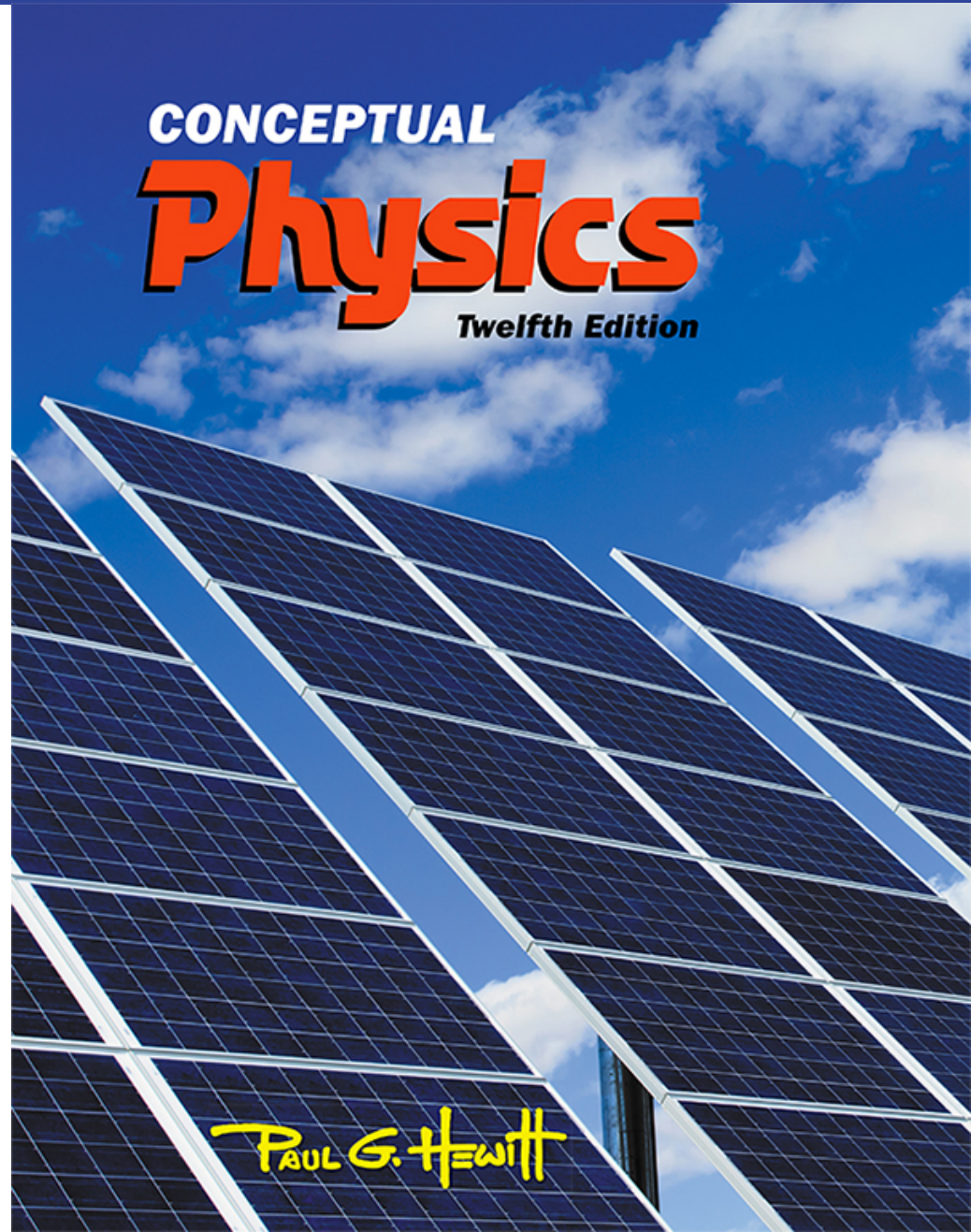


Lecture Outline

Chapter 22: Electrostatics



This lecture will help you understand:

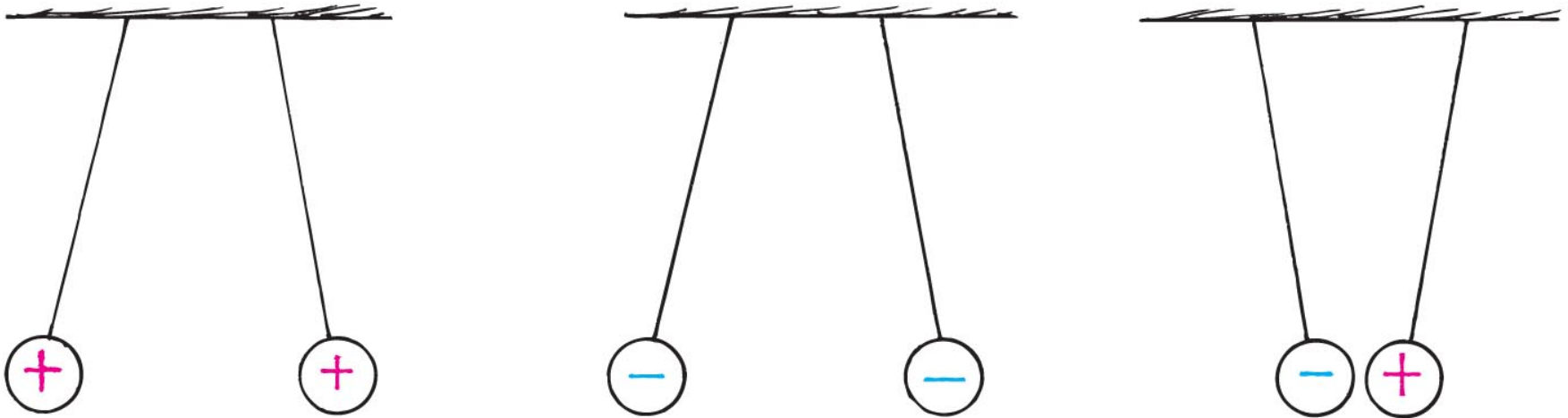
- Electrical Forces and Charges
- Conservation of Charge
- Coulomb's Law
- Conductors and Insulators
- Superconductors
- Charging
- Charge Polarization
- Electric Field
- Electric Potential
- Electric Energy Storage

Electricity

- Electricity is the name given to a wide range of electrical phenomena, such as
 - lightning.
 - spark when we strike a match.
 - what holds atoms together.
- Electrostatics involves electric charges,
 - the forces between them,
 - the force field (really) that surrounds them, and
 - their behavior in materials.

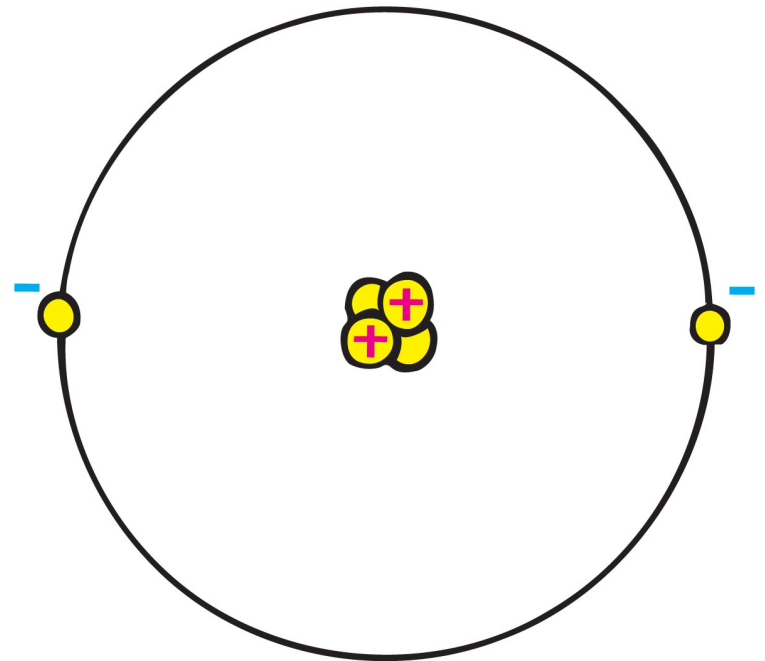
Electric Force and Charges

- Central rule of electricity
 - Opposite charges attract one another; like charges repel.



Electric Force and Charges, Continued

- Protons
 - Positive electric charges
 - Repel positives, but attract negatives
- Electrons
 - Negative electric charges
 - Repel negatives, but attract positives
- Neutrons
 - Neutral electric charge



Electric Force and Charges, Continued-1

- Fundamental facts about atoms
 1. Every atom is composed of a positively charged nucleus surrounded by negatively charged electrons.
 2. Each of the electrons in any atom has the same quantity of negative charge and the same mass.

Electric Force and Charges, Continued-2

- Fundamental facts about atoms (continued)
 3. Protons and neutrons compose the nucleus. Protons are about 1800 times more massive than electrons, but each one carries an amount of positive charge equal to the negative charge of electrons. Neutrons have slightly more mass than protons and have no net charge.
 4. Atoms usually have as many electrons as protons, so the atom has zero net charge.

Electric Force and Charges, Continued-3

- Ion
 - Positive ion—atom losing one or more electrons has positive net charge.
 - Negative ion—atom gaining one or more electrons has negative net charge.

Electric Force and Charges, Continued-4

- Electrons in an atom
 - Innermost—attracted very strongly to oppositely charged atomic nucleus
 - Outermost—attracted loosely and can be easily dislodged

Electric Force and Charges, Continued-5

- Electrons in an atom
 - Examples:
 - When rubbing a comb through your hair, electrons transfer from your hair to the comb. Your hair has a deficiency of electrons (positively charged).
 - When rubbing a glass rod with silk, electrons transfer from the rod onto the silk and the rod becomes positively charged.

Electric Force and Charges

CHECK

When you brush your hair and scrape electrons from your hair, the charge of your hair is

- A. positive.
- B. negative.
- C. Both A and B.
- D. Neither A nor B.

Electric Force and Charges

CHECK

When you brush your hair and scrape electrons from your hair, the charge of your hair is

A. positive.

Comment:

And if electrons were scraped off the brush onto your hair, your hair would have a negative charge.

Conservation of Charge

- Conservation of charge
 - In any charging process, no electrons are created or destroyed. Electrons are simply transferred from one material to another.



