

Announcements

- Help room hours (1248 BPS)
 - ◆ Ian La Valley(TA)
 - ◆ Mon 4-6 PM (except not Monday Sept 17)
 - ◆ Tues 12-3 PM
 - ◆ Wed 6-9 PM
 - ◆ Fri 10 AM-noon
- Answers for exam 1 posted on course webpage
 - ◆ average is 31/40
- LON-CAPA #5 due Oct. 11
- Final Exam Tuesday Dec 11 7:45-9:45 AM

Exam 1

Score	# students	Grade
40	7	4
39	8	4
38	14	3.5
37	10	3.5
36	18	3.5
35	15	3
34	20	3
33	24	3
32	20	3
31	21	3
30	16	3
29	10	2.5
28	12	2.5
27	9	2.5
26	11	2.5
25	12	2
24	9	2
23	4	2
22	3	2
21	3	2
20	1	2
<20	7	1.5
254		

This is just to give you an idea. Grades based on 1 exam don't mean too much.

I think there was a mistake in the grading of question 31 in the blue exam. If so, I'll have the blue exam re-graded and your score will be revised.

Nobel Prize In Physics 2012: Serge Haroche, David Wineland Win For Inventing Methods To Observe Quantum World

AP | Posted: 10/09/2012 5:51 am EDT Updated: 10/09/2012 6:38 am EDT

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STOCKHOLM (AP) — A French-American duo shared the 2012 Nobel Prize in physics Tuesday for inventing methods to observe the bizarre properties of the quantum world, research that has led to the construction of extremely precise clocks and helped scientists take the first steps toward building superfast computers.

Serge Haroche of France and American David Wineland opened the door to new experiments in quantum physics by showing how to observe individual quantum particles without destroying them, the Royal Swedish Academy of Sciences said.

Haroche and Wineland, both 68, work in the field of quantum optics, which deals with the interaction between light and matter.

This helps the development of quantum computing, which is to regular computers as a regular computer is to an abacus.

Electrostatics

- ...and thus back to the ancient Greeks
- The Greeks started the science of electrostatics (like almost everything else)
 - ◆ they observed that when amber was rubbed, it would attract small objects like feathers or straw
 - ▲ or like rubbing a balloon against your shirt
 - ◆ in fact our word for electricity comes from the Greek word for amber, *electron*



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So not much happened for 2000 years or so

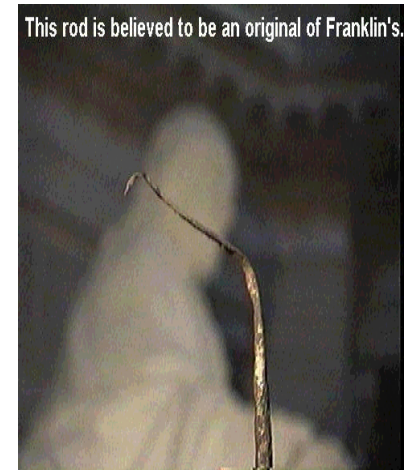
- In the 16th century, investigations revealed that there appeared to be two types of electricity
 - ◆ vitreous: from rubbed glass, animal hair
 - ◆ resinous: from rubbed amber, silk
- How is one different from the other?
 - ◆ 2 bodies charged with vitreous electricity repel each other, as do 2 bodies charged with resinous electricity
 - ◆ a body charged with resinous electricity will attract a body charged with vitreous



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Is this the final story (should you write down vitreous and resinous)?

- No...and no
- In the mid-1700's, Benjamin Franklin proposed what he called a "one-fluid" theory of electricity. He proposed that every body had a normal amount of electricity.
- When a body is rubbed against another, some of the electricity is transferred from one body to another
- One body has an excess of electricity, the other a deficit
 - ◆ this is a great advance, one of the first conservation laws
- He described the excess as having a + charge and the deficit a -charge
- Opposite sign charges attract and like sign charges repel



Can we stop now?

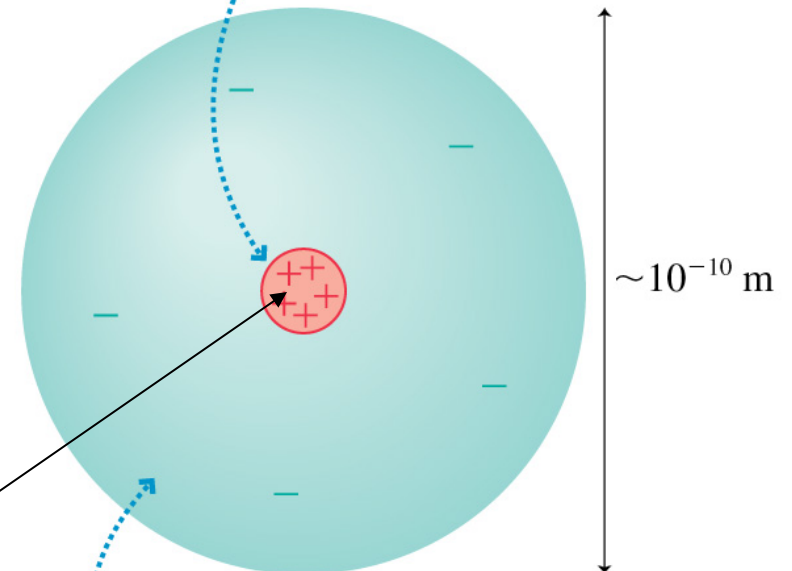
- Benjamin Franklin's theory was an advance
 - ◆ he unified the concepts of lightning and static electricity
- but not quite right
- In particular his choice of signs will come back to haunt us when we get to circuits
- Let's briefly review atomic structure

to give you an idea of the relative scale of the nucleus, Rutherford referred to it as the “fly in the cathedral”

The nucleus of the atom consists of protons + neutrons

Charge on proton = $e = +1.6 \times 10^{-19} \text{ C}$

The nucleus, exaggerated for clarity, contains positive protons.



The electron cloud is negatively charged.

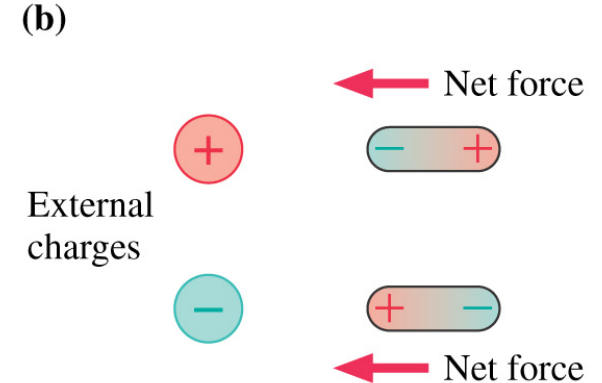
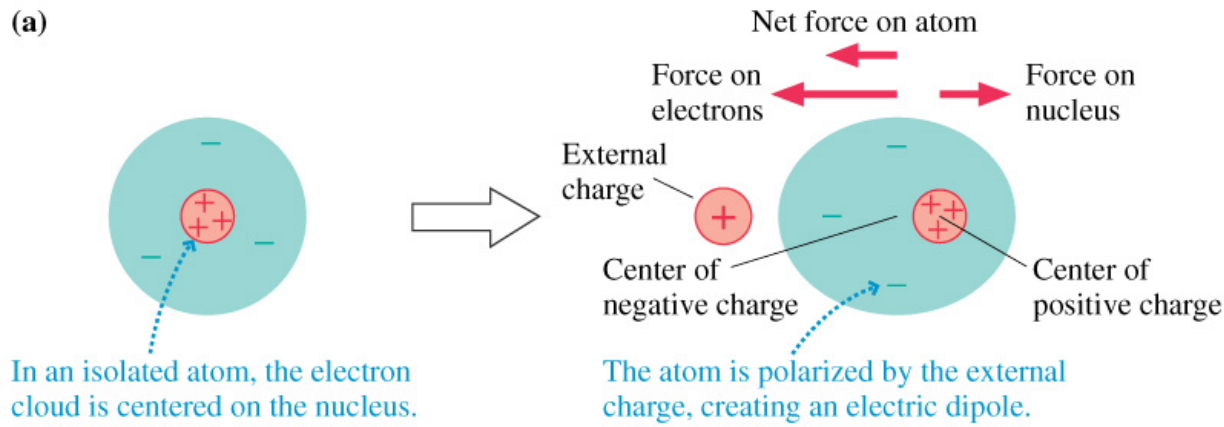
Each normal atom has as many electrons as protons

