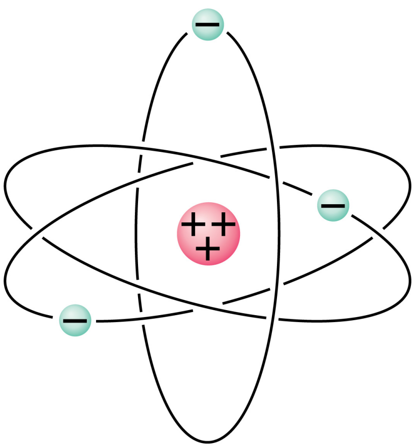
August 23, 2020

Albert Huang, 26 August 2020

Electrostatics



Many materials are described as *conductors* or *insulators.* What are the broad properties of each?

Conductors	Insulators
Metals	Rubber
Graphite	Silicone
Plasma	wood
Salt Water	air
	vacuum

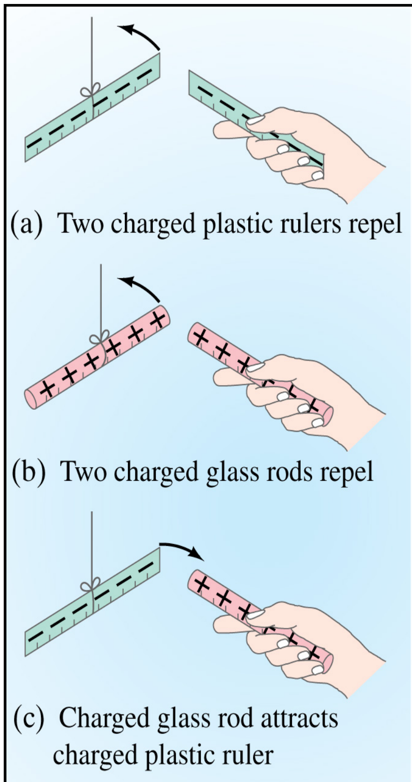
Common Materials: Tendency to become Positive or Negative When Rubbed (triboelectric effect)

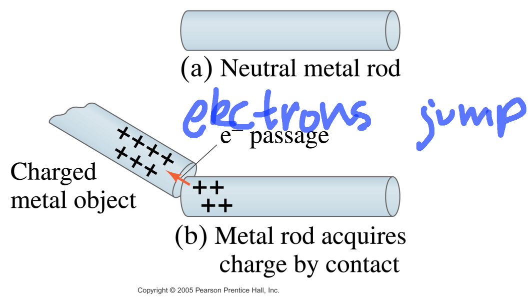
* Human hands (usually too moist, though) *Very positive*
* Rabbit Fur
* Glass
* Human hair
* Nylon
* Wool
* Cotton
* Steel
* Wood
* Polyester
* Styrene (Styrofoam)
* Saran Wrap
* Polyurethane
* Polyethylene (like Scotch Tape)
* Polypropylene
* Vinyl (PVC)
* Silicon
* Teflon

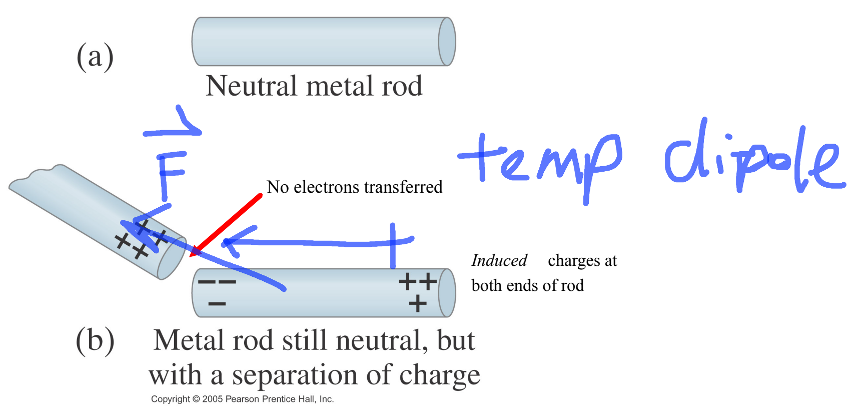
Fur, etc + glass

Neutral

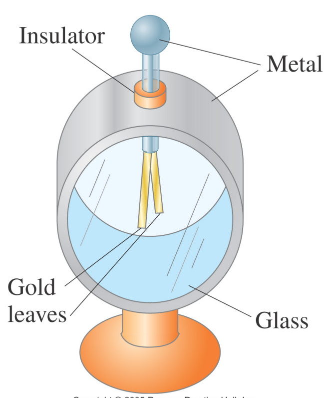
Very negative

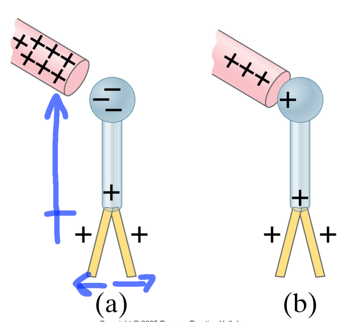




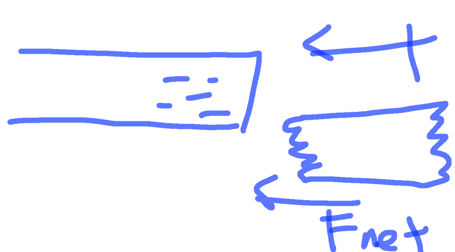


The Electroscope



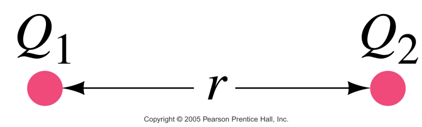


What happens to an insulator (like chips of paper) if charged object is brought nearby?



