Physics 9 — Monday, November 12, 2018

- The main goals for the electricity segment (the last segment of the course) are for you to feel confident that you understand the meaning of electric potential (volts), electric current (amps), how these relate to energy and power, and also for you to understand the basic ideas of electric circuits (e.g. things wired in series vs in parallel). We'll get there soon.
- For today, you read Richard Muller's PTFP chapter 6 (electricity & magnetism)
- For Wednesday, read Giancoli ch17 (electric potential)
- HW9 due this Friday.
- If I can work out the practical details, I may have us spend the last several days of class working in groups on your laptop/notebook computers running acoustical and/or thermal simulations.

- Matter is made up of atoms: positively charged nuclei (protons and neutrons), surrounded by a cloud of electrons.
- Elementary charge $e = 1.6 \times 10^{-19}$ C.
- Proton has positive charge ($+e$). Neutron is uncharged (electrically neutral). Electron has negative charge ($-e$).
- In an insulator (glass, plastic, rubber, cloth, etc.), electrons tend to be stuck to their own atoms.
- In a solid conductor (e.g. metal), electrons can freely move around within the conductor, whereas the positive ions are fixed in place in a lattice-like pattern.
- In a liquid conductor (e.g. impure water), positive and negative ions can both move around freely.
- Chemical bonds involve the transfer of electrons from one atom to another, or the sharing of electrons between atoms.
- When a chemical bond is formed between two unlike materials, electrons tend to be more closely attracted to one kind of atom than the other.
- If you rub unlike insulators together, you transfer some electrons to whichever material more closely attracts electrons.

- http://en.wikipedia.org/wiki/Triboelectric_effect
- fur + plastic leaves negative charge on plastic
- cotton + acrylic leaves positive charge on acrylic
- Rubbing just about any other insulating material against a rubber balloon leaves negative charge on the rubber balloon!

- Only a tiny fraction of the electrons are transferred, but this tiny fraction results in a *surplus* of electrons on one material and a surplus of positive ions on the other material.

- Surplus electrons deposited on an insulator are stuck where they were deposited, unless you rub them off.
- But surplus electrons deposited on a conductor will spread out, to try to get as far away from one another as possible.
- Since your body contains a lot of water (but not pure water), you are a pretty good conductor (but dry skin is an insulator). So surplus electrons deposited on me will try to spread out as far as possible!

Triboelectric series (who knew?!)

most positively charged
air
human skin (dry)
leather
rabbit fur
glass
quartz
mica
human hair
nylon
wool
lead
cat fur
silk
aluminum
paper
(small positive charge)

(small negative charge)
wood
rubber balloon
resins
hard rubber
nickel, copper
brass, silver
gold, platinum
synthetic rubber
polyester
styrofoam
plastic wrap
scotch tape
vinyl
teflon
silicone rubber
most negatively charged

Be sure to put a “handle” on the end of your bottom piece of tape, so that it is easy to remove it from your desk at the end of class. If we leave tape stuck to the desks at the end of class, the housekeeping folks may put an end to our experiments . . . .

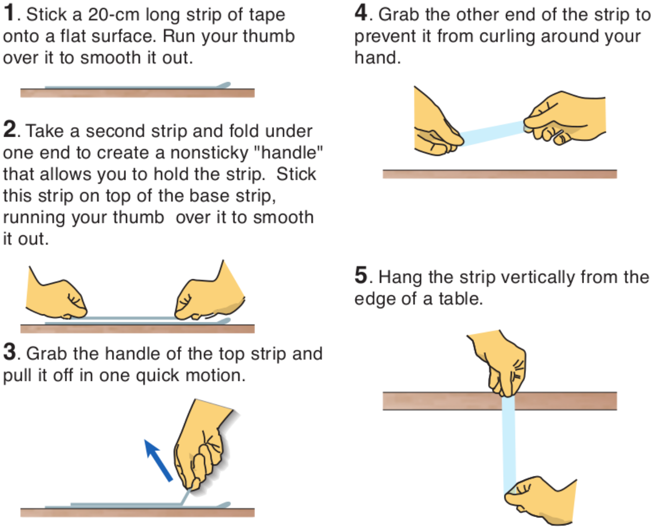


Figure 22.3 Procedure for making strips of transparent tape that interact electrically. The lower strip is used to provide a standard surface—the top side of a piece of tape — because surface properties may vary from one tabletop or desktop to another.

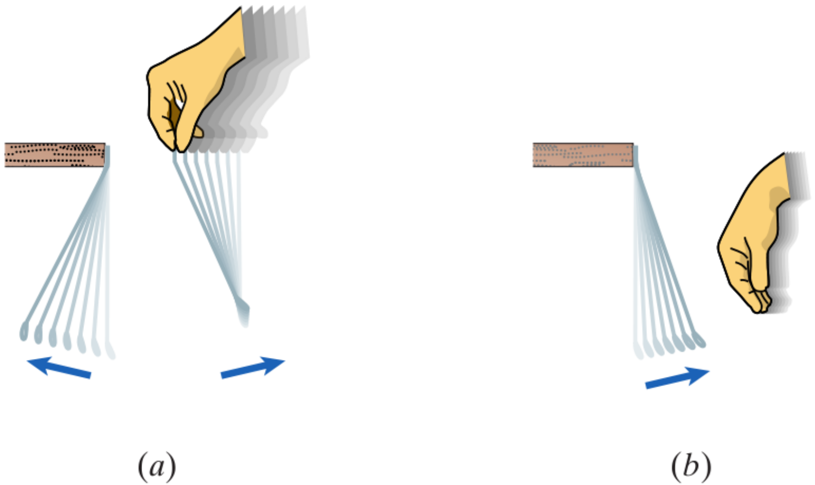


Figure 22.4 A strip of tape is (*a*) repelled by a second strip and (*b*) attracted to your hand.

22.4 (*a*) Prepare a charged strip of transparent tape as described in Figure 22.3 and then suspend the strip from the edge of your desk. Verify that the tape interacts as you would expect with your hand, with a strip of paper, and with another charged strip of tape. (*b*) Rub your fingers along the hanging strip to remove all the charge from it and then verify that it no longer interacts with your hand. If it does interact, rub again until it no longer interacts. (*c*) Predict and then verify experimentally how the uncharged suspended strip interacts with a strip of paper and with a charged strip of tape.

To restore the charge on a discharged strip, stick the strip on top of the base strip from which you pulled it off (step 1 in Figure 22.3), smooth it out, and then quickly pull it off again. You can recharge a strip quite a few times before it loses its adhesive properties. Once the tape does lose its adhesiveness, however, recharging it becomes impossible. It is generally a good idea to rub your finger over the base strip before you reuse it to make sure that it, too, is uncharged.

22.5 Recharge the discharged strip from Checkpoint 22.4 and verify that it interacts as before with your hand, with a strip of paper, and with another charged strip of tape.

A discharged tape strip interacts in the same way as objects that carry no charge. Such objects are said to be electrically **neutral**. They do not interact electrically with other neutral objects, but they do interact electrically with charged objects. We shall examine this surprising fact in more detail in Section 22.4.

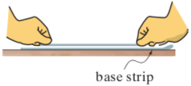
Where does the electrical charge on a charged tape strip come from? Is charge *created* when two strips are pulled apart as in Figure 22.3? This is something we can check by sticking two strips of tape together, rubbing with our fingers to remove all charge from the combination, and then quickly separating the two strips (Figure 22.5).

22.6 Follow the procedure illustrated in Figure 22.5 to separate a pair of charged strips. (*a*) How does strip B interact with a neutral object? How does strip T interact with a neutral object? (*b*) Create a third charged strip and see how it interacts with strip B and with strip T. (*c*) Is strip T charged? (*d*) Is strip B charged? (*e*) Check what happens to the interactions with B and T strips when you discharge a B or a T strip by rubbing your fingers along its length.

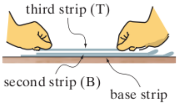
As this checkpoint shows, separating an uncharged pair of strips produces two charged ones, but the behavior of strip B is different from that of the other strips we have encountered so far!

22.7 Make two charged pairs of strips (B and T) following the procedure illustrated in Figure 22.5. Investigate the interaction of B with T, T with T, and B with B.

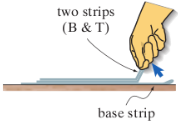
1. Run your finger over the base strip and stick a second strip with a handle on top of it. Press down and smooth it out. Write “B” on the handle of the top strip.



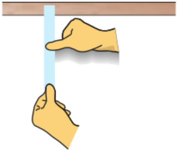
2. Stick a third strip on top. Press down and smooth it out. Write “T” on the handle of the top strip.



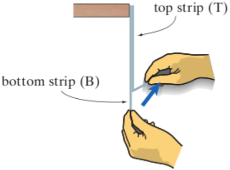
3. Grab the handles of the top two strips and **very slowly** pull the combination as one unit off the base strip leaving the base strip stuck on the table.



4. Stick the combination to the edge of a table with the handles at the bottom and rub your thumb over it until completely discharged.



5. Holding the bottom strip, grab the handle of the top strip and quickly pull the top strip off the bottom one.



6. Stick the top strip to the edge of the table 0.5 m away from the bottom strip.

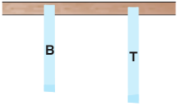


Figure 22.5 Procedure for making strips of transparent tape carrying opposite charge.

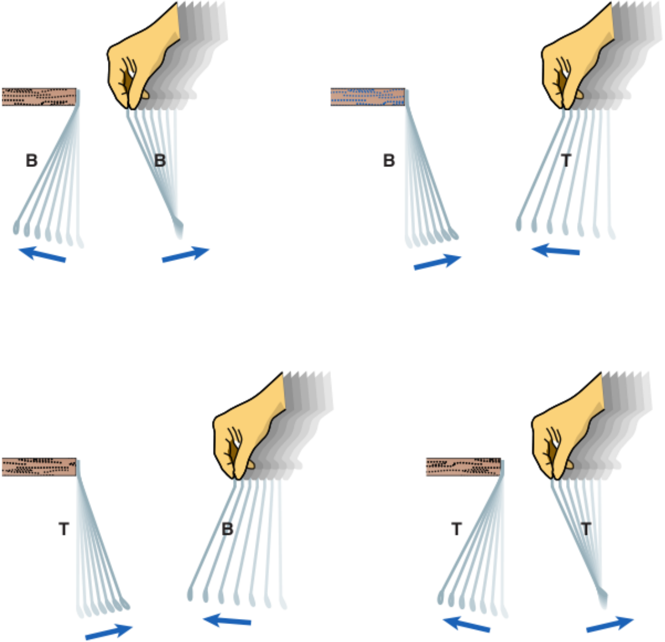


Figure 22.6 Interactions of B and T charged strips.

opposite charge. Combining these equal amounts of opposite charge produces zero charge. These observations indicate that all neutral matter contains equal amounts of positive and negative charge. The two types of charge are called **positive** and **negative charges**. The definition of negative charge is as follows:[*]

> *Negative charge is the type of charge acquired by a plastic comb that has been passed through hair a few times.*

22.9 Does the B strip you created in Checkpoint 22.8 carry a positive charge or a negative charge?

When two neutral objects touch, some charge can be transferred from one object to the other, with the result that one object ends up with a surplus of one type of charge and the other object ends up with an equal surplus of the other type of charge. For example,

Troubleshooting B and T strips

If your experiment with B and T strips doesn't work as expected, check the following:

1. You must pull off the combination in step 3 of Figure 22.5 *very* slowly. (The amount of charge that builds up on the strips is roughly proportional to the speed at which you separate them.) Be sure to remove *all* charge before proceeding.