Charge on electron = $-e = -1.6 \times 10^{-19} \text{ C}$

So every normal atom is neutral

Electric dipoles

I can induce a dipole on an insulator by bringing a charge close.

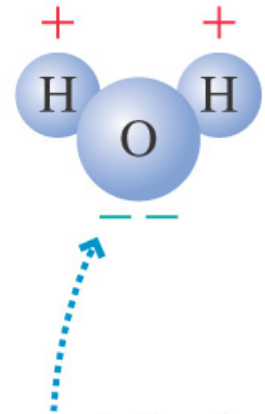
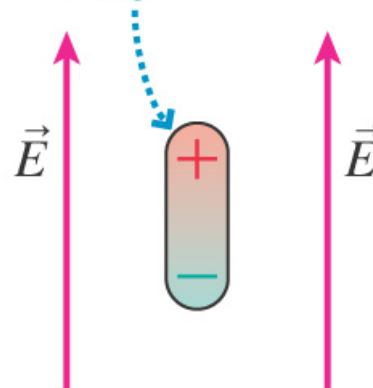


Electric dipoles can be created by either positive or negative charges. In both cases, there is an attractive net force toward the external charge.

Natural electric dipoles

- Can also have molecules in nature that are natural electric dipoles
- Water is the best example

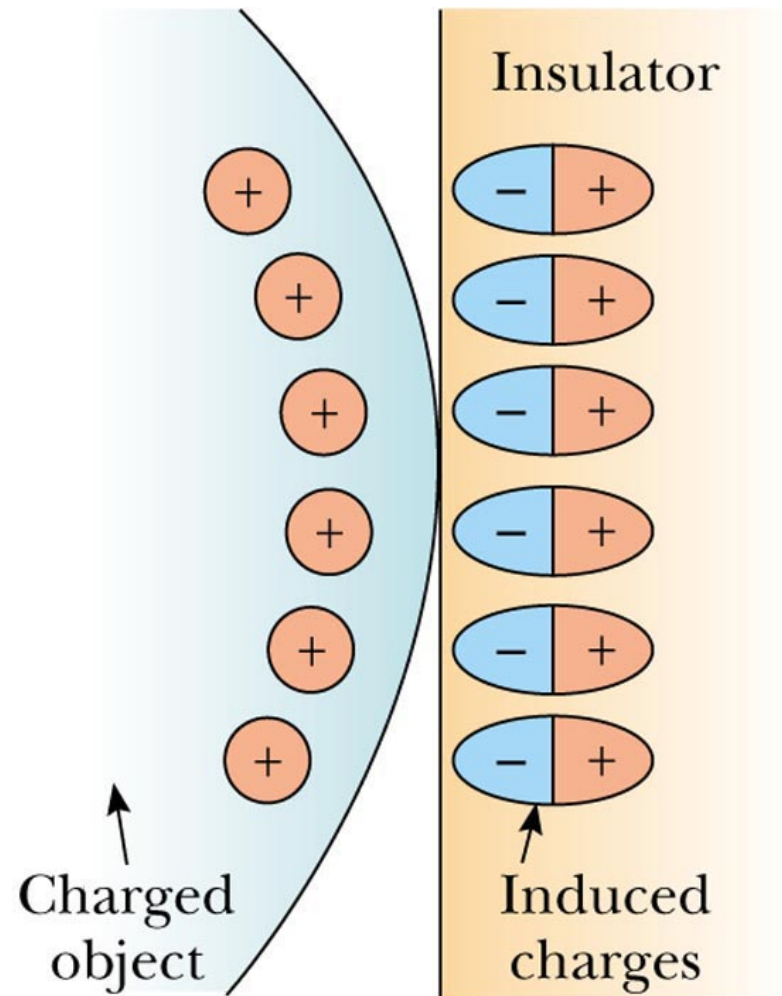
This dipole is *induced*, or stretched, by the electric field acting on the + and - charges.



A water molecule is a *permanent* dipole because the negative electrons spend more time with the oxygen atom.

Electric dipoles

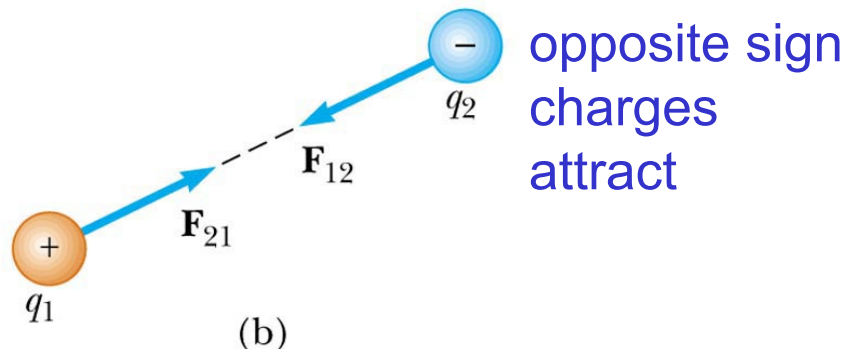
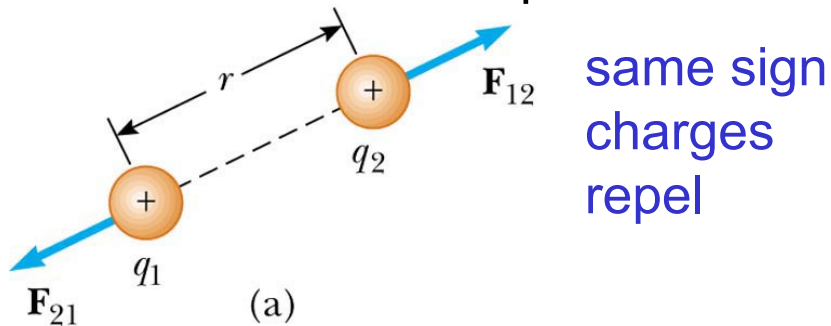
- The charged rod can attract an uncharged insulator if the insulator has electric dipoles inside it
- ...or by inducing electric dipoles (separation of charges)