until electrons jump

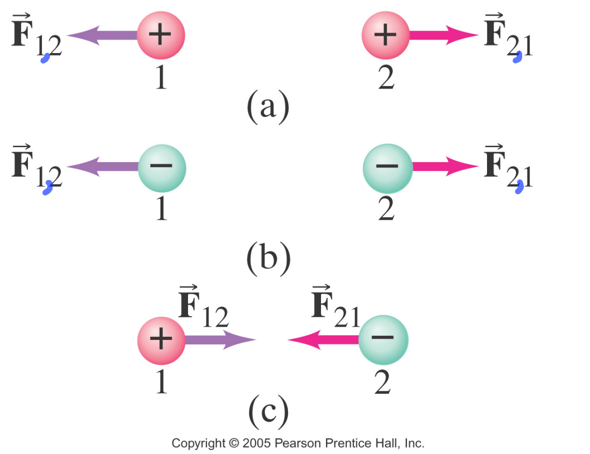
The Electrical Force: Coulomb's Law



Point charge
center to center diff

F_{12} = force on 1 due to 2

F_{21} = force on 2 due to 1



The standard unit of charge (Q) is the *Coulomb*. koo lomb

Like a mole in chemistry, one Coulomb represents the amount of charge on many electrons (or protons).

Specifically,

1 C = 6.2415 x 10^{18} protons

-1 C = 6.2415 x 10^{18} electrons

So one electron has -1.602 x 10^{-19} Coulombs, etc.

$\frac{Nm^2}{C^2}\frac{\mu C^2}{m^2}$

Coulomb's Law

$$F = \frac{1}{4\pi\varepsilon_0}\left(\frac{q_1 q_2}{r^2}\right) = k\frac{q_1 q_2}{r^2}$$

(k = 8.99 x 10^9 N m^2 / $Coulomb^2$)

This equation should remind you of something from first-year Physics.

The *sign* of the force calculated this way has significance.

If force > 0, repulsive (same sign)

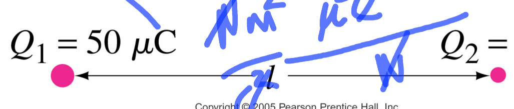
If force < 0, attractive (opp. sign)

$F = k\frac{Q_1 Q_3}{r^2}$

$r = 0.5m$

= Plug!

speed of light?



$\frac{Nm^2}{C^2}\frac{\mu C^2}{N}$

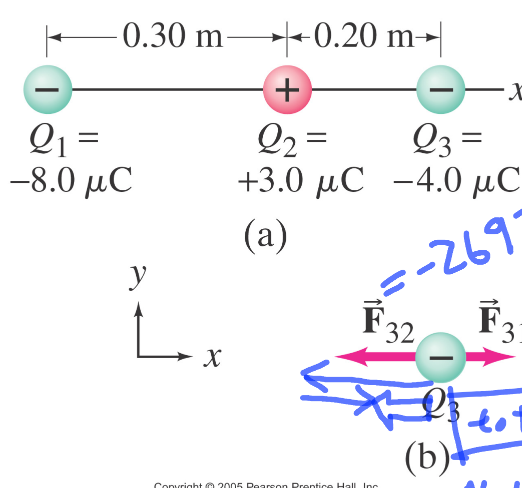
How far apart are these two charges if the force between them is 2 N?

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

$r^2 = \frac{kq_1 q_2}{F}$

$r = \sqrt{k\frac{q_1 q_2}{F}} = 0.47m$

Calculate the net force on charge Q_3



$= -2697\ \mu N$

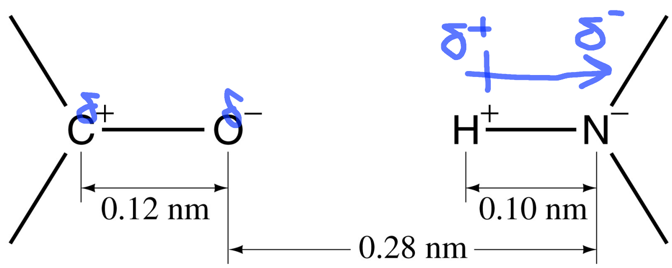
$= 1150\ \mu N$

$\boxed{total = -1547\ \mu N}$

Not const

An Important Application of Electrical Forces: DNA Replication

Below: A diagram showing two molecules. Although the carbon and oxygen atoms at left are labeled C+ and O-, this labeling does not mean that the oxygen has acquired an entire electron from the carbon. It may be that a *shared* electron spends more than half of its time near the oxygen, perhaps giving the oxygen a net effective negative charge of 0.1 electrons, for example.