2. Separating the B and T strips, on the other hand, must be done fairly raplidly. (If you do it too fast, however, so much charge may build up on your strips that it becomes hard to prevent them from being attracted to your hands. If they curl around and touch your hands, you must start over.)

3. Avoid any air currents on the suspended strips.

4. If the humidity of the air is high, the strips may lose their charge rapidly; you may need to repeat the experiment in a drier environment.

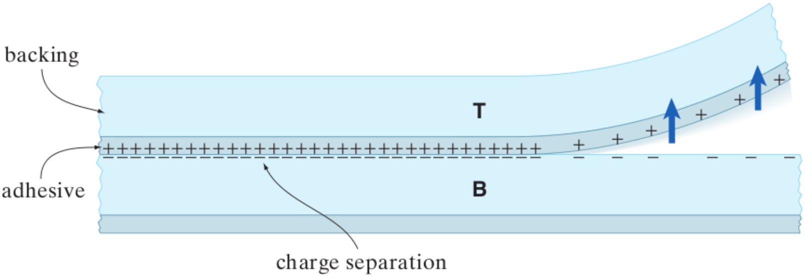


Figure 22.17 Chemical bonds between two strips of tape are responsible for transfer of electrons from the top strip to the bottom strip. When the strips are separated, some of these electrons remain on the bottom strip, giving it a negative charge and the top strip a positive charge.

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* Depending on the type of adhesive and the material of the backing, the transfer of electrons can also be in the other direction.

Who wants a great photo to share with friends?

The net force ON a due to a set of N charged objects is

$$\vec{F}_a^E = k \sum_{i=1}^{N} \frac{q_i \; q_a}{r_{ia}^2} \; \hat{r}_{ia}$$

where r_{ia} is the distance from object i to object a and $\hat{r}_{ia}$ is the **unit vector** pointing from object i toward object a.

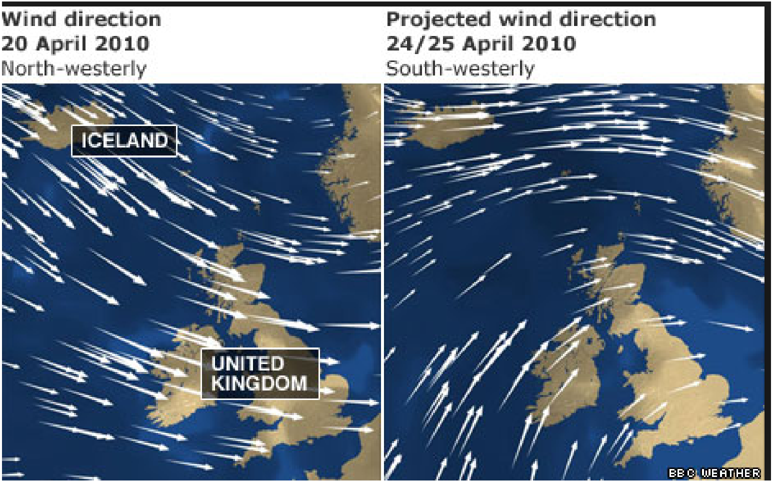
We'll spend some class time soon talking about unit vectors and generally refreshing your memory about working with vectors. For the moment, we'll just draw arrows.

Math reminder: the unit vector pointing in direction $\vec{r} = (x, y, z)$ is

$$\hat{r} = \frac{\vec{r}}{r} = \frac{(x, y, z)}{\sqrt{x^2 + y^2 + z^2}}$$

So $\hat{r}$ points in the same direction as $\vec{r}$, but $\hat{r}$ has a length of 1.

The **electric field** associates, with each position in space, a magnitude and a direction of the electrostatic force that a small positive "test charge" would feel if it were placed at that position.



A "field map" of wind velocity is familiar from a weather map. Each position in space gets a vector indicating wind velocity.

Electric field (E)

$\vec{E}(x, y, z)$ is force-per-unit-charge that a "test charge" q, if placed at position $\vec{r} = (x, y, z)$, would feel as a result of the other charges.

If we put an object of charge Q at the origin, the force on q is

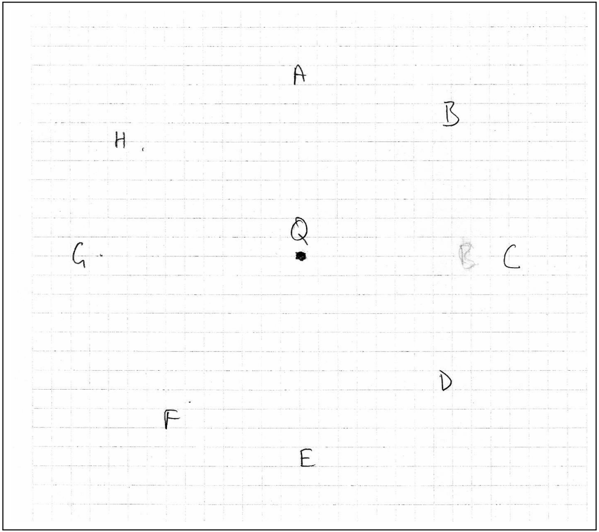
$$\vec{F}_q = k \, \frac{Qq}{r_{Qq}^2} \, \hat{r}_{Qq} = +k \, \frac{qQ}{r^2} \, \hat{r}$$

So the electric field $\vec{E}(\vec{r})$ is

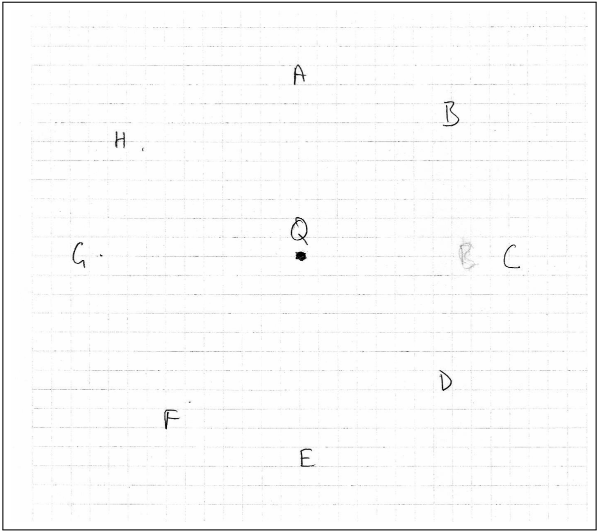
$$\vec{E}(x, y, z) = \frac{\vec{F}_{\mathrm{on\ q}}}{q} = k \, \frac{Q}{r^2} \, \hat{r}$$

The magnitude of $\vec{E}$ falls off like $1/r^2$, and (for positive Q) $\vec{E}$ points away from Q. $\vec{E}$ points away from positive source charges and points toward negative source charges.

(Try this on a sheet of paper, and compare your drawing with your neighbor's drawing.) I place **a single object** of positive charge $Q > 0$ at the origin. Draw arrows to indicate the direction of the electric field at the points A,B,C,D,E,F,G,H.



(Try this on a sheet of paper, and compare your drawing with your neighbor's drawing.) I place a single object of **negative** charge $Q < 0$ at the origin. Draw arrows to indicate the direction of the electric field at the points A,B,C,D,E,F,G,H.



Electric field due to N charged objects $Q_1, Q_2, \ldots, Q_N$

Just as the force experienced by a test charge q (positioned at point P) is the vector sum of the forces due to the other charges, the electric field $\vec{E}$ (evaluated at point P) due to N charged objects is the vector sum of the contributions from each charge:

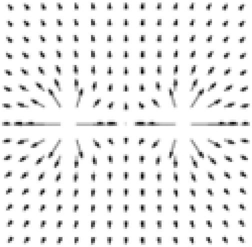
$$\vec{E}(P) = \sum \frac{\vec{F}_{\mathrm{on\ q}}}{q} = k \sum_{i=1}^{N} \frac{Q_i}{r_{iP}^2} \hat{r}_{iP}$$

That implies that the electric field due to N different source objects is just the *superposition* (i.e. the vector sum) of the electric fields due to the individual sources.

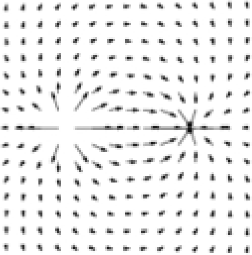
(Draw $\vec{E}$ surrounding $Q > 0$ and surrounding $Q < 0$.)

A positively charged particle is placed at $(x = -1, y = 0)$ and a negatively charged particle (having charge of the same magnitude) is placed at $(x = +1, y = 0)$. Which diagram correctly shows the electric field in the region surrounding these two charged particles?

1.



2.



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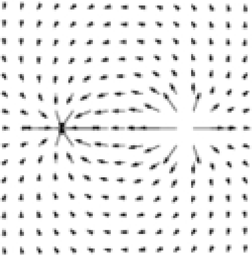
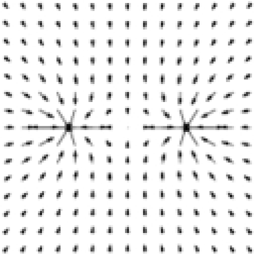
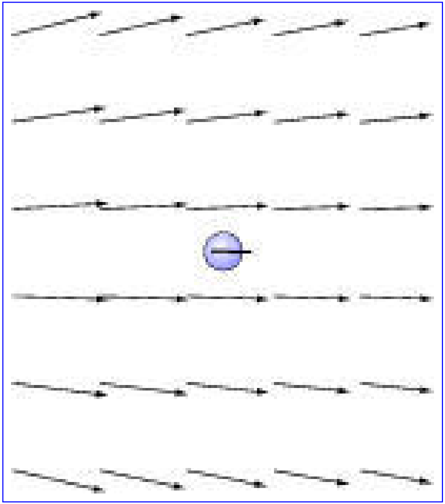


4.



https://phet.colorado.edu/sims/html/charges-and-fields/latest/charges-and-fields_en.html

A negatively charged object is placed in an electric field as shown below. The direction of the electostatic force on the object is



(A) to the right

(B) to the left

(C) neither right nor left

(D) depends on whether the field was created by a positively or negatively charged object

(E) There is no force on the object at the location shown in the figure.

Now let's try this more quantitatively

The net force ON object a due to a set of N charged objects is

$$\vec{F}_a^E = k \sum_{i=1}^{N} \frac{q_i \; q_a}{r_{ia}^2} \; \hat{r}_{ia}$$

where r_{ia} is the distance from object i to object a and $\hat{r}_{ia}$ is the **unit vector** pointing from object i toward object a.