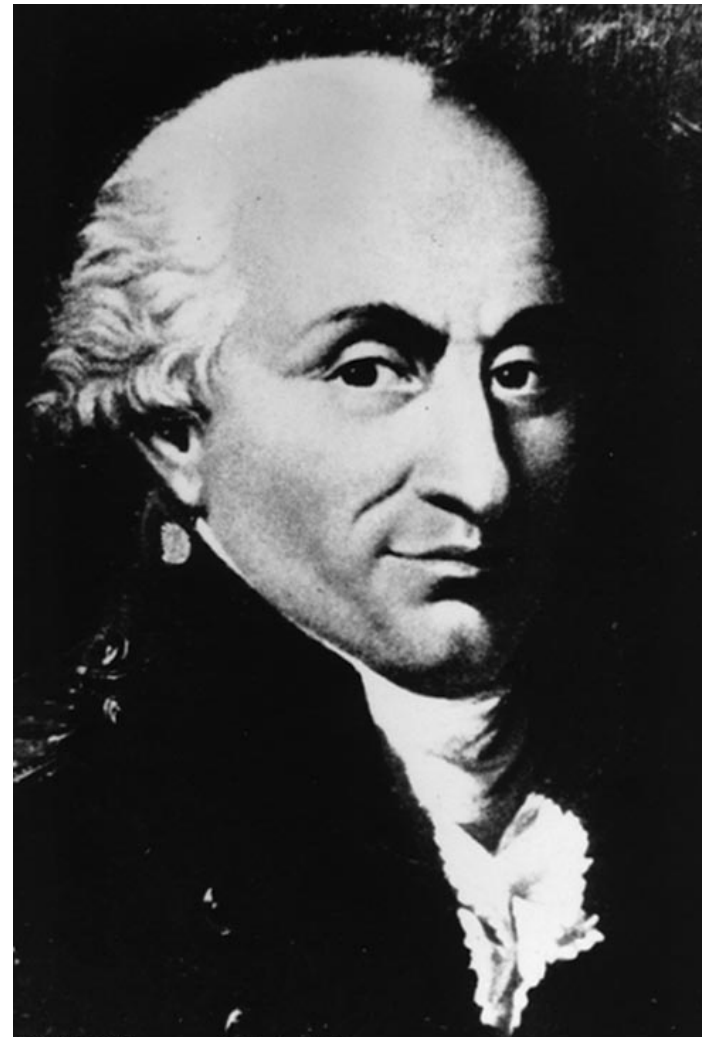
Coulomb's Law

There is a force between 2 charges along the line joining them (a central force).

The size of the force drops as $1/r^2$



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Where have we seen this before?

Gravity

- Both gravity and this electrostatic force we've been discussing are
 - ◆ central
 - ▲ this means we can define a type of function called a potential (later)
 - ◆ vary as $1/r^2$
- But the electrostatic force is incredibly stronger than gravity



Comparison of Coulomb's law and Newton's law of gravity

Let's consider a hydrogen atom consisting of one proton and one electron separated by a distance of $5.3 \times 10^{-11} \text{ m}$

- Coulomb force

$$F = k \frac{q_e q_p}{r^2}$$

- ◆ where $k=9 \times 10^9 \text{ N} \cdot \text{m}^2/\text{C}^2$
- ◆ and $|q_e|=|q_p|=1.6 \times 10^{-19} \text{ C}$

- Gravitational force

$$F = G \frac{m_e m_p}{r^2}$$

- ◆ where $G=6.67 \times 10^{-11} \text{ N} \cdot \text{m}^2/\text{kg}^2$
- ◆ and $m_e=9.1 \times 10^{-31} \text{ kg}$ and $m_p=1.67 \times 10^{-27} \text{ kg}$

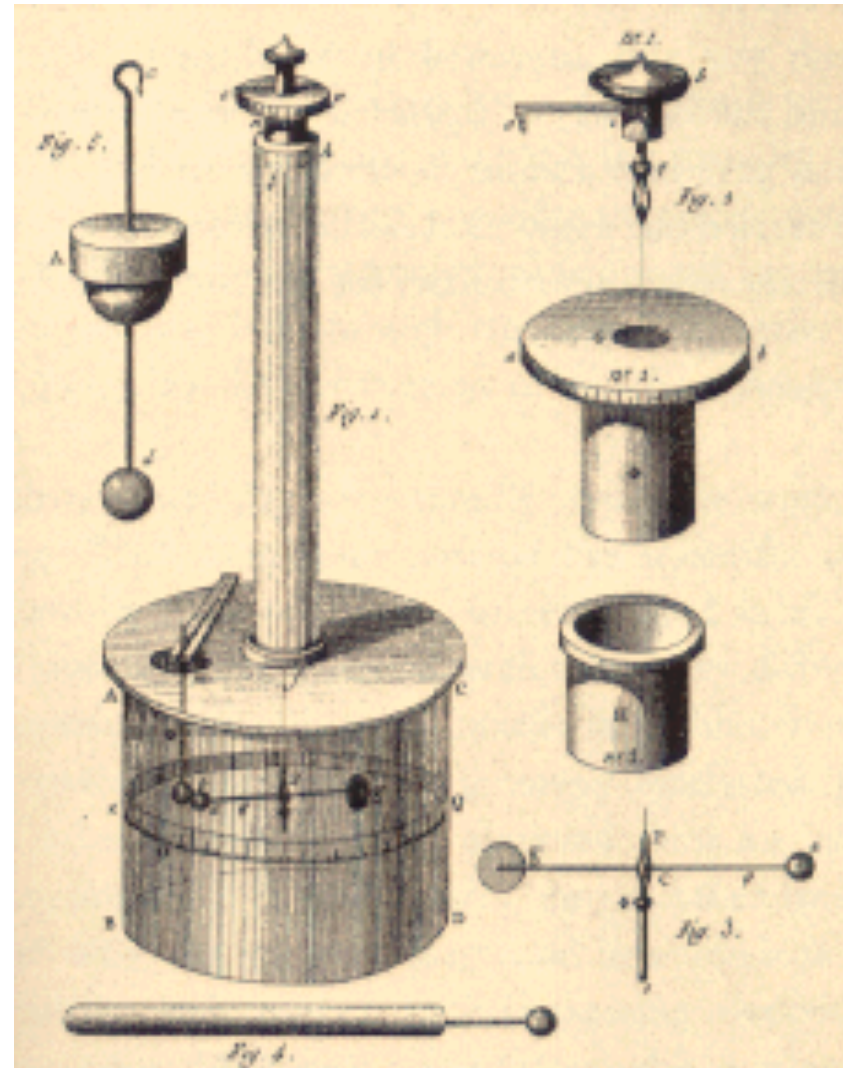
- $F_{\text{Coulomb}} = 8.2 \times 10^{-8} \text{ N}$

- $F_{\text{gravity}} = 3.6 \times 10^{-47} \text{ N}$

The Coulomb force is about 39 orders of magnitude larger.