Summarizing the properties of charge:

- 1. Charge is quantized in units of $|e| = 1.6 \times 10^{-19} \text{ C}$
- 2. Electrons carry one unit of negative charge, $-e$
- 3. Protons carry one unit positive charge, $+e$
- 4. Objects become charged by gaining or losing electrons, not protons
- 5. Electric charge is always conserved

Table 3.1: *Properties of electrons, protons, and neutrons*

Particle	Charge [C]	[e]	Mass [kg]
electron (e^-)	-1.60×10^{-19}	-1	9.11×10^{-31}
proton (p^+)	$+1.60 \times 10^{-19}$	$+1$	1.67×10^{-27}
neutron (n^0)	0	0	1.67×10^{-27}

Coulomb's Law

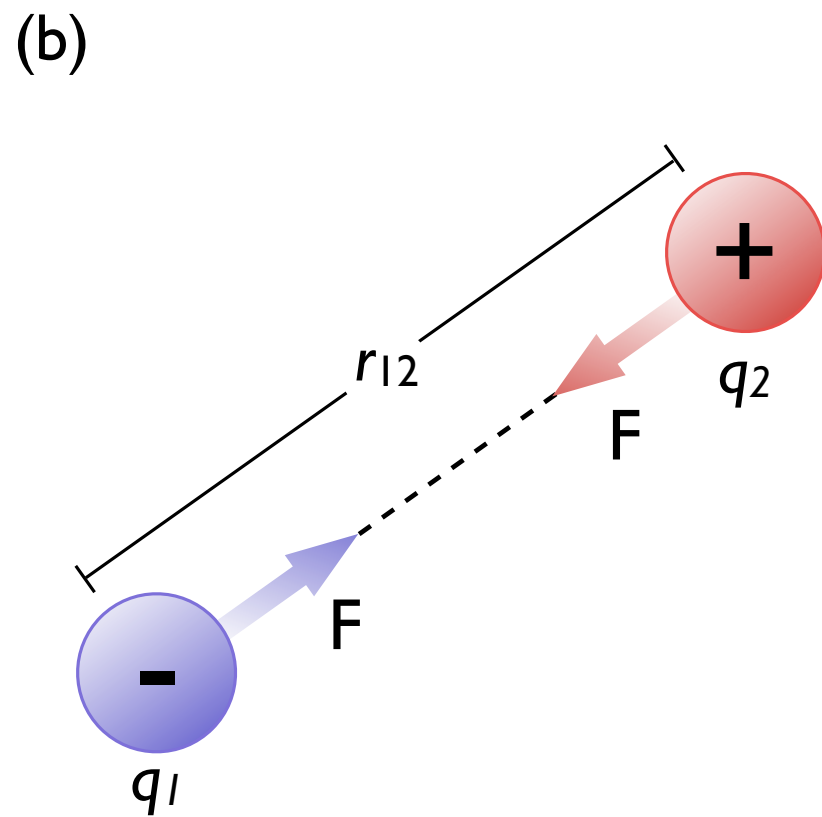
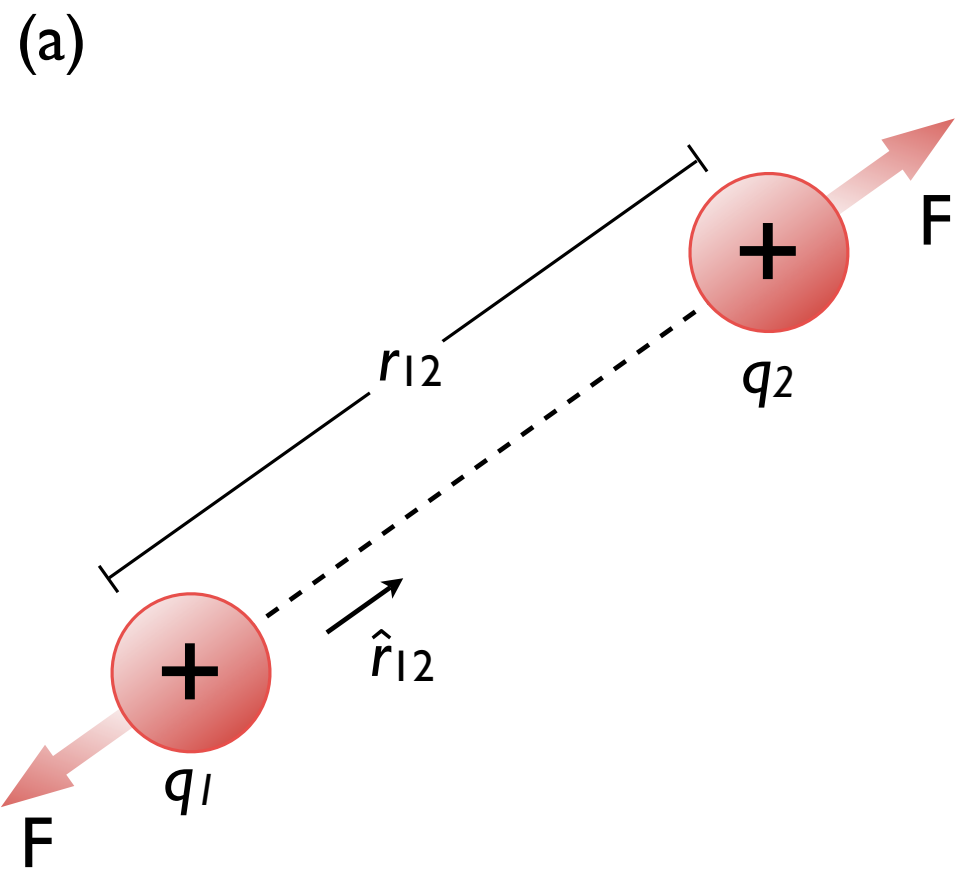
- Coulomb's law
 - Relationship among electrical force, charge, and distance discovered by Charles Coulomb in the 18th century
 - States that for a pair of charged objects that are much smaller than the distance between them, the force between them varies directly, as the product of their charges, and inversely, as the square of the separation distance

Coulomb's Law, Continued

- Coulomb's law (continued)
 - If the charges are alike in sign, the force is repelling; if the charges are not alike, the force is attractive.
 - In equation form:

$$F = k \frac{q_1 q_2}{d^2} \quad k = 9,000,000,000 \text{ Nm}^2/\text{C}^2$$

- Unit of charge is coulomb, C
- Similar to Newton's law of gravitation for masses
- Underlies the bonding forces between molecules



The electric force is crazy strong

- we are lucky matter is electrically neutral
- illustrative problem:

1. 10 points. (a) How much negative charge and how much positive charge are there on the electrons and the protons in a cup of water (0.25 kg)? Note Avogadro's number is $N_A = 6.022 \times 10^{23}$, and each oxygen atom has 8 electrons. (b) What is the magnitude of the attractive force exerted by the electrons in a cup of water on the protons in a second cup of water at a distance of 10 m?

Note 10m is about 10 yards or 30 ft!

The “molecular mass” of water is 18 g/mol, so 250 g of water amounts to 250/18 mol. For each mole of water, there are 6.02×10^{23} molecules. Each molecule has two hydrogen atoms (with one electron) and one oxygen atom (with eight electrons), with a total of ten electrons per molecule. Thus, we can calculate the total amount of negative charge in the cup of water readily:

$$\begin{aligned} [\text{neg. chg.}] &= 0.25 \text{ kg} \left[\frac{1000 \text{ g}}{1 \text{ kg}} \right] \left[\frac{1 \text{ mol}}{18 \text{ g}} \right] \left[\frac{6.02 \times 10^{23} \text{ molecules}}{\text{mol}} \right] \left[\frac{10 \text{ electrons}}{\text{molecule}} \right] \left[\frac{-1.6 \times 10^{-19} \text{ C}}{\text{electron}} \right] \\ &= 1.3 \times 10^7 \text{ C} \end{aligned}$$

Clearly, since the cup of water is overall electrically neutral, the positive charge on the protons is just the opposite of this.

If we treat the total charge in each glass of water as point charges, then in the first cup of water we have one point charge of $-1.3 \times 10^{-7} \text{ C}$ and another of $1.3 \times 10^{-7} \text{ C}$, separated by 10 m. The force is then:

$$\begin{aligned} |\vec{\mathbf{F}}| &= \frac{k_e q_1 q_2}{r_{12}^2} \\ &= \frac{[9 \times 10^9 \text{ N} \cdot \text{m}^2/\text{C}^2] [-1.3 \times 10^{-7} \text{ C}] [+1.3 \times 10^{-7} \text{ C}]}{[10 \text{ m}]^2} \\ &= -1.5 \times 10^{22} \text{ N} \end{aligned}$$

This is an *enormous* force, equivalent to a weight of a billion billion tons! Thankfully, this attractive force on the protons is precisely canceled by an equally large repulsive force exerted by the protons in one cup on the protons in the other.

So what?

- force is 10^{22} N, or a million billion billion newtons
- the gravitational force between earth and moon is 100 times smaller than this
- if even one atom out of a billion billion atoms were not electrically neutral, nothing would survive
- electrical charge is exquisitely well balanced in the universe, because the results would be catastrophic otherwise (and we would not be around to see it)

Coulomb's Law

CHECK

According to Coulomb's law, a pair of particles that are placed twice as far apart will experience forces that are

- A. half as strong.
- B. one-quarter as strong.
- C. twice as strong.
- D. 4 times as strong.

Coulomb's Law

CHECK

According to Coulomb's law, a pair of particles that are placed twice as far apart will experience forces that are

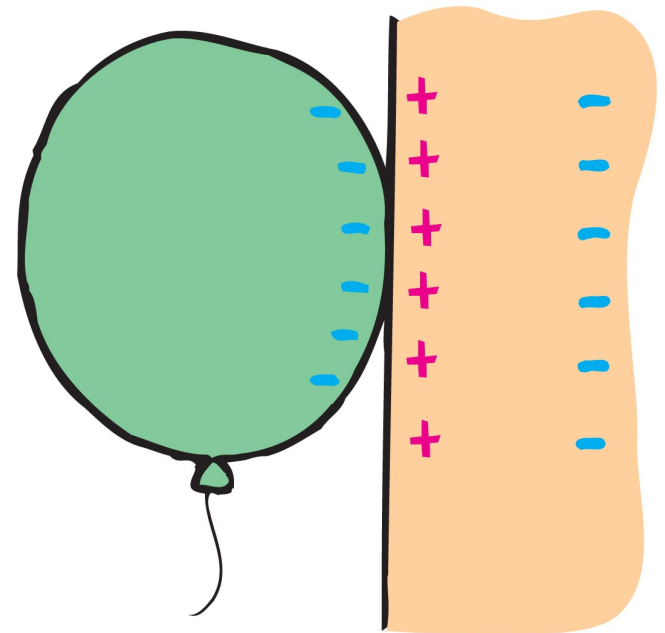
B. one-quarter as strong.

Coulomb's Law, Continued-1

- Differences between gravitational and electrical forces
 - Electrical forces may be either attractive or repulsive.
 - Gravitational forces are only attractive.