Math reminder: the unit vector pointing in direction $\vec{r} = (x, y, z)$ is

$$\hat{r} = \frac{\vec{r}}{r} = \frac{(x, y, z)}{\sqrt{x^2 + y^2 + z^2}}$$

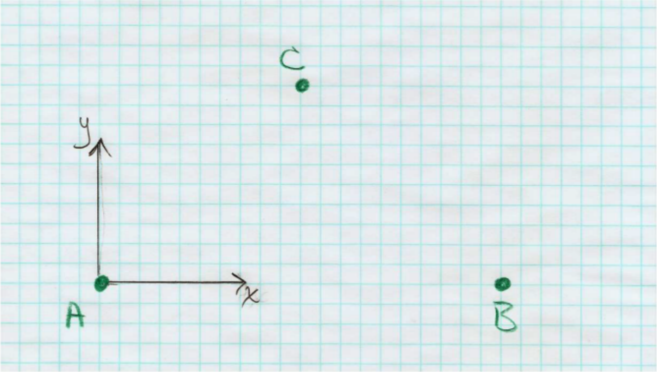
So $\hat{r}$ points in the same direction as $\vec{r}$, but $\hat{r}$ has a length of 1.

That brings us to worksheet Q#1. (Work on it, then we'll vote.)

Physics 9 worksheet: electric forces.

Work with your neighbor. Ask me for help if you're stuck. Then we'll discuss & check work all together.

Particles A, B, C carry identical positive charges $q_A = q_B = q_C = +10\ \mu\text{C} = 1.0 \times 10^{-5}$ C. Particle A is located at $(x_A, y_A) = (0, 0)$ meters. Particle B is at $(x_B, y_B) = (+2.0, 0.0)$ meters. Particle C is at $(x_C, y_C) = (+1.0, +1.0)$ meters. The angles $\angle_{CAB}$ and $\angle_{CBA}$ are both 45°. If you don't have a calculator, you can approximate $k = 9 \times 10^9\ \text{N m}^2/\text{C}^2 \approx 10^{10}\ \text{N m}^2/\text{C}^2$.

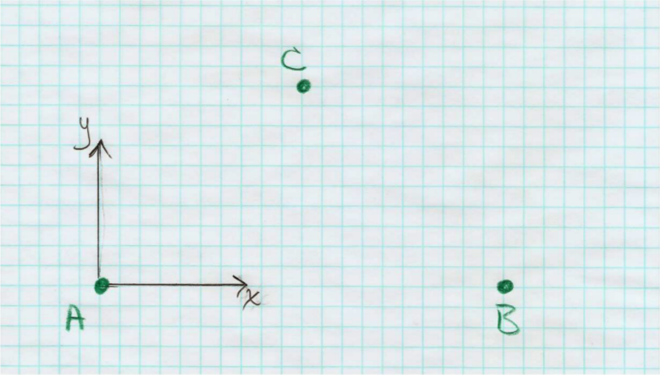


(1) What is the magnitude (in newtons) of the electric force between each pair of particles?

$F^E_{AB} =$ $\qquad$ $F^E_{AC} =$ $\qquad$ $F^E_{BC} =$

$F^E_{BA} =$ $\qquad$ $F^E_{CA} =$ $\qquad$ $F^E_{CB} =$

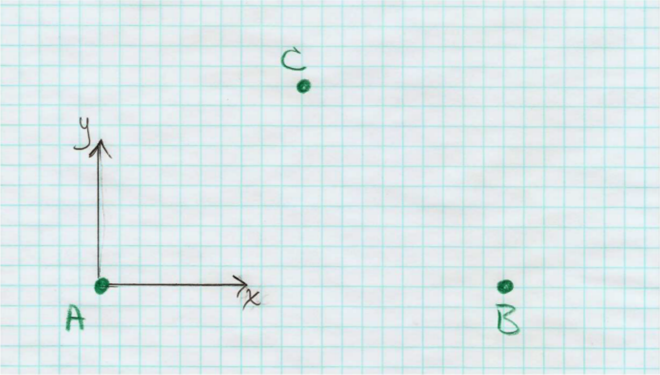
Particles A, B, C carry identical positive charges $q_A = q_B = q_C = +10\ \mu\text{C} = 1.0 \times 10^{-5}$ C. Particle A is located at $(x_A, y_A) = (0, 0)$ meters. Particle B is at $(x_B, y_B) = (+2.0, 0.0)$ meters. Particle C is at $(x_C, y_C) = (+1.0, +1.0)$ meters. The angles $\angle_{CAB}$ and $\angle_{CBA}$ are both 45°. If you don't have a calculator, you can approximate $k = 9 \times 10^9\ \text{N m}^2/\text{C}^2 \approx 10^{10}\ \text{N m}^2/\text{C}^2$.



The magnitude of the electric force F^E_{AB} exerted by A on B is

(A) 0.125 N (B) 0.225 N (C) 0.45 N (D) 0.90 N (E) 4.5 N

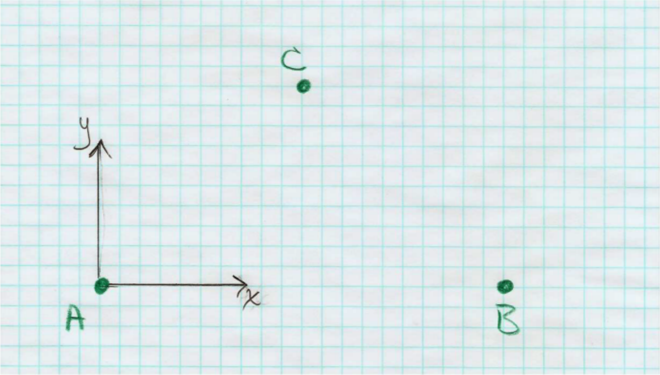
Particles A, B, C carry identical positive charges $q_A = q_B = q_C = +10\ \mu\text{C} = 1.0 \times 10^{-5}$ C. Particle A is located at $(x_A, y_A) = (0, 0)$ meters. Particle B is at $(x_B, y_B) = (+2.0, 0.0)$ meters. Particle C is at $(x_C, y_C) = (+1.0, +1.0)$ meters. The angles $\angle_{CAB}$ and $\angle_{CBA}$ are both 45°. If you don't have a calculator, you can approximate $k = 9 \times 10^9\ \text{N m}^2/\text{C}^2 \approx 10^{10}\ \text{N m}^2/\text{C}^2$.



The magnitude of the electric force F^E_{BA} exerted by B on A is

(A) 0.125 N (B) 0.225 N (C) 0.45 N (D) 0.90 N (E) 4.5 N

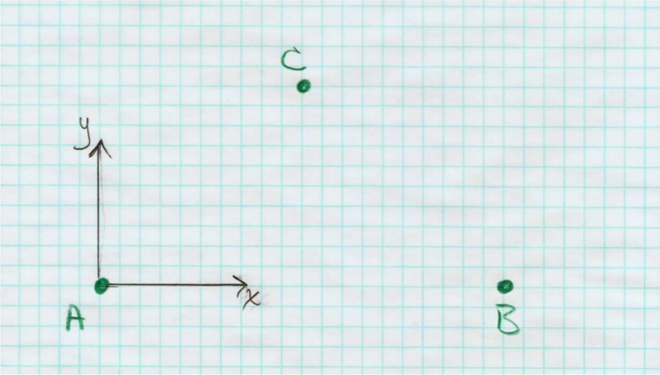
Particles A, B, C carry identical positive charges $q_A = q_B = q_C = +10\ \mu\text{C} = 1.0 \times 10^{-5}$ C. Particle A is located at $(x_A, y_A) = (0, 0)$ meters. Particle B is at $(x_B, y_B) = (+2.0, 0.0)$ meters. Particle C is at $(x_C, y_C) = (+1.0, +1.0)$ meters. The angles $\angle_{CAB}$ and $\angle_{CBA}$ are both 45°. If you don't have a calculator, you can approximate $k = 9 \times 10^9$ N m^2/C^2 $\approx 10^{10}$ N m^2/C^2.



The magnitude of the electric force F^E_{AC} exerted by A on C is

(A) 0.125 N (B) 0.225 N (C) 0.45 N (D) 0.90 N (E) 4.5 N

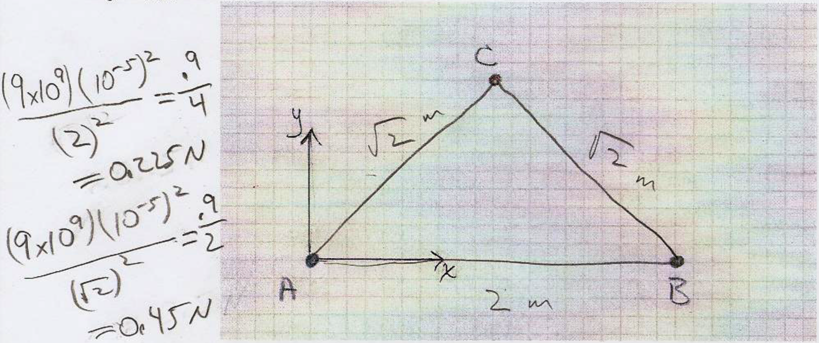
Particles A, B, C carry identical positive charges $q_A = q_B = q_C = +10\ \mu\text{C} = 1.0 \times 10^{-5}$ C. Particle A is located at $(x_A, y_A) = (0, 0)$ meters. Particle B is at $(x_B, y_B) = (+2.0, 0.0)$ meters. Particle C is at $(x_C, y_C) = (+1.0, +1.0)$ meters. The angles $\angle_{CAB}$ and $\angle_{CBA}$ are both 45°. If you don't have a calculator, you can approximate $k = 9 \times 10^9$ N m^2/C^2 $\approx 10^{10}$ N m^2/C^2.



The magnitude of the electric force F^E_{BC} exerted by B on C is

(A) 0.125 N (B) 0.225 N (C) 0.45 N (D) 0.90 N (E) 4.5 N

Particles A, B, C carry identical positive charges $q_A = q_B = q_C = +10\ \mu\text{C} = 1.0 \times 10^{-5}$ C. Particle A is located at $(x_A, y_A) = (0, 0)$ meters. Particle B is at $(x_B, y_B) = (+2.0, 0.0)$ meters. Particle C is at $(x_C, y_C) = (+1.0, +1.0)$ meters. The angles $\angle_{CAB}$ and $\angle_{CBA}$ are both 45°.



(1) What is the magnitude (in newtons) of the electric force between each pair of particles?

$F^E_{AB} =$ 0.225 N (≈ 0.25 N) $F^E_{AC} =$ 0.45 N (≈ 0.5 N) $F^E_{BC} =$ 0.45 N

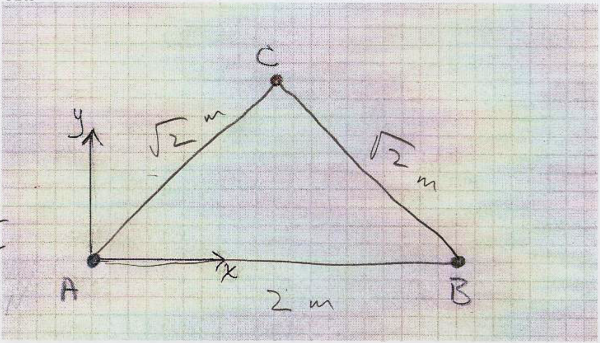
$F^E_{BA} =$ 0.225 N $F^E_{CA} =$ 0.45 N $F^E_{CB} =$ 0.45 N

My answers (A) did (B) did not look something like this.

