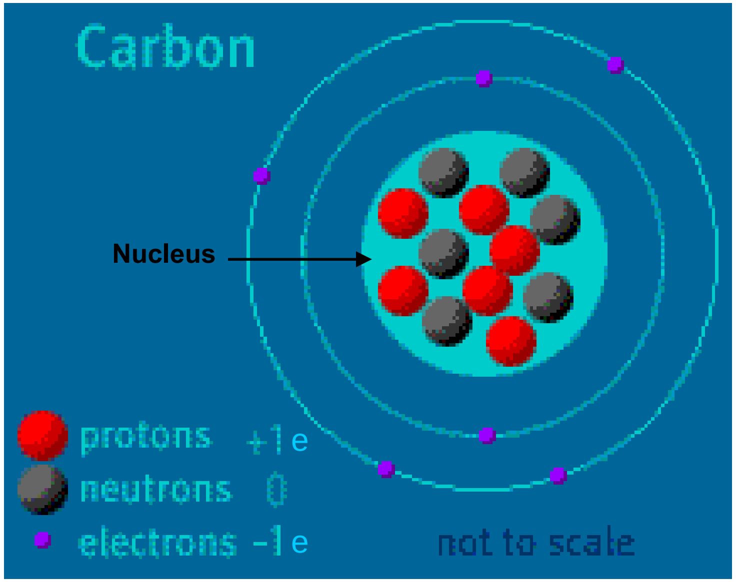
Like mass, charge is an intrinsic property of matter, and it comes in 2 types:

<u>Positive and Negative</u>

Chap. 18 – Electric Forces and Electric Fields

18.1 – Electricity

Review the standard model of the atom:



***The SI unit of charge is the Coulomb [C].**

Proton charge is positive: +1e = +1.602 × 10^{-19} C

Electron charge is negative: -1e = -1.602 × 10^{-19} C

Neutrons are neutral: No charge

18.2 Charged Objects and the Electrical Force

*** In nature, atoms like to have equal numbers of protons and electrons, so that their net charge is zero.**

These atoms are *electrically neutral*.

Electrical charges can be transferred between different objects.

For example: If we remove an electron from a neutral atom, we are left with a positively charged *ion*.

We can transfer electrons between to objects by touching them together:

Hard rubber / Animal fur → Electrons are transferred from the fur to the rod

The rod becomes *negatively charged*, and the fur *positively charged*.

Glass / Silk → Electrons are transferred from the glass to the silk

The silk becomes *negatively charged*, and the glass *positively charged*.

When objects become electrified, it results only from a transfer of charge, <u>not</u> a creation of charge:

Charge can neither be created or destroyed

Law of Conservation of Electrical Charge

Or, the net electrical charge of an isolated system remains constant.

Electrical Force

Take any two objects: Since they have <u>mass</u>, they exert a force on one another → Gravitational Force

It's always attractive!

Objects with excess <u>charge</u> will also exert forces on each other:

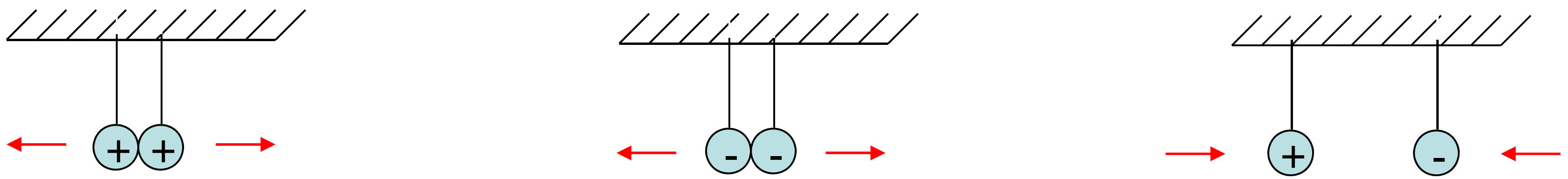
An Electrical Force

But unlike the gravitational force, the electrical force can be either *attractive* or *repulsive*.

Opposite charges attract

Like charges repel

Hanging charged pith balls:



Charged objects exert forces on one another. This is a new force called the Electrostatic Force.

Forces overcome an object's inertia and produce accelerations.

$$\sum F = ma$$ **Newton's 2nd Law**

***Electrostatic forces can accelerate charged objects**

18.3 Conductors and Insulators

Not only can electrical charge reside on the surface of an object, but it can also move through it.

Charges move through some materials more easily than others:

- **Charge moves easily: Conductor**

  i.e. copper, silver, aluminum (metals)

- **Charge can't move: Insulator**

  i.e. wood, paper, rubber, plastic,

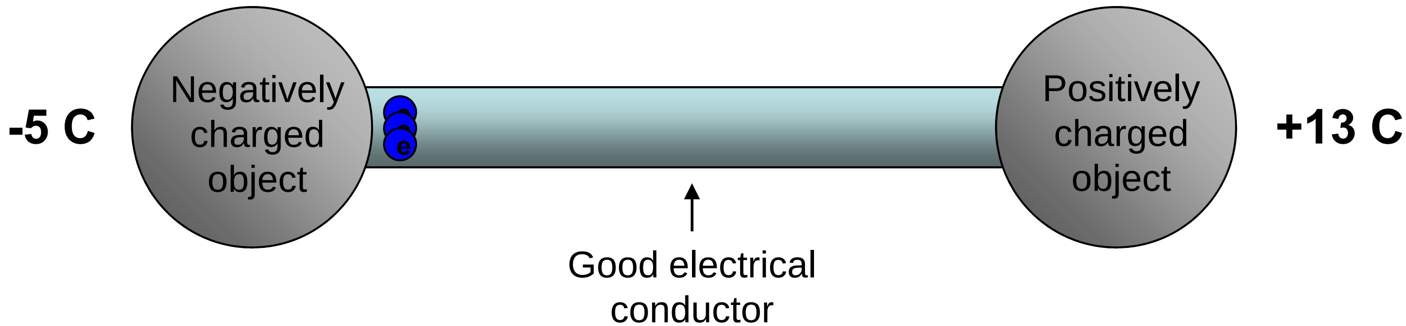
***Charge can stick on the surface of insulators, but it doesn't really move.**

Electrical Wire

What determines whether a material is a good conductor or insulator?

→ **Ultimately, it's the atomic structure.**

***The outer most electrons (valence electrons) in an atom are more weakly bound to the nucleus. They can "break free" and move through the material. These are called conduction electrons.**



Let's say the object on the left starts out with a charge of -5 C, and the object on the right starts out with +13 C.

Electrons will continue to flow until the charge on each object is….?

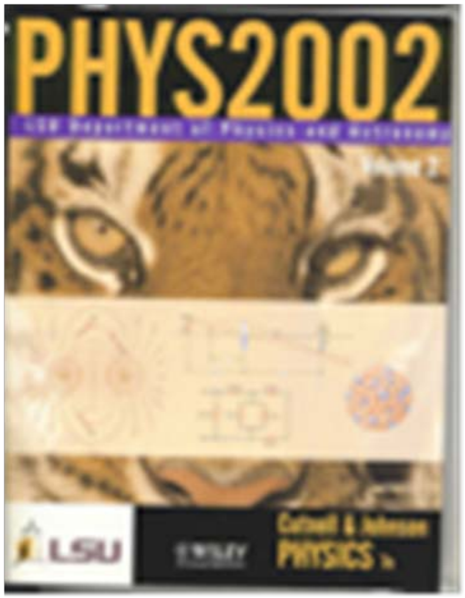
EQUAL!

And, each must end up with a charge of +4C, since the total (+8C) must remain constant!

Electrons can "flow" through a good conductor.