Coulomb's Law, Continued-2

- Charge polarization
 - Atom or molecule in which the charges are aligned with a slight excess of positive charge on one side and slight excess of negative charge on the other
 - Example: Rub an inflated balloon on your hair and place the balloon on the wall. The balloon sticks to the wall due to charge polarization in the atoms or molecules of the wall.



Conductors and Insulators

- Conductor: Materials in which one or more of the electrons in the outer shell of its atoms are not anchored to the nuclei of particular atoms but are free to wander in the material
 - Example: Metals such as copper and aluminum
 - charges are very mobile and thus evenly distributed over the surface
- Insulators: Materials in which electrons are tightly bound and belong to particular atoms and are not free to wander about among other atoms in the material, making them flow
 - Example: Rubber, glass
 - charges are not mobile and stay where deposited

Conductors and Insulators, Continued

- Semiconductors: A material that can be made to behave sometimes as an insulator and sometimes as a conductor.
 - Fall in the middle range of electrical resistivity between insulators and conductors.
 - They are insulators when they are in their pure state.
 - They are conductors when they have impurities.
- Semiconductors conduct when light shines on it.
 - If a charged selenium plate is exposed to a pattern of light, the charge will leak away only from the areas exposed to light.

Conductors and Insulators

CHECK

When you buy a water pipe in a hardware store, the water isn't included. When you buy copper wire, electrons

- A. must be supplied by you, just as water must be supplied for a water pipe.
- B. are already in the wire.
- C. may fall out, which is why wires are insulated.
- D. None of the above.

Conductors and Insulators

CHECK YOUR ANSWER

When you buy a water pipe in a hardware store, the water isn't included. When you buy copper wire, electrons

B. are already in the wire.

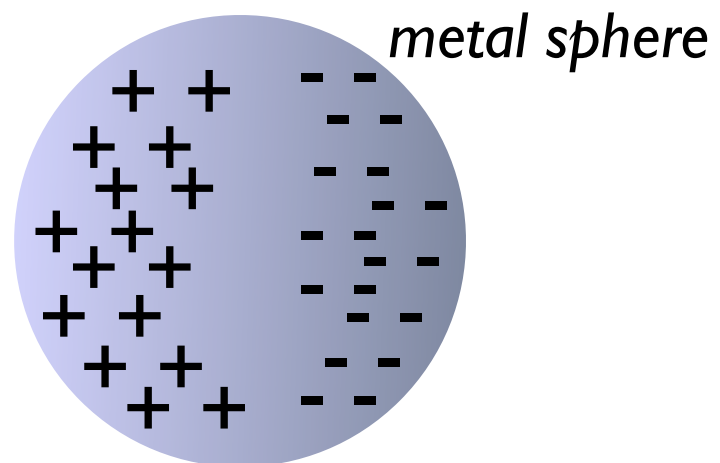
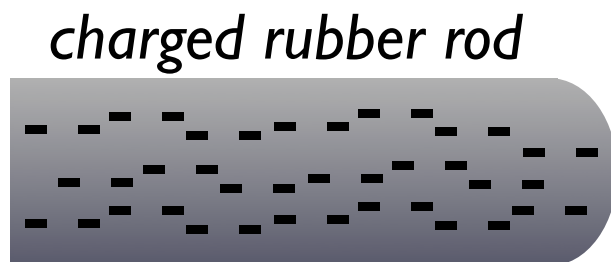
Superconductors

- Superconductors: Materials acquire zero resistance (infinite conductivity) to the flow of charge.
 - Once electric current is established in a superconductor, the electrons flow indefinitely.
 - With no electrical resistance, current passes through a superconductor without losing energy.
 - No heat loss occurs when charges flow.

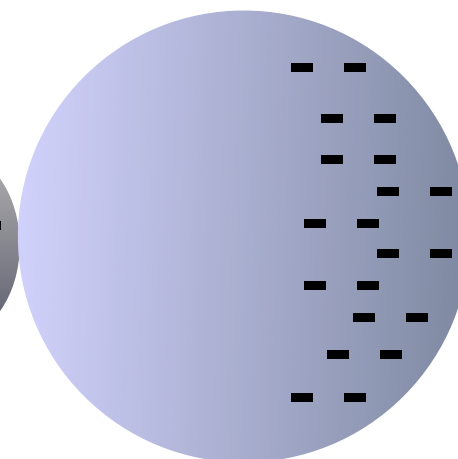
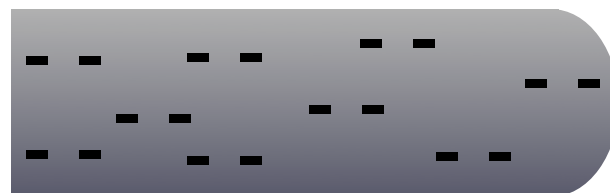
Charging

- Charging by friction and contact.
 - Example:
 - Stroking cats fur, combing your hair, rubbing your shoes on a carpet
 - Electrons transfer from one material to another by simply touching. For example,
 - when a negatively charged rod is placed in contact with a neutral object, some electrons will move to the neutral object.
 - easier with an *insulator* since charges stay put

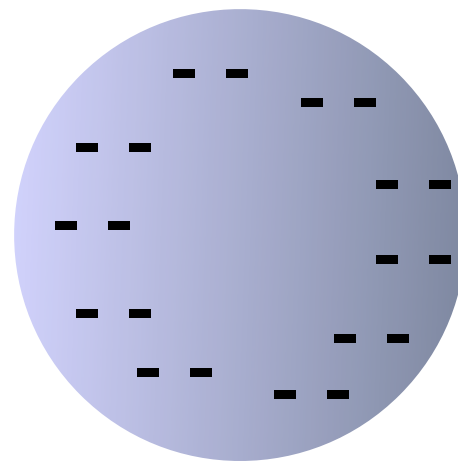
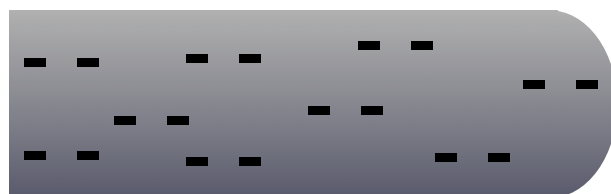
a) before



b) contact



c) after



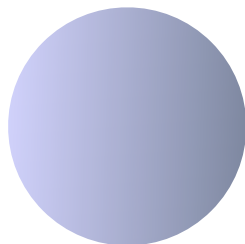
Charging, Continued

- Charging by induction
 - If you bring a charged object *near a conducting surface*, *electrons are made to move* in the surface material, even without physical contact.
 - Example: The negative charge at the cloud induces a positive charge on the buildings below.



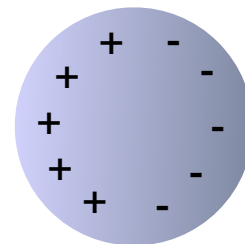
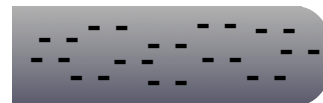
a)

*neutral
metal sphere*

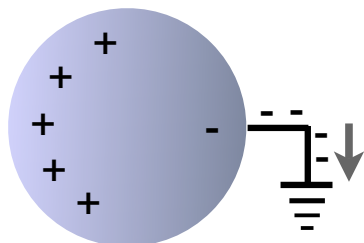
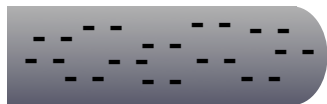


b)

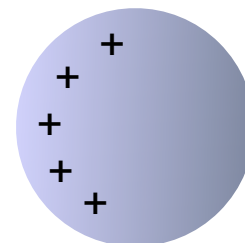
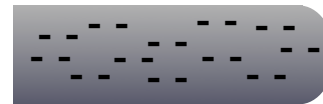
*charged
rubber rod*



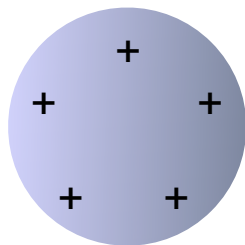
c)



d)

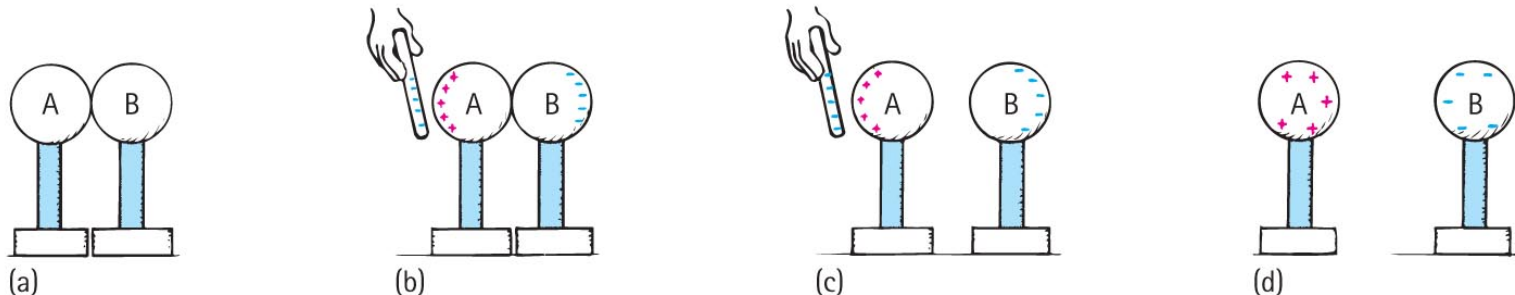


e)



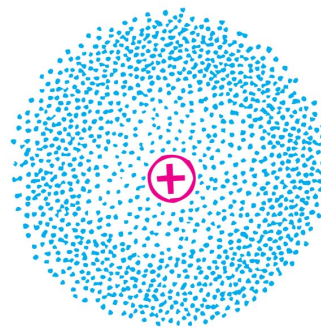
Charging, Continued-1

- Induction: Consider two insulated metal spheres A and B.
 - a. They touch each other, so in effect they form a single uncharged conductor.
 - b. When a negatively charged rod is brought near A, electrons in the metal, being free to move, are repelled as far as possible until their mutual repulsion is big enough to balance the influence of the rod. The charge is redistributed.
 - c. If A and B are separated while the rod is still present, each will be equal and oppositely charged.

