Physics 9 — Monday, November 19, 2018

- Pick up handout for HW10 (due Friday 11/30).
- For today, you read Giancoli ch18 (electric currents): so we're finally ready to talk about both "volts" and "amps."
- Anyone still need a textbook?
- 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.
- On Wednesday, I will do an optional class on Py-Processing.

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:

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

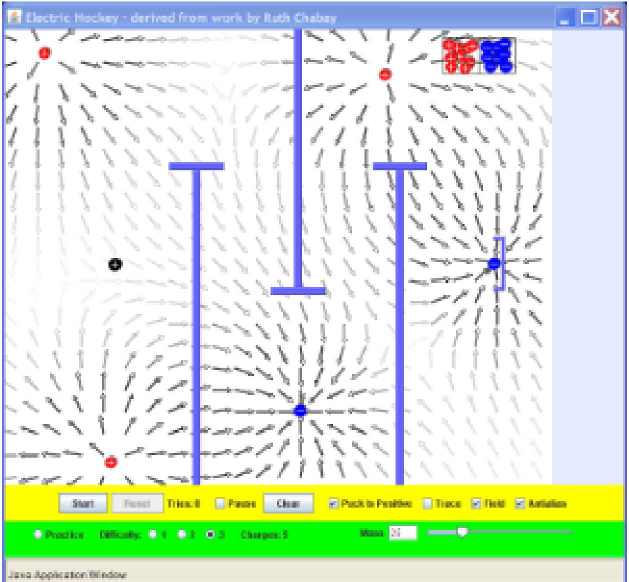
If some other force $\vec{F}_{\mathrm{other}}$ is also acting (e.g. gravity), then

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

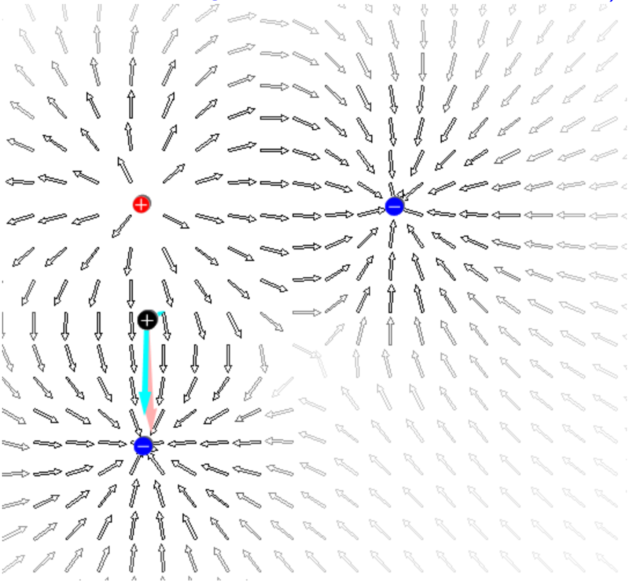
Electric field hockey: may help with $\vec{F} = q\vec{E}$

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



(Note "vector field diagram" vs drawing "field lines")

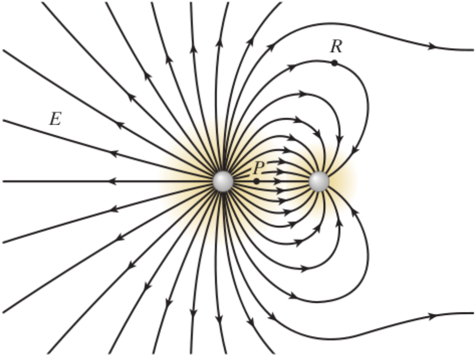
Someone else seems to have written an HTML5 version of Electric Field Hockey, which can be run without starting up a Java applet.

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

Note that "difficulty level 1" on the real E.F.H. corresponds to "difficulty level 2" on the HTML5 version. Also, I don't think the HTML5 version draws the electric field or draws a coordinate grid.

"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.



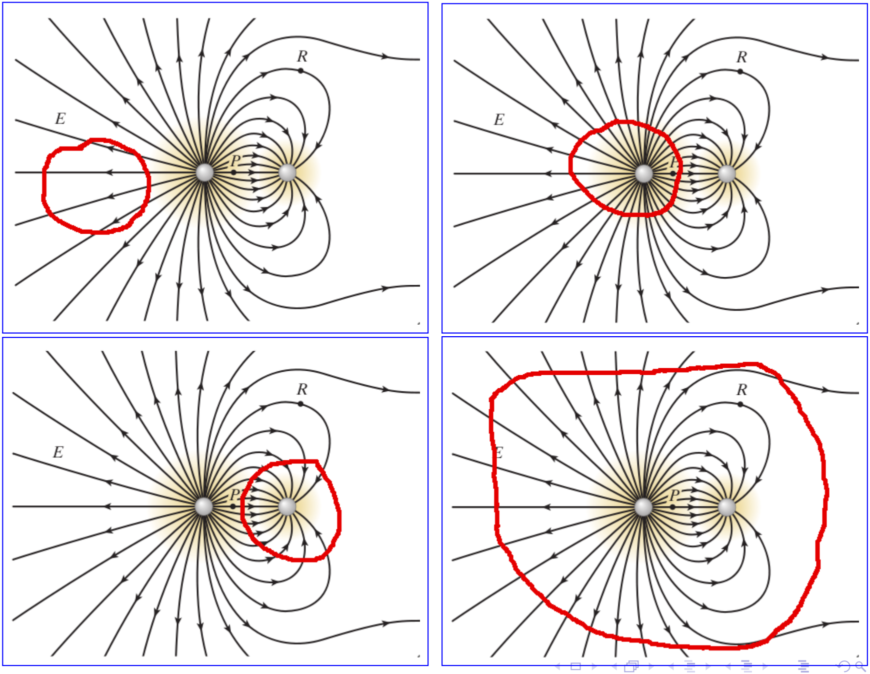
Where is $|\vec{E}|$ largest here?