Particles A, B, C carry identical positive charges $q_A = q_B = q_C = +10\ \mu C = 1.0 \times 10^{-5}$ C. Particle A is located at $(x_A, y_A) = (0,0)$ meters. Particle B is at $(x_B, y_B) = (+2.0, 0.0)$ meters. Particle C is at $(x_C, y_C) = (+1.0, +1.0)$ meters. The angles $\angle_{CAB}$ and $\angle_{CBA}$ are both 45°.

$$\frac{(9\times10^9)(10^{-5})^2}{(2)^2} = \frac{.9}{4} = 0.225\,N$$

$$\frac{(9\times10^9)(10^{-5})^2}{(\sqrt{2})^2} = \frac{.9}{2} = 0.45\,N$$



(1) What is the magnitude (in newtons) of the electric force between each pair of particles?

$F^E_{AB} =$ 0.225N (≈ 0.25N) $F^E_{AC} =$ 0.45N (≈0.5N) $F^E_{BC} =$ 0.45N

$F^E_{BA} =$ 0.225N $F^E_{CA} =$ 0.45N $F^E_{CB} =$ 0.45N

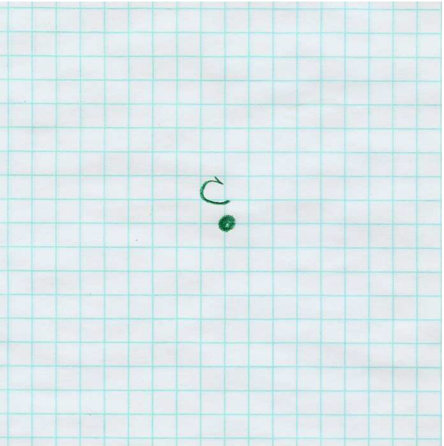
(A) Question (1) is too easy. Not a good use of classroom time.

(B) I understand question (1) now. This was helpful.

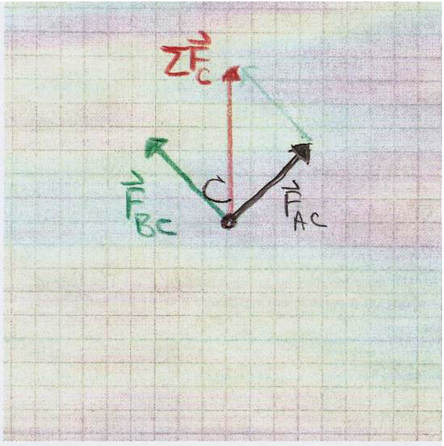
(C) I still don't understand how to do question 1.

(D) None of the above.

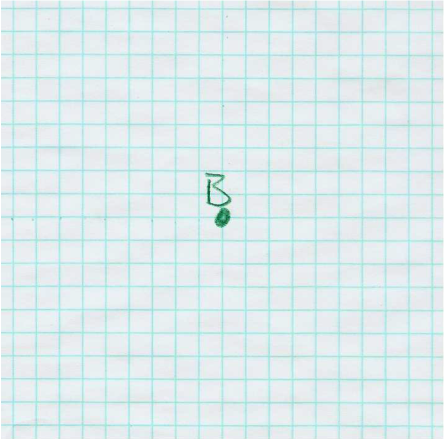
(2) Draw arrows for the two electric forces that are acting ON particle C. (The electric force exerted by A on C is written $\vec{F}^{E}_{AC}$. The electric force exerted by B on C is written $\vec{F}^{E}_{BC}$.) Then draw an arrow for the vector sum of forces (a.k.a. the "net force") acting on particle C, which is written $\sum \vec{F}^{E}_{C}$. To make it easier to compare results, choose the length of your arrows so that the grid size on your force diagram is 0.1 N. (Use the left grid below.)



(2) Draw arrows for the two electric forces that are acting ON particle C. (The electric force exerted by A on C is written $\vec{F}^E_{AC}$. The electric force exerted by B on C is written $\vec{F}^E_{BC}$.) Then draw an arrow for the vector sum of forces (a.k.a. the "net force") acting on particle C, which is written $\sum \vec{F}^E_C$. To make it easier to compare results, choose the length of your arrows so that the grid size on your force diagram is $0.1\ \mathrm{N}$. (Use the left grid below.)

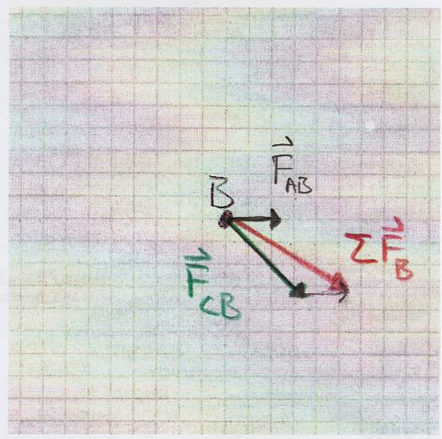


My answer
(A) did
(B) did not
look something like this.



(3) Now draw (above right) arrows for the forces acting on particle B and their vector sum. Again use a grid size of 0.1 N.

My answer
(A) did
(B) did not
look something like this.



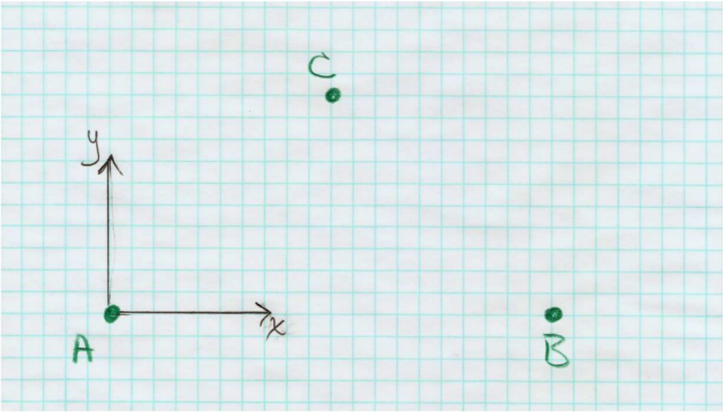
(3) Now draw (above right) arrows for the forces acting on particle B and their vector sum. Again use a grid size of $0.1\ \mathrm{N}$.

(4) Next, work out the Cartesian coordinates (F_x, F_y) for the forces acting on particle C and their vector sum.

$F^E_{AC,x} =$ $F^E_{AC,y} =$

$F^E_{BC,x} =$ $F^E_{BC,y} =$

$\sum F^E_{C,x} =$ $\sum F^E_{C,y} =$



This may be helpful for Q4.

The electrostatic force due to b acting ON c is

$$\vec{F}^{E}_{bc} = k \; \frac{q_b \; q_c}{r_{bc}^2} \; \hat{r}_{bc}$$

where $k = 9.0 \times 10^9 \ \mathrm{N \cdot m^2/C^2}$.

The net force ON c due to a set of N charged objects is

$$\vec{F}^{E}_{c} = k \; \sum_{i=1}^{N} \; \frac{q_i \; q_c}{r_{ic}^2} \; \hat{r}_{ic}$$

where r_{ic} is the distance from object i to object c and $\hat{r}_{ic}$ is the **unit vector** pointing from object i toward object c.

(In practice, you usually draw $\hat{r}_{ic}$ equivalently as the unit vector pointing from object c away from object i, which is the same direction as the direction from i to c.)

(4) Next, work out the Cartesian coordinates (F_x, F_y) for the forces acting on particle C and their vector sum.

$F^E_{AC,x} = (0.45N)\cos(45^\circ) = +0.318N$

$F^E_{AC,y} = (0.45N)\sin(45^\circ) = +0.318N$

$F^E_{BC,x} = -0.318N$

$F^E_{BC,y} = +0.318N$

$\sum F^E_{C,x} = 0\,N$

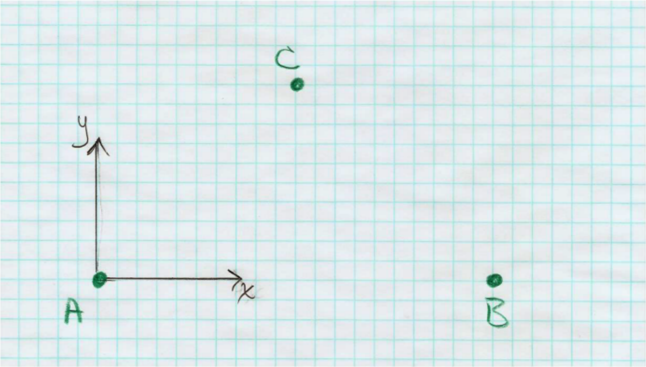
$\sum F^E_{C,y} = +0.636N$

Electric field due to N charged objects $Q_1, Q_2, \ldots, Q_N$

Just as the force experienced by a test charge q (positioned at point P) is the vector sum of the forces due to the other charges, the electric field $\vec{E}$ (evaluated at point P) due to N charged objects is the vector sum of the contributions from each charge:

$$\vec{E}(P) = \sum \frac{\vec{F}_{\mathrm{on\ q}}}{q} = k \sum_{i=1}^{N} \frac{Q_i}{r_{iP}^2} \hat{r}_{iP}$$

That implies that the electric field due to N different source objects is just the *superposition* (i.e. the vector sum) of the electric fields due to the individual sources.



(5) Draw an arrow indicating the direction of the electric field $\vec{E}(P)$ at the point P given by $P_x = 1.0$ m, $P_y = 0.0$ m.

(6) Work out the Cartesian components (E_x, E_y) for the electric field $\vec{E}$ at the same point P.

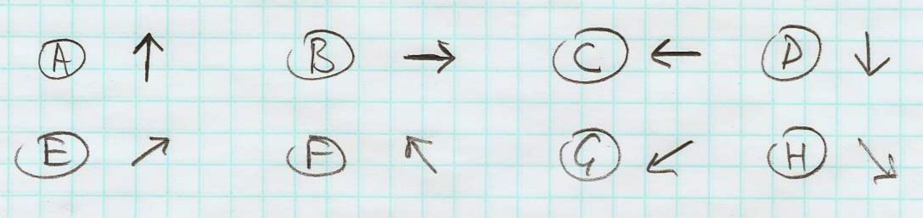
If we let $\vec{E}_A$, $\vec{E}_B$, and $\vec{E}_C$ be the electric field created by particle A, by particle B, and by particle C, respectively, then the combined electric field is the vector sum of these individual electric fields:

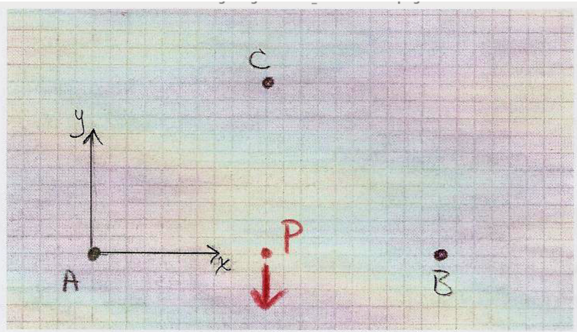
$$\vec{E}(P) = \vec{E}_A(P) + \vec{E}_B(P) + \vec{E}_C(P) = \sum_i k \frac{q_i}{r_{iP}^2} \hat{r}_{iP}$$

$E_x(P) =$

$E_y(P) =$

In which direction did you draw your $\vec{E}(P)$ arrow for question 5?



