Physics 9 — Wednesday, November 14, 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 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.
- HW help sessions: Wed 4–6pm DRL **4C2** (Bill), Thu 6:30–8:30pm DRL 2C8 (Grace)

It turns out that on Monday my shoes were “grounding” me.

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

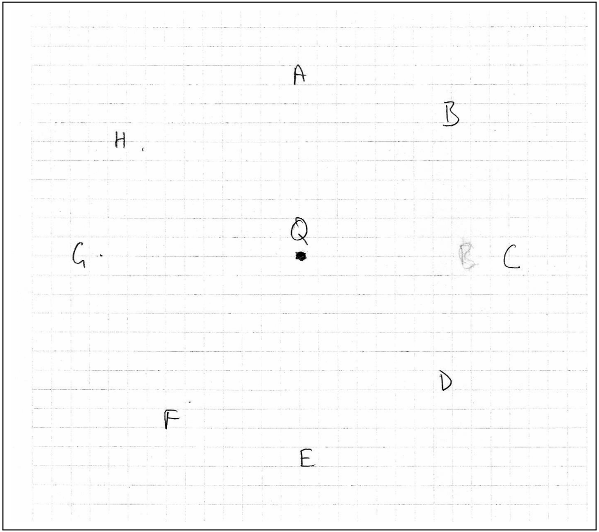
$$\vec{F}_q = k\ \frac{Qq}{r_{Qq}^2}\ \hat{r}_{Qq} = +k\ \frac{qQ}{r^2}\ \hat{r}$$

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

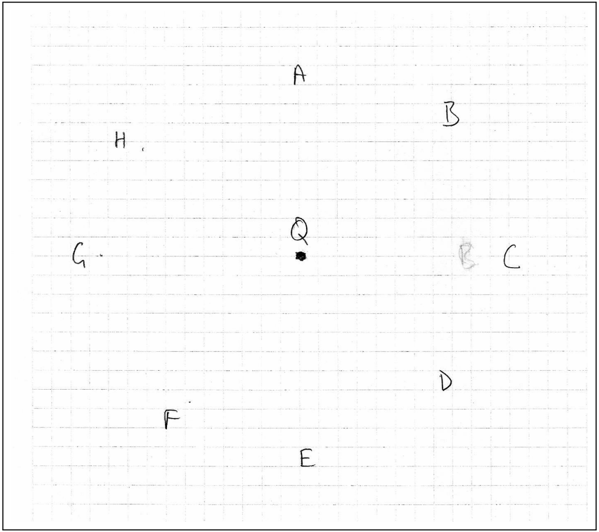
$$\vec{E}(x, y, z) = \frac{\vec{F}_{\text{on q}}}{q} = k\ \frac{Q}{r^2}\ \hat{r}$$

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, since that would be the direction of the electric force on a small positive test charge.

(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:

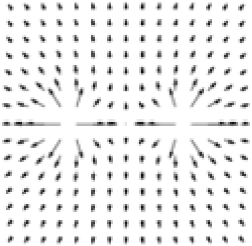
$$\vec{E}(P) \;=\; \sum \frac{\vec{F}_{\mathrm{on\ q}}}{q} \;=\; k \sum_{i=1}^{N} \frac{Q_i}{r_{iP}^2}\, \hat{r}_{iP}$$

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.

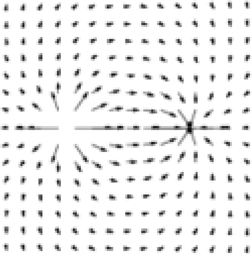
(Draw $\vec{E}$ surrounding $Q > 0$ and surrounding $Q < 0$.)

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?

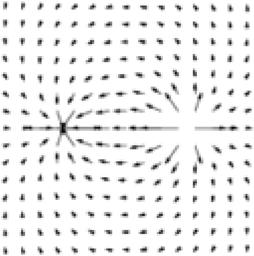
1.



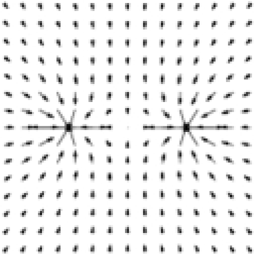
2.



3.



4.

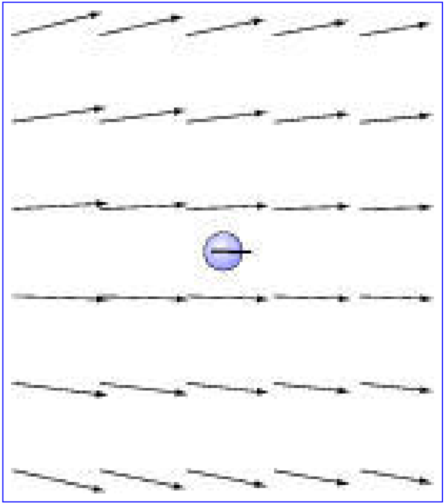


https://phet.colorado.edu/sims/html/charges-and-fields/latest/charges-and-fields_en.html

While we're at it, here's another simulation by the same group at Colorado Boulder

https://phet.colorado.edu/en/simulation/balloons-and-static-electricity_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

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

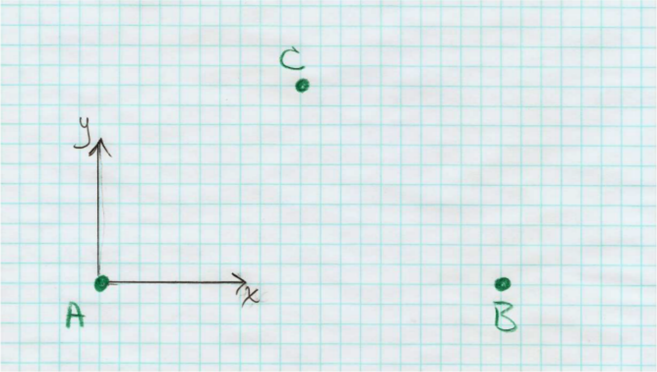
So $\hat{r}$ points in the same direction as $\vec{r}$, but $\hat{r}$ has a length of 1.

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 $k = 9 \times 10^9$ N m^2/C^2 $\approx 10^{10}$ N m^2/C^2.