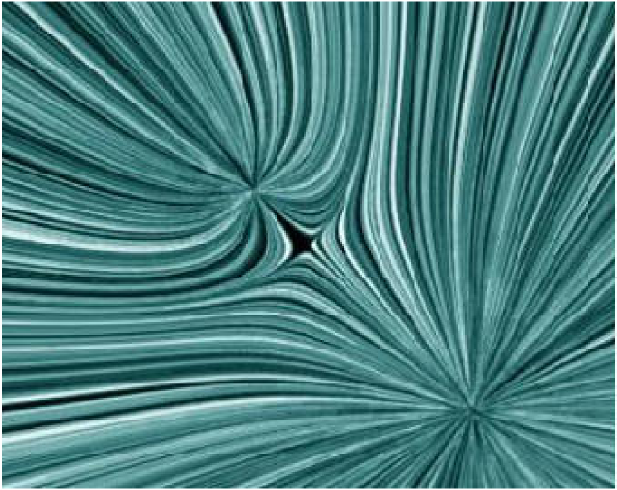
What are the signs of the two particles' charges?

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

$$\oint \vec{E} \cdot \mathrm{d}\vec{A} = \frac{Q_{\text{enclosed}}}{\epsilon_0}$$

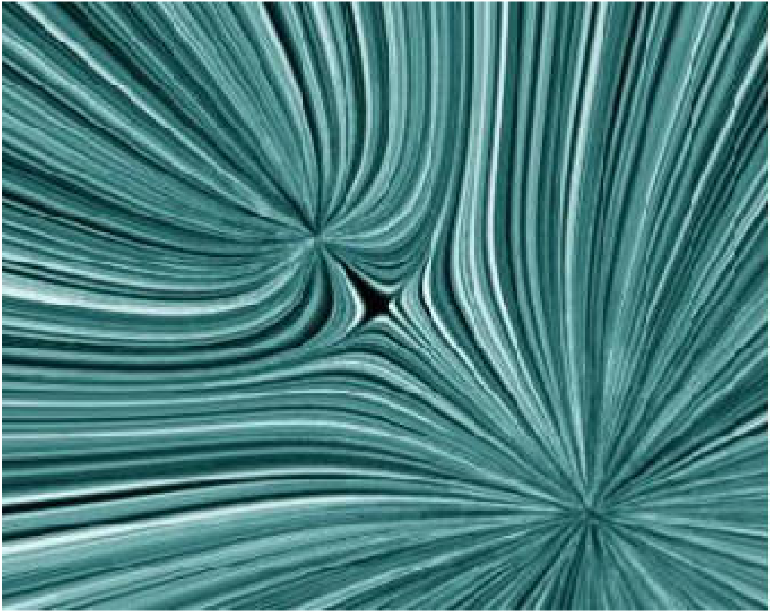
Is net charge enclosed by each circle $+$, $-$, or 0 ?