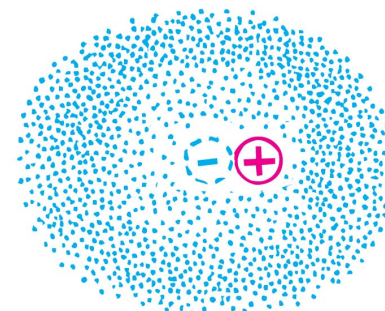


Charge Polarization

- One side of the atom or molecule is induced into becoming more negative (or positive) than the opposite side. The atom or molecule is said to be **electrically polarized**.
- An electron buzzing around the atomic nucleus produces an electron cloud.
 - a. The center of the negative cloud normally coincides with the center of the positive nucleus in an atom.
 - b. When an external negative charge is brought nearby to the right, the electron cloud is distorted so that the centers of negative and positive charge no longer coincide. The atom is now electrically polarized



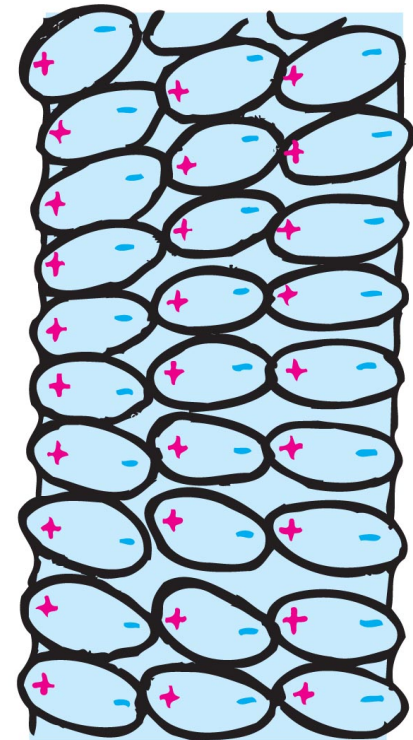
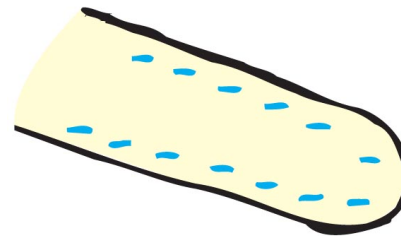
(a)



(b)

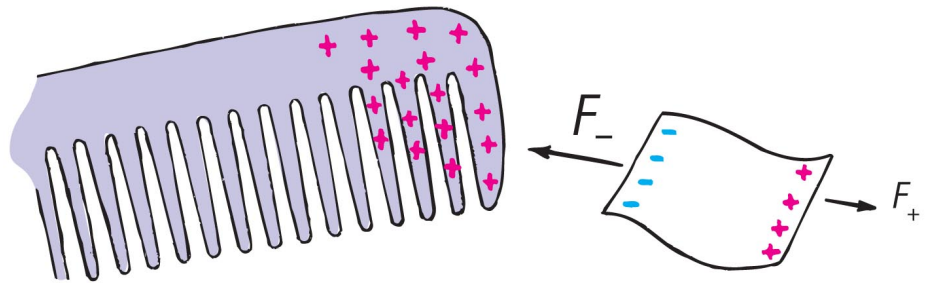
Charge Polarization, Continued

- If the charged rod is negative, then the positive part of the atom or molecule is tugged in a direction toward the rod, and the negative side of the atom or molecule is pushed in a direction away from the rod.
- The positive and negative parts of the atoms and molecules become aligned. They are electrically polarized.



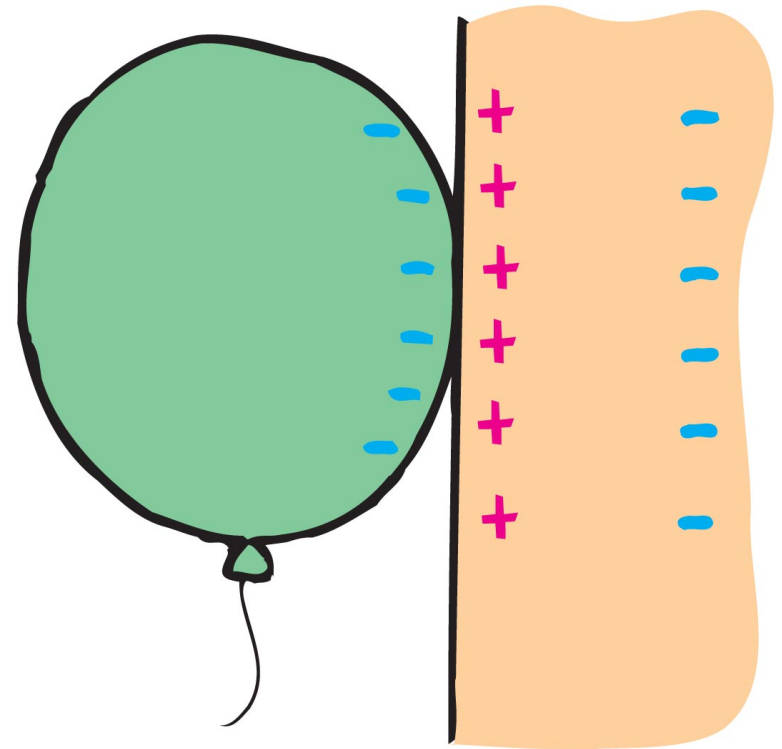
Charge Polarization, Continued-1

- When a charged comb is brought nearby, molecules in the paper are polarized.
- The sign of charge closest to the comb is opposite to the comb's charge.
- Charges of the same sign are slightly more distant. Closeness wins, and the bits of paper experience a net attraction.



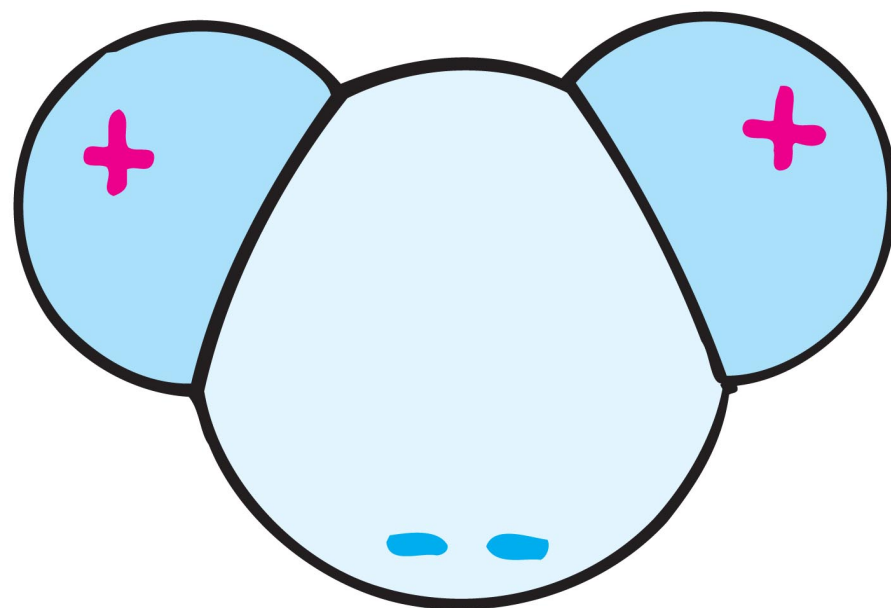
Charge Polarization, Continued-2

- Rub an inflated balloon on your hair, and it becomes charged.
- Place the balloon against the wall, and it sticks.
- This is because the charge on the balloon induces an opposite surface charge on the wall.
- Again, closeness wins, for the charge on the balloon is slightly closer to the opposite induced charge than to the charge of same sign

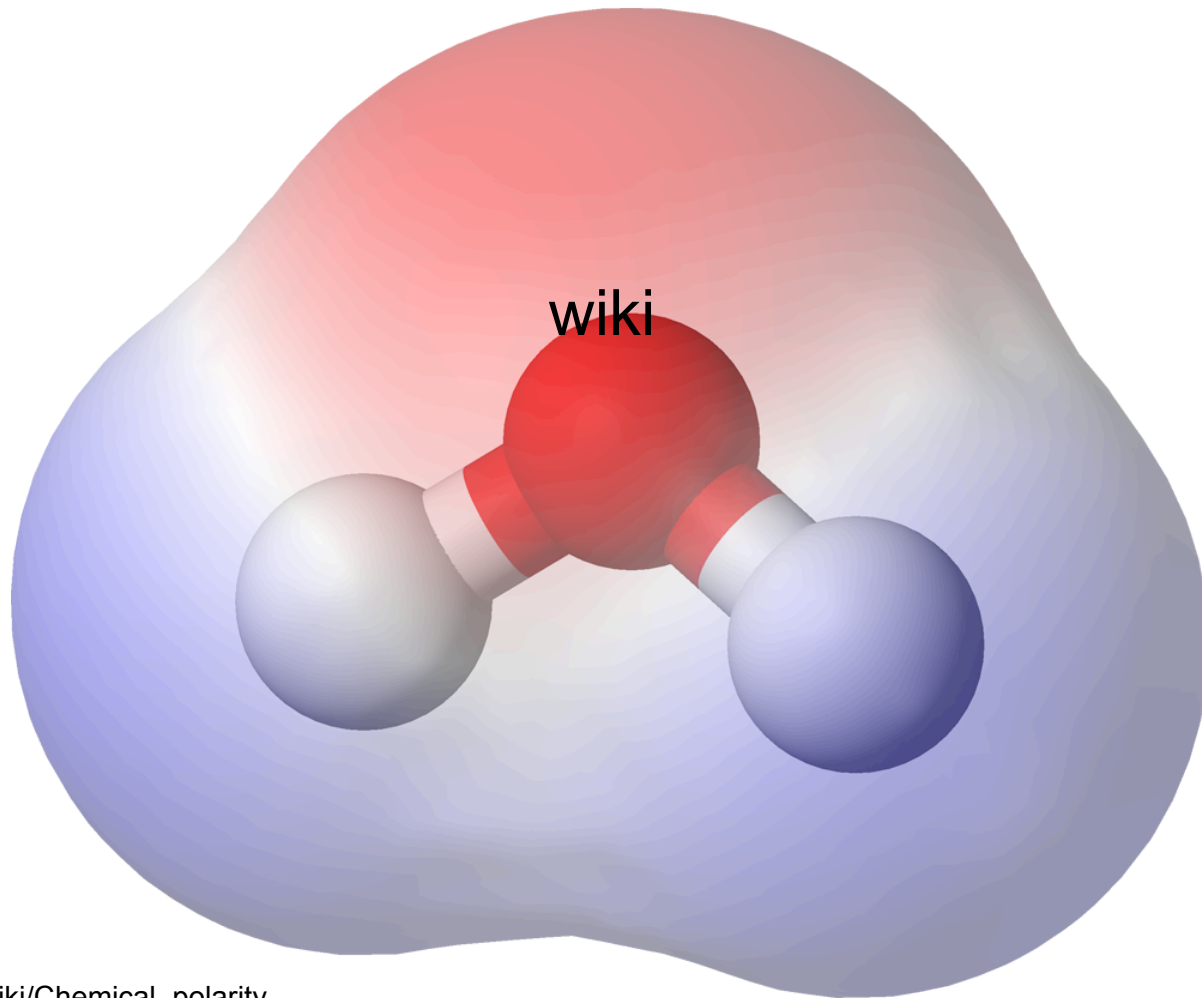


Charge Polarization, Continued-3

- Many molecules— H_2O , for example—are electrically polarized in their normal states.
- The distribution of electric charge is not perfectly even.
- There is a little more negative charge on one side of the molecule than the other.
- Such molecules are said to be *electric dipoles*.