***There would be <u>no</u> charge flow if the bridge above was an insulator.**

Algebra-based Physics II



Aug. 25, Chap. 18

Announcements:

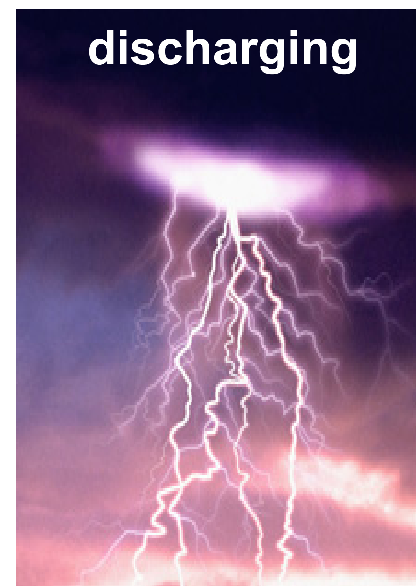
1. 1st-homework is posted
2. Start quiz today
3. Make sure you register on Masteringphysics for HW and PAW for your clicker

Class Website:

http://www.phys.lsu.edu/~jzhang/teaching.html

What we have learned:

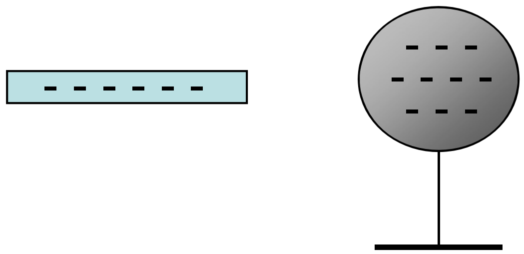
1. Charges are part of our universe: in electrons, protons
2. Electron charge: e = 1.602 x 10 -19 Coulomb (C)
3. Conservation of charge: charge can neither be created nor destroyed
4. Charging an object can be done only by charge transfer (normally electrons)
5. Conductor vs. insulator



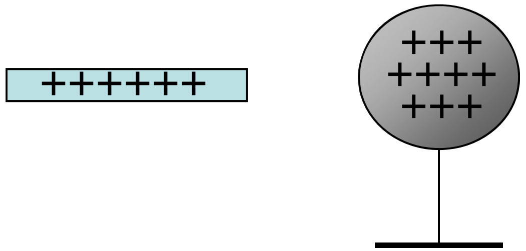
18.4 Charging an Object

Charging by contact:

Touching a metal sphere with a negatively charged rod can give the sphere a negative charge.



Similarly, if we started with a positively charged rod:

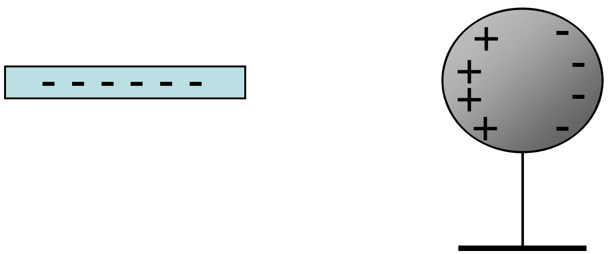


This is charging by contact.

Charging by Induction:

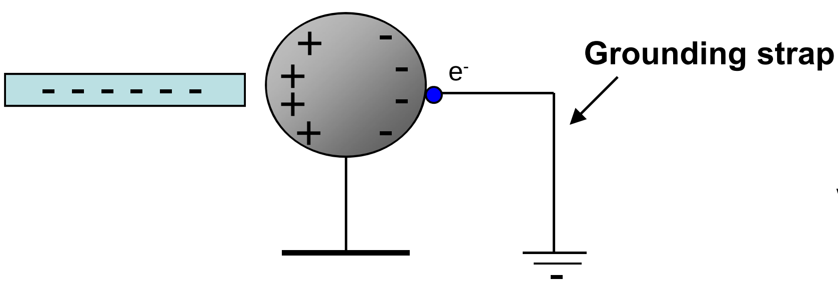
We can also charge a conductor without actually touching it.

Bring a negatively charged rod close to the surface of an electrically neutral metal sphere:



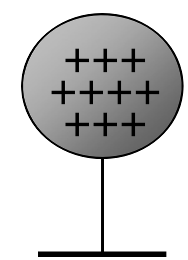
***The free charges separate on the sphere's surface.**

Now attach a metal wire between the sphere and ground:



The electrons travel down the strap to ground.

This leaves the sphere with a net positive charge

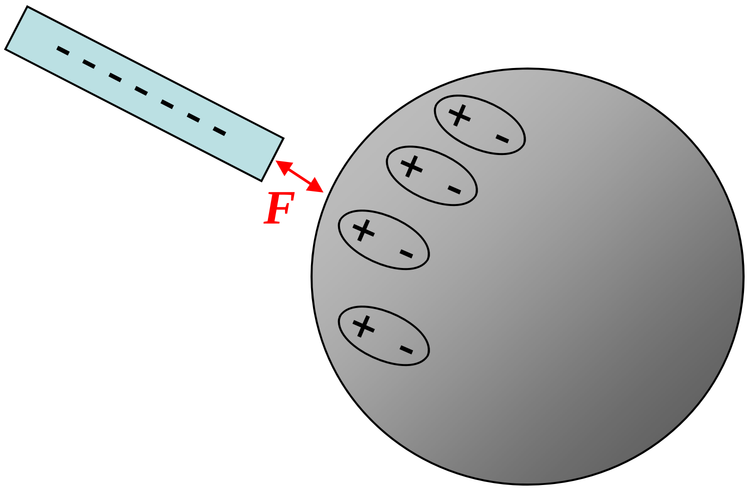


This is charging by <u>Induction</u>.

* Charging by induction doesn't work for insulators, since the charge can't move through the material or down the grounding strap.

But it does have an effect….

Bring a negatively charged rod close to the surface of an insulating sphere:



***Even though the electrons can't move through the insulator, the positive and negative charge in each atom separates slightly and forms dipoles, since the positive protons in the atoms are attracted to the rod, and the negative electrons are repelled.**

This is called <u>Polarization</u>.

***However, due to the separation of charge, the surface does acquire a slight positive charge, and is thus attracted to the rod.**

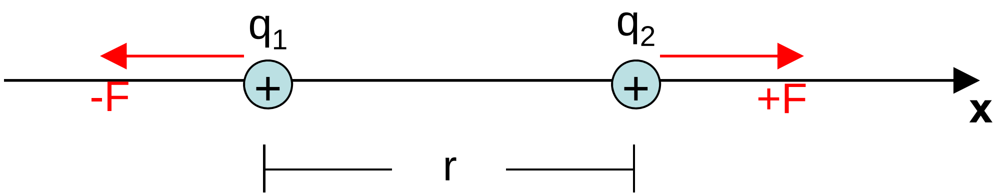
This is the process that produces <u>static cling</u>.

18.5 Coulomb's Law

So charged objects exert forces on one another:

Let's consider two positive point charges separated by some distance r:

Point charges: the charges are much smaller than the distance between them.



***Since they are like charges, they repel each other, and Newton's 3rd Law tells us they do this with equal and opposite force.**

So what do we know about this force?

1. **It grows weaker with distance.**
2. **It gets stronger for increasing charges.**
3. **It's directed along the line containing the two charges.**

Coulomb determined that:

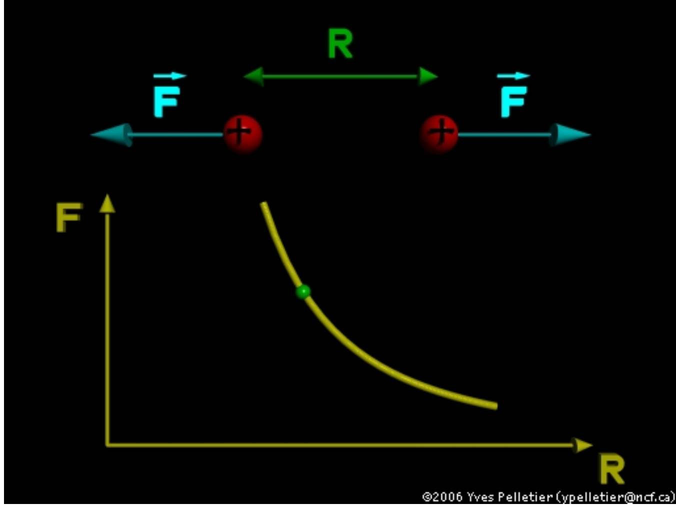
$$F = k\frac{q_1 q_2}{r^2}$$

$$F = k\frac{q_1 q_2}{r^2}$$

This is Coulomb's Law

$$F \propto \frac{1}{r}$$

$\vec{F}$ has direction



***k* is a constant:**

$$k = \frac{1}{4\pi\varepsilon_o} = 8.99\times10^9 \frac{N\cdot m^2}{C^2}$$

$$\varepsilon_o = 8.85\times10^{-12}\frac{C^2}{N\cdot m^2}$$

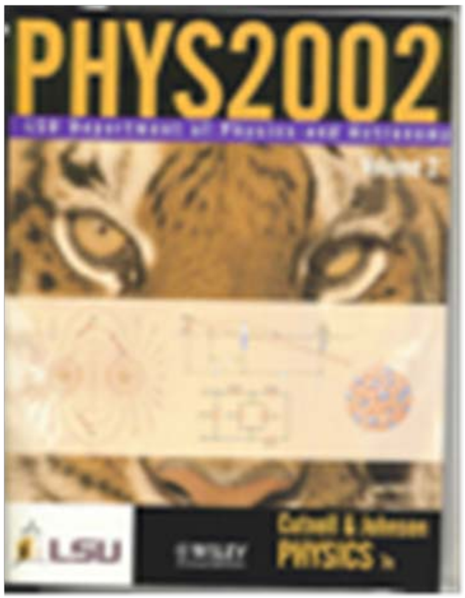
This is the permitivity of free space.

Coulomb's Law, like Newton's Universal Law of Gravitation, is an inverse square law.

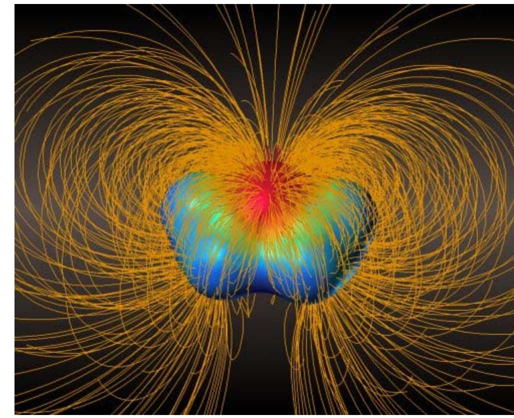
$$F = G\frac{m_1 m_2}{r^2}$$

Nature likes inverse square laws. They will show up again.

Algebra-based Physics II



Aug. 27, Chap. 18.5-7
Force to field


Electric field around a molecule

Announcements:

1. Problem #3 part b is not appropriate! Variable is incorrect

2. RF clicker channel is **41**

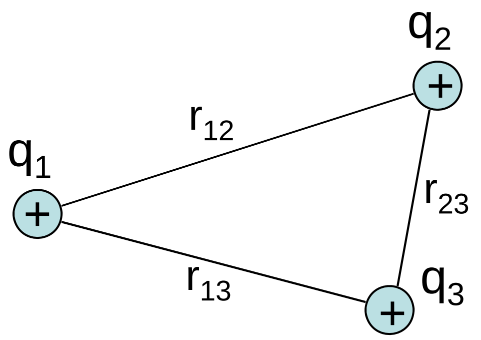
Class Website:

http://www.phys.lsu.edu/~jzhang/teaching.html

Coulomb's Law with more than two charges:

So if we have more than two charges, how do we calculate the magnitude and direction of the force on a third (or more) charge(s)???

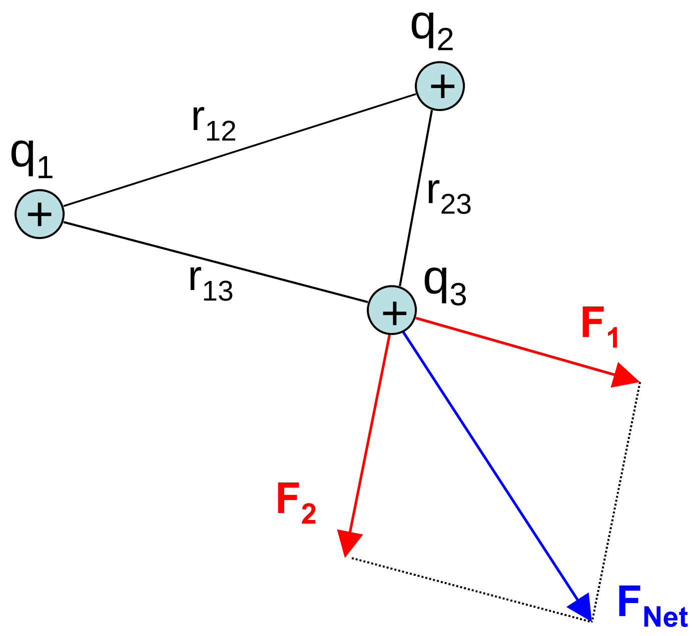
Let's consider 3 positive point charges in a plane:



What is the magnitude and direction of the net force on q_3?

q_3 feels a force from both q_1 (call it F_1) and q_2 (F_2):

Both of these forces are repulsive since all the charges have the same sign.



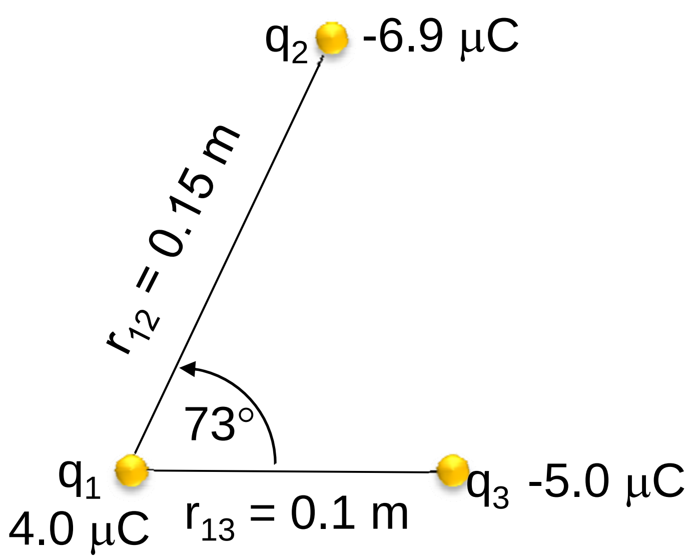
Thus, the net force is the **VECTOR SUM** of the two other forces!

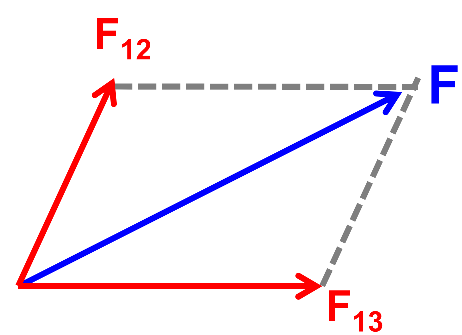
The magnitudes of F_1 and F_2 are just calculated using Coulomb's Law:

$$F_1 = k\frac{q_1 q_3}{r_{13}^2}$$

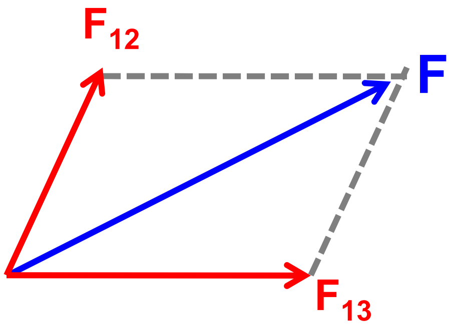
$$F_2 = k\frac{q_2 q_3}{r_{23}^2}$$

* Example 5 in textbook





Free-body diagram for q_1



Free-body diagram for q_1

* Calculate force magnitudes

$$F_{12} = k\frac{|q_1||q_2|}{r_{12}} = 9.6N$$

$$F_{13} = k\frac{|q_1||q_3|}{r_{13}} = 18.0N$$

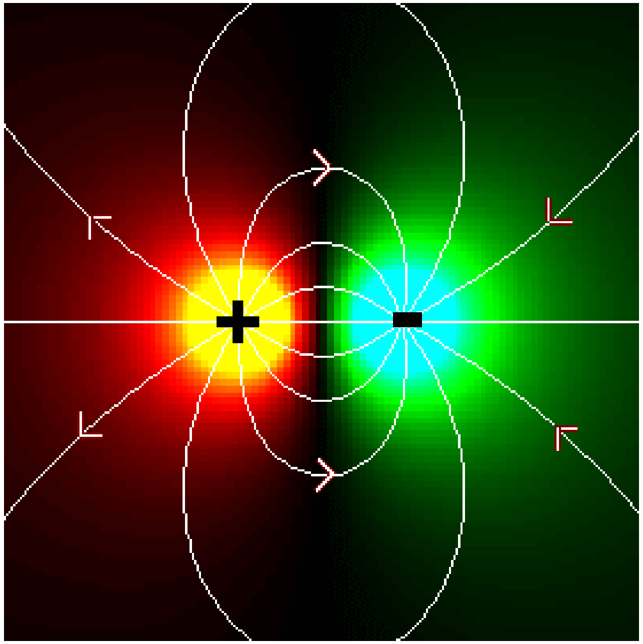
* Calculate both x- and y-components

Force	x-component	x-component
F_{12}	9.6 N cos 73° = 2.8 N	9.6 N sin 73° = 9.2 N
F_{13}	18 N	0
F	F_x = 21 N	F_x = 9.2 N

* Calculate the magnitude and direction

18.6 The Electric Field

The earth exerts a force on the moon and vice versa, even though they are 240,000 miles apart.



Likewise, two charged objects located far apart exert forces on each other too.

How can they do this if they are not in physical contact?

In the case of the earth/moon system, we say that the earth fills all space with a **gravitational field**, and the moon feels the effect of this field.

Masses feel forces in gravitational fields.

Similarly, a charge creates an **electric field** that fills all space. Any other charge in that field will feel a force.

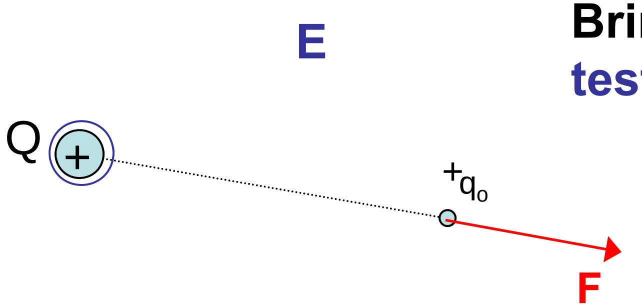
Stationary charges create electric fields that fill all space.

Other charges will feel forces in these electric fields.

Think of the electric field as a real physical entity!

Let's say we have a positive point charge Q sitting somewhere in space:

This charge creates an **electric field (E)** that fills all space, so any other charge should feel a force due to the field.



Bring a small positive charge q_o (often called a **test charge**), near Q:

The test charge will feel a force, **F**, directed away from Q since they are like charges.

We define the electric field as: $$\vec{E} \equiv \frac{\vec{F}}{q_o}$$

The electric field is a vector!

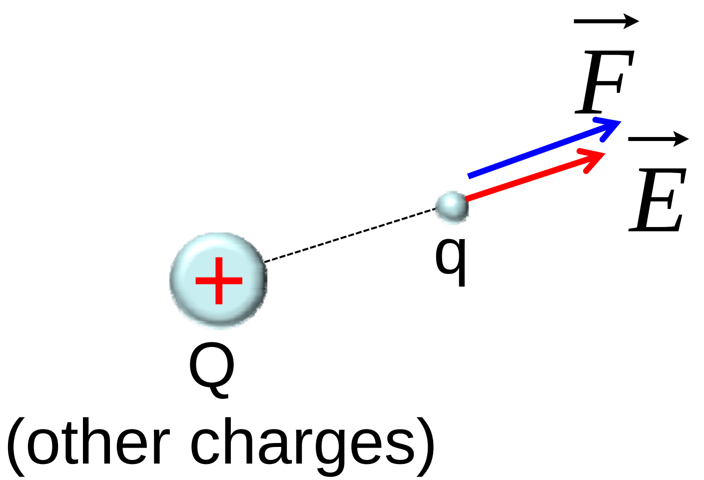
i.e. the electric field is force per unit charge:

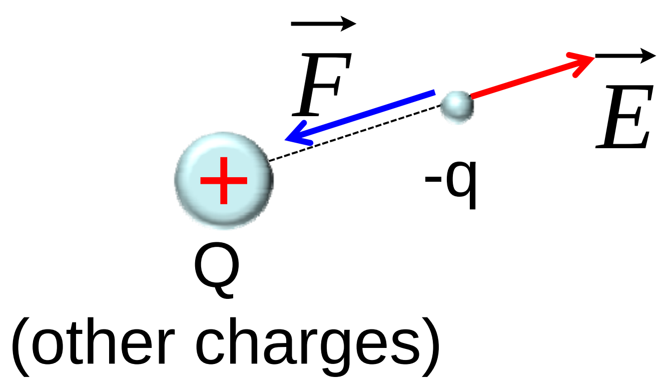
Units? $$\left[\frac{\text{Force}}{\text{Charge}}\right] = \left[\frac{N}{C}\right]$$

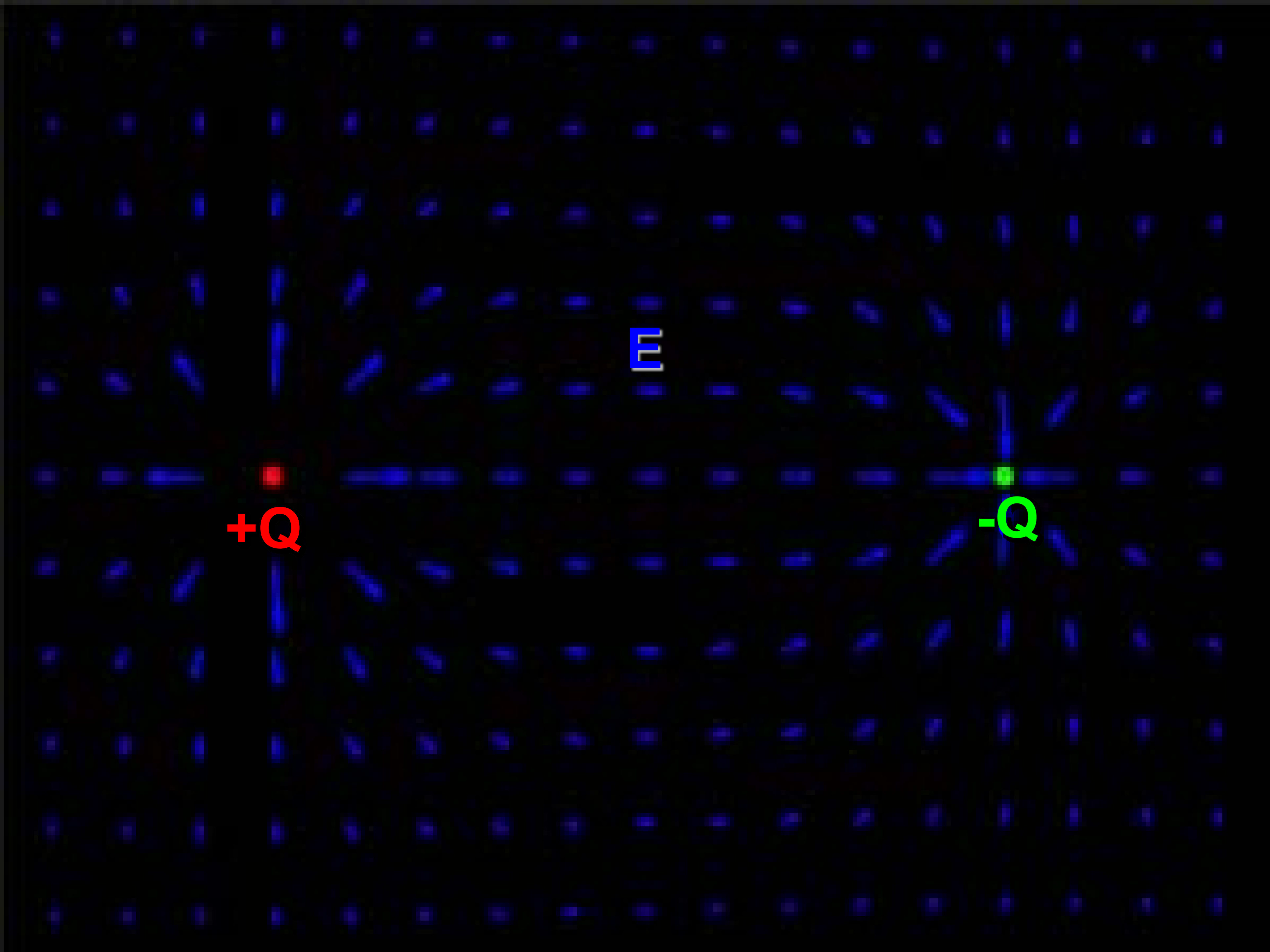
If we place a charge q in an electric field, it will feel a force given by:

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

***Note: E is created by other charges, not q.**



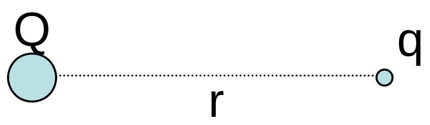



E
+Q
-Q

Electric field of a point charge

Can we find an expression for the electric field of a point charge?

Place a charge q at some distance r from a point charge Q:



There is a force on q due to the electric field that Q creates:

$$F = qE$$

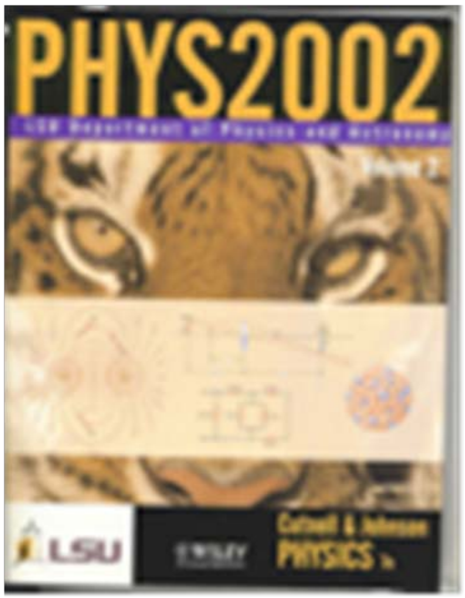
But, we can also calculate the force on q using Coulomb's Law:

$$F = k\frac{qQ}{r^2}$$

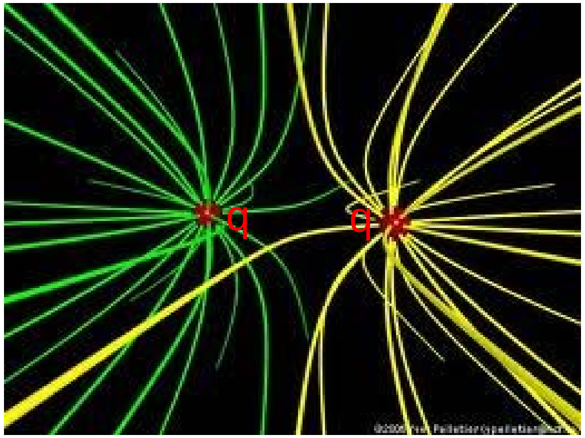
These must be equal: $qE = k\frac{qQ}{r^2} \longrightarrow \boxed{E = k\frac{Q}{r^2}}$

This is the electric field of a point charge.

Algebra-based Physics II



Aug. 30, Chap. 18.7-9
Field-Field lines-Field flux



Announcements:

1. RF clicker channel is **41**
2. HW # 1 is due on Wed.

<u>Class Website</u>:

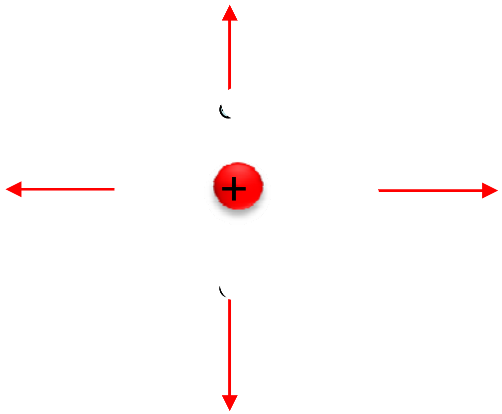
http://www.phys.lsu.edu/~jzhang/teaching.html

18.7 Electric Field Lines

So a charged object fills all space with an electric field. Can we visualize the field???

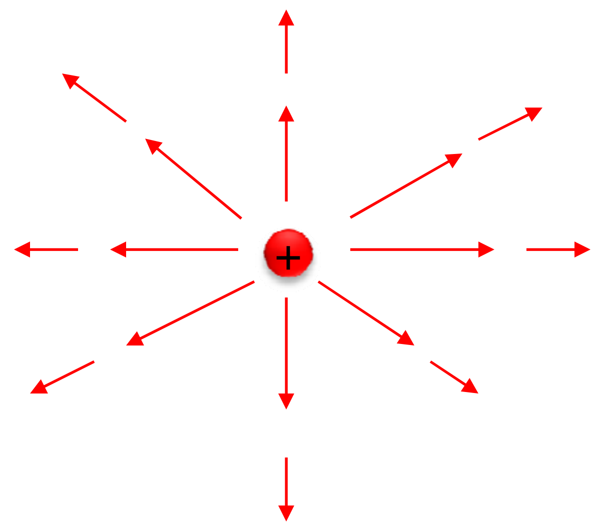
Yes!!! And we can do this by using a positive test charge. ⊕

Let's start simple and try to map out the field lines around a positive point charge:



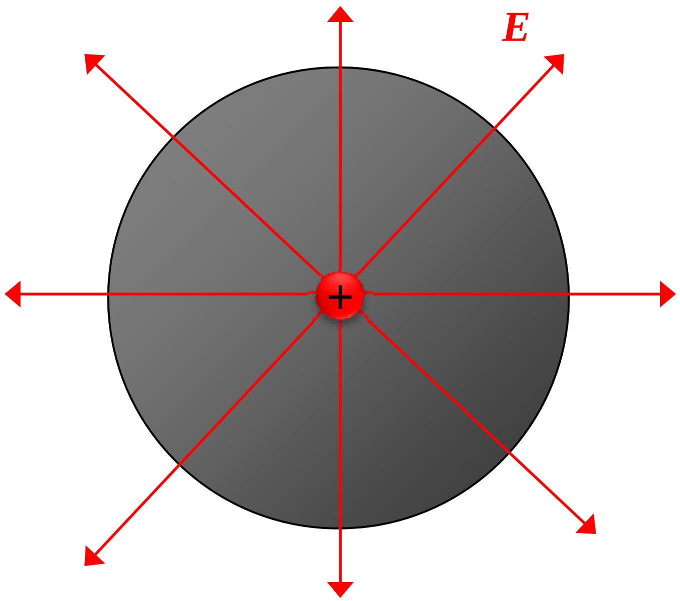
Move the test charge around the point charge and note the direction of the force on it.

Continue this process:



***Notice that the force vector arrows get shorter as we go farther away from the charge, since the force gets smaller.**

Now let's connect the arrows!!!...

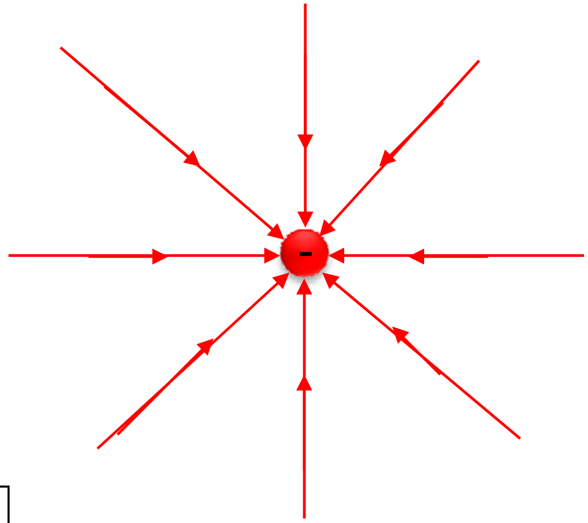


$$E = k\frac{Q}{r^2}$$

*The electrical field lines of a positive point charge point radially outward away from the charge and fill all space.