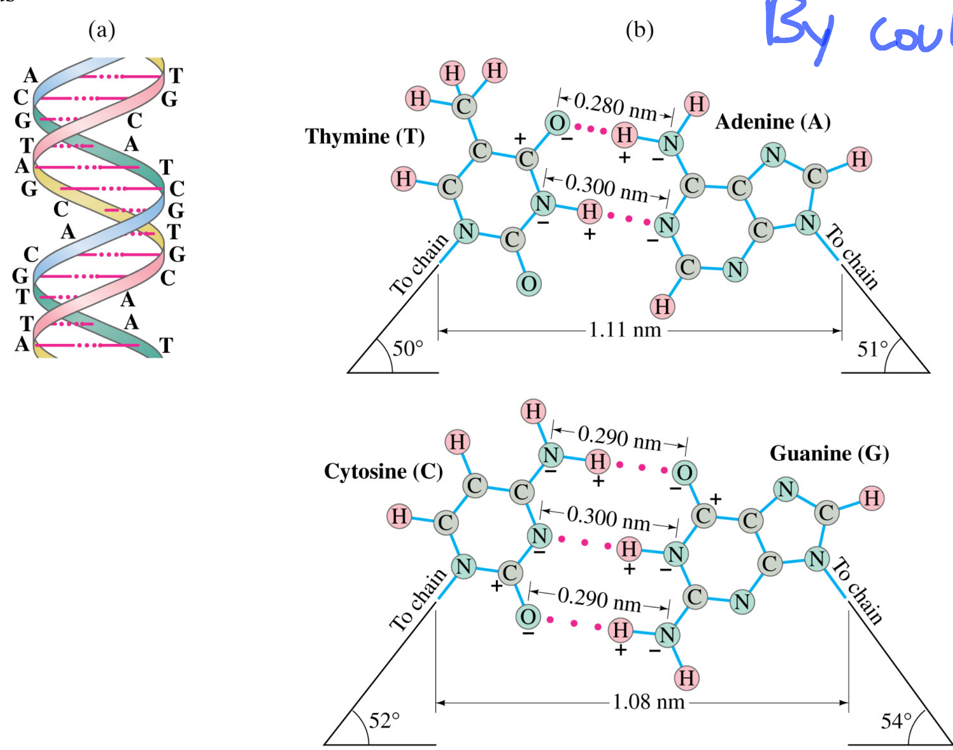


How many forces would you have to calculate to determine whether the two molecules above attract, or repel? 4

In general, the net force between two molecules depends on the charges on each atom, the separation between the molecules, and the orientation (angle) of approach.

Protien Folding simulated By coulomb's LAW

DNA replication is successful because of electrostatic forces between the various nucleic acids



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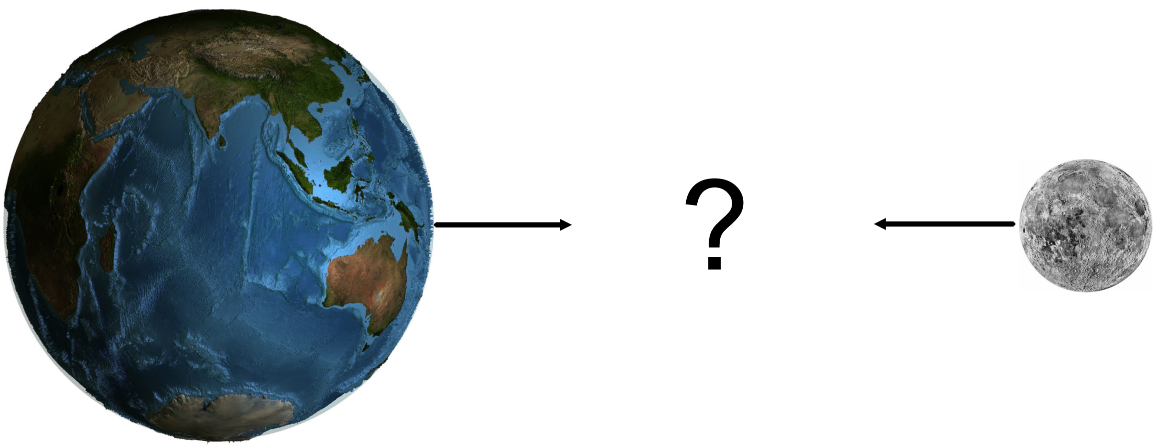
Fields (in general) and the Electric Field

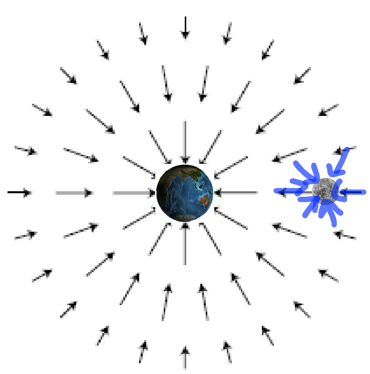


An early objection to Newton's law of universal gravity is that it described forces between objects that were not touching each other. How could the force of gravity reach out across empty space?

Today of course, we know that every atom consists of a tiny nucleus surrounded by distant electrons. So even when seemingly solid objects make contact, what we are really observing is the interactions of particles that are widely separated from each another relative to their size.

But this realization doesn't make it any easier to understand how objects at a distance interact with each other; it just means that every interaction or force should be thought of this way.

exists own it's own



Representation of earth's gravitational field

The earth's "gravitational field" represents the influence of the earth's mass on any other mass.

Earth's gravitational field is a vector at every point in space. The direction of the vector points toward the center of the earth. (This is the direction in which a mass interacting with earth would feel a force.) Its magnitude depends on how far you are from the center of the earth.

In principle, earth's gravitational field extends to infinite distance. In practice, far from the earth, it will be difficult to detect earth's field, and other mass(es) will have much more influence.

The strength or magnitude of earth's gravitational field depends on the mass of the earth and the distance from the earth. It does not depend on your mass. (Here, "you" are a mass interacting gravitationally with the earth, or a "test mass.") But the magnitude of the gravitational *force* that you experience certainly depends on your mass. (If it didn't, low-mass things like feathers would accelerate toward earth much more rapidly than high-mass things like battleships.)