Torsion balance

- In fact Coulomb derived his law using the same sort of torsion balance that Cavendish used to measure the gravitational constant G
- But Cavendish had an easier time of it since mass does not tend to leak away as charge does
- Did Coulomb's data decisively determine a $1/r^2$ force law, or did he jump to that conclusion in order to match Newton?
- In any case, the force law does go as $1/r^2$



Clicker question

- An electron and a proton are separated by a distance of 1 m. What happens to the magnitude of the force on the proton if a second electron is placed next to the first electron
 - ◆ A) the force increases by a factor of 4
 - ◆ B) the force decreases by a factor of 4
 - ◆ C) the force increases by a factor of 2
 - ◆ D) the force decreases by a factor of 2
 - ◆ E) the force stays the same

Clicker question

- An electron and a proton are separated by a distance of 1 m. What happens to the magnitude of the force on the proton if a second electron is placed next to the first electron
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 - ◆ E) the force stays the same

Clicker question

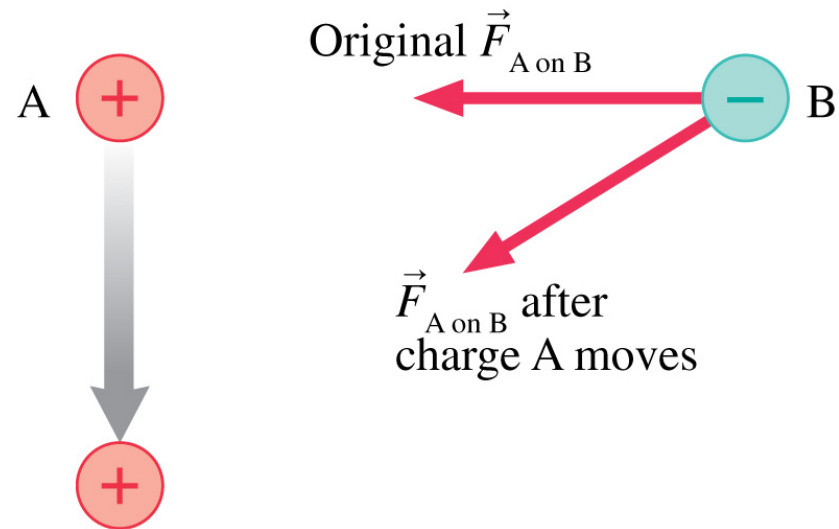
- An electron and a proton are separated by a distance of 1 m. What happens to the magnitude of the force on the proton if the distance between the two is doubled?
 - ◆ A) the force increases by a factor of 4
 - ◆ B) the force decreases by a factor of 4
 - ◆ C) the force increases by a factor of 2
 - ◆ D) the force decreases by a factor of 2
 - ◆ E) the force stays the same

Clicker question

- An electron and a proton are separated by a distance of 1 m. What happens to the magnitude of the force on the proton if the distance between the two is doubled?
 - ◆ A) the force increases by a factor of 4
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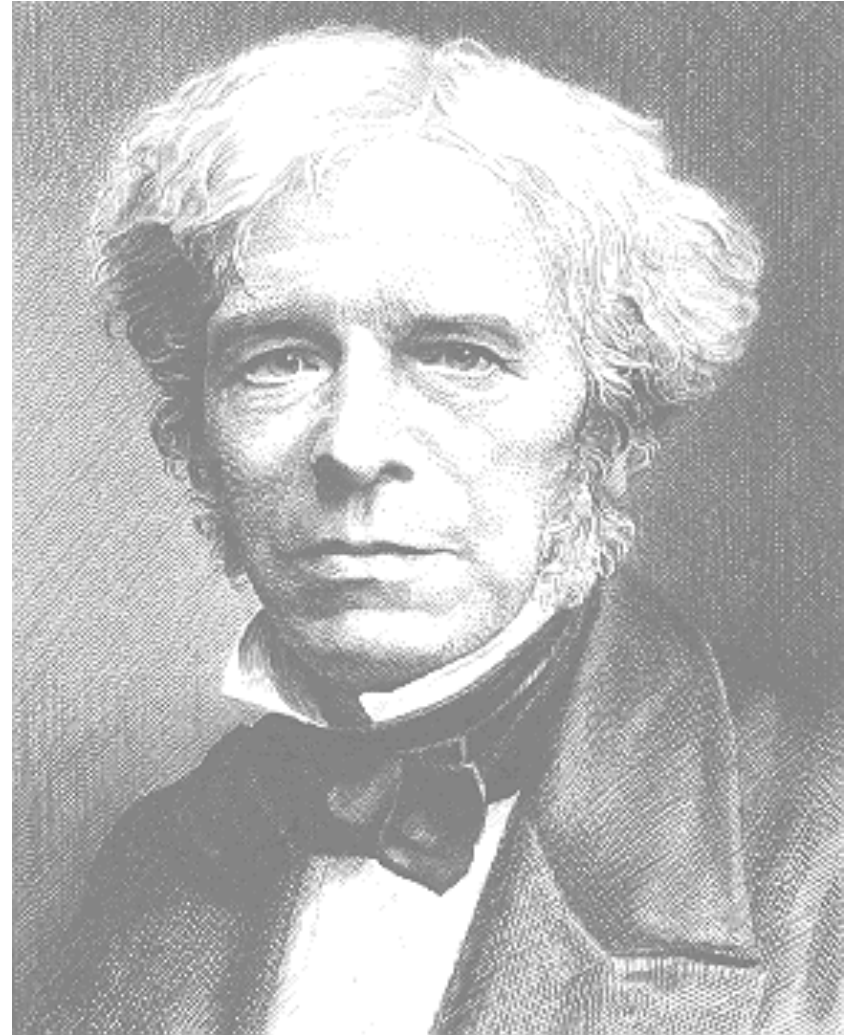
Action at a distance

- How is force from A to B transmitted through space?
- Best Newton could come up with was *action at a distance*
- Unsatisfying since no mechanism to explain how force is transmitted
- And what if A is moving with respect to B
- How quickly does B know about A's new position?
 - ◆ Newton would say instantaneously