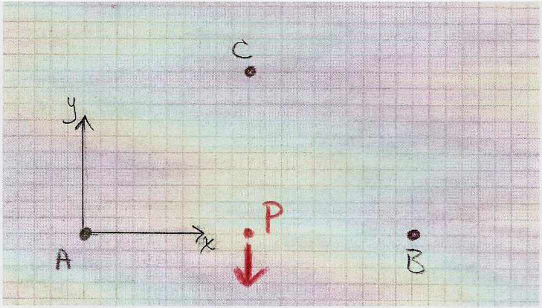


OK, now back to Question 6:

Work out the Cartesian components (E_x, E_y) for the electric field $\vec{E}$ at the same point P.

If we let $\vec{E}_A$, $\vec{E}_B$, and $\vec{E}_C$ be the electric field created by particle A, by particle B, and by particle C, respectively, then the combined electric field is the vector sum of these individual electric fields:

$$\vec{E}(P) = \vec{E}_A(P) + \vec{E}_B(P) + \vec{E}_C(P) = \sum_i k \frac{q_i}{r_{iP}^2} \hat{r}_{iP}$$



(5) Draw an arrow indicating the direction of the electric field $\vec{E}(P)$ at the point P given by $P_x = 1.0$ m, $P_y = 0.0$ m.

(6) Work out the Cartesian components (E_x, E_y) for the electric field $\vec{E}$ at the same point P.

If we let $\vec{E}_A$, $\vec{E}_B$, and $\vec{E}_C$ be the electric field created by particle A, by particle B, and by particle C, respectively, then the combined electric field is the vector sum of these individual electric fields:

$$\vec{E}(P) = \vec{E}_A(P) + \vec{E}_B(P) + \vec{E}_C(P) = \sum_i k \frac{q_i}{r_{iP}^2} \hat{r}_{iP}$$

$E_x(P) =$ 0 N/C

$E_y(P) =$ −90 kN/C

$$\frac{\left(9\times10^{-9}\,\frac{Nm^2}{C^2}\right)\left(10^{-5}C\right)}{(1.0m)^2} = 9\times10^{4}\,N/C$$

(7) Using your answer for part (6) and the equation $\vec{F}^E = q\vec{E}$ for the force exerted by an electric field $\vec{E}$ on a particle of charge q, what is the net electric force (magnitude and direction) acting on a particle having charge $q = -1\ \mu\text{C}$ and placed at point P ?

$F_x =$

$F_y =$

(7) Using your answer for part (6) and the equation $\vec{F}^E = q\vec{E}$ for the force exerted by an electric field $\vec{E}$ on a particle of charge q, what is the net electric force (magnitude and direction) acting on a particle having charge $q = -1\ \mu C$ and placed at point P ?

$F_x =$ 0 N

$F_y =$ $q E_y = (-1.0\times10^{-6} C)(-90\times10^{3} \frac{N}{C})$

$= +0.090 N = +9\times10^{-2} N$

Motion in electric field.

Remember that the vector sum of forces acting ON an object causes the object to accelerate:

$$m\vec{a} = \sum \vec{F}$$

In an electric field $\vec{E}$, the force $\vec{F}$ on an object with charge q is

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

If the force $\vec{F} = q\vec{E}$ is not balanced by any other force, a charged object will *accelerate* in an electric field:

$$\vec{a} = \frac{q}{m}\,\vec{E}$$

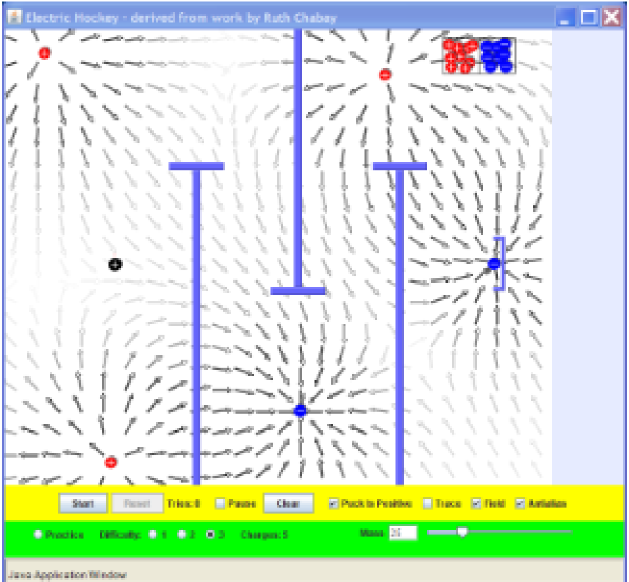
If some other force $\vec{F}_{\mathrm{other}}$ is also acting (e.g. gravity), then

$$\vec{a} = \frac{q}{m}\,\vec{E} + \frac{1}{m}\,\vec{F}_{\mathrm{other}}$$

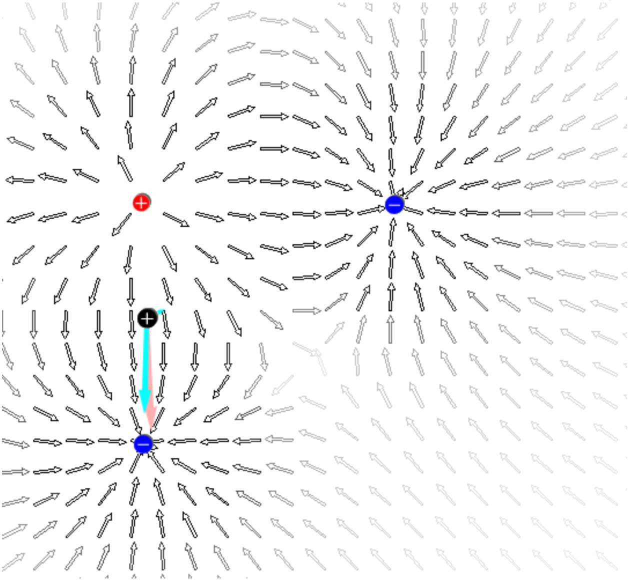
Electric field hockey: may help with $\vec{F} = q\vec{E}$

phet.colorado.edu/en/simulation/electric-hockey

http://www.youtube.com/watch?v=VuG4eG_KaUw



E.F.H can draw the electric field e.g. from HW problem 5. (The black $\oplus$ is the "test charge" and doesn't contribute to $\vec{E}$.)

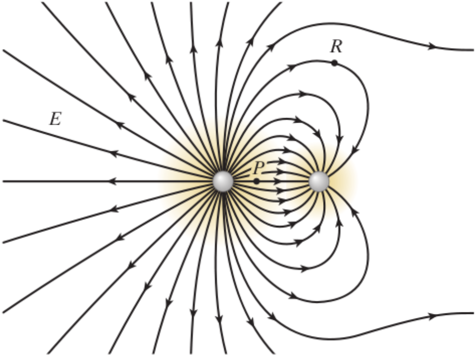


Someone else seems to have written an HTML5 version of Electric Field Hockey, which can be run without starting up a Java applet.

https://www.physicsclassroom.com/PhysicsClassroom/media/interactive/ElectricFieldHockey/index.html

"Flux" of electric field lines.

- $|\vec{E}|$ is proportional to the density of electric field lines. More closely spaced lines $\rightarrow$ bigger $|\vec{E}|$.
- Think of the field lines "flowing" (or radiating, like light) out from the $(+)$ charges and into the $(-)$ charges.
- The total "flux" of $\vec{E}$ through a hypothetical **closed** surface is proportional to the total charge enclosed by that surface.

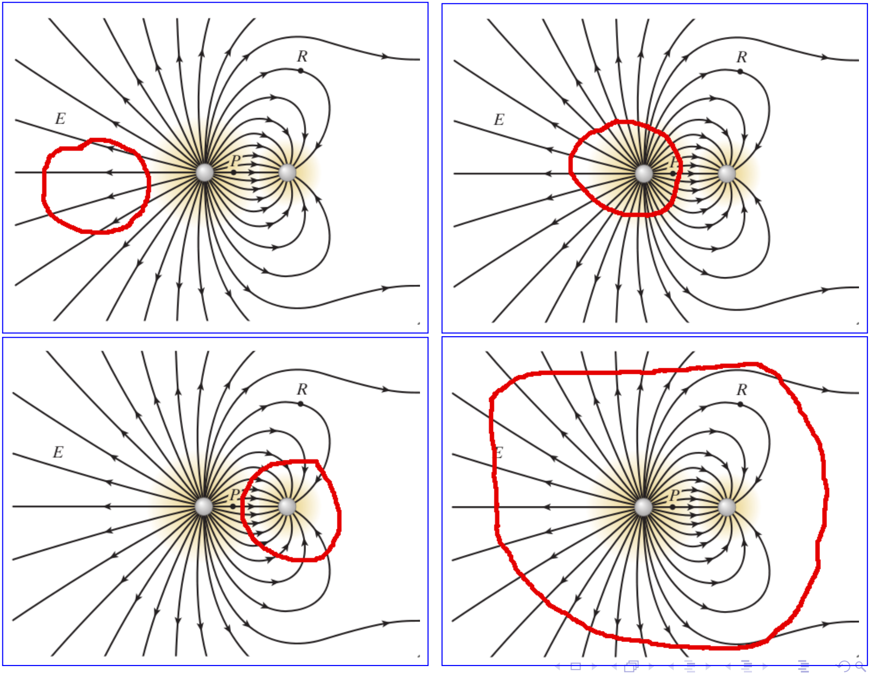


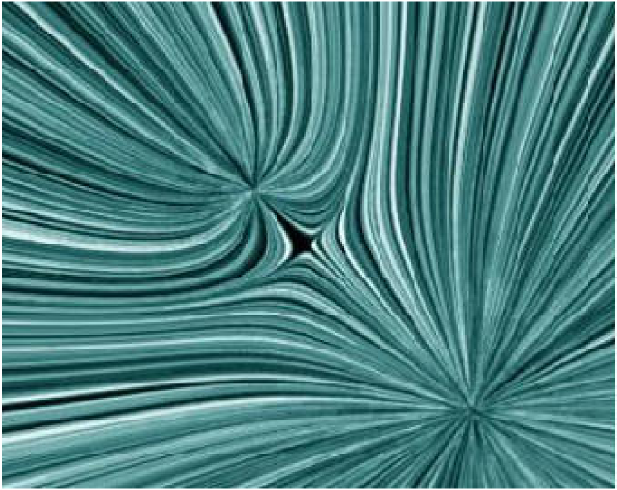
Where is $|\vec{E}|$ largest here?

What are the signs of the two particles' charges?

If you draw a circle that encloses no net charge, what is the net flux through the circle?