Actually depends on YOU

$F_{grav} = G\, M_{earth}\, M_{you} / R^2$ (Newton's law of gravitation)

The sensible thing to do is to group together the properties that have to do with the earth and distance, and separate out your mass:

Gravitational field of Earth = $G\, M_{earth} / R^2$

any obj

$F_{grav} = M_{you}$ * Gravitational field of Earth

Note, we could have said that the earth is a test mass in the gravitational field created by you. Also note, grav. forces and fields are vectors and have a direction. The direction of both is pretty easy - an object's grav field points toward its center of mass, and an object in that field feels a force in the same direction as the grav field.

Gravitational field represents the force per kg of the test mass, so its units are N/kg. This is the same as m/s^2, or an acceleration.

Electric field works the same way. It represents a region of influence near a charged object, to which other charged objects respond.

The equation for the magnitude of the electrical force between two objects is very similar to the equation for the magnitude of the gravitational force.

$F_{elec} = k\, Q_1\, Q_2 / R^2$

$F_{grav} = G\, M_1\, M_2 / R^2$

So as with gravity, we can think of one charge (say, Q_2) as the source of an electric field, in which the second (Q_1) is a test charge. Then

$\mathbf{F}_{elec} = \mathbf{E}\, Q_1$ Field from Q_2 in N/C

E is the *electric field* caused by Q_2, or simply "the electric field of Q_2." You can calculate its strength just as for gravitational field:

$|E|$ = absolute value of ($k\, Q_2 / R^2$) or $|\, k\, Q_2 / R^2\, |$ [Not sure why the font got weird there]

*** The direction of the electric field will be discussed on the next slide. ***

E represents the electrical force per Coulomb of test charge. It has units of N/C. This is *not* the same as an acceleration.

VERY IMPORTANT: Every mass creates a *gravitational field*. Every charge creates an *electric field*. Although we have so far described these fields primarily in terms of how they influence other objects (a "test mass" or "test charge"), fields have a physical reality of their own; they are not merely abstract tools used to describe the interactions between two objects. Start getting comfortable with fields; they will appear frequently in the future. We may learn later that the interactions we describe through fields have a different interpretation in quantum mechanics. But for macroscopic (large) objects, the field model is correct for all practical purposes.

Direction of the Electric Field

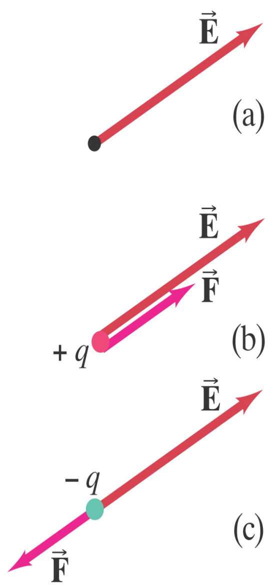
A mass always *attracts* another mass. This makes it easy to choose the direction of the gravitational field: toward the center of the object creating the field. Then the gravitational force on a test mass is always in the same direction as the field. But an electric charge may attract or repel another charge. So we have two choices:

1) each vector has two values

2) only one direction, Force depends on Sign of charge

Scientists and engineers have chosen ____________________.

Summary: Relationship between E-field, test charge, and electric force on the test charge



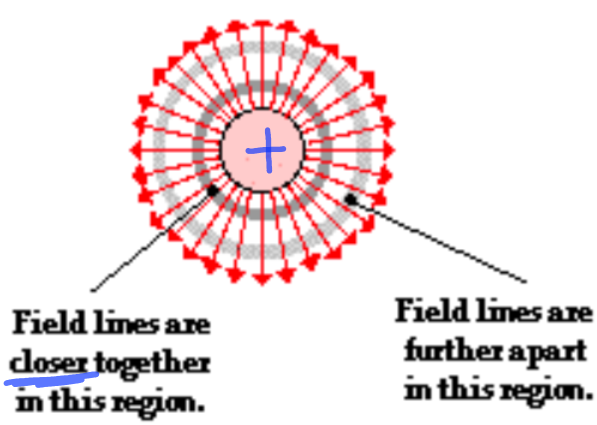
The diagrams at left show an electric field vector created by charge(s) that are not illustrated.

Positive test charge $+q$: Electrical force is in same direction as E-field.

Negative test charge $-q$: Electrical force is directly opposite the E-field.

Whether the test charge is + or -, we can write $\vec{\mathbf{F}} = q\vec{\mathbf{E}}$

away = positive particle



density ≈ magnitude

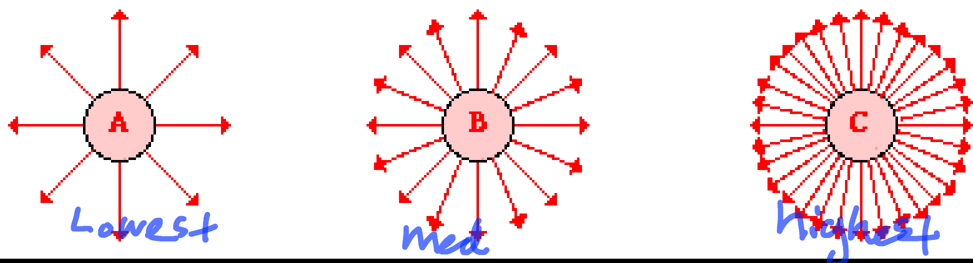
So far, we have illustrated fields by drawing a vector at (theoretically) every point in space. But fields can also be shown as "lines" with direction arrows. Field lines originate on positive charges and terminate on negative ones.