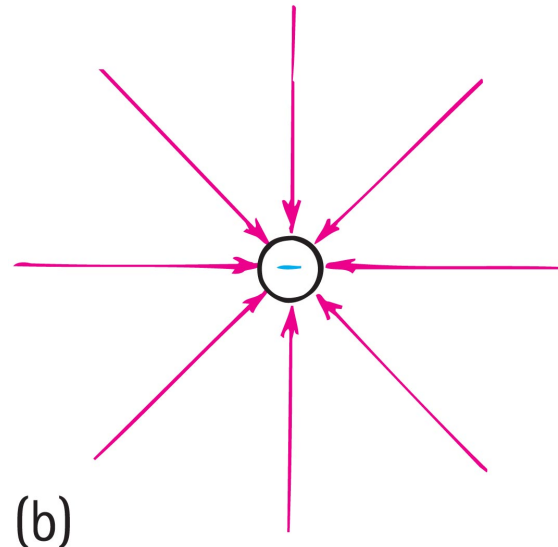


Water molecules have uneven charge distribution
leads to bonding between molecules, anomalous properties



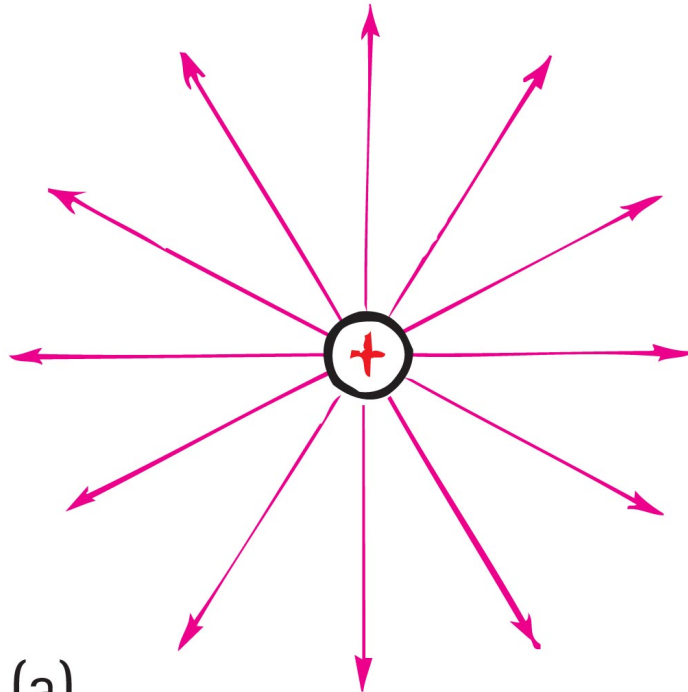
Electric Field

- Electric field
 - Space surrounding an electric charge (an energetic force field or 'aura')
 - Describes electric force
 - Around a charged particle obeys inverse-square law
 - Force per unit charge

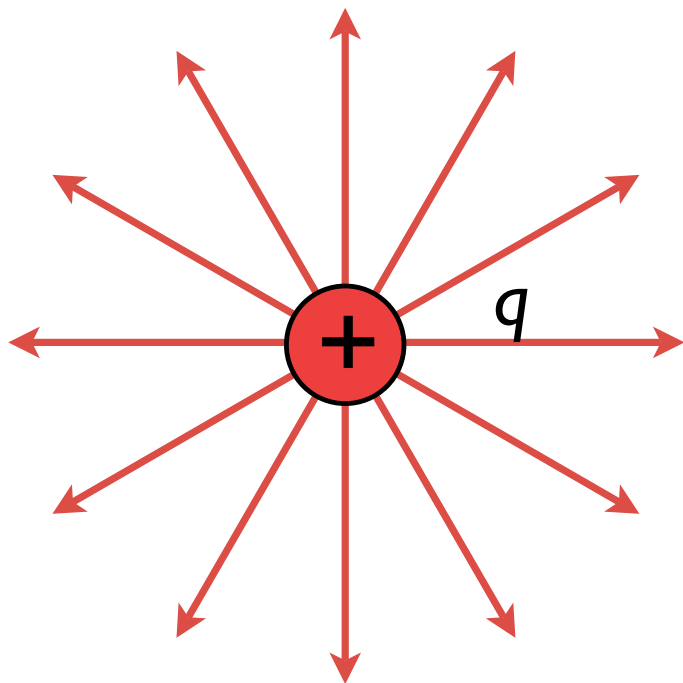


Electric Field, Continued

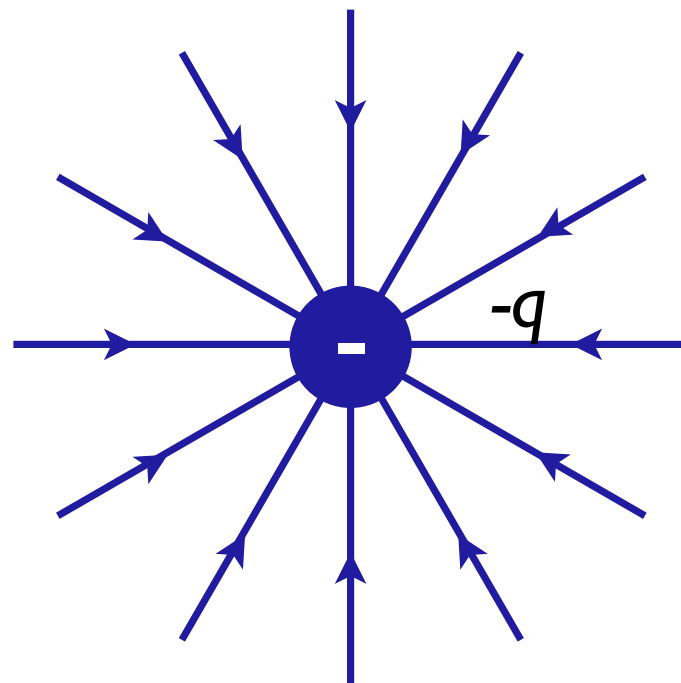
- Electric field direction
 - Same direction as the force on a positive charge
 - Opposite direction to the force on an electron



(a)

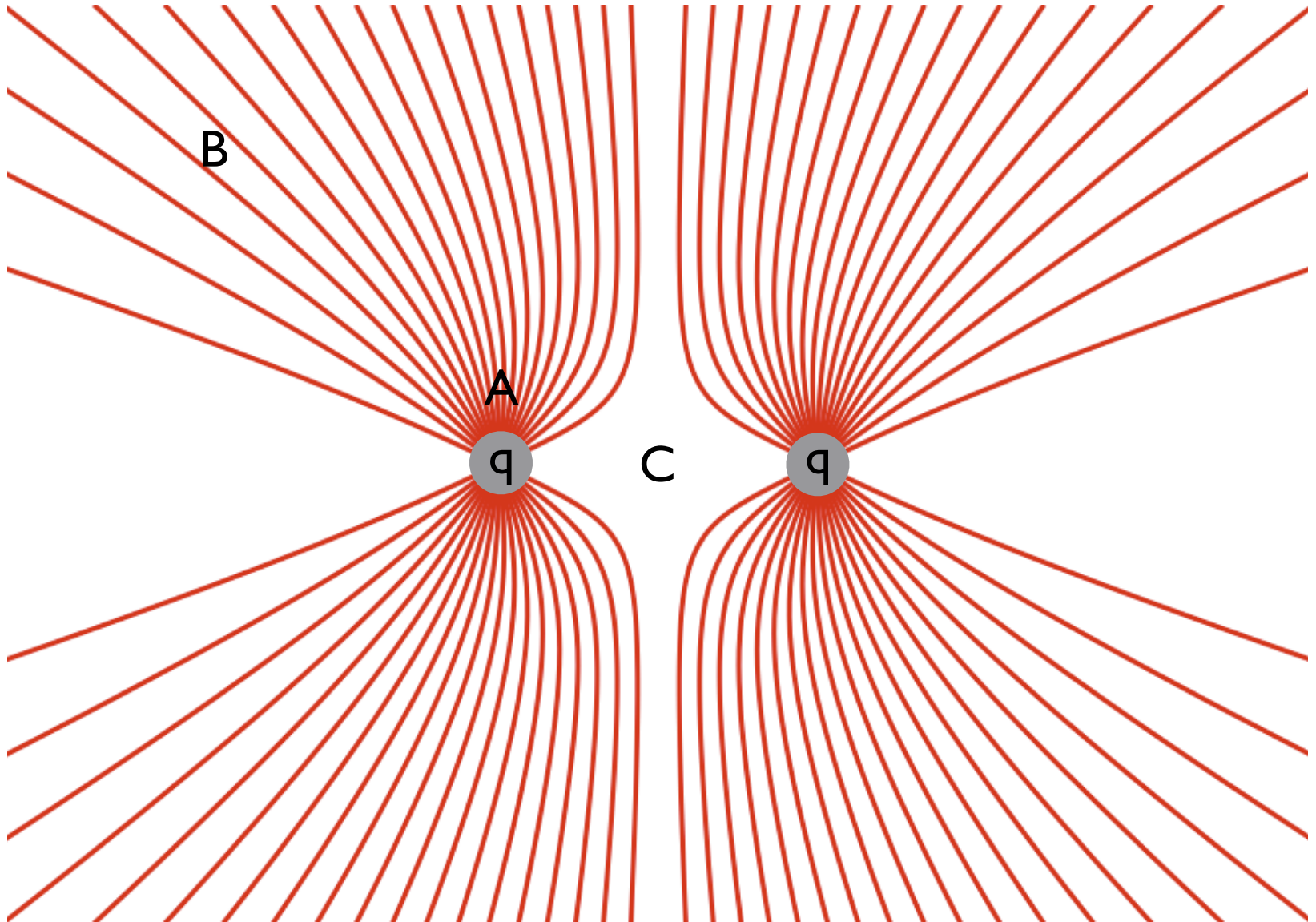


(a)