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

$F^E_{AB} =$

$F^E_{AC} =$

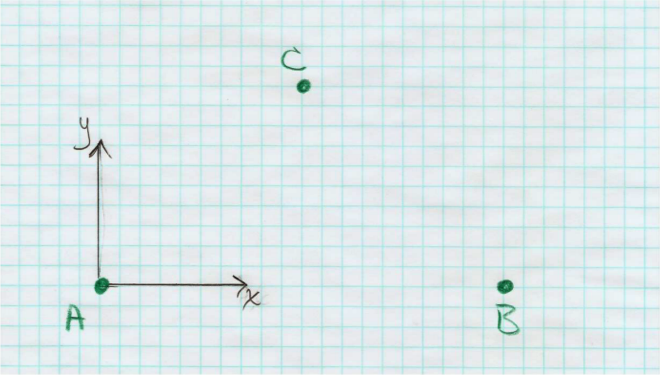
$F^E_{BC} =$

$F^E_{BA} =$

$F^E_{CA} =$

$F^E_{CB} =$

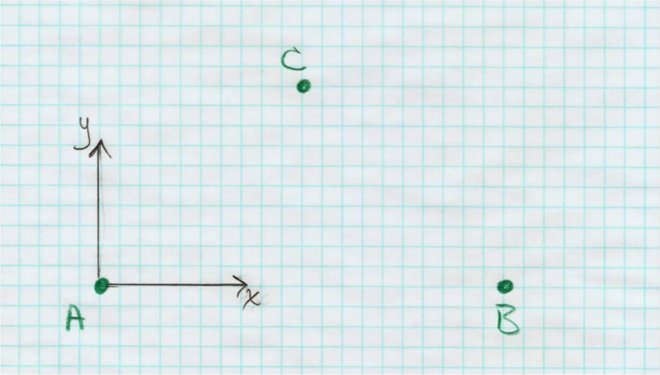
Particles A, B, C carry identical positive charges $q_A = q_B = q_C = +10\ \mu\text{C} = 1.0 \times 10^{-5}$ C. Particle A is located at $(x_A, y_A) = (0, 0)$ meters. Particle B is at $(x_B, y_B) = (+2.0, 0.0)$ meters. Particle C is at $(x_C, y_C) = (+1.0, +1.0)$ meters. The angles $\angle_{CAB}$ and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

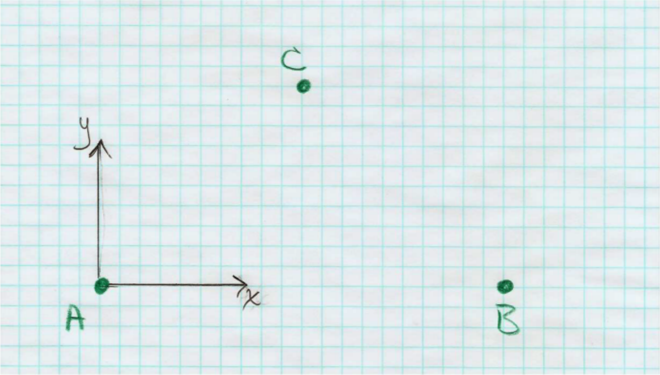
Particles A, B, C carry identical positive charges $q_A = q_B = q_C = +10\ \mu\text{C} = 1.0 \times 10^{-5}$ C. Particle A is located at $(x_A, y_A) = (0, 0)$ meters. Particle B is at $(x_B, y_B) = (+2.0, 0.0)$ meters. Particle C is at $(x_C, y_C) = (+1.0, +1.0)$ meters. The angles $\angle_{CAB}$ and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

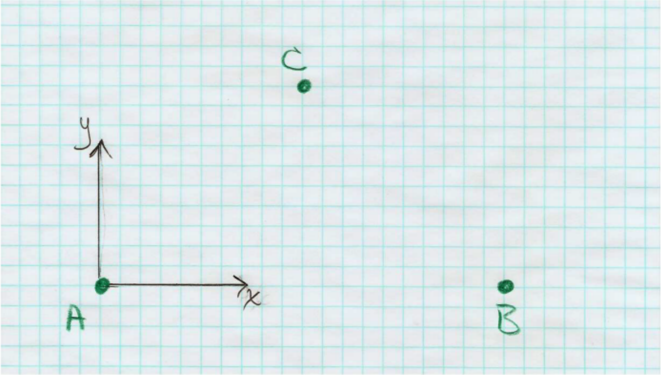
Particles A, B, C carry identical positive charges $q_A = q_B = q_C = +10\ \mu\text{C} = 1.0 \times 10^{-5}$ C. Particle A is located at $(x_A, y_A) = (0, 0)$ meters. Particle B is at $(x_B, y_B) = (+2.0, 0.0)$ meters. Particle C is at $(x_C, y_C) = (+1.0, +1.0)$ meters. The angles $\angle_{CAB}$ and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



The magnitude of the electric force F^E_{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 $k = 9 \times 10^9\ \text{N m}^2/\text{C}^2 \approx 10^{10}\ \text{N m}^2/\text{C}^2$.



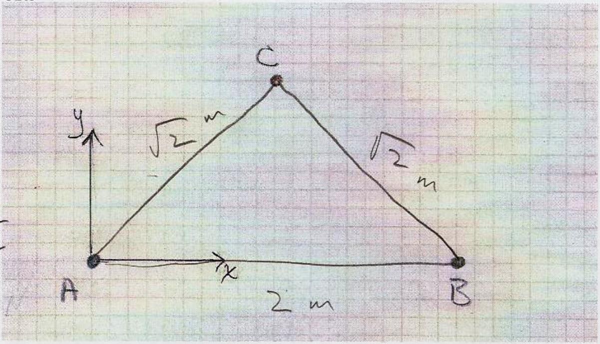
The magnitude of the electric force F^E_{BC} exerted by B on C is

(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°.

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

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



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

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

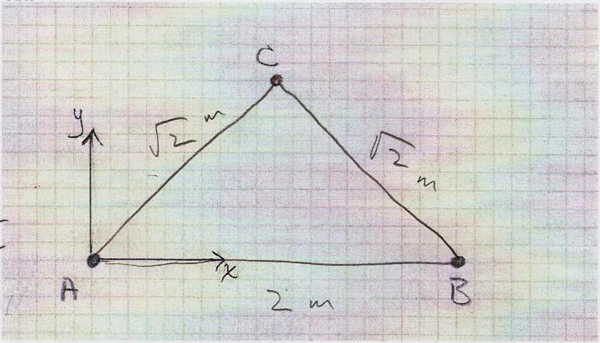
$F^E_{BA} =$ 0.225 N $F^E_{CA} =$ 0.45 N $F^E_{CB} =$ 0.45 N

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

Particles A, B, C carry identical positive charges $q_A = q_B = q_C = +10\ \mu\text{C} = 1.0 \times 10^{-5}$ 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°.

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

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



(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

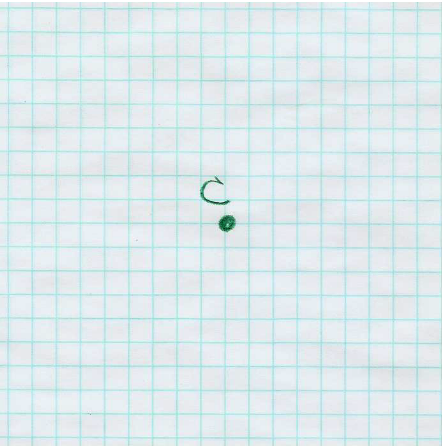
(A) Question (1) is too easy. Not a good use of classroom time.

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

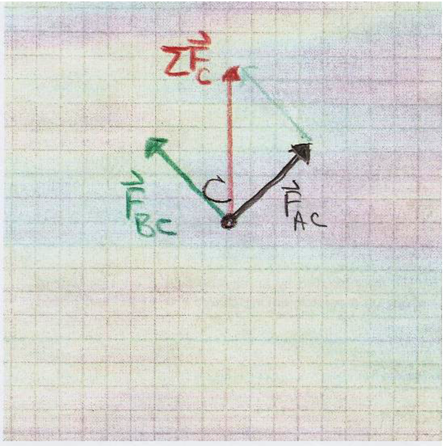
(C) I still don't understand how to do question 1.

(D) None of the above.