Is the charge at left + or - ?

For a single charge like this, the "lines" with arrows look a lot like vectors at the surface of the charge. You'll get a better understanding of how the "lines" method differs in the coming slides.

Rank A, B, and C in Terms of Magnitude of Charge

[redacted]



[redacted]

L

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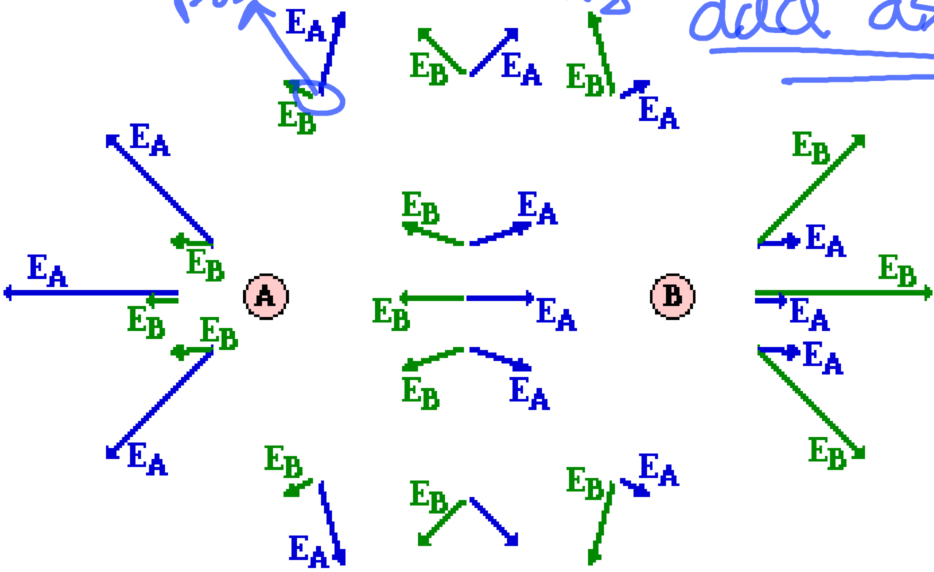
distributive property

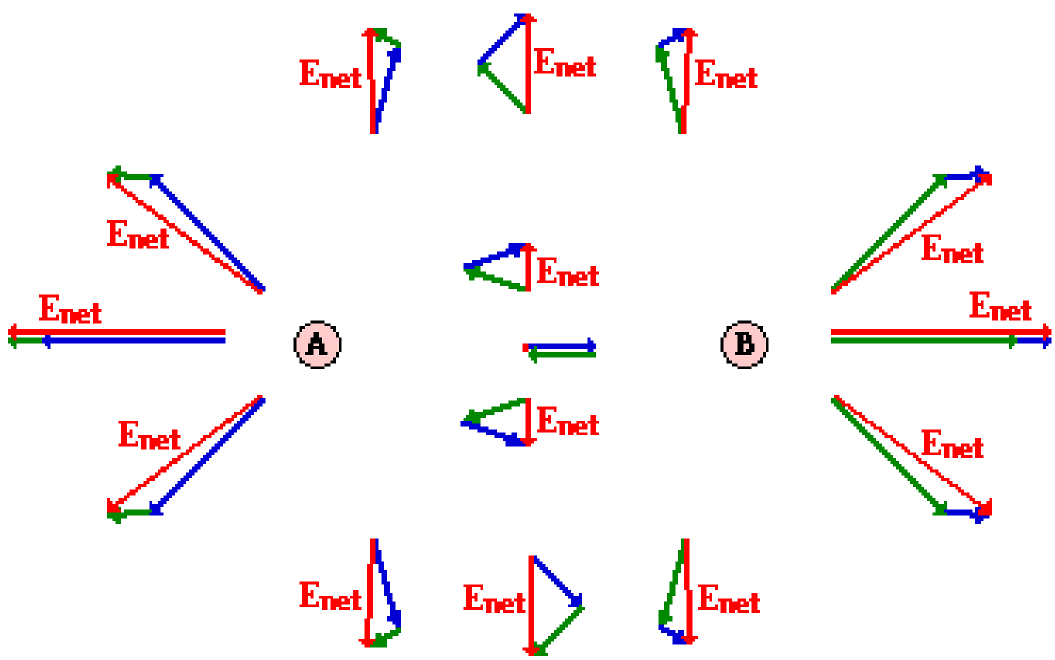
E-Field Caused by Two Equal Positive Charges

unit positive test charge

add as vectors



Important: Charges A and B are both positive and will repel each other. But that repulsion isn't shown in this E-field diagram. The E-field diagram illustrates the combined effects of charges A and B on a ***third*** *charge (test charge).*