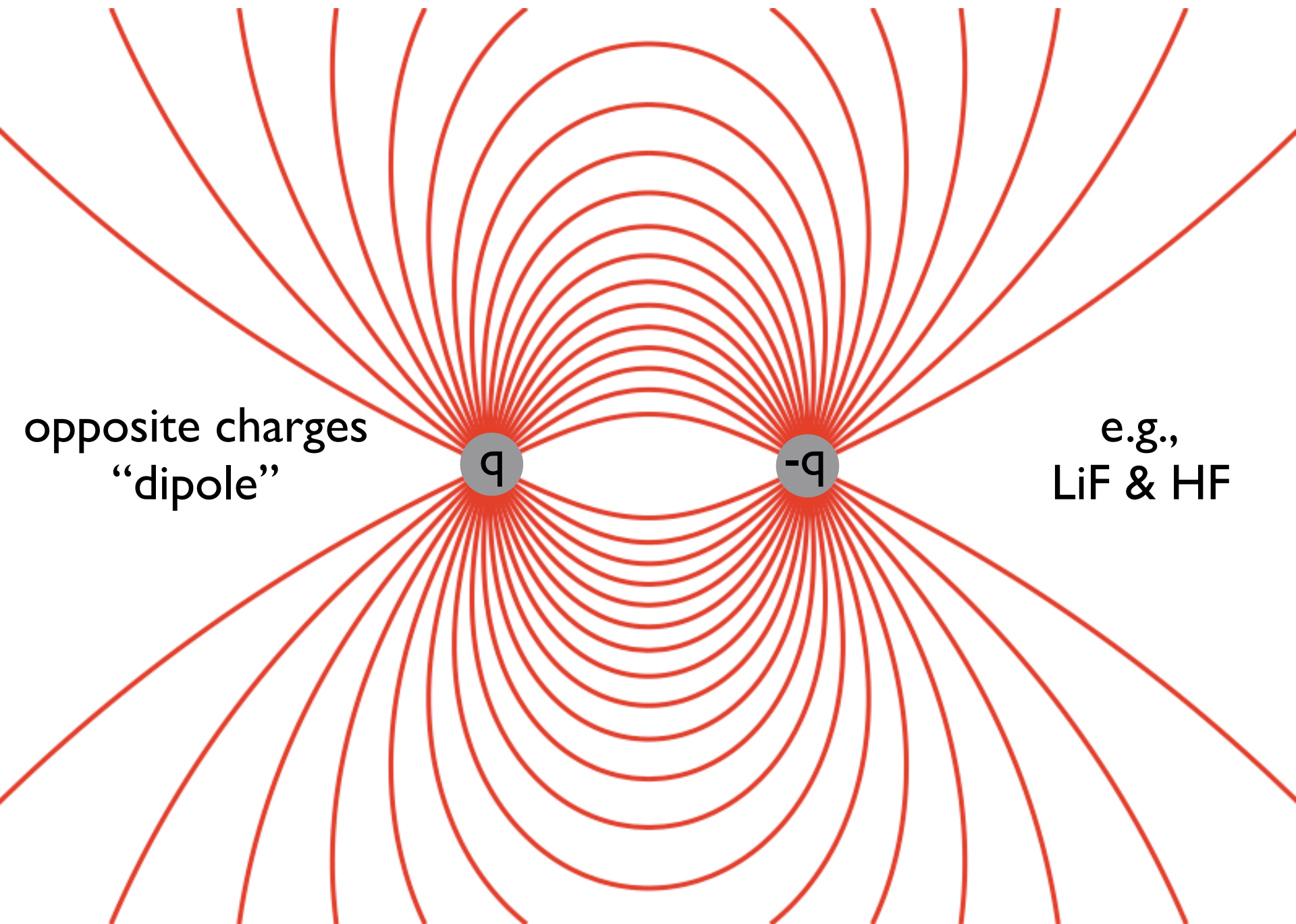


(b)

equal charges



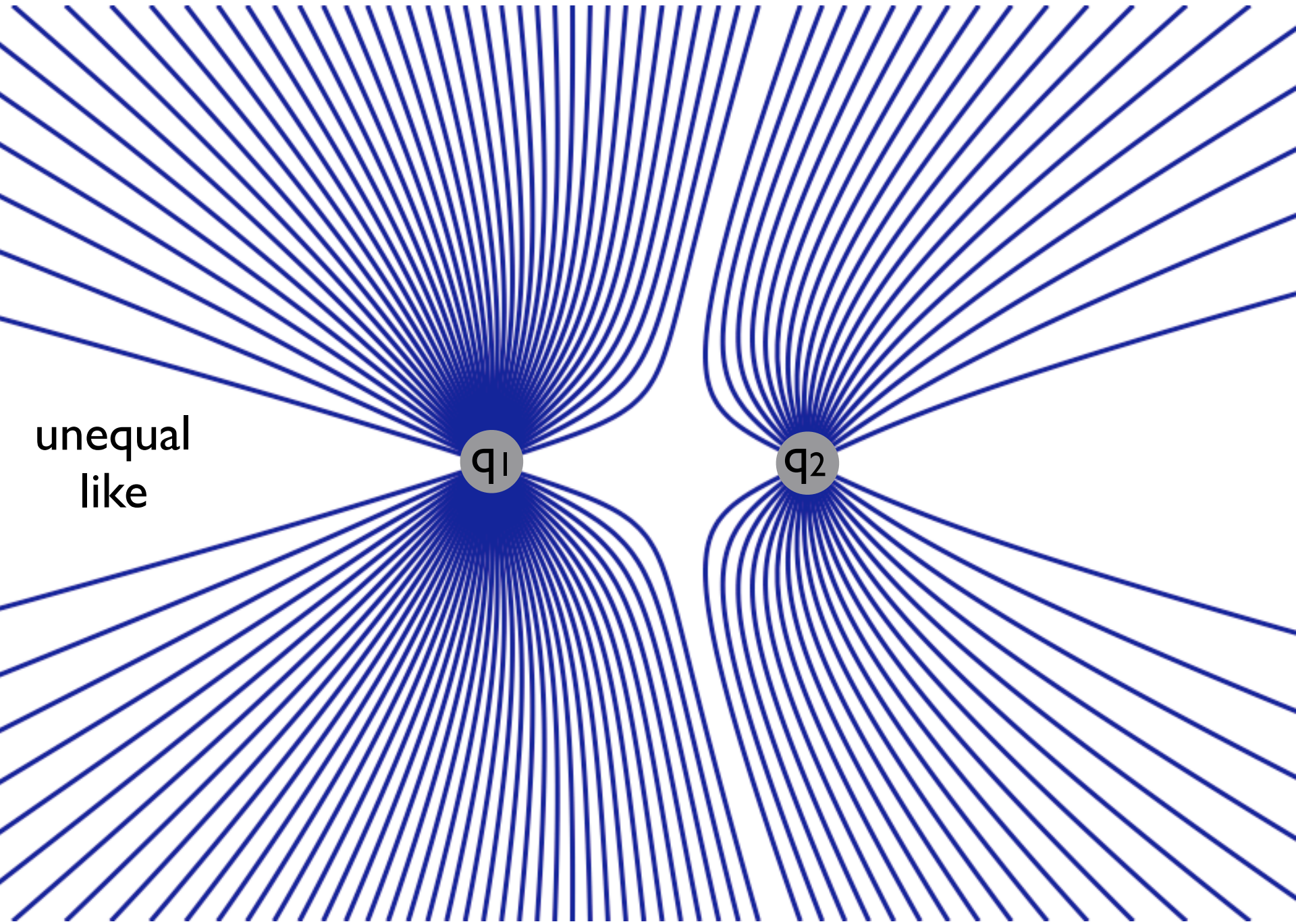
field: $A > B > C$



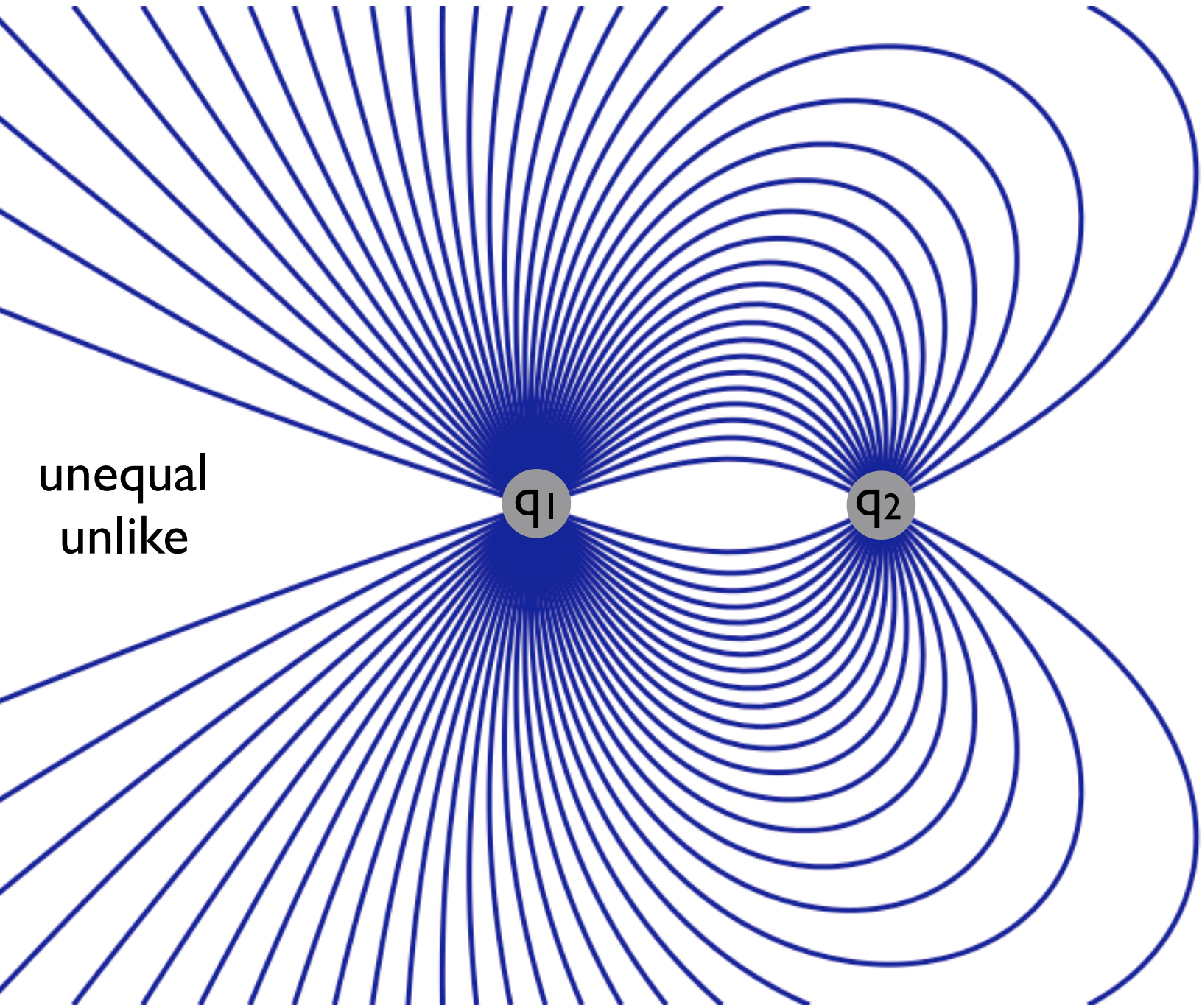
opposite charges
“dipole”