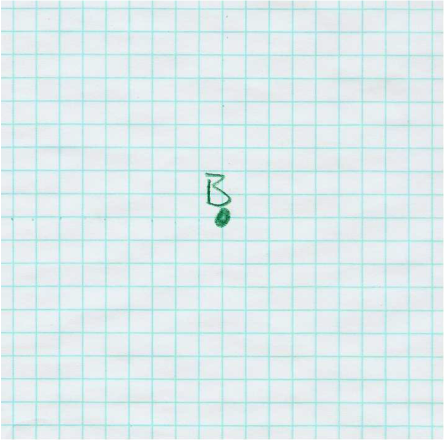
(2) Draw arrows for the two electric forces that are acting ON particle C. (The electric force exerted by A on C is written $\vec{F}^E_{AC}$. The electric force exerted by B on C is written $\vec{F}^E_{BC}$.) Then draw an arrow for the vector sum of forces (a.k.a. the "net force") acting on particle 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 N. (Use the left grid below.)

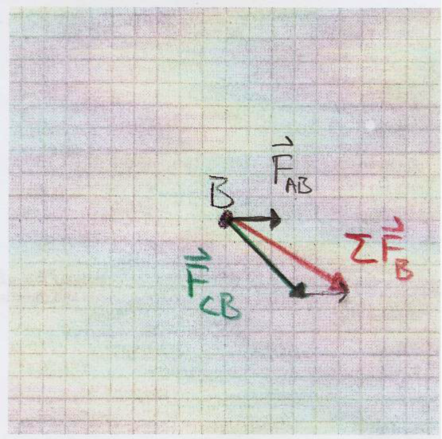


My answer
(A) did
(B) did not
look something like this.



(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 N.

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

$F^E_{AC,x} =$

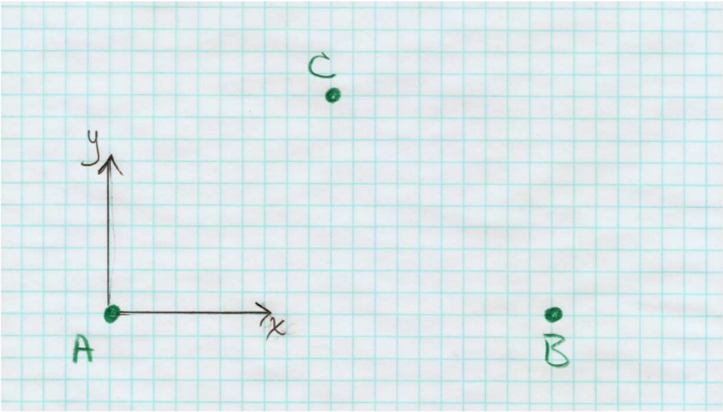
$F^E_{AC,y} =$

$F^E_{BC,x} =$

$F^E_{BC,y} =$

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

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



This may be helpful for Q4.

The electrostatic force due to b acting ON c is

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

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

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

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.

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

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

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

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

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

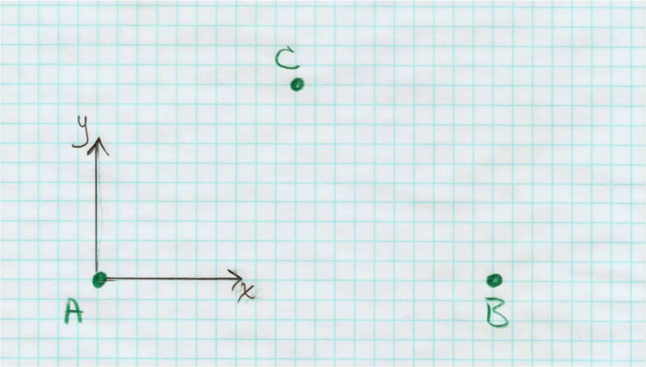
$\sum F^E_{C,y} = +0.636N$

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:

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

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.

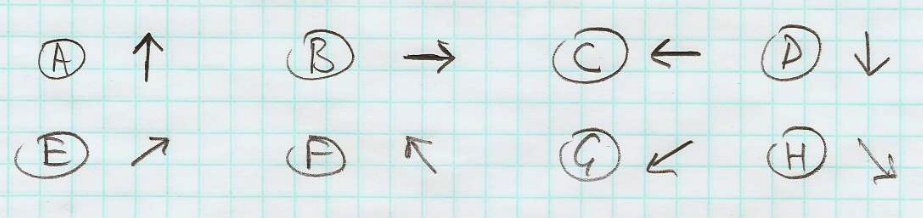
If we let $\vec{E}_A$, $\vec{E}_B$, and $\vec{E}_C$ be the electric field created by particle A, by particle B, and by particle C, respectively, then the combined electric field is the vector sum of these individual electric fields:

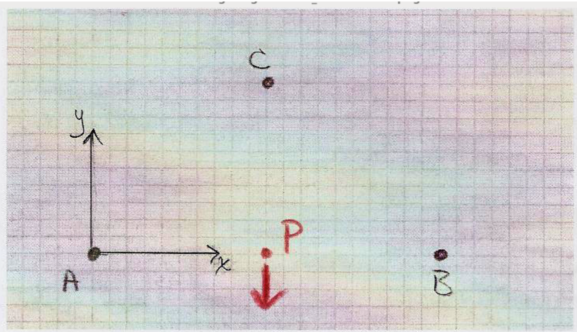
$$\vec{E}(P) = \vec{E}_A(P) + \vec{E}_B(P) + \vec{E}_C(P) = \sum_i k \frac{q_i}{r_{iP}^2} \hat{r}_{iP}$$

$E_x(P) =$

$E_y(P) =$

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



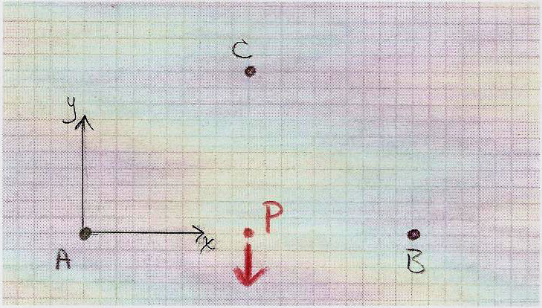


OK, now back to Question 6:

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 $q = -1$ μC 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 ?

$F_x =$ $0\,N$

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

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

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:

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

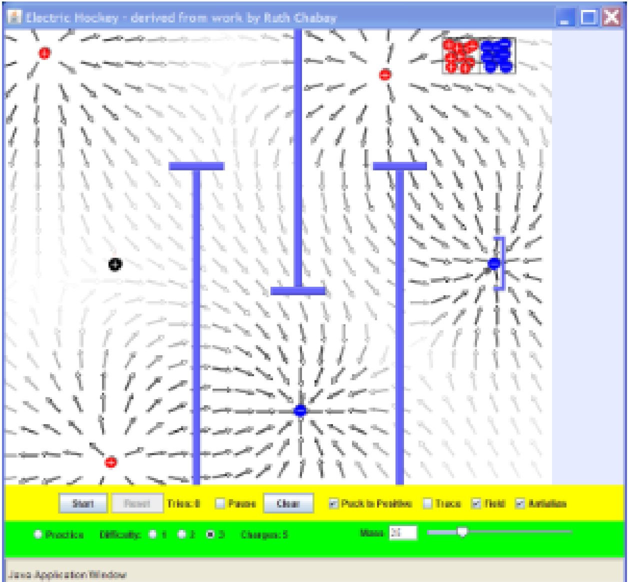
If some other force $\vec{F}_{\mathrm{other}}$ is also acting (e.g. gravity), then