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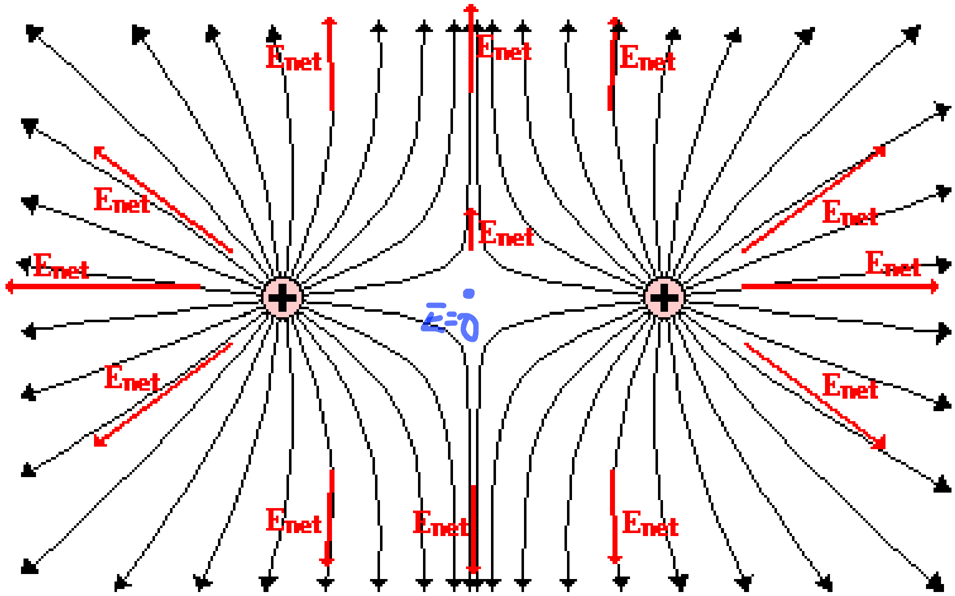
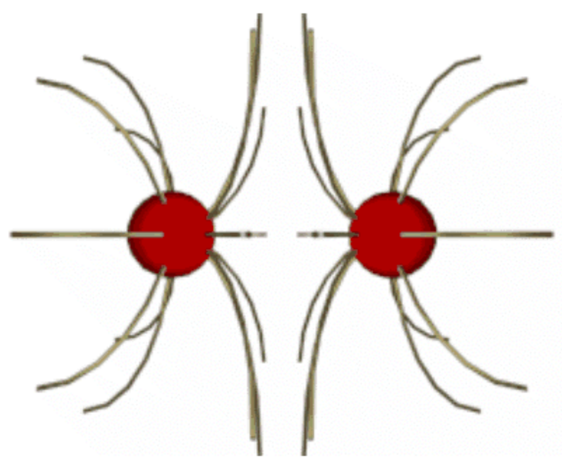
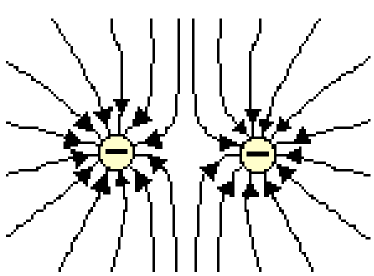
E-Field Caused by Two Equal Positive Charges



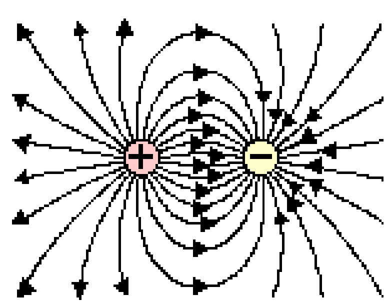
Of course the diagram above is just a 2-dimensional slice of the 3-dimensional field as shown below.