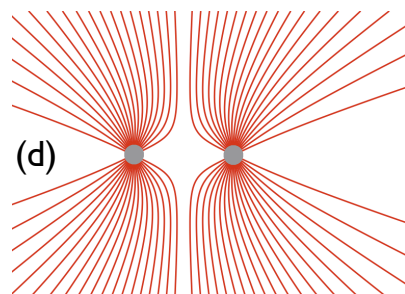
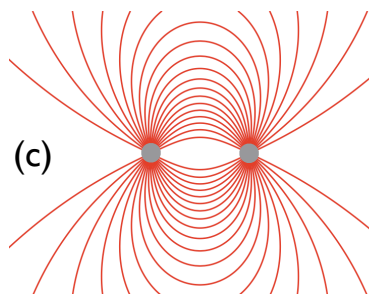
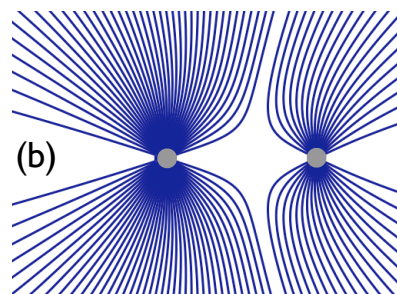
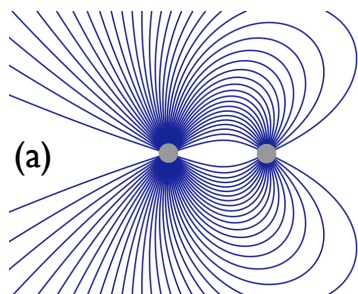
e.g.,
LiF & HF

unequal
like



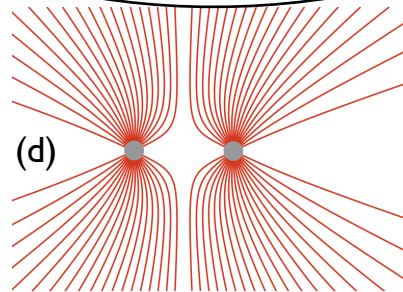
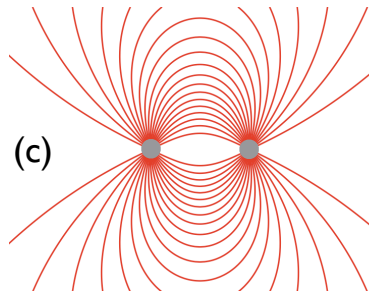
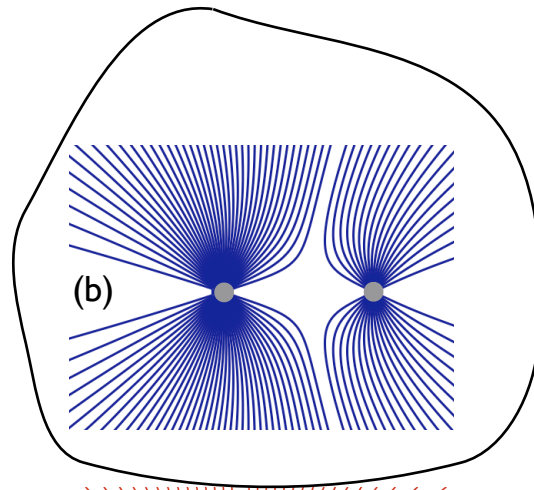
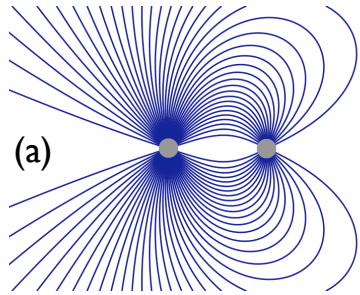
unequal
unlike





9. Which set of electric field lines could represent the electric field near two charges of the *same sign*, but *different magnitudes*?

- ☐ a
- ☐ b
- ☐ c
- ☐ d



9. Which set of electric field lines could represent the electric field near two charges of the *same sign*, but *different magnitudes*?

- ☐ a
- ☐ b
- ☐ c
- ☐ d

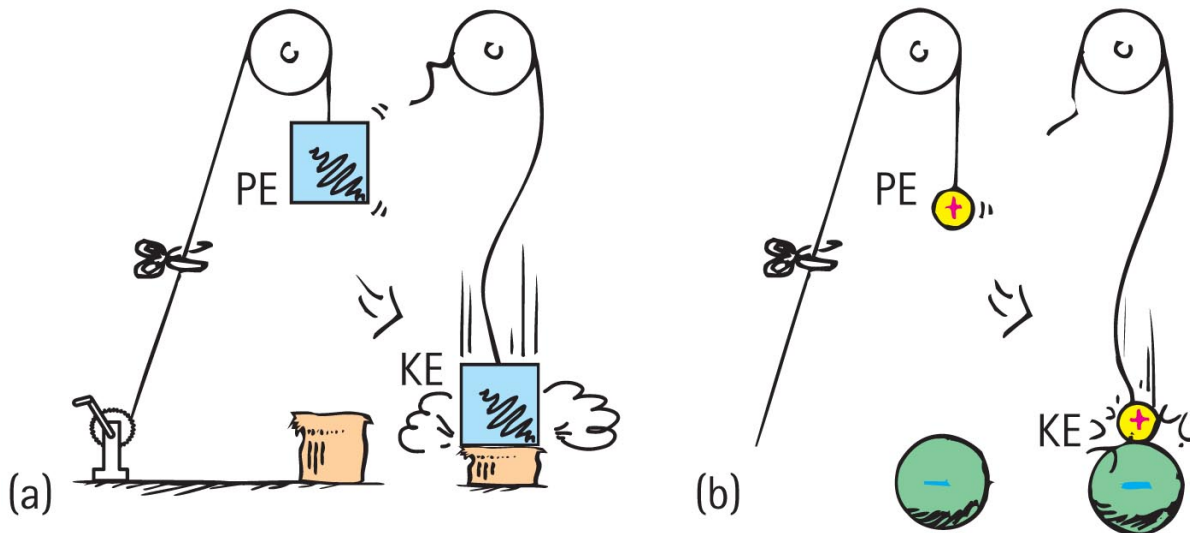
Electric Field, Continued-1

- Both Lillian and the spherical dome of the Van de Graaff generator are electrically charged.



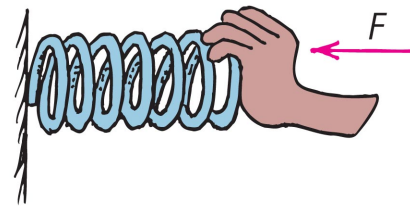
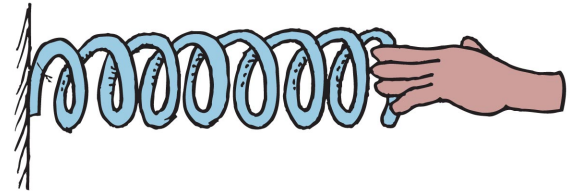
Electric Potential

- Electric potential energy
 - Energy possessed by a charged particle due to its location in an electric field. Work is required to push a charged particle against the electric field of a charged body.

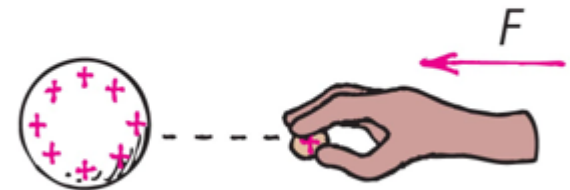


Electric Potential, Continued

- (a) The spring has more mechanical PE when compressed.
- (b) The charged particle similarly has more electric PE when pushed closer to the charged sphere. In both cases, the increased PE is the result of work input.



(a)



(b)

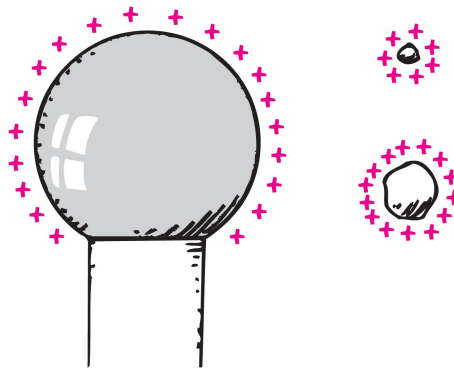
Electric Potential, Continued-1

- Electric potential (voltage)
 - Energy *per charge* possessed by a charged particle due to its location
 - May be called **voltage**—potential energy per charge
 - In equation form:

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

Electric Potential, Continued-2

- Electric potential (voltage) (continued)
 - Unit of measurement: volt, $1 \text{ volt} = \frac{1 \text{ joule}}{1 \text{ coulomb}}$
 - Example:
 - Twice the charge in same location has twice the electric potential energy but the same electric potential.



- 3 times the charge in same location has 3 times the electric potential energy but the same electric potential
($2 E/2 q = 3 E/3 q = V$)

Electric Potential

CHECK

Electric potential energy is measured in joules. Electric potential, on the other hand (electric potential energy per charge), is measured

- A. in volts.
- B. in watts.
- C. in amperes.
- D. also in joules.