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

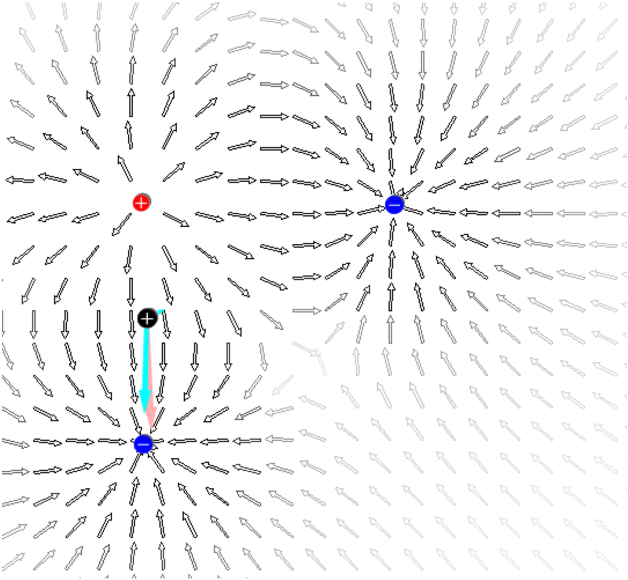
Electric field hockey: may help with $\vec{F} = q\vec{E}$

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 HW10 problem 5. (The black $\oplus$ is the "test charge" and doesn't contribute to $\vec{E}$.)

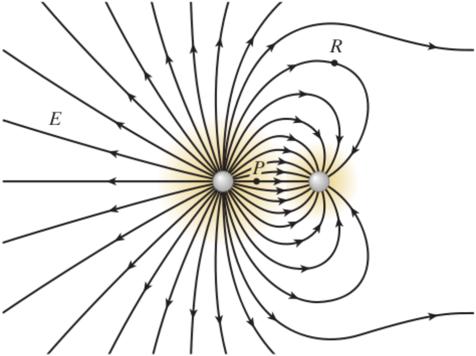


Someone else seems to have written an HTML5 version of Electric Field Hockey, which can be run without starting up a Java applet.

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.

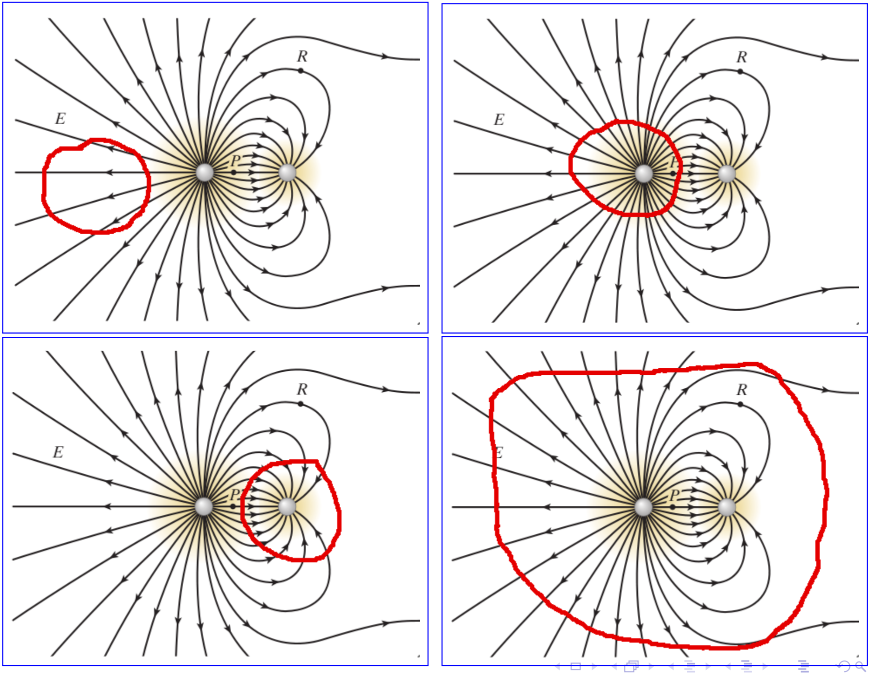


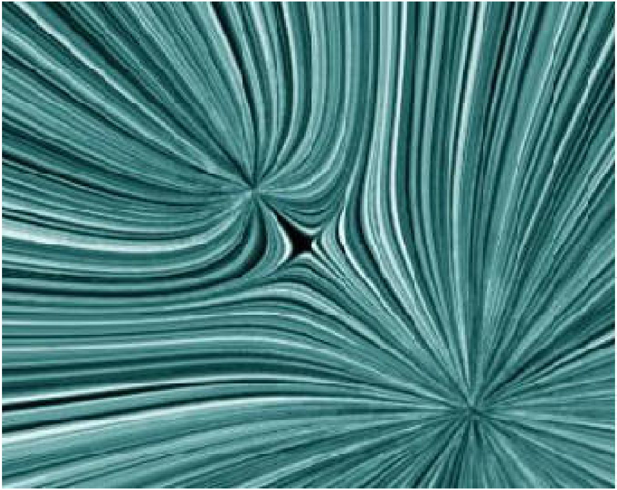
Where is $|\vec{E}|$ largest here?

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?

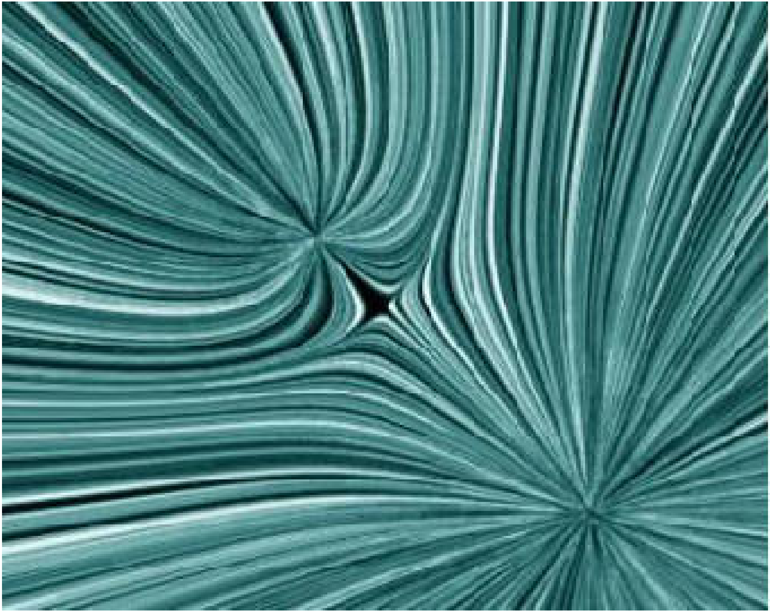
Is net charge enclosed by each circle $+$, $-$, or 0 ?