Spherical in 3 dimensions!!!

By a similar construction, we can show that the field lines around a negative point charge look like this:

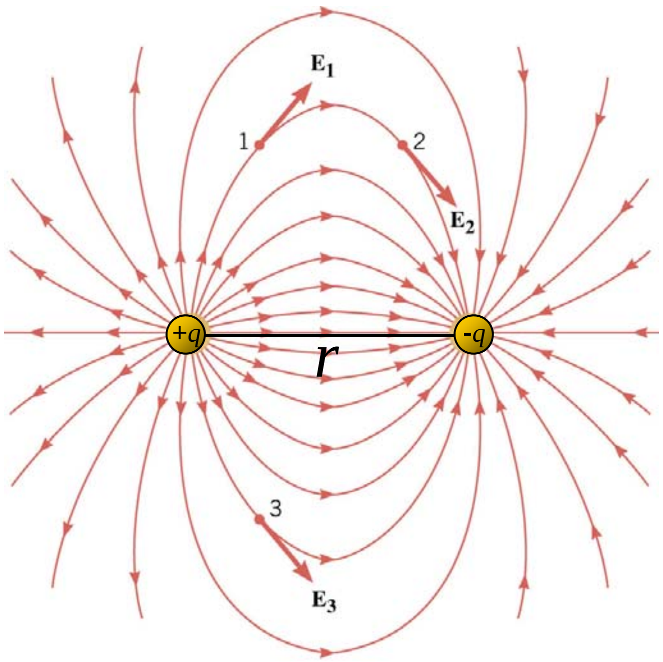


i.e. the field lines around a negative charge point radially in toward the charge.

Electric field lines always start at and are directed away from positive charges and always end at and are directed toward negative charges.

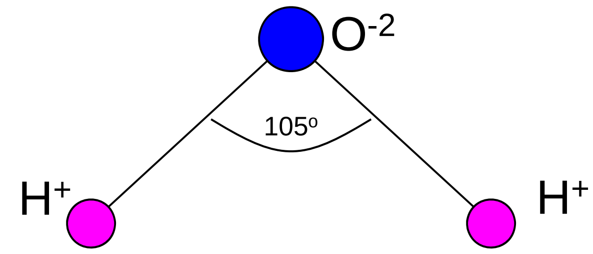
But what would the electric field look like in a region of space with more than one charge?

Consider an electric dipole: **Two equal but opposite charges separated by some distance r.**



What would the field lines look like for the dipole?

Due to their structure, many molecules have a dipole moment. For example, water:



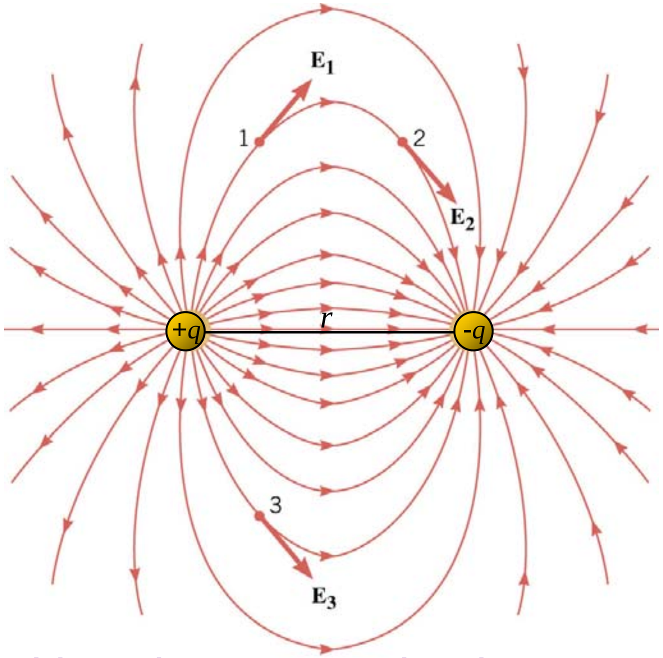
***Note: The lines start at the positive charge and end on the negative one.**

Electric Field Lines

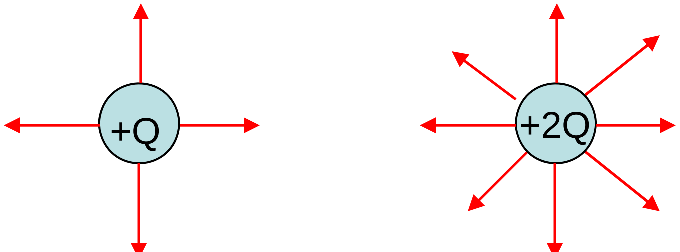
1. Start from positive charges and end on negative charges.

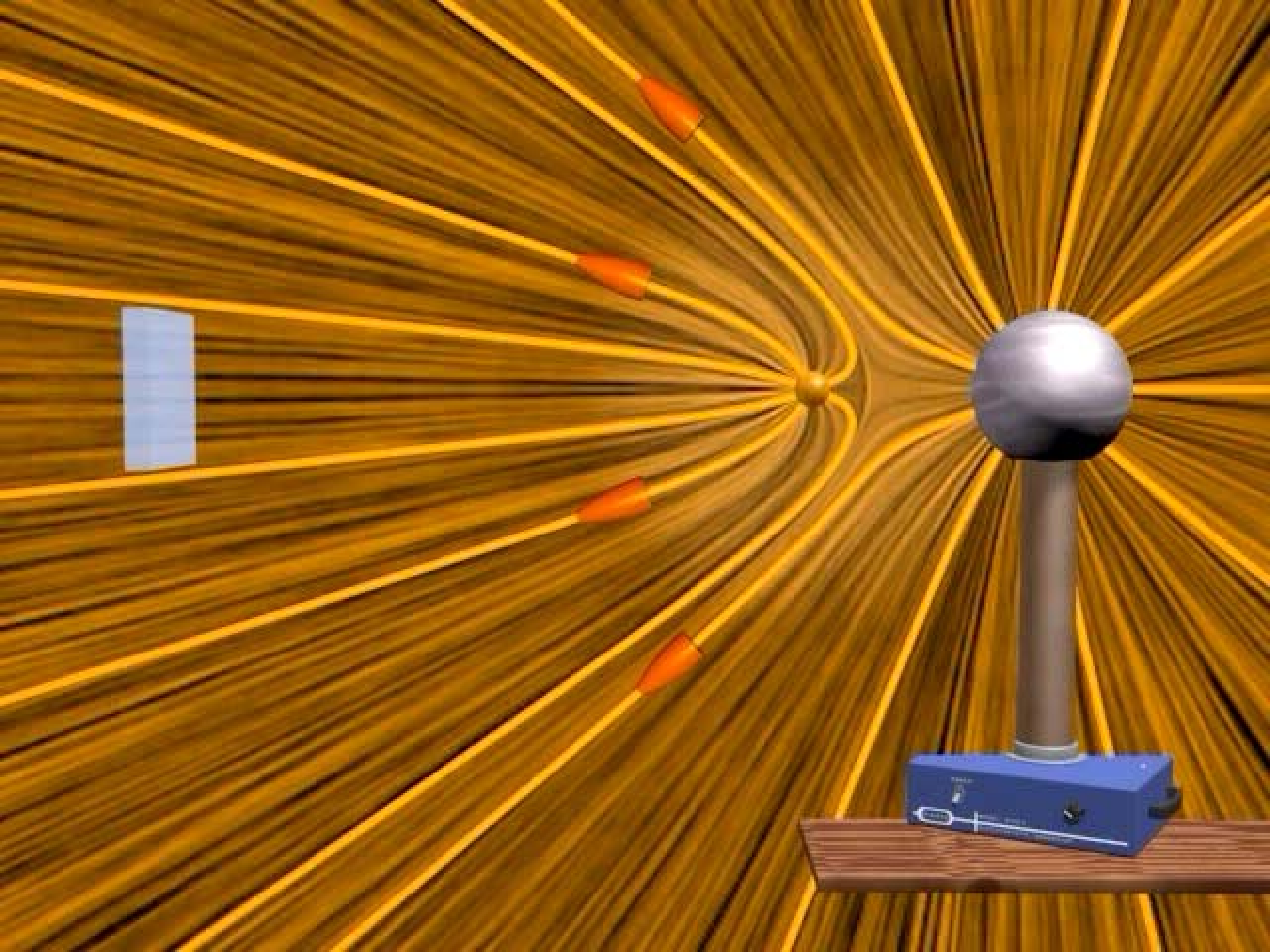
2. The electric field vector at some point in space is always tangent to the ….field line at that point.