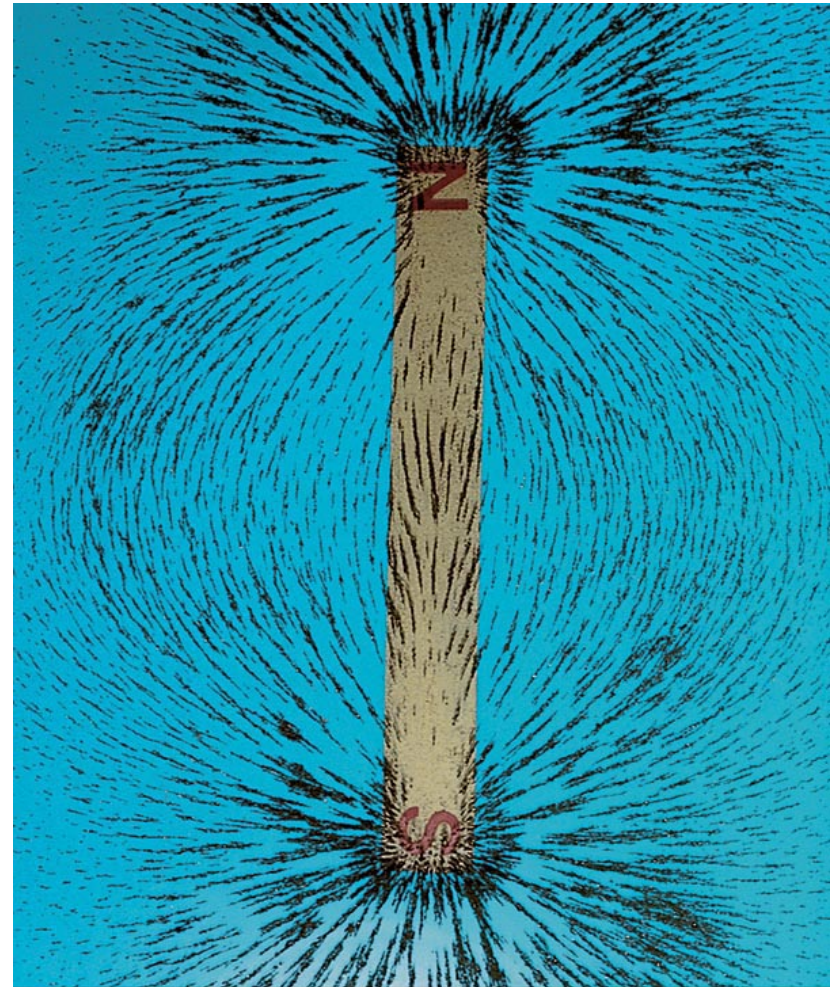
Enter Michael Faraday

- 1791 – 1867
- Chemist and Physicist
- Self-taught
- Responsible for
 - modern electric motor, generator, and transformer
- We'll see his name many times during the course



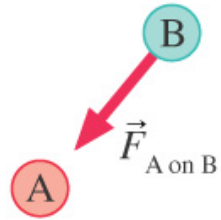
Fields

- Faraday was struck by the way iron filings lined up around a bar magnet
- Perhaps the magnet is altering space around itself, and this alteration is responsible for the long range force
- Faraday's idea came to be called a field
- It's very intuitive (like most of Faraday's thoughts) but the idea of a field was placed on a firm mathematical footing only by James Clerk Maxwell

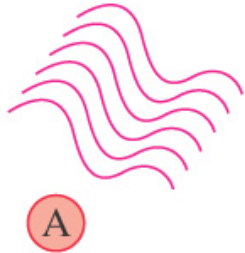


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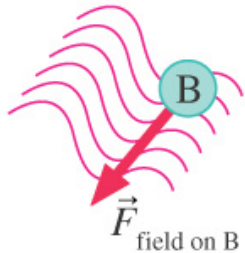
Compare action at a distance and field



In the Newtonian view, A exerts a force directly on B.



In Faraday's view, A alters the space around it. (The wavy lines are poetic license. We don't know what the alteration looks like.)

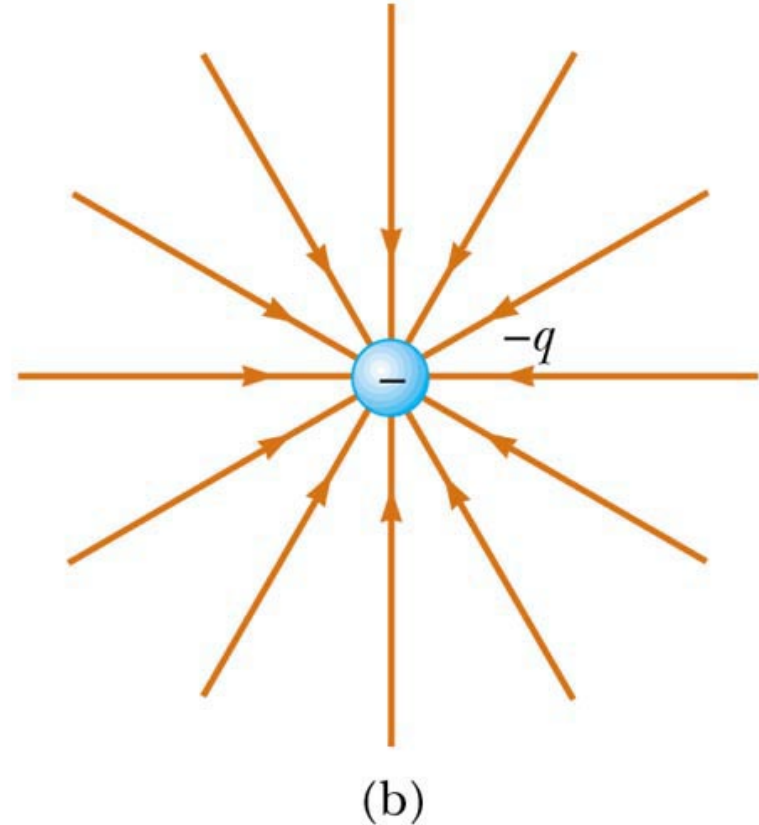
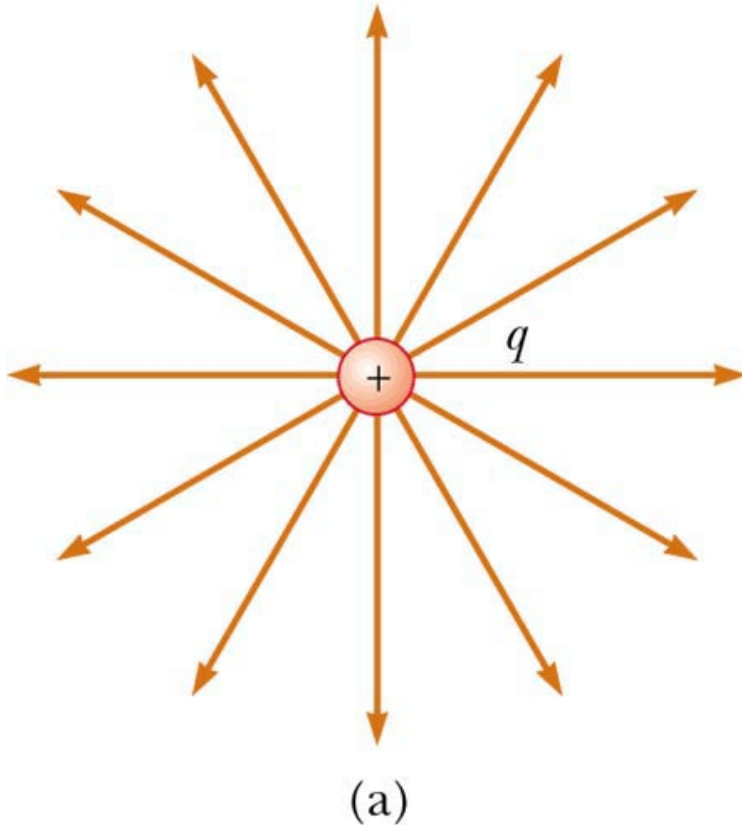


Particle B then responds to the altered space. The altered space is the agent that exerts the force on B.