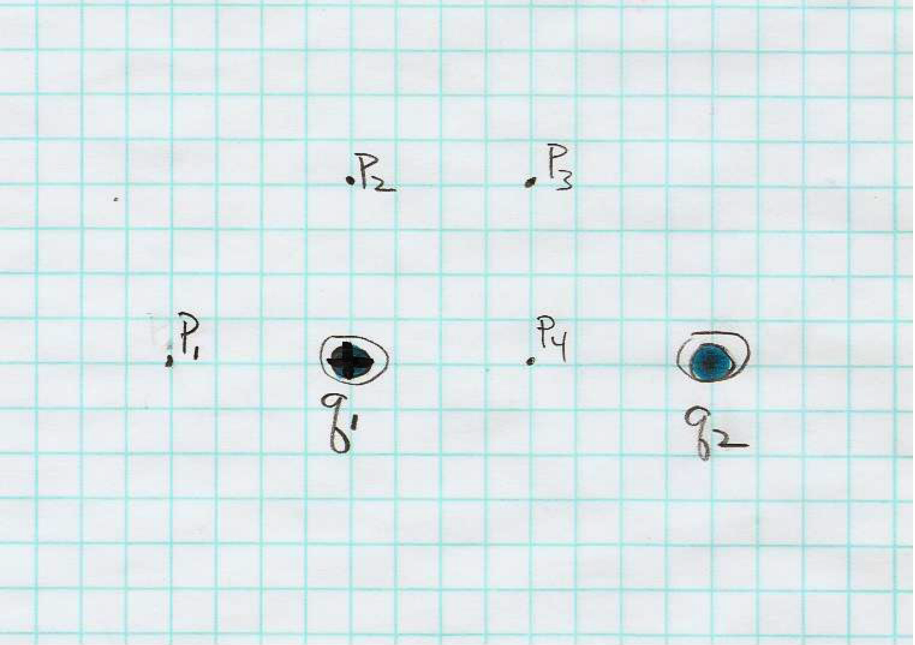


The image shows the electric field around two charged particles, using the “grass seed” representation of field lines. From this picture you can conclude that

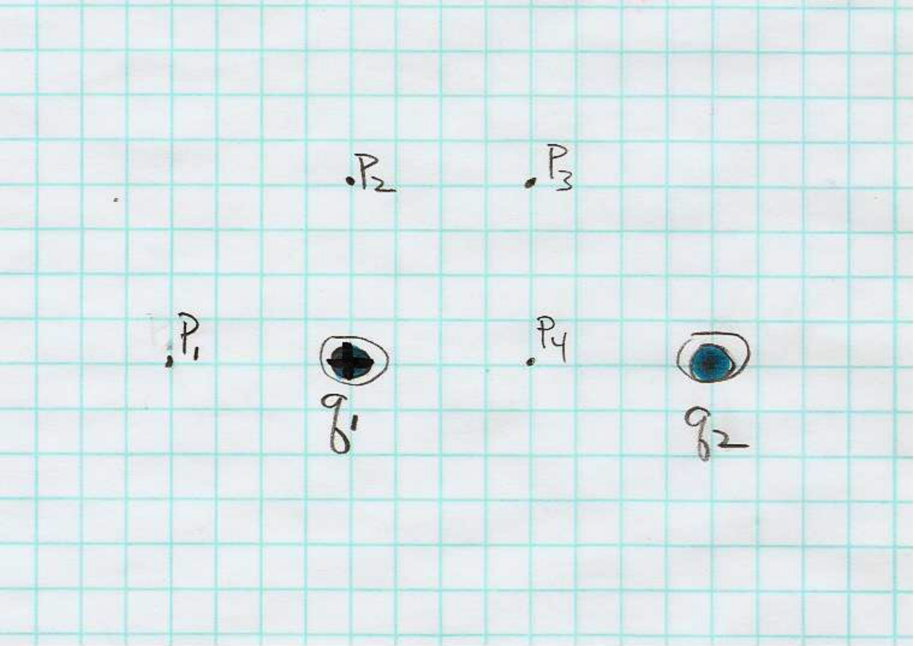
(A) The two charges attract one another.
(B) The two charges repel one another.
(C) Not enough information to tell whether they repel or attract.



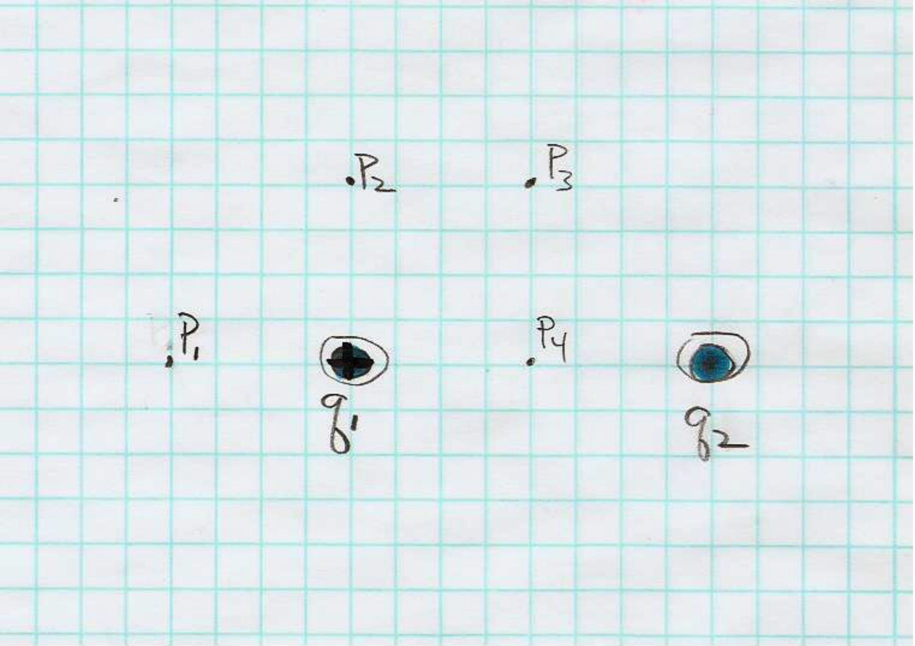
(Follow-up: Where are the two particles located? Can you say what the signs of the charges are? Can you tell whether the charge magnitudes are the same or different?)



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



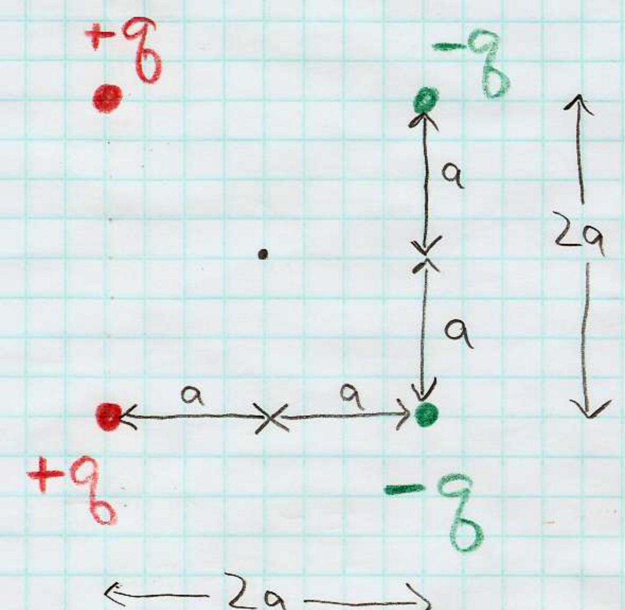
Using **superposition,** draw $\vec{E}$ at points $P_1 \ldots P_4$ if $q_2 = +2q_1$.