Electric Potential

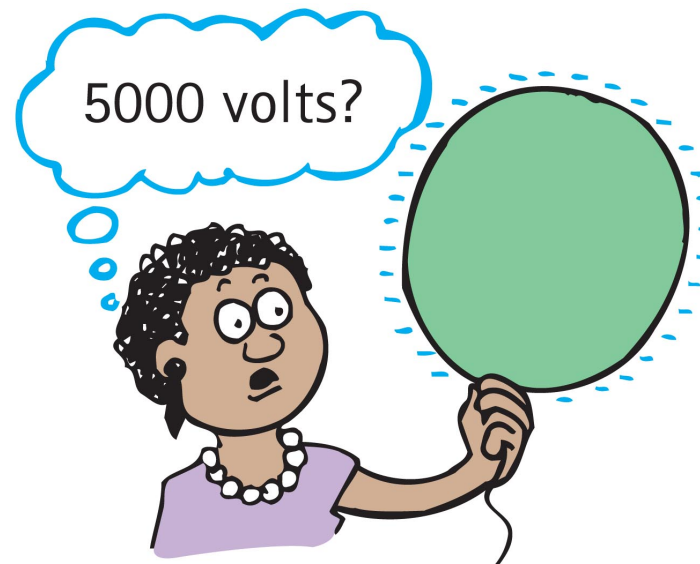
CHECK YOUR ANSWER

Electric potential energy is measured in joules. Electric potential, on the other hand (electric potential energy per charge), is measured

A. in volts.

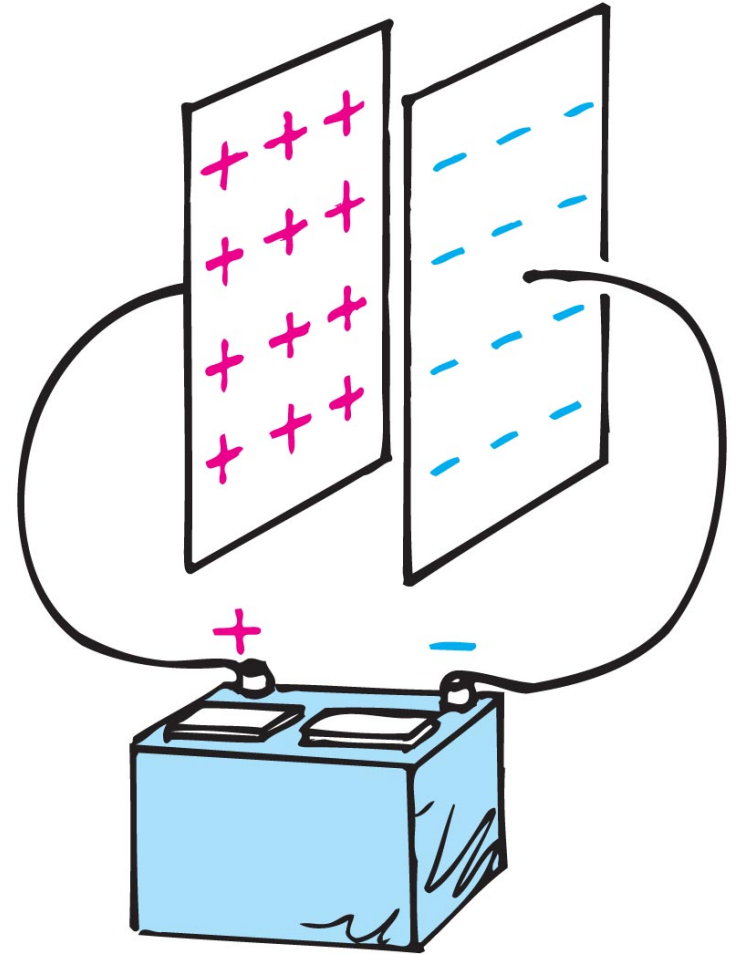
Electric Potential, Continued-3

- Electric potential (voltage) (continued)
 - High voltage can occur at low electric potential energy for a small amount of charge.
 - High voltage at high electric potential energy occurs for lots of charge.



Electric Energy Storage

- Electrical energy can be stored in a common device called a **capacitor**.
- The simplest capacitor is a pair of conducting plates separated by a small distance, but not touching each other.
- When the plates are connected to a charging device, such as the battery, electrons are transferred from one plate to the other.



Electric Energy Storage, Continued

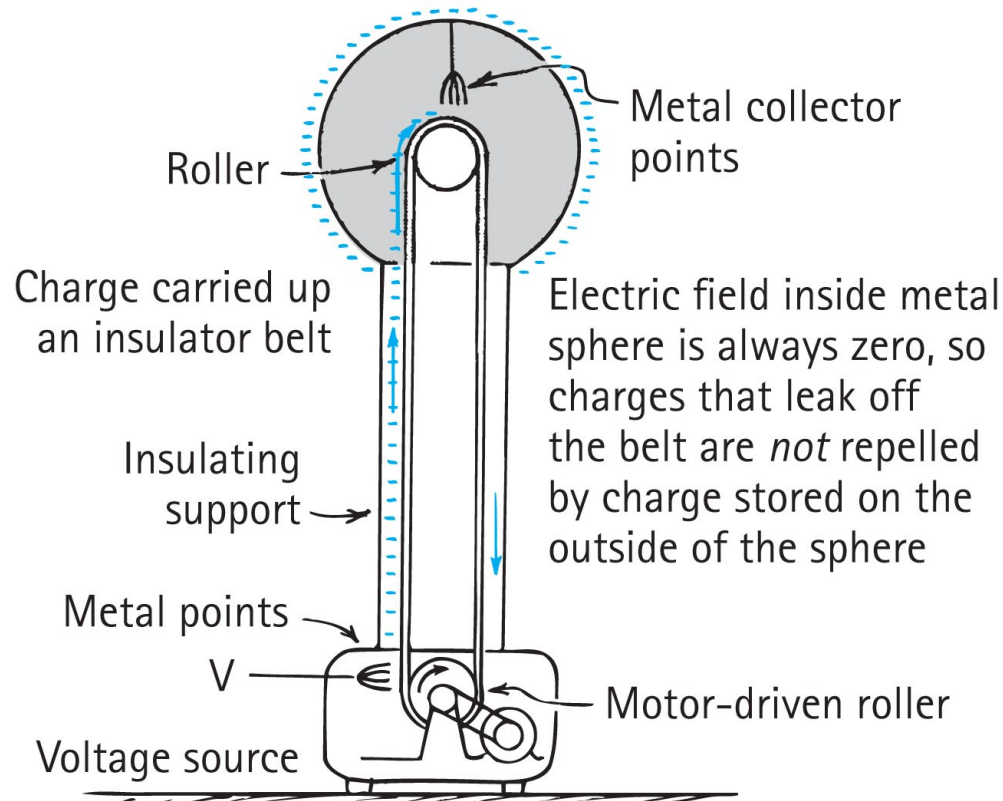
- This occurs as the positive battery terminal pulls electrons from the plate connected to it.
- These electrons, in effect, are pumped through the battery and through the negative terminal to the opposite plate.
- The capacitor plates then have equal and opposite charges:
 - The positive plate connected to the positive battery terminal, and
 - The negative plate connected to the negative terminal.

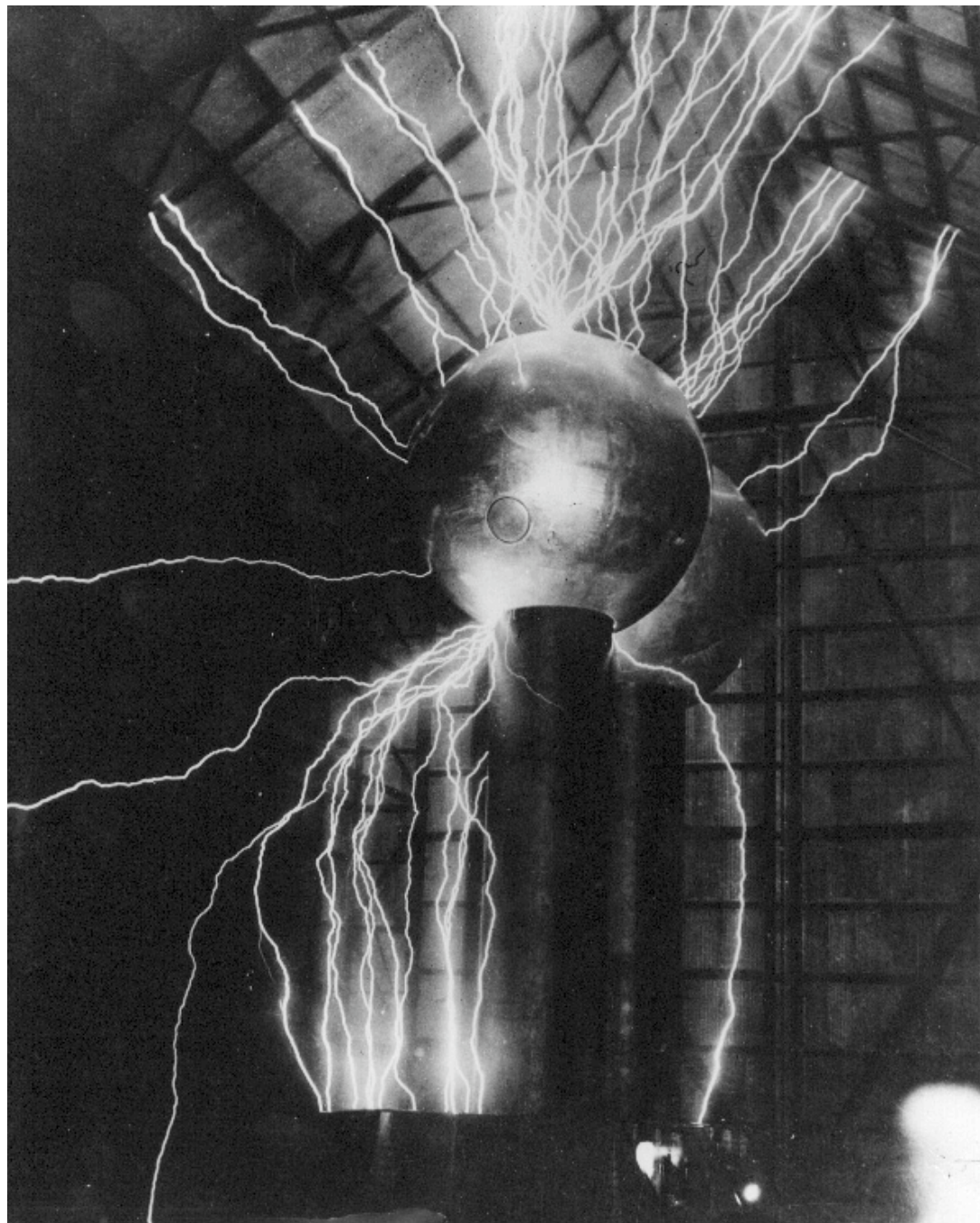
Electric Energy Storage, Continued-1

- The charging process is complete when the potential difference between the plates equals the potential difference between the battery terminals—the battery voltage.
- The greater the battery voltage, and the larger and closer the plates, the greater the charge that can be stored.
- The energy stored in a capacitor comes from the work required to charge it.
- Discharging a charged capacitor can be a shocking experience if you happen to be the conducting path.

Electric Energy Storage, Continued-2

- A common laboratory device for producing high voltages and creating static electricity is the *Van de Graaff generator*.
- The name may be familiar for other reasons
- Idea: take ideas about charging and scale them up as much as possible





AT ROUND HILL SPARKING TO HANGAR (LONG EXPOSURE)