The more field lines you have per unit volume (density), the stronger the field.

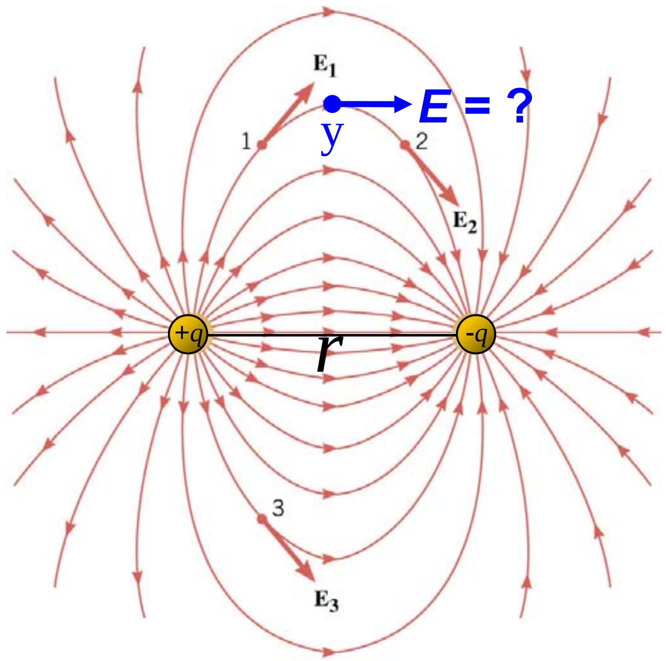


3. The number of field lines leaving a positive charge or going into a negative charge is proportional to the magnitude of the charge.



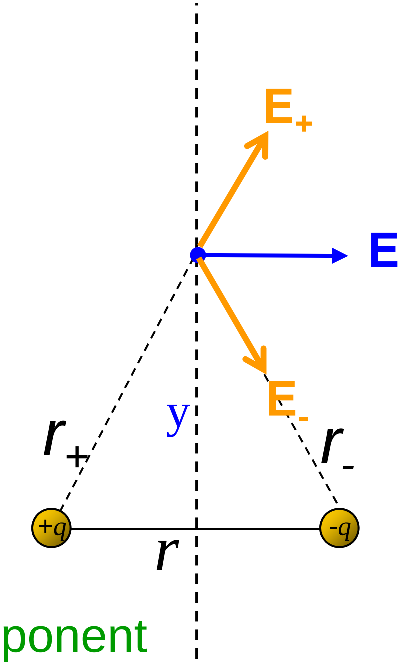


How to calculate the net field at a space position? VECTOR Addition!!



EXAMPLE

You know: q; r; y



Symmetry:

1. $E_+ = E_-$
2. No vertical component

Trigonometry: $r_+ = r_- = \sqrt{y^2 + (r/2)^2}$ and $\cos\theta = \dfrac{r/2}{\sqrt{y^2 + (r/2)^2}}$

Field created by a charge $$E_+ = k\frac{q}{r_+^2} = k\frac{q}{y^2 + (r/2)^2}$$

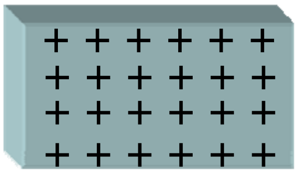
Net field $$E = E_x = E_+\cos\theta + E_-\cos\theta$$ $E_+ = E_-$

$$= 2E_+\cos\theta$$

$$= 2k\frac{q}{y^2 + (r/2)^2}\frac{r/2}{\sqrt{y^2 + (r/2)^2}} = k\frac{qr}{[y^2 + (r/2)^2]^{3/2}}$$

Parallel Plate Capacitor

Consider a metallic plate with a total charge $+q$ distributed uniformly over its surface.



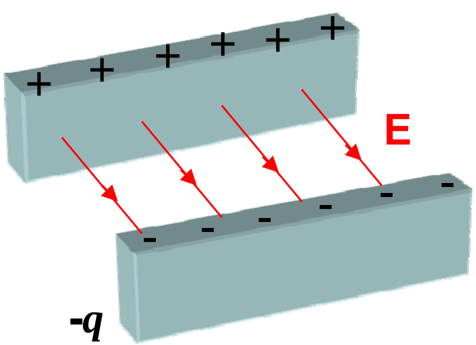
If the face of the plate has a surface area A, then

$$\sigma = \frac{q}{A}$$

where σ is the surface charge density.

Units? $$\left[\frac{\text{Charge}}{\text{Area}}\right] = \left[\frac{C}{m^2}\right]$$

Now let's take two identical metal plates, one with total charge $+q$ and one with total charge $-q$.



So the magnitude of σ is q/A for each plate.

***In between the plates there exists a uniform electric field that points from the positive plate to the negative one.**

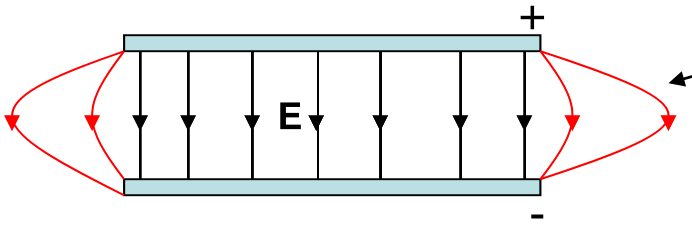
This is called a parallel plate capacitor.

The electric field between the plates is given by:

$$E = \frac{q}{\varepsilon_o A} = \frac{\sigma}{\varepsilon_o}$$

Notice: The field does not depend on the distance from the charged plates! It's uniform!

One more note on parallel plate capacitors: **The field is only uniform near the middle of the plates.**

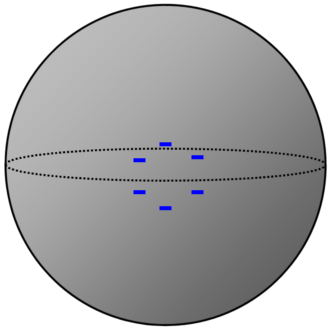


***This is a fringing effect. Also called the fringe field.**

18.8 Electric Field Inside a Conductor

Remember that charges can easily move through the interior of a conductor.

Let's place a bunch of electrons at the center of a solid conducting sphere:



Repulsion spreads the electrons out!

They move as far away from each other as they can. Thus, they move to the surface.

At equilibrium under electrostatic conditions, any excess charge resides on the surface of a conductor.

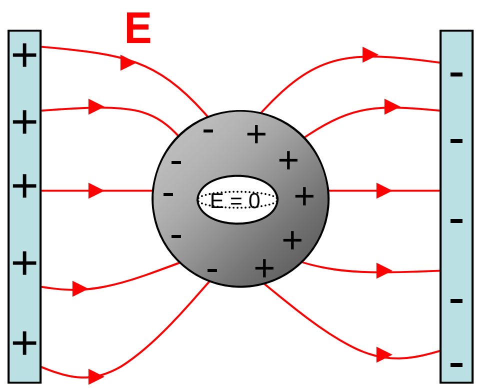
But what about the interior of the conductor?

There are still electrons there, but they are compensated exactly by the positive charges in the interior. Thus, the interior is electrically neutral.