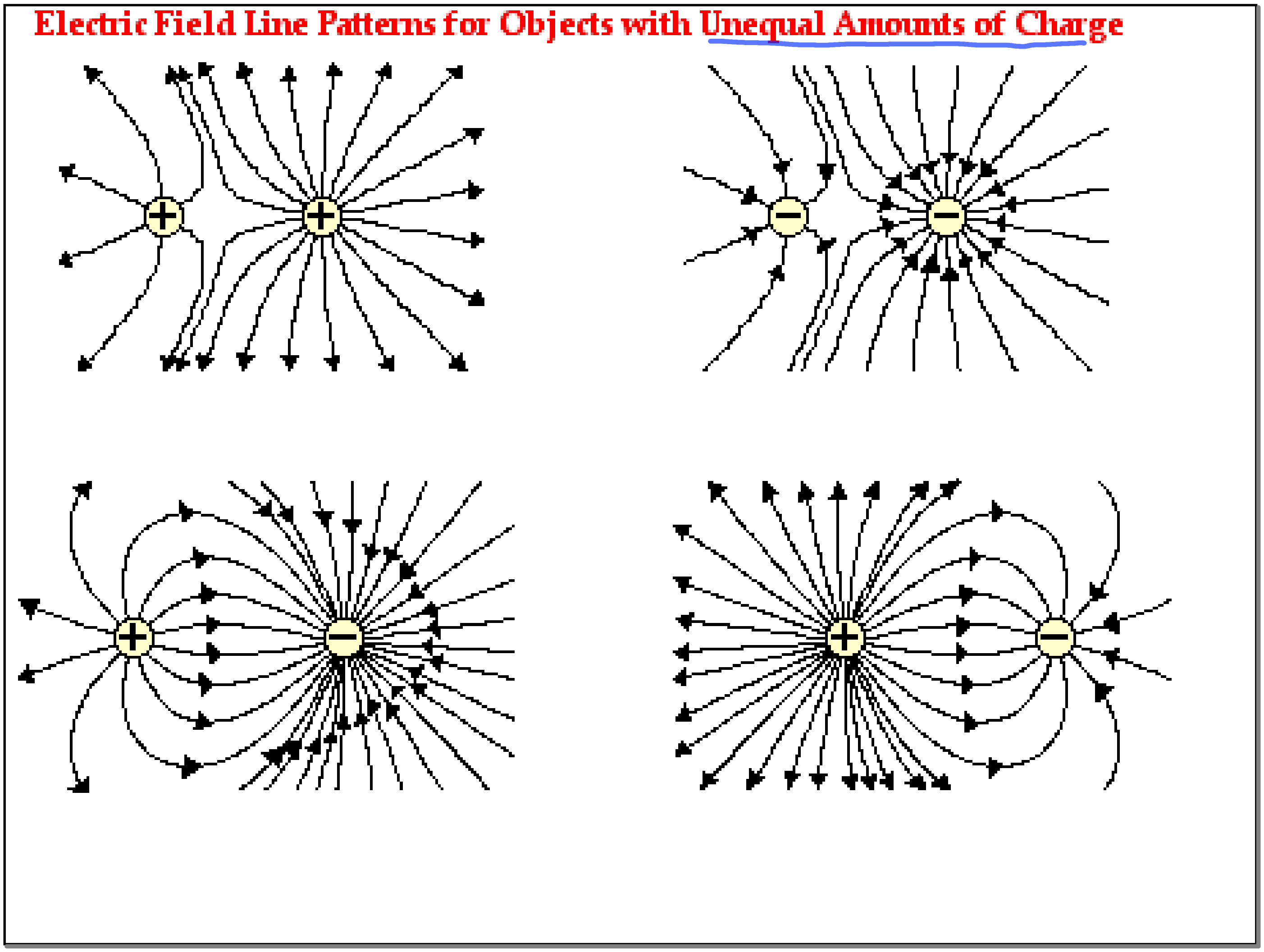
Other Charge Configurations

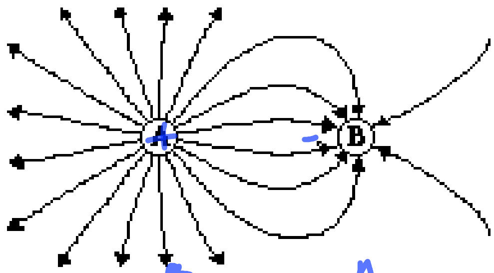


Two Negatively-Charged Objects

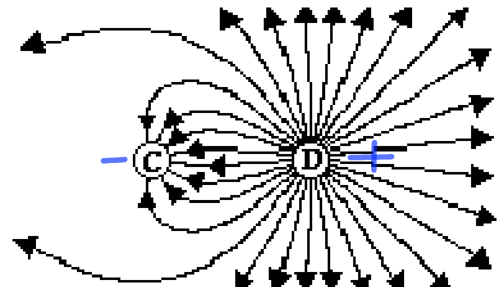


A Positively and a Negatively-Charged Object

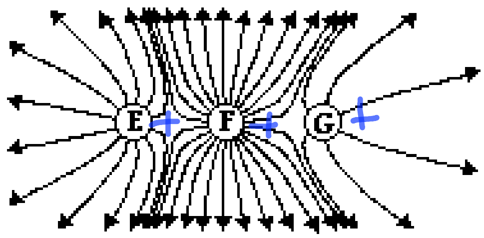

Electric Field Line Patterns for Objects with Unequal Amounts of Charge



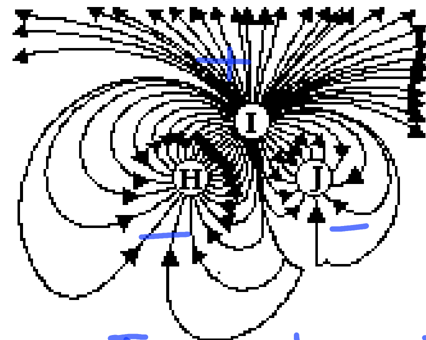
Ranking: B < A



Ranking: C < D

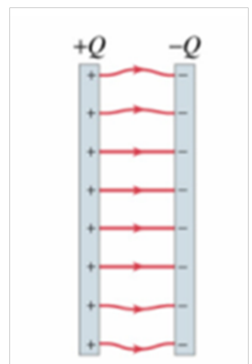


Ranking: G < E < F



Ranking: J < H < I

Calculating the E-field for continuously distributed charges usually involves calculus. But there are a couple of special cases worth learning. For example, the E-field caused by two charged plates is almost uniform (constant magnitude, constant direction) between the plates.



(d)

Sample Questions in Electric Field

1. Calculate the magnitude of the E-field at a distance 2.0 cm from a +7 microcoulomb charge.

2. At a point 3 mm directly above a charge of -1 millicoulombs, calculate the E-field strength and indicate its direction.

3. An electron is located in an E-field of strength 8.4 N/C directed East. What is the force on the electron?

4. The charged plates shown above create an E-field of 1E-5 N/C in the region between them. A proton starts at rest between the plates, near the positive plate. How long does it take the proton to fly across the gap, which is 1.0 cm wide? How fast is it traveling when it reaches the negative plate?

5. (Tougher) A charge of +3 C is located at coordinates (0,0). A charge of -5 C is located at coordinates (4,0) m. What is the E-field arising from these two charges at location (2,2) m ?

6. Students commonly fall into the trap of thinking that a test charge in an electric field will follow whatever field line it happens to start out on. In fact, this can happen, but only under special circumstances. When will a a test charge follow its field line? What is the more general idea about fields and the trajectory of a test charge?