- So we're going to replace the idea of action at a distance by the concept of a field
- Particles don't interact directly with each other
- They create fields which then interact with the other particles
 - ◆ we will need this when we start talking about dynamic situations
- We'll be dealing with electric and magnetic fields in this course

Electric Field Lines

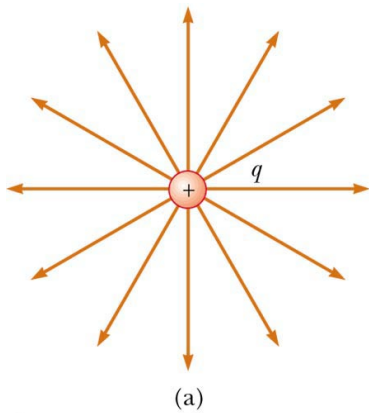
Indicate direction and magnitude of electric field at any point in space



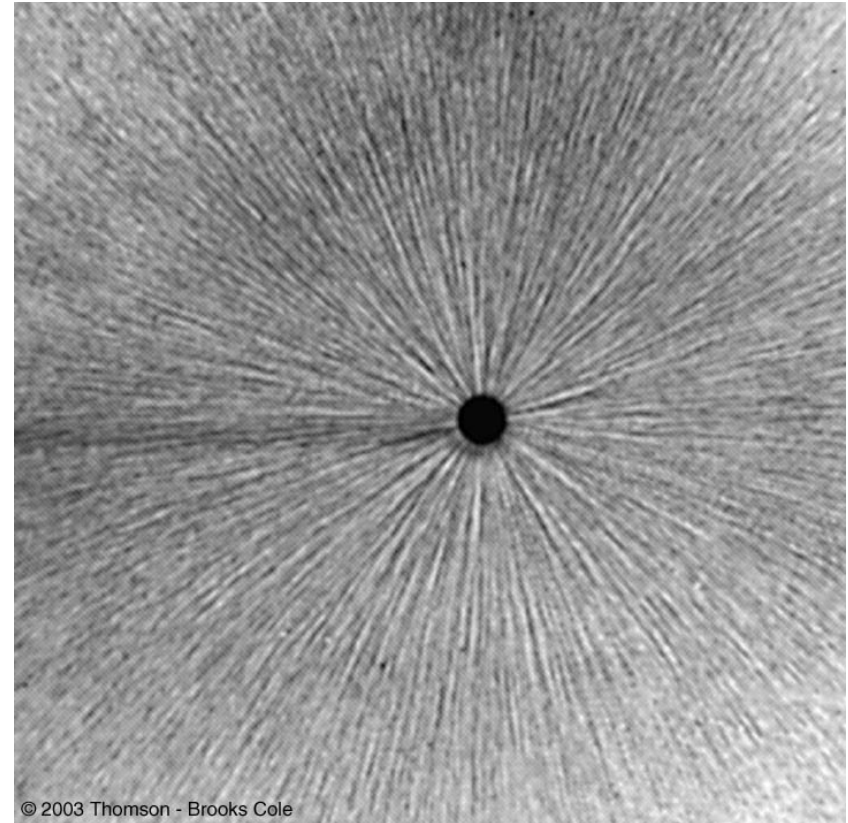
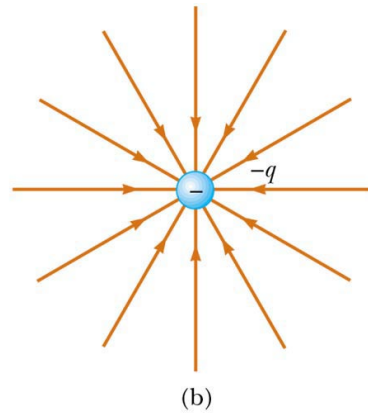
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If only there was some way to see them.

Single Point Charge

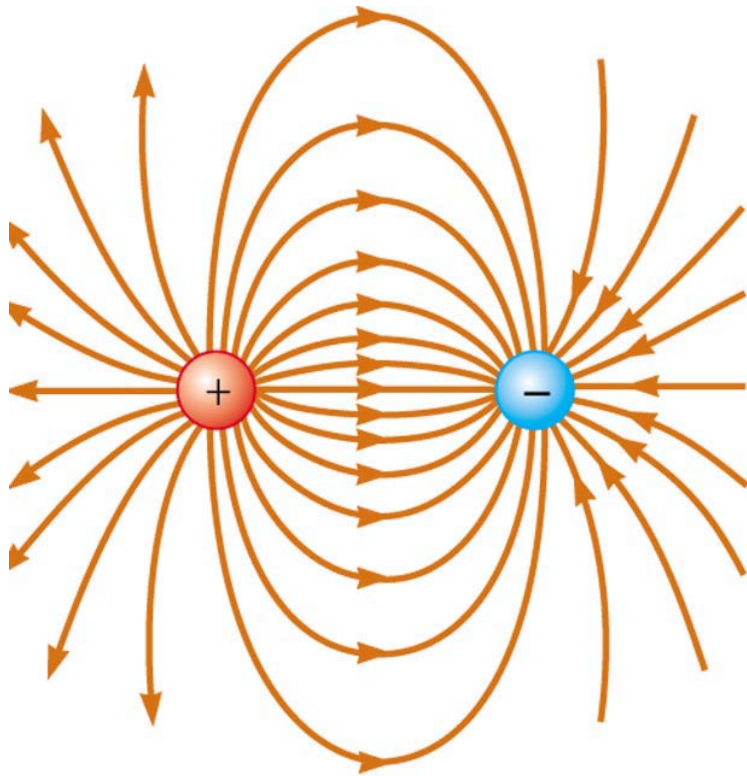


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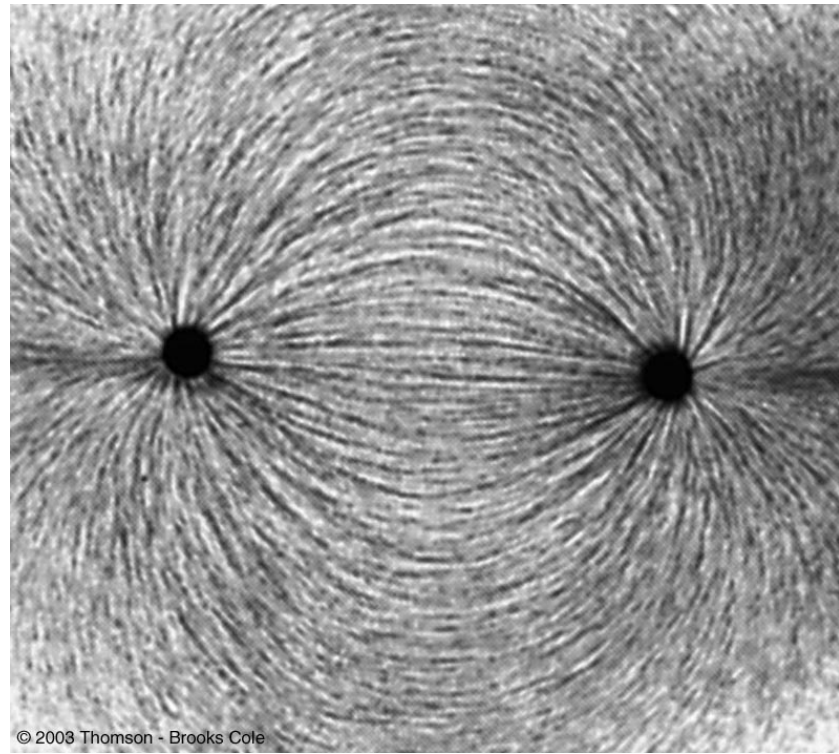
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Electric Dipole