Since the charges are static, i.e. not moving, the force on them is zero, thus E must be zero inside the conductor!

E = 0 inside a conductor.

Let's place a conducting sphere in a uniform electric field:



No field lines penetrate the sphere, since E=0 inside a conductor.

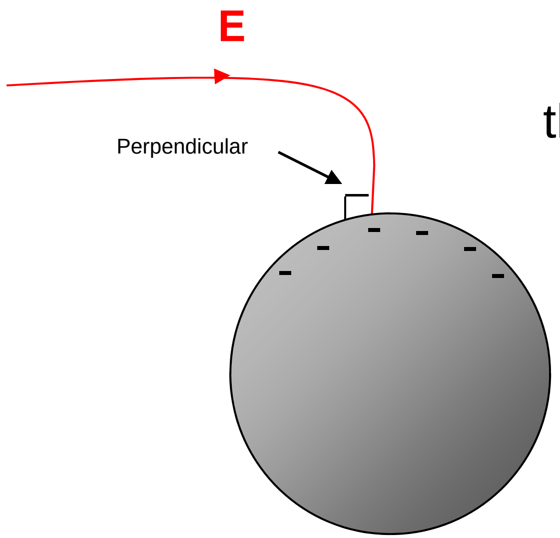
The field lines end or begin at the surface charges!

Cut out a cavity in the sphere interior:

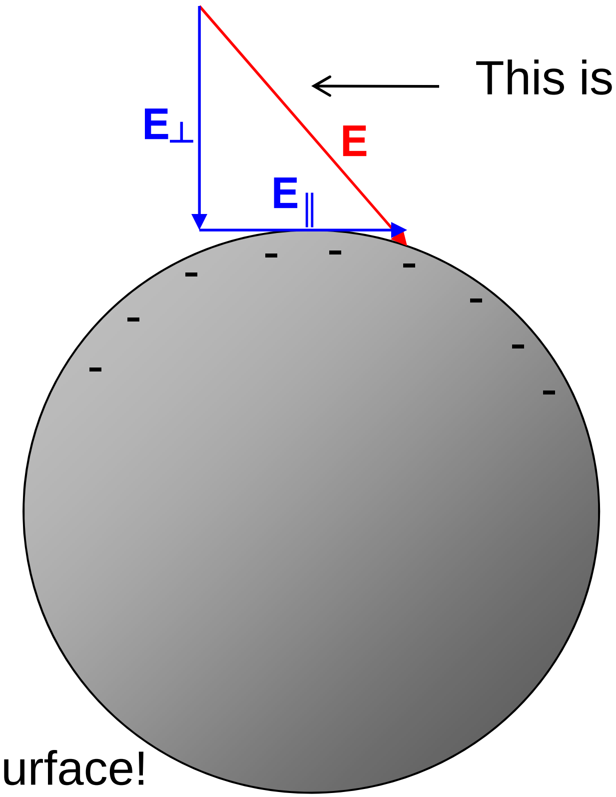
E = 0 inside! Whatever we put inside the conductor will be shielded from electric fields.

This is a static condition, so once the surface charges are induced, they don't move.

This tells us something special about the electric field at the surface of a conductor: It must be perpendicular to the surface!



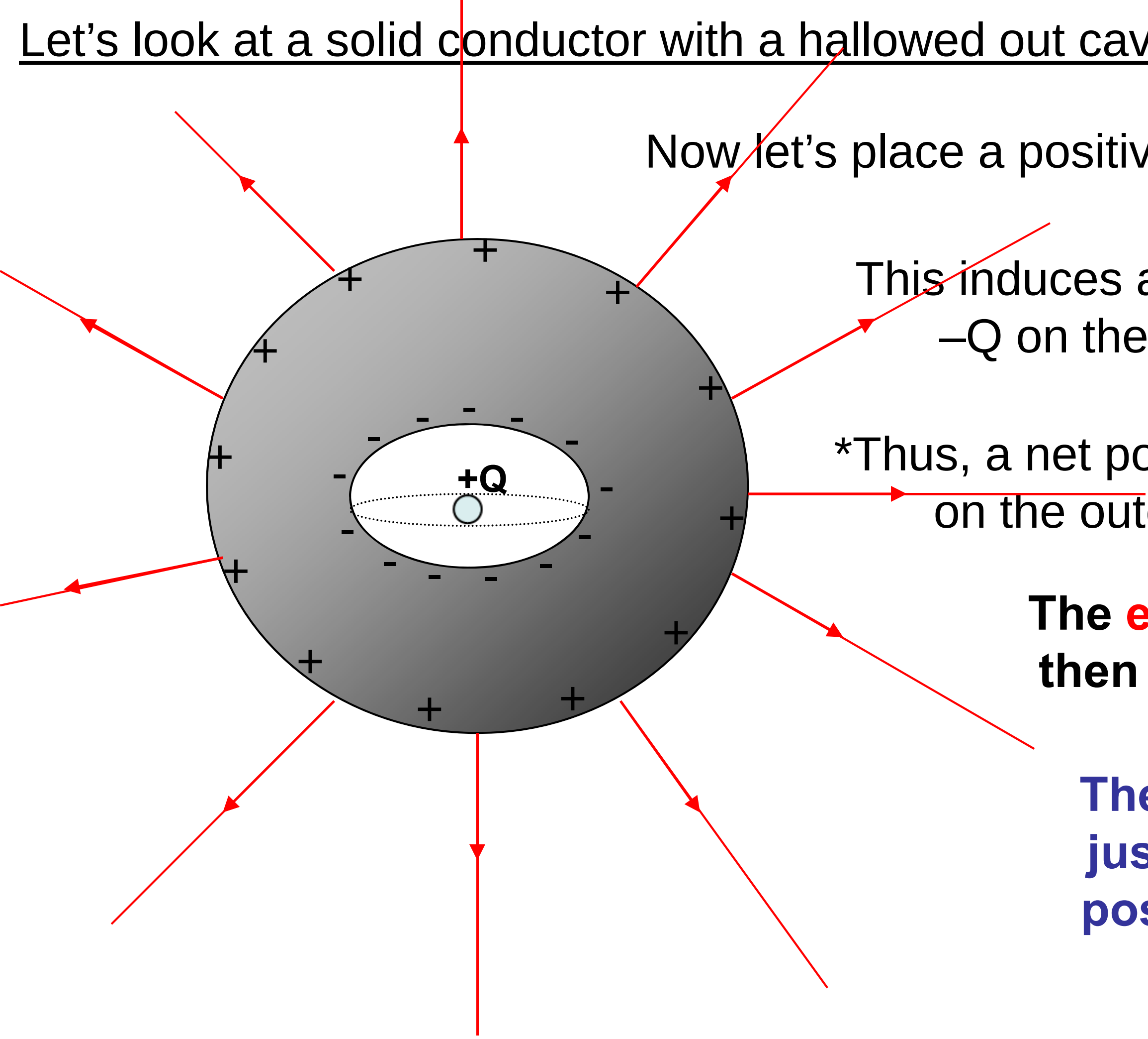
If the electric field was not perpendicular to the surface, then there would be a component of the field along the surface, and thus a force on the charges along the surface.



This is not correct!

E must be perpendicular to the conductor's surface!

Let's look at a solid conductor with a hallowed out cavity inside:



Now let's place a positive point charge inside the cavity:

This induces a net negative surface charge of –Q on the inside surface of the cavity.

*Thus, a net positive surface charge is induced on the outer surface of the conductor.

The electric field lines would then look like the following:

The electric field lines look just like the field lines of a positive point charge if the sphere wasn't there!

18.9 Electric Flux

Flux is a measure of how much field passes perpendicularly through a surface.

Given a surface of area A, the **electric flux** passing through the surface is given by:

$$\Phi_E = E_\perp A = (E\cos\phi)A ,$$

where Φ_E is the electric flux.

Units? $$[(\text{Electric Field})(\text{Area})] = \left[\frac{N\cdot m^2}{C}\right]$$

Note: ϕ is the angle between **E and the **normal to the surface!**

Thus, **$E\cos\phi$** gives us the perpendicular component of E passing through the surface.