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.

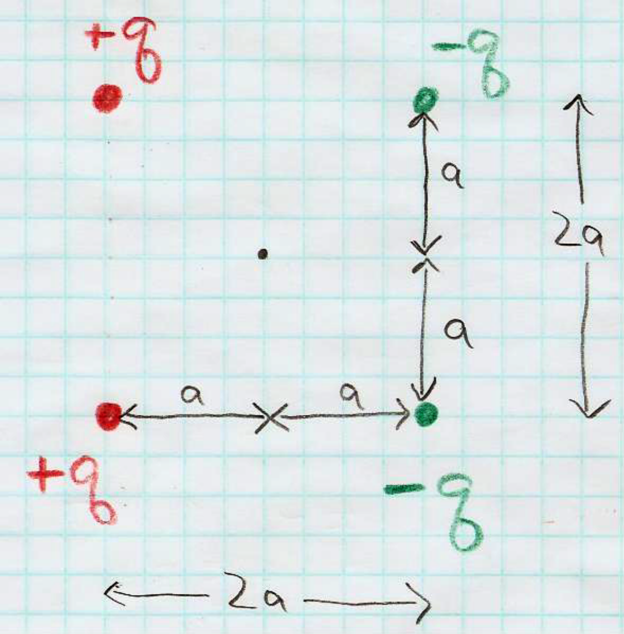


(We'll see on next page that Electric Field Hockey can draw the E field diagram for charge configurations like this.)

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

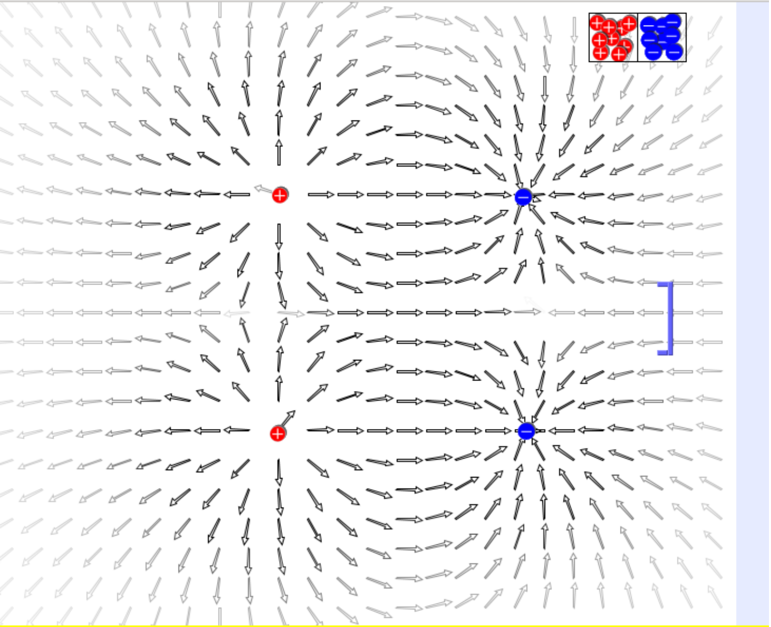
$$E_y = 0$$

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



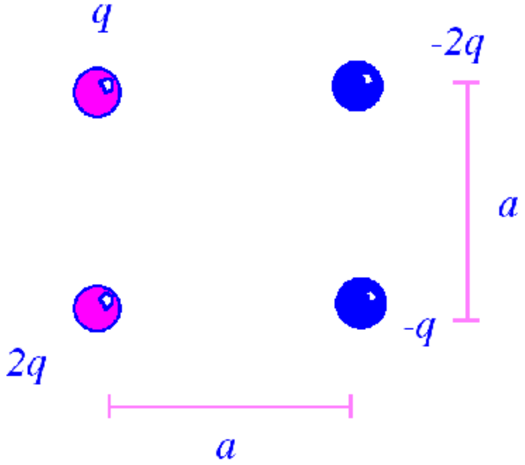
Electric Field Hockey - derived from work by Ruth Chabay (1.10)

File Help

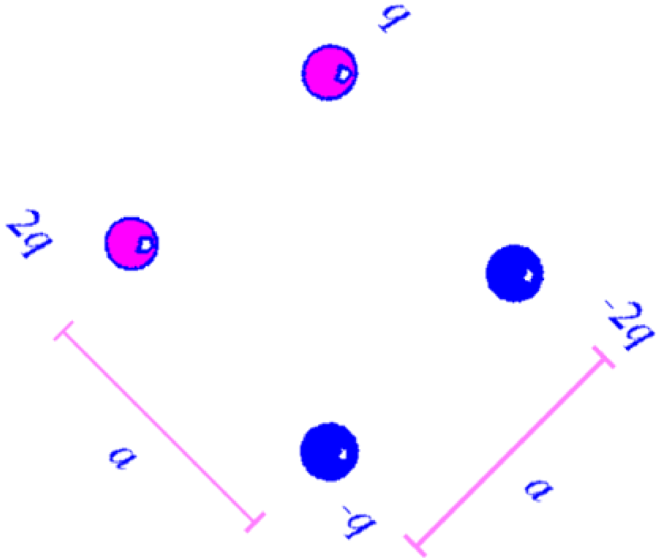


Start | Reset | Tries: 0 | ☐ Pause | Clear | ☑ Puck Is Positive | ☐ Trace | ☑ Field | ☑ Antialias

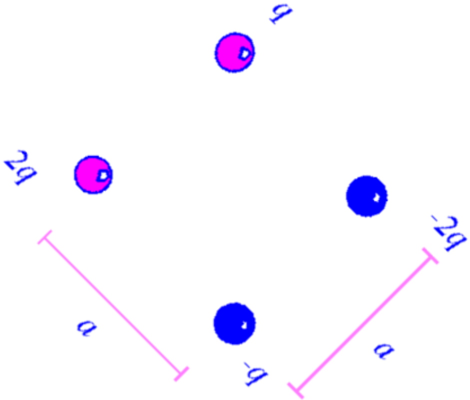
Is anyone interested in working through this example? Four charged particles are arranged in a square, as shown. Find (and draw) the electric field at the center of the square. (Let's instead solve this problem in a friendlier coordinate system.)



Four charged particles are arranged in a square, as shown. Find (and draw) the electric field at the center of the square. For convenience, define $d = a/\sqrt{2}$, which is the distance of each particle to the center of the square.

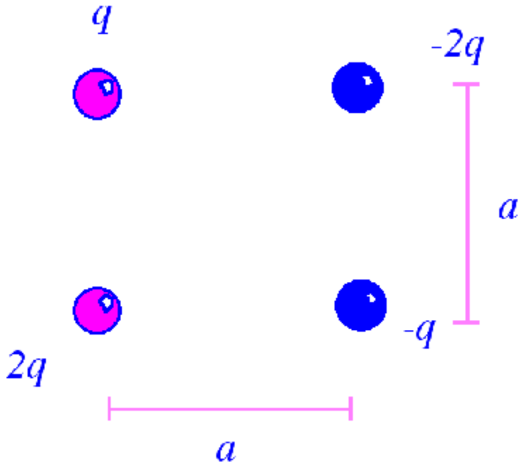


Four charged particles are arranged in a square, as shown. Find (and draw) the electric field at the center of the square. For convenience, define $d = a/\sqrt{2}$, which is the distance of each particle to the center of the square.