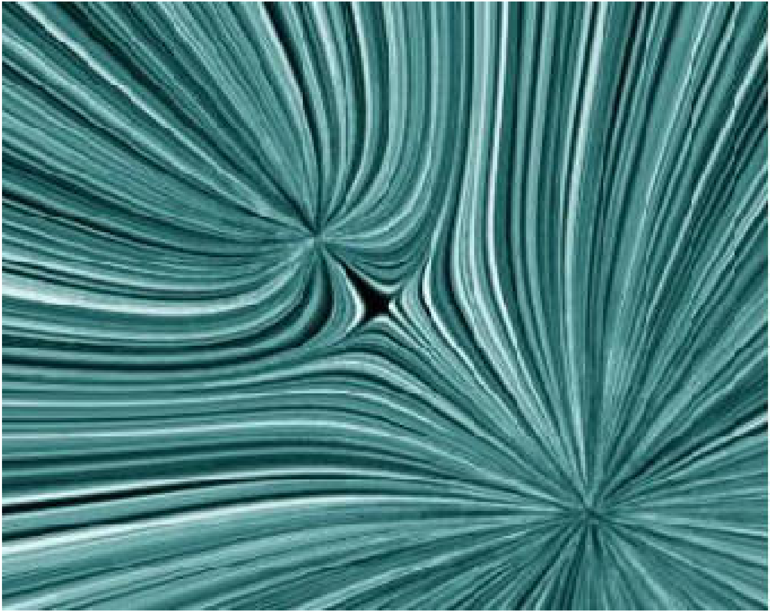
Is net charge enclosed by each circle $+$, $-$, or 0 ?



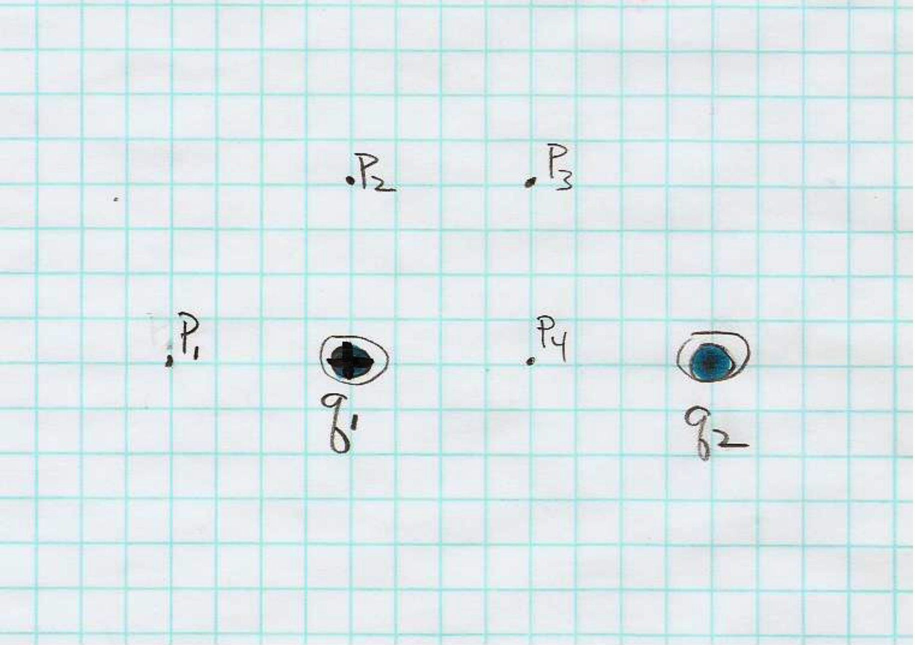


The image shows the electric field around two charged particles, using the “grass seed” representation of field lines. From this picture you can conclude that

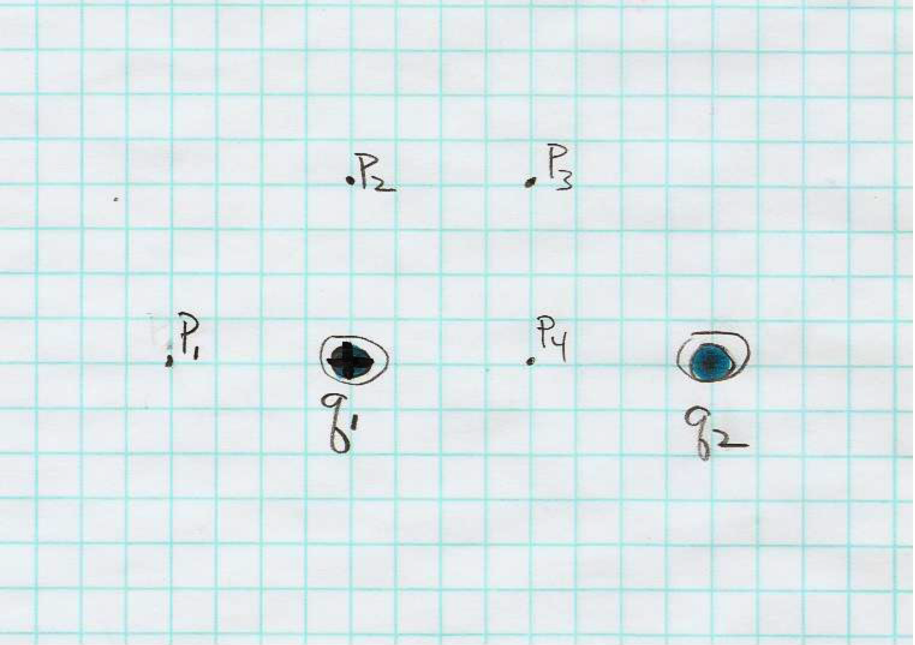
(A) The two charges attract one another.
(B) The two charges repel one another.
(C) Not enough information to tell whether they repel or attract.



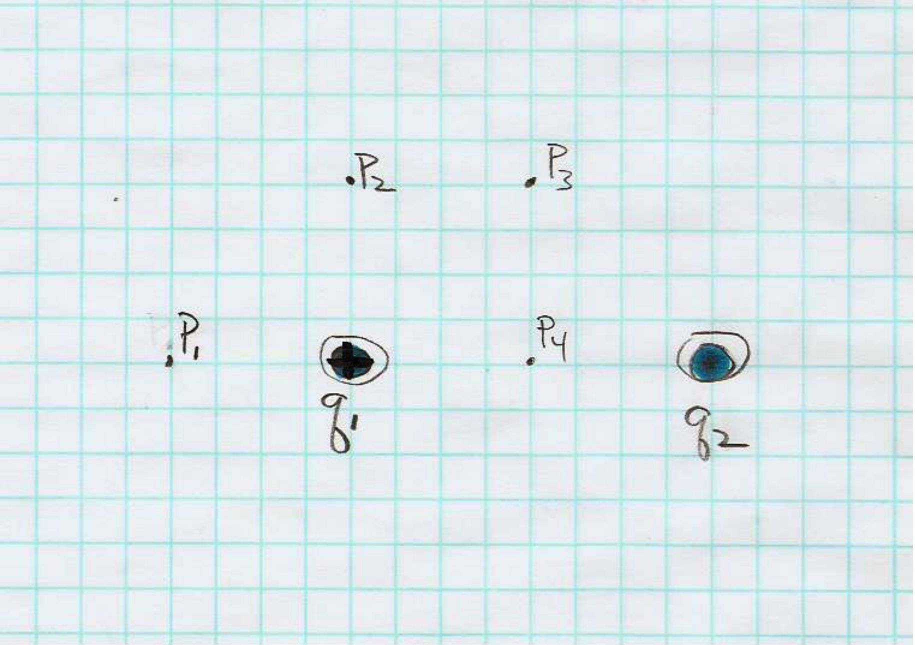
(Follow-up: Where are the two particles located? Can you say what the signs of the charges are? Can you tell whether the charge magnitudes are the same or different?)



Using **superposition,** draw $\vec{E}$ at points $P_1 \ldots P_4$ if $q_2 = +q_1$.



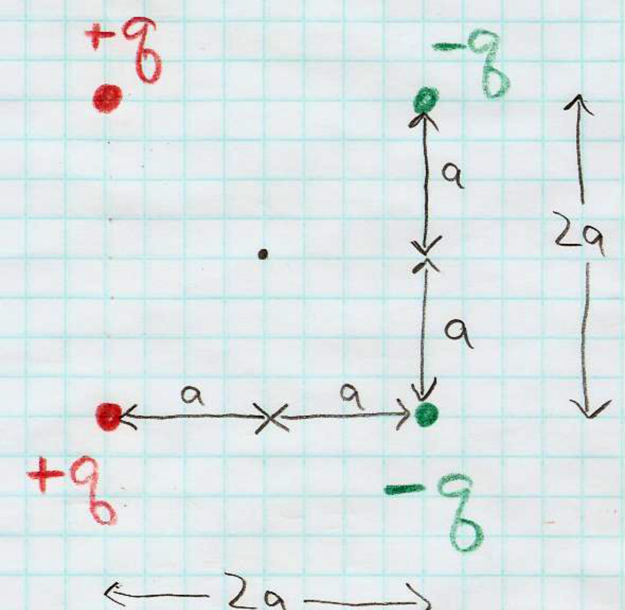
Using **superposition,** draw $\vec{E}$ at points $P_1 \ldots P_4$ if $q_2 = +2q_1$.



Using **superposition,** draw $\vec{E}$ at points $P_1 \ldots P_4$ if $q_2 = -q_1$.

https://phet.colorado.edu/sims/html/charges-and-fields/latest/charges-and-fields_en.html

Is anyone interested in working through this example? Four charged particles are arranged in a square (side length $2a$), as shown. Find & draw the electric field at the center of the square.

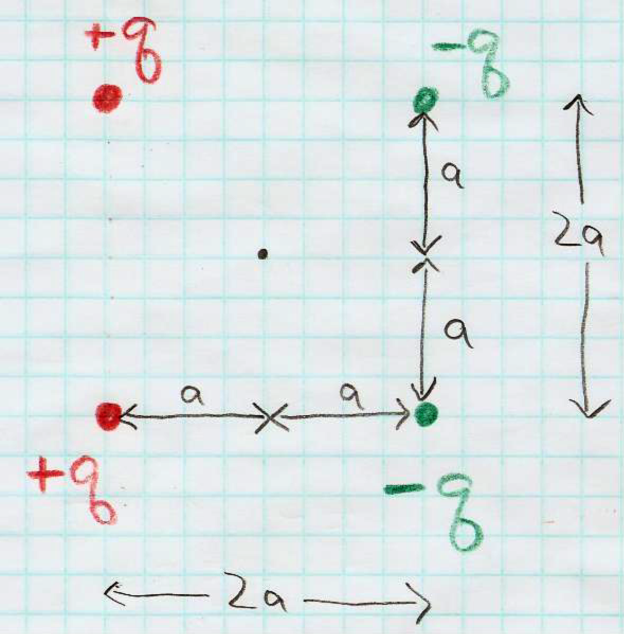


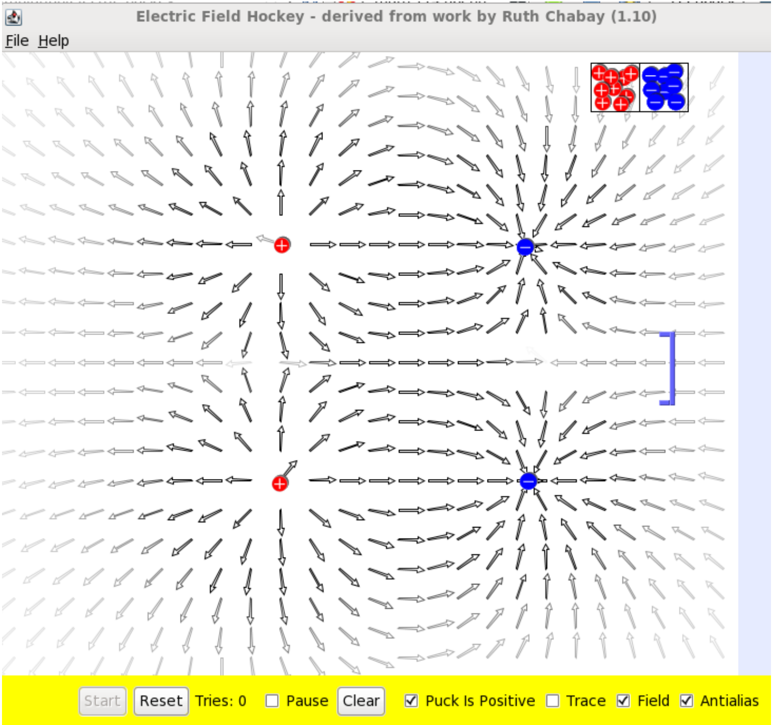
(We'll see on next page that Electric Field Hockey can draw the E field diagram for charge configurations like this.)