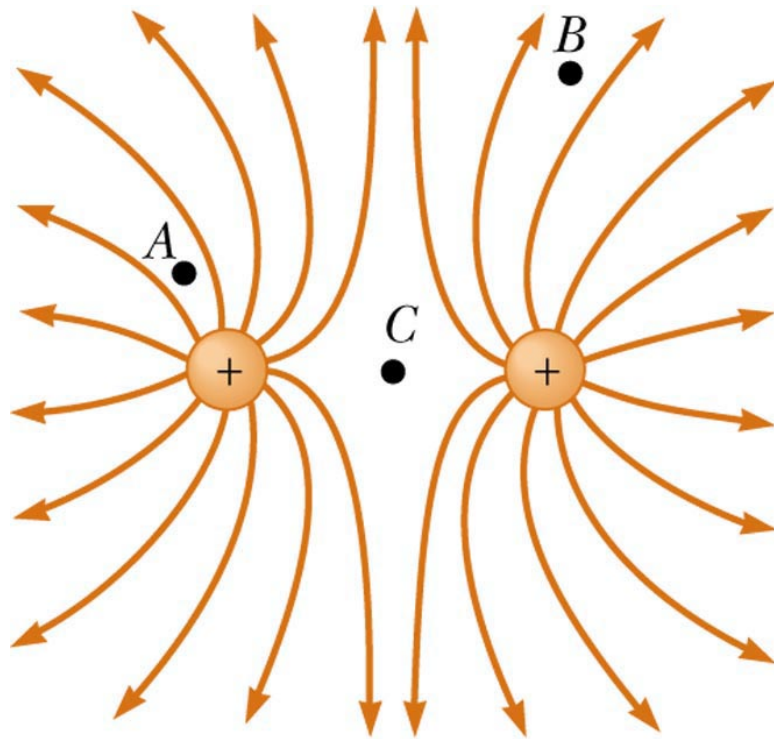
(a)

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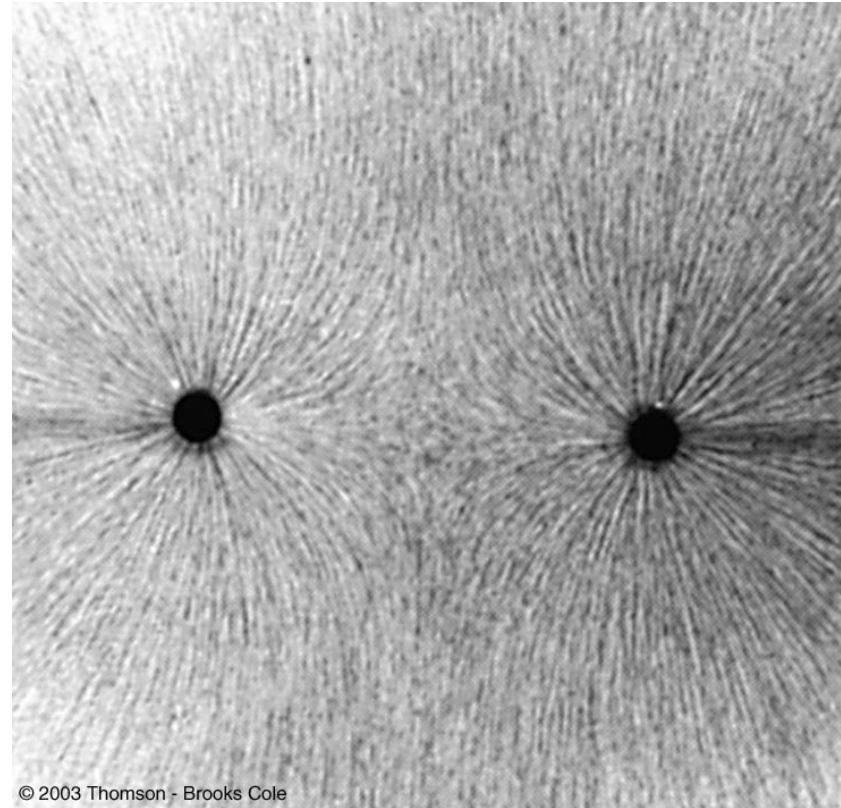
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2 equal positive charges



(a)

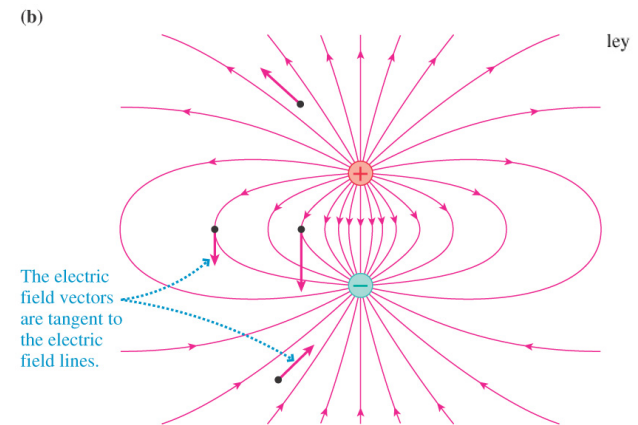
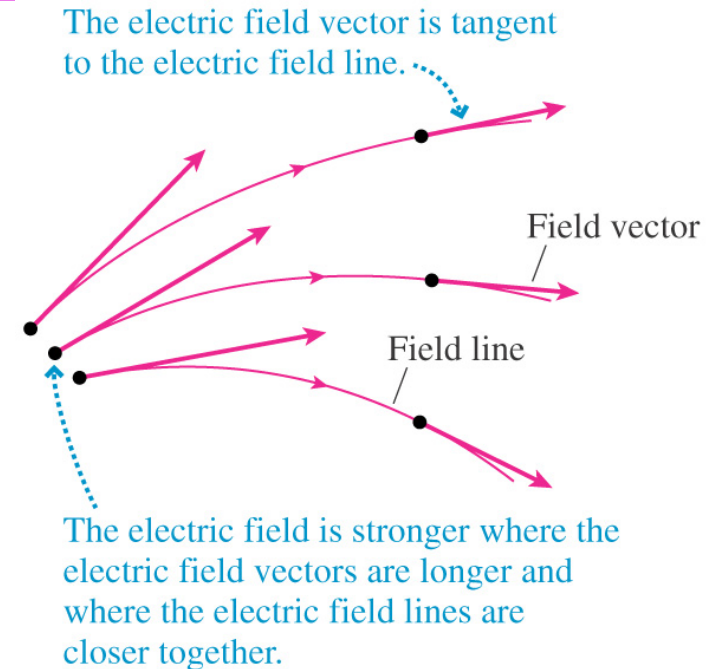
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Drawing/interpreting electric field lines

- Pretty useful idea but we need some guidelines
 - ◆ electric field lines point in direction of field at that point in space
 - ◆ the total number of electric field lines is proportional to the size of the charge
 - ◆ close to an electric charge, the field lines look like that due to the point charge alone
 - ◆ the density of field lines is proportional to the strength of the electric field
 - ◆ electric field lines originate on + charges and terminate on - charges
 - ◆ no 2 field lines can cross in free space
 - ▲ don't cross the streams