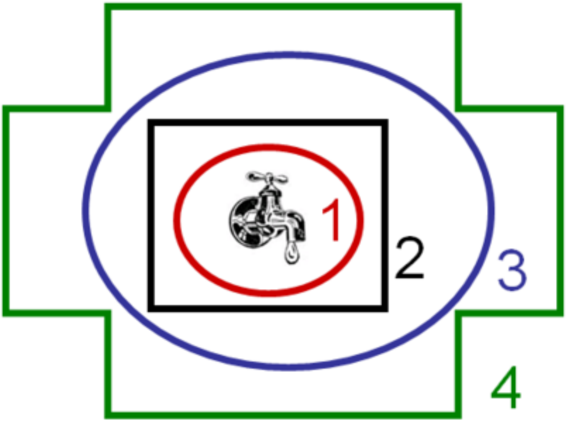
$$E_x = +4\,\frac{kq}{d^2} \qquad E_y = -2\,\frac{kq}{d^2} \qquad |E| = \sqrt{20}\,\frac{kq}{d^2} = 4\sqrt{5}\,\frac{kq}{a^2}$$

Four charged particles are arranged in a square, as shown. Find (and draw) the electric field at the center of the square. (Here was the messier solution to the original problem.)



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

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) $1 > 2 > 3 > 4$

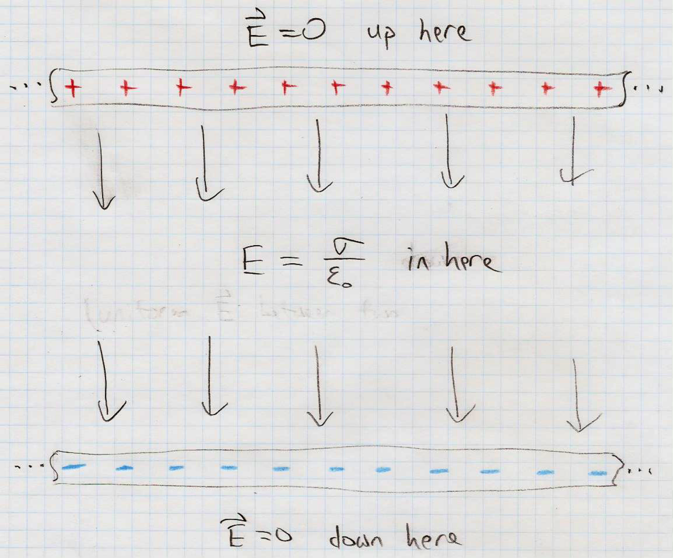
(B) $1 = 2 > 3 > 4$

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

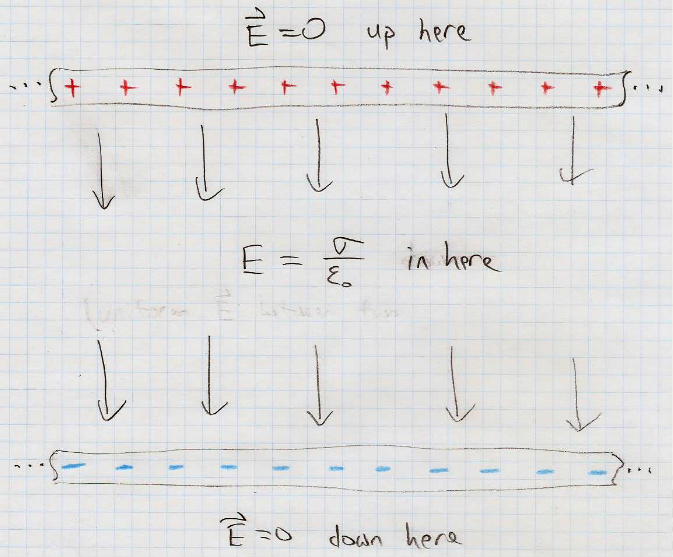
(D) $4 > 3 > 2 > 1$

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

(F) none of the above

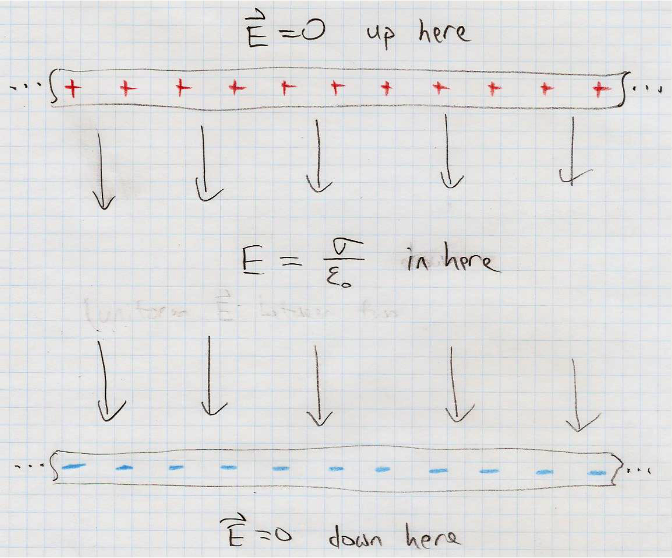


The most commonly used way to create a uniform electric field is to use the area between two large, parallel, oppositely-charged planes of uniform charge-per-unit-area, $\sigma = Q/A$.



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:

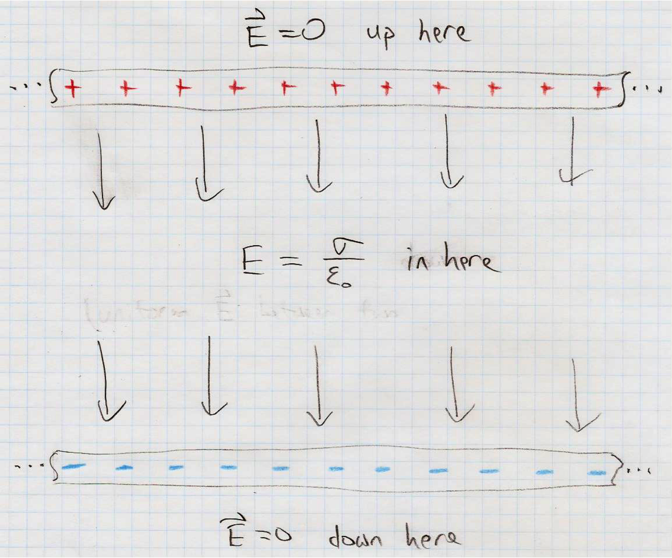


(A) positive

(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:

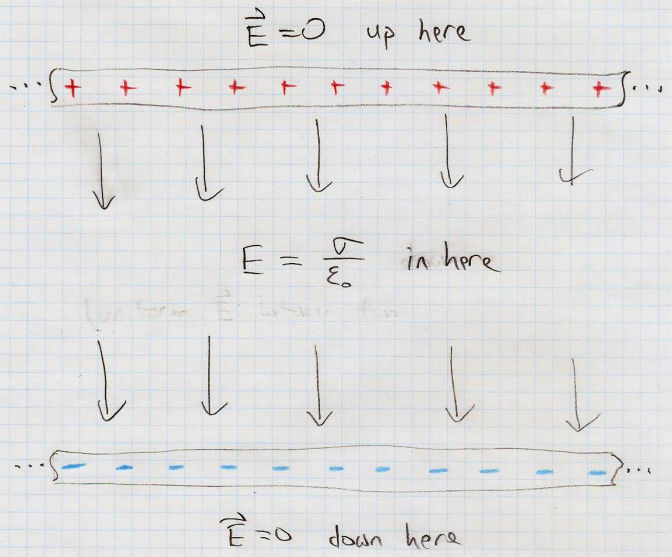


(A) positive

(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:

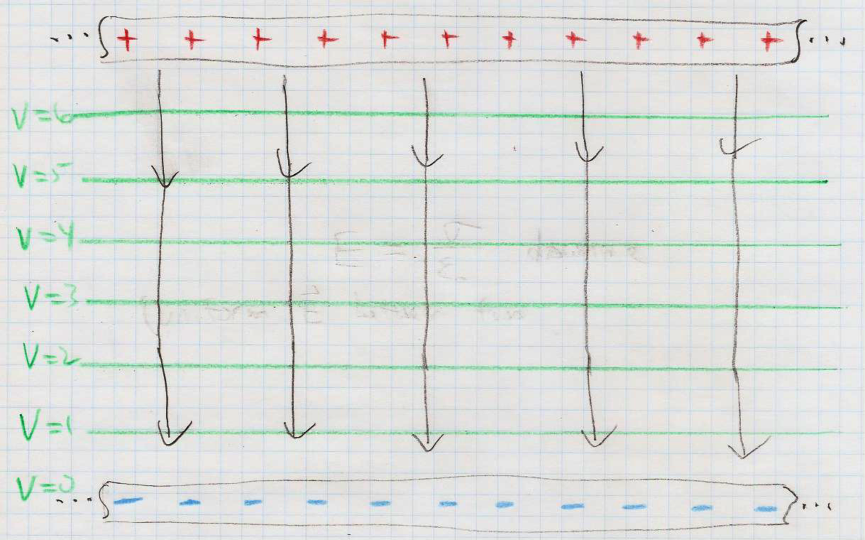


(A) positive

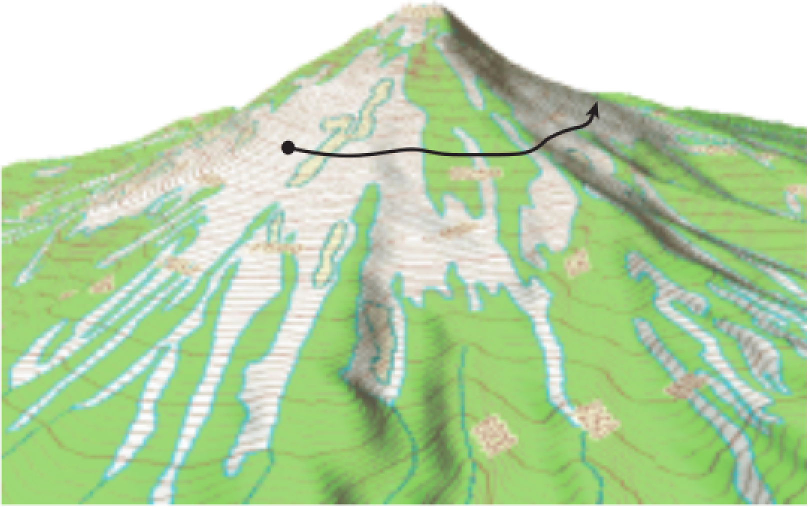
(B) negative

(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.

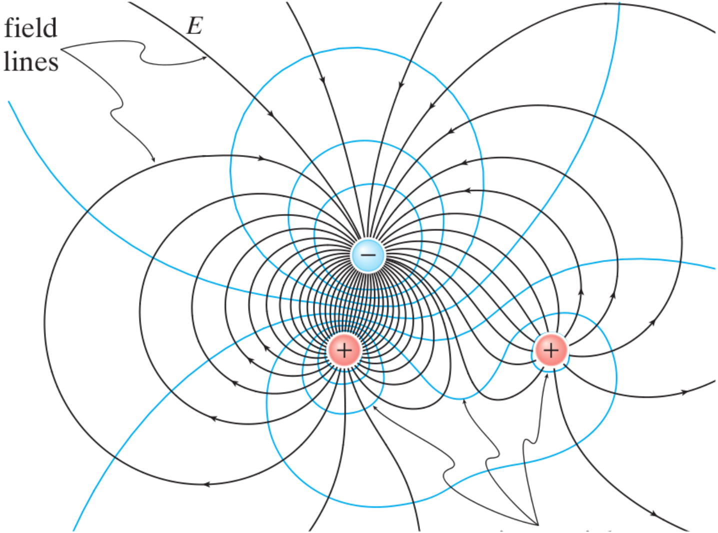
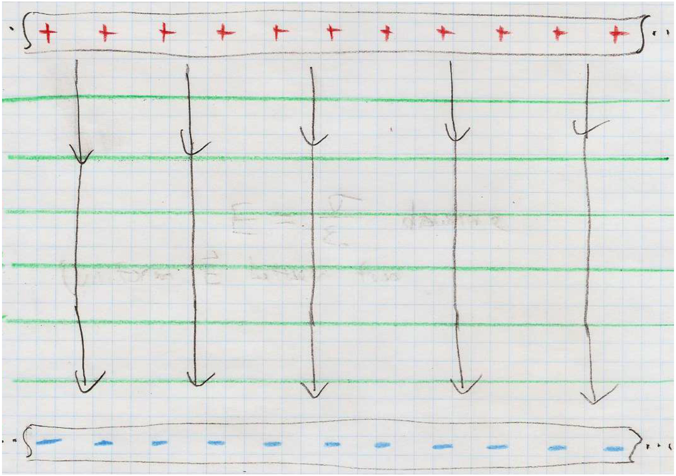


Figure 25.9 Field lines and equipotentials for three stationary charged particles.

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

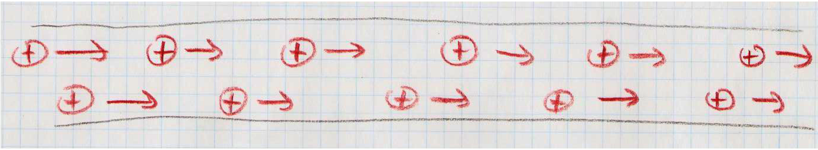
$$U^G = m\ g\ h$$

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 $\vec{E}$.

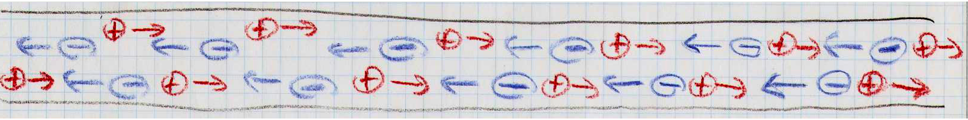


Inside a wire, positively charged particles are moving to the right. What is the direction of the electric current (symbol I, unit = ampere, or "amp") ?

(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 — Wednesday, November 14, 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 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.
- HW help sessions: Wed 4–6pm DRL **4C2** (Bill), Thu 6:30–8:30pm DRL 2C8 (Grace)