$$E_x = \sqrt{2}\,\frac{kq}{a^2}$$

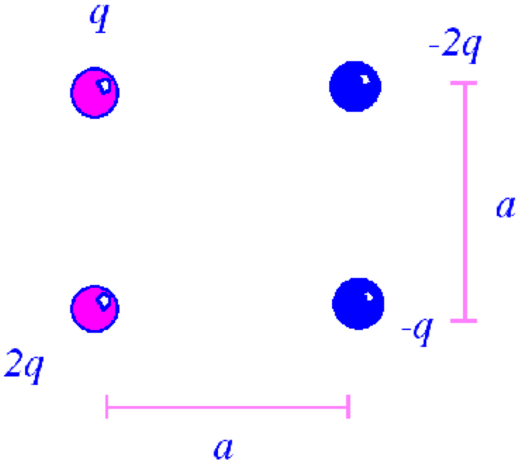
$$E_y = 0$$

$$\vec{E} = \sqrt{2}\,\frac{kq}{a^2}\,\hat{i}$$

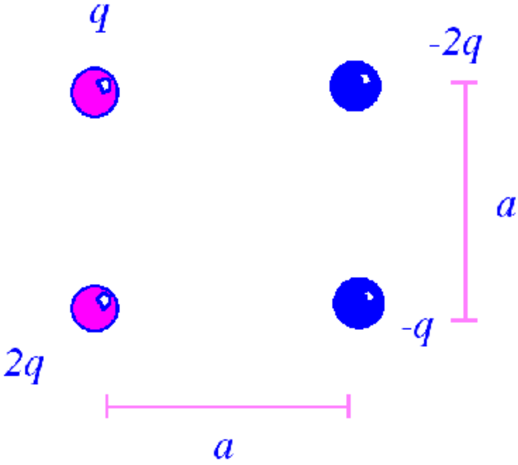



Electric Field Hockey - derived from work by Ruth Chabay (1.10)
File
Help
Start
Reset
Tries: 0
Pause
Clear
Puck Is Positive
Trace
Field
Antialias

Is anyone interested in working through this example? Four charged particles are arranged in a square, as shown. Find (and draw) the electric field at the center of the square.

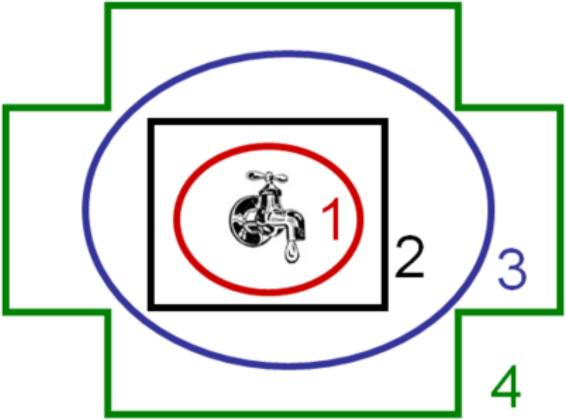


Four charged particles are arranged in a square, as shown. Find (and draw) the electric field at the center of the square.



$$E_x = 6\sqrt{2}\,\frac{kq}{a^2} \qquad E_y = 2\sqrt{2}\,\frac{kq}{a^2} \qquad |\vec{E}| = 4\sqrt{5}\,\frac{kq}{a^2}$$

A faucet tap is turned on at the center. Rank order which closed line has the most (to the least) water flowing across the line per unit time. (The faucet has been on for a long time.)



(A) $1 > 2 > 3 > 4$

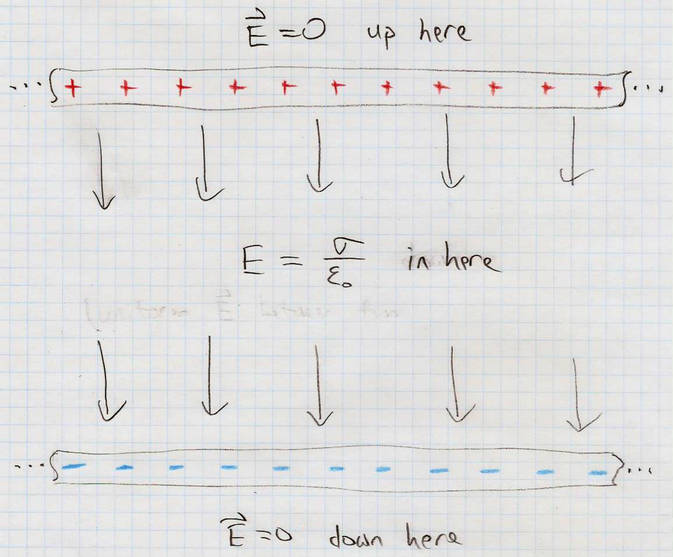
(B) $1 = 2 > 3 > 4$

(C) $1 = 3 > 2 > 4$

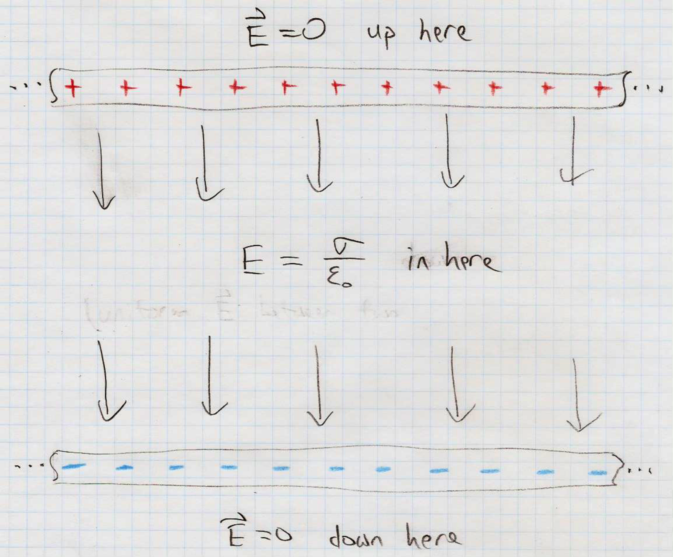
(D) $4 > 3 > 2 > 1$

(E) $1 = 2 = 3 = 4$

(F) none of the above

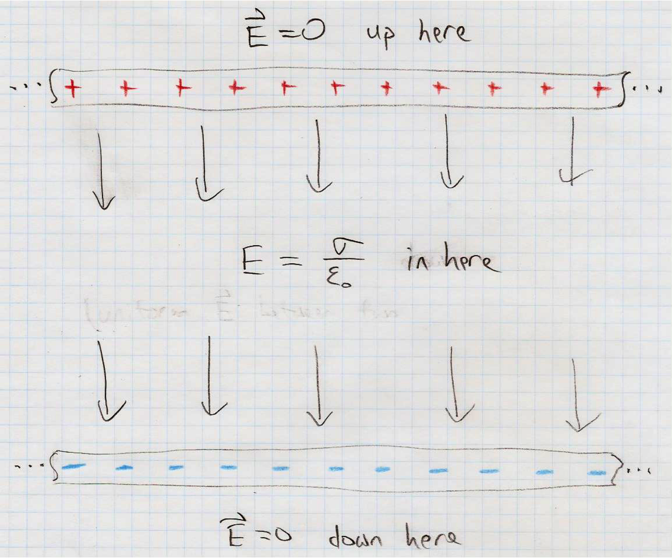


The most commonly used way to create a uniform electric field is to use the area between two large, parallel, oppositely-charged planes of uniform charge-per-unit-area.



Notice that if you do this, a positive particle will "fall" in the direction that $\vec{E}$ points, just as a rock will fall in the direction gravity points — toward Earth's surface. To lift up a positive particle, you would have to add energy (do + work).

Suppose I move a charged particle vertically upward in the region where $\vec{E}$ is uniform and points downward. The work-per-unit-charge that I have to do to move the particle up is:

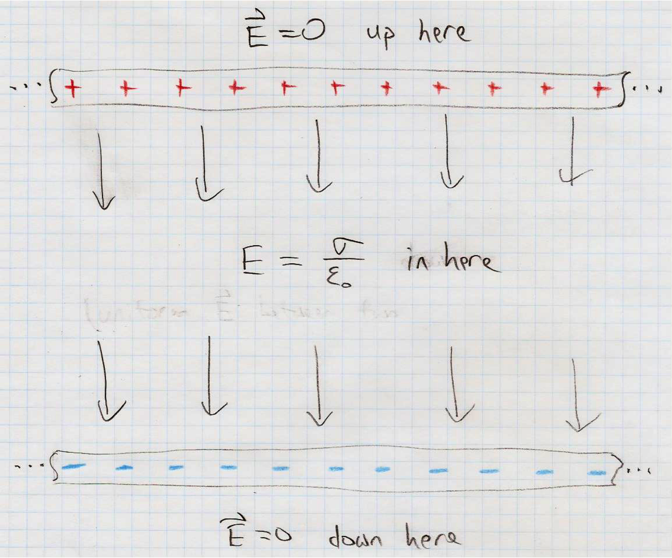


(A) positive

(B) negative

(C) zero

Suppose I move a charged particle vertically **downward** in the region where $\vec{E}$ is uniform and points downward. The work-per-unit- charge that I have to do to move the particle is:

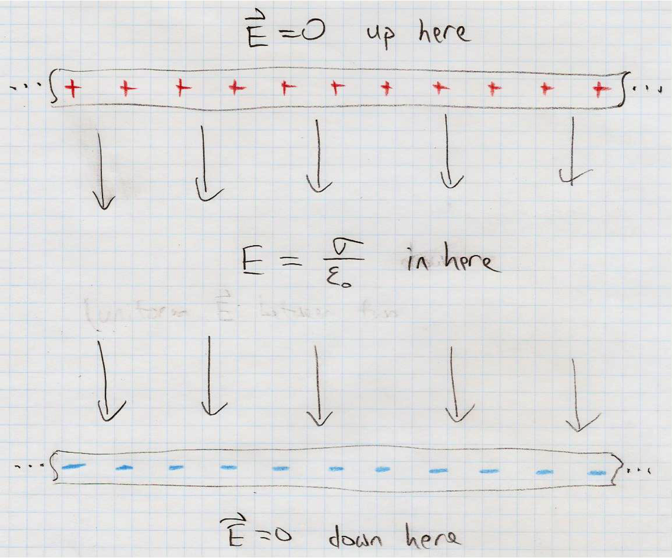


(A) positive

(B) negative

(C) zero

Suppose I move a charged particle **horizontally** in the region where $\vec{E}$ is uniform and points downward. The work-per-unit-charge that I have to do to move the particle is:

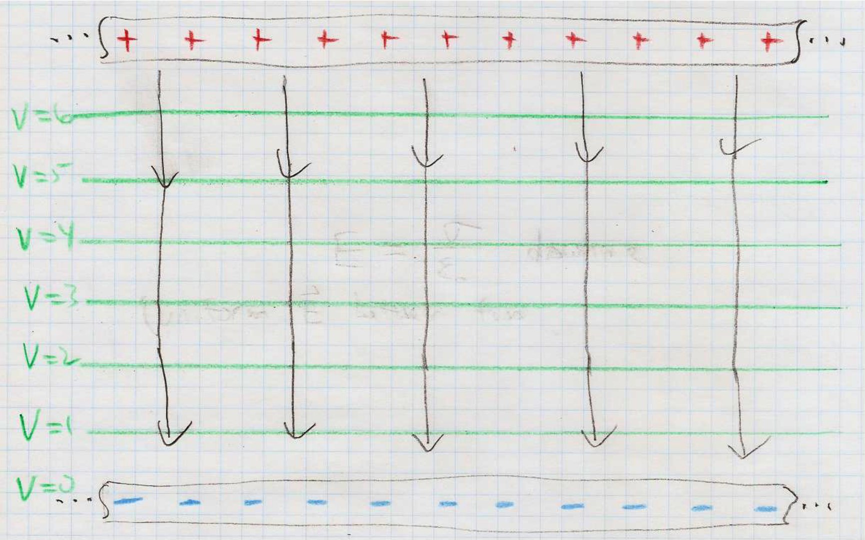


(A) positive

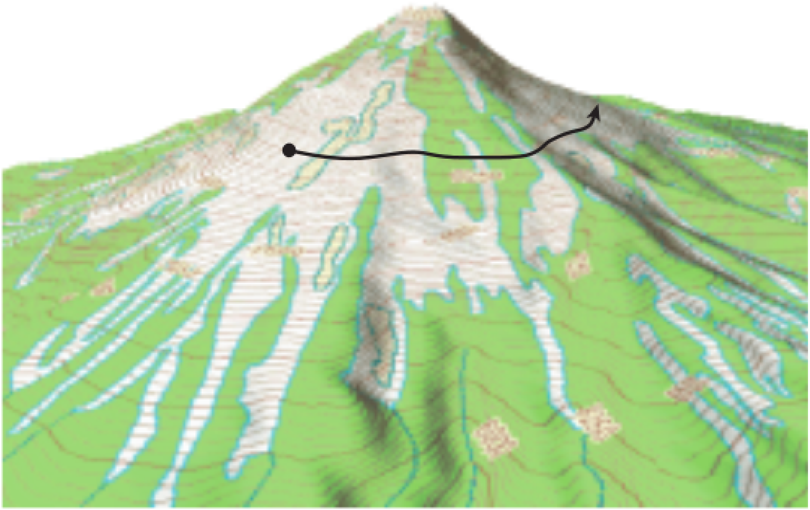
(B) negative

(C) zero

Electrostatic potential is analogous to altitude. Gravity points in the direction in which altitude decreases most quickly. $\vec{E}$ points in the direction in which "voltage" decreases most quickly. Equipotential lines are perpendicular to $\vec{E}$.



Contour lines on a topo map are always perpendicular to gravity. Contour lines are lines of constant elevation. Moving along a contour line, you do no work against gravity. Along a contour line, G.P.E. (per unit mass) is constant.



Equipotential lines (constant V) are perpendicular to $\vec{E}$. Moving along an equipotential, you do no work against $\vec{E}$. Along an equipotential, E.P.E. (per unit charge) is constant.

Equipotential lines (constant V) are perpendicular to $\vec{E}$. Moving along an equipotential, you do no work against $\vec{E}$. Along an equipotential, E.P.E. (per unit charge) is constant.

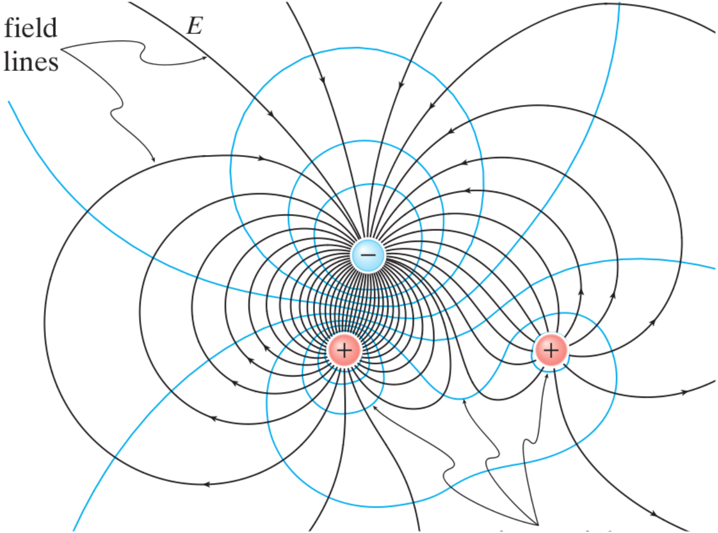
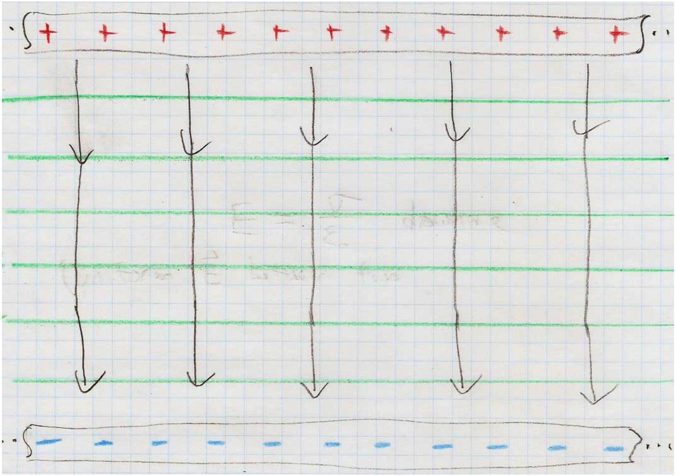


Figure 25.9 Field lines and equipotentials for three stationary charged particles.

I am standing in a uniform electric field, of magnitude 1 N/C, which points downward. I climb up 1 meter. What is the potential difference, $V_{1\to 2} = V_2 - V_1$, between my old location and my new location? (Note: 1 N/C is the same as 1 volt per meter.)



(A) $V_{1\to 2} = +1$ volt

(B) $V_{1\to 2} = -1$ volt

(C) $V_{1\to 2} = 0$ volts

The "potential difference" between point *a* and point *b* is **minus** the work-per-unit-charge done by the electric field in moving a test particle from *a* to *b*.

$$V_{ab} \; = \; -\frac{1}{q}\int_a^b \vec{F}^E \cdot \mathrm{d}\vec{\ell} \; = \; -\int_a^b \vec{E} \cdot \mathrm{d}\vec{\ell}$$

More intuitively, V_{ab} is (**plus**) the work-per-unit-charge that an external agent (like me) would have to do to move a particle from *a* to *b*. I would be working against the electric field to do this.

But a much easier-to-remember definition of voltage is "electric potential energy per unit charge."

Just as $\vec{E}$ is electric force per unit charge, V is electric potential energy per unit charge.

$$V \; = \; \frac{U^E}{q}$$

Moving a **positive** particle to higher V means moving it to a position of higher electric potential energy.

Near Earth's surface, gravitational potential energy is

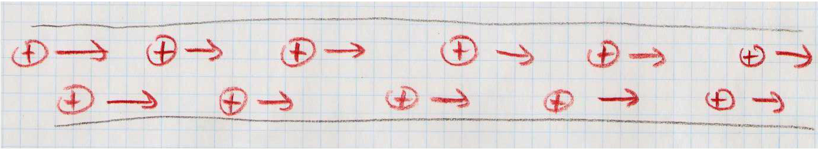
$$U^G = m\ g\ h$$

G.P.E. per unit mass would be just $(U/m) = gh$, which is proportional to altitude. Moving an object (no matter what mass) along a contour of equal gh does not require doing any work against gravity, and does not change the object's G.P.E.

In a uniform downward-pointing electric field, electric potential energy is

$$U^E = q\ E\ y$$

E.P.E. per unit charge would be just $V = (U/q) = E\ y$. So if $\vec{E}$ is uniform and points down, then potential (or "voltage") V is analogous to altitude. Moving perpendicular to $\vec{E}$ does not require doing any work against $\vec{E}$, and does not change E.P.E. So "equipotential" lines (constant V) are always perpendicular to $\vec{E}$.

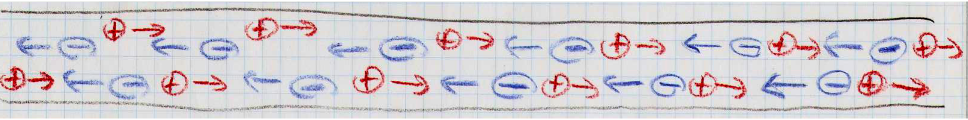


Inside a wire, positively charged particles are moving to the right. What is the direction of the electric current (symbol I, unit = ampere, or "amp") ?

(A) up
(B) down
(C) left
(D) right
(E) into the page
(F) out of the page
(G) zero

Inside a wire, negatively charged particles are moving to the right. What is the direction of the electric current?

(A) up
(B) down
(C) left
(D) right
(E) into the page
(F) out of the page
(G) zero



Inside a wire, positively charged particles are moving to the right. An equal number of negatively charged particles is moving to the left, at the same speed. The electric current is

(A) flowing to the right

(B) flowing to the left

(C) zero

Physics 9 — Monday, November 12, 2018

- The main goals for the electricity segment (the last segment of the course) are for you to feel confident that you understand the meaning of electric potential (volts), electric current (amps), how these relate to energy and power, and also for you to understand the basic ideas of electric circuits (e.g. things wired in series vs in parallel). We'll get there soon.
- For today, you read Richard Muller's PTFP chapter 6 (electricity & magnetism)
- For Wednesday, read Giancoli ch17 (electric potential)
- HW9 due this Friday.
- If I can work out the practical details, I may have us spend the last several days of class working in groups on your laptop/notebook computers running acoustical and/or thermal simulations.