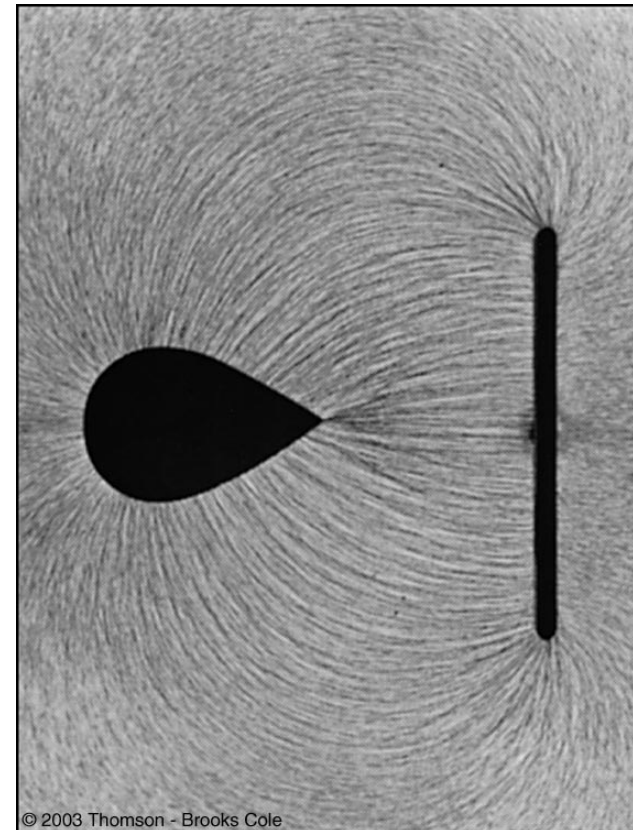
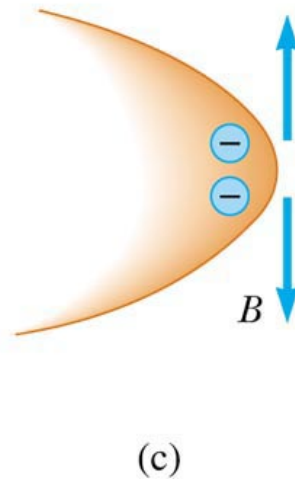
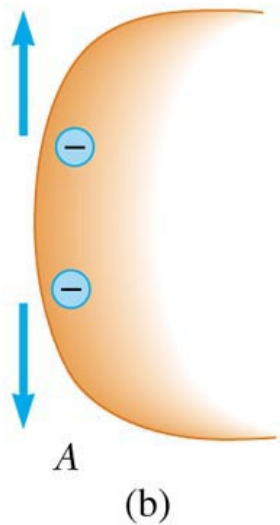
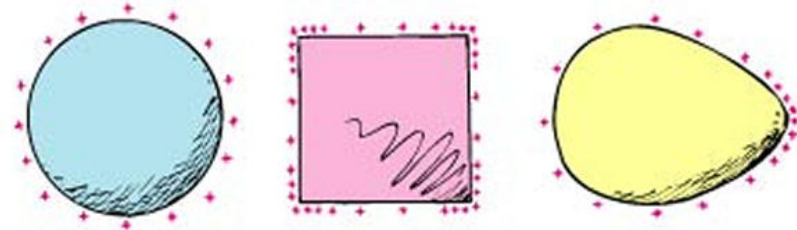
Don't cross the electric field lines

- Dr. Egon Spengler: There's something very important I forgot to tell you
- Peter Venkman: What?
- Egon Spengler: Don't cross the streams.
- Peter Venkman: Why?
- Egon Spengler: It would be bad.
- Peter Venkman: I'm fuzzy on the whole good/bad thing. What do you mean, "bad?"
- Egon Spengler: Try to imagine all life as you know it stopping instantaneously and every molecule in your body exploding at the speed of light.
- Ray Stantz: Total protonic reversal.
- Peter Venkman: Right. That's bad. Okay. All right. Important safety tip. Thanks, Egon.



Sharp edges

- If I have a charged object with a pointy end, then the electric field lines are more concentrated there
 - ◆ electrons are more concentrated there
- So lightning rods have pointy ends



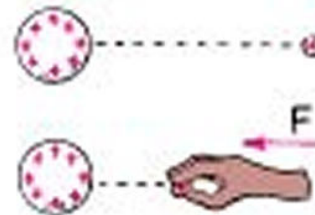
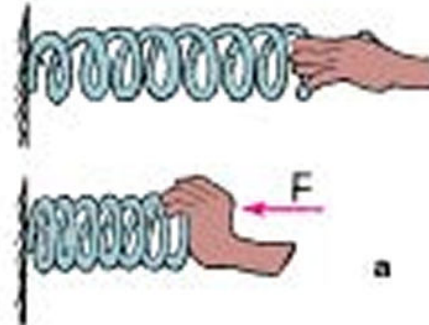
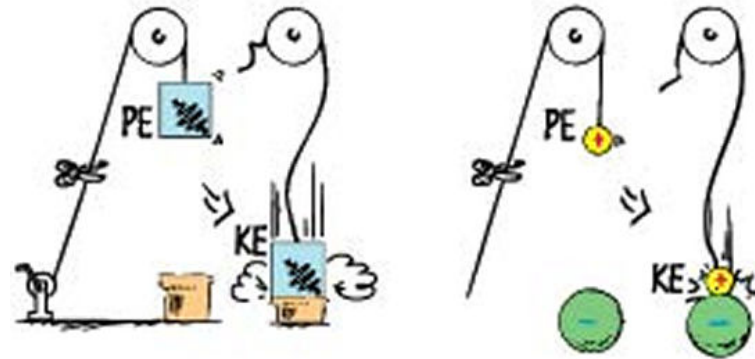
Lightning rods

- In the United States, the pointed lightning rod conductor, also called a “lightning attractor” or “Franklin rod” was invented by Benjamin Franklin in 1749 as part of his groundbreaking explorations of electricity
- Franklin speculated that with an iron rod sharpened to a point at the end, *“The electrical fire would, I think, be drawn out of a cloud silently, before it could come near enough to strike [...].”*



Electric potential energy

- When we talked about gravity, we learned that an object has gravitational energy because of its location in a gravitational field
- Just as work is required to lift a massive object against a gravitational field of Earth, work is required to push a charged particle against the electric field of a charged body
- The work changes the potential energy of a charged particle
- Work done in compressing a spring increases the potential energy of the spring
- Work done in pushing a + charged particle towards a + charged sphere increases the potential energy of the charged particle



If I let go of the charged particle, it accelerates away to the right, changing potential energy to kinetic

Electric potential

- It is convenient to define the electric potential energy per unit charge
- Simply divide the amount of energy by the amount of charge

$$\text{electric potential} = \frac{\text{electric potential energy}}{\text{amount of charge}}$$

- The unit of measurement for electric potential is the Volt, so electric potential is often called voltage
 - ◆ 1 Volt = 1 Joule/Coulomb
- Thus a 1.5 Volt battery gives 1.5 Joules of energy to every 1 Coulomb of charge flowing through the battery

- The voltage can be defined at any point in space, whether a charge is present at that point or not
- When the ends of a heat conductor are at different temperatures, heat energy flows from the hotter end to the cooler end
- When the ends of an electrical conductor are at different electric potentials-when there is a potential difference-charges in the conductor flow from the higher potential to the lower potential
- Without a potential difference, no charge will flow

Potential differences

- Water will flow from a region of higher gravitational potential to lower gravitational potential, but not vice versa unless something does work to make it so
- That something could be a pump for example
 - ◆ with a pump, there can be a continuous flow of water
- Electric charge also moves naturally from a region of higher electric potential to lower electric potential
- To go the opposite direction, something has to perform work
- That something can be a battery for example
 - ◆ with a battery, there can be a continuous flow of electric current