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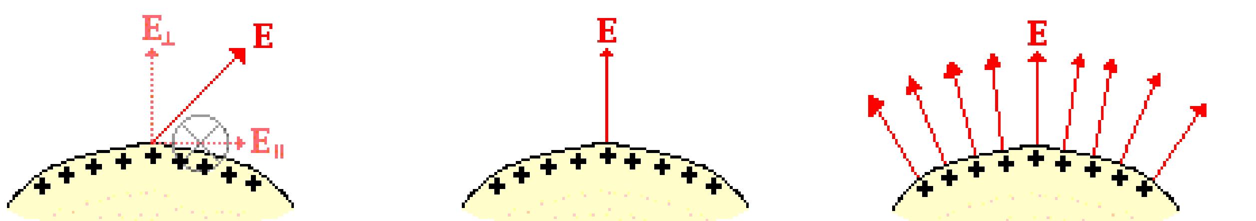
If the charges on a conductor are stationary or *static*,

1) E-field in the conducting material must be zero, and
2) At the surface, E-field (if any) must be perpendicular to the surface

1) Must be true because...

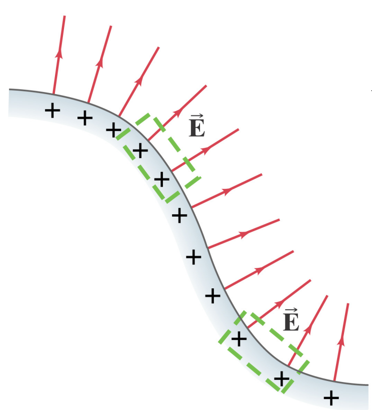
2) Must be true because...



A component of E parallel to the surface would move excess charge.

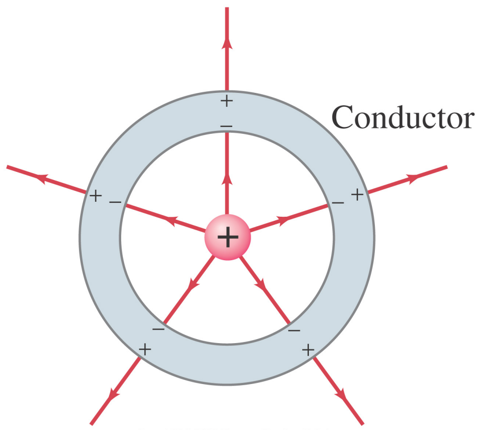
If an object has reached electrostatic equilibrium, there is no ∥ component of E.

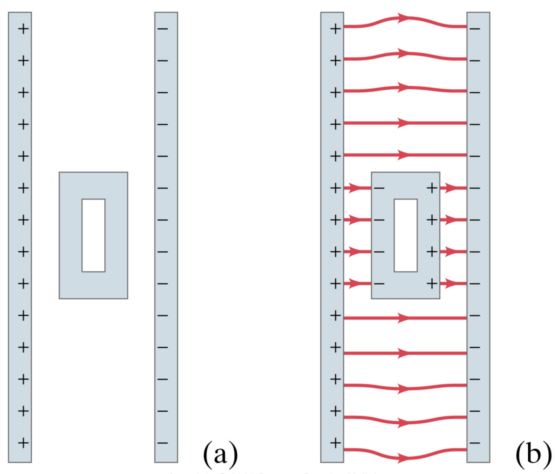
The electric field must be directed perpendicular to the surface at each location.



This figure shows the E-field near the surface of a conductor w/ various curves. Note that the E-field is stronger in some places than in others (higher density of red lines).

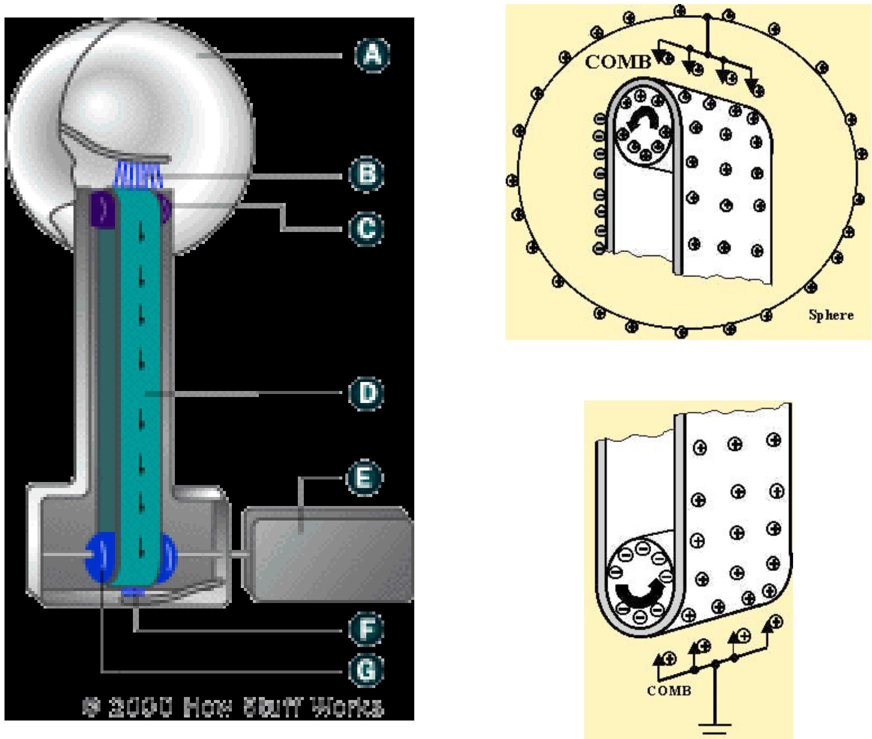
Examples of Charge Distribution and E-field in / near / inside Conductors





At left, before equilibrium
is reached. At right, after.

Van de Graaff Generator



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