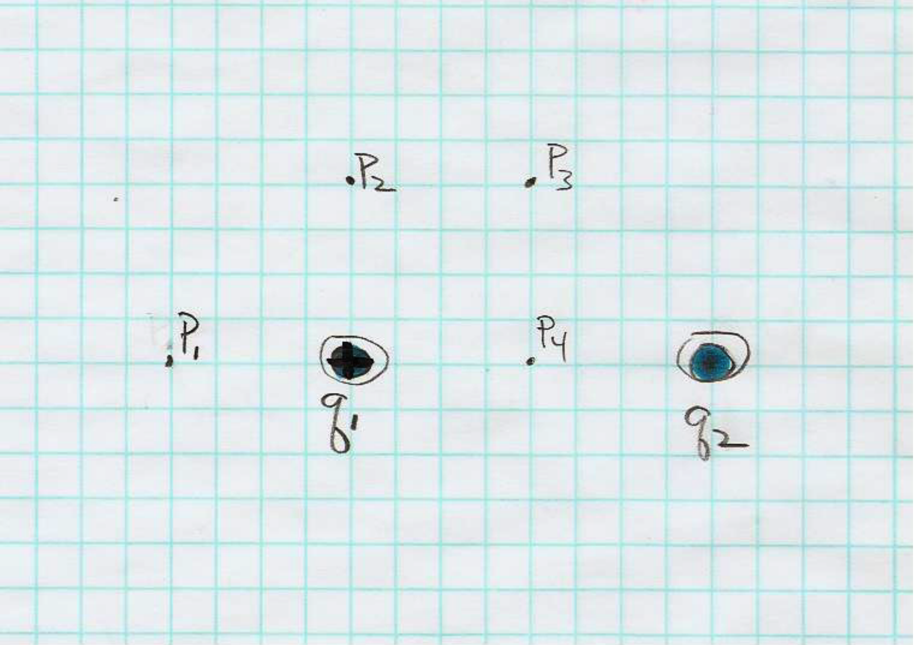


The image shows the electric field around two charged particles, using the “grass seed” representation of field lines. From this picture you can conclude that

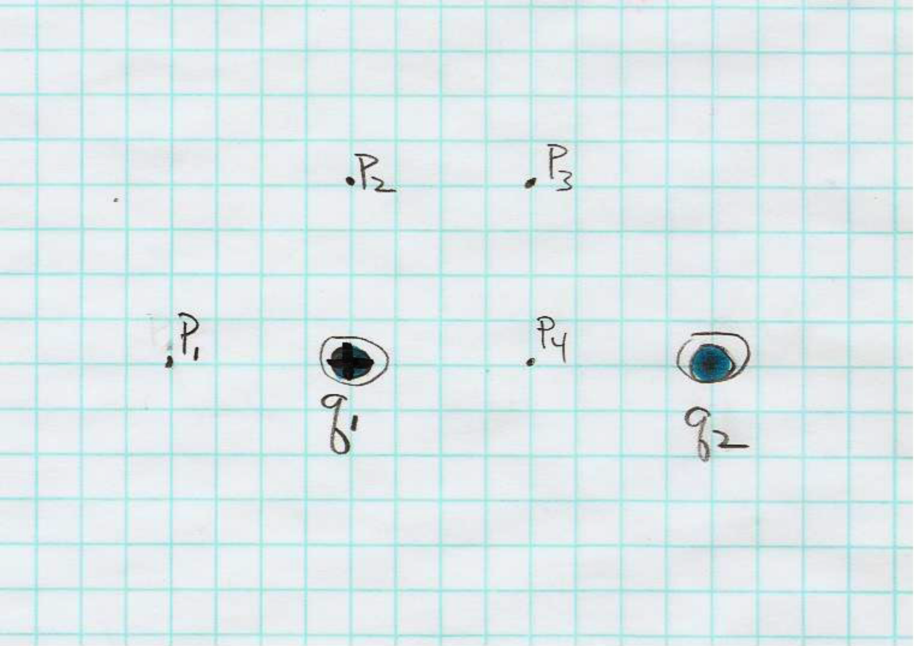
(A) The two charges attract one another.
(B) The two charges repel one another.
(C) Not enough information to tell whether they repel or attract.



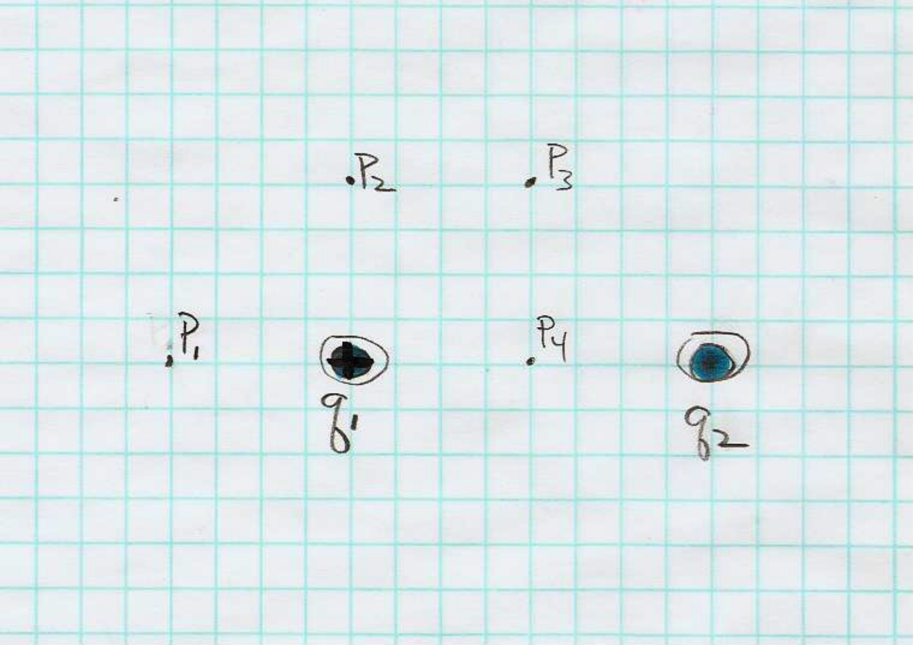
(Follow-up: Where are the two particles located? Can you say what the signs of the charges are? Can you tell whether the charge magnitudes are the same or different?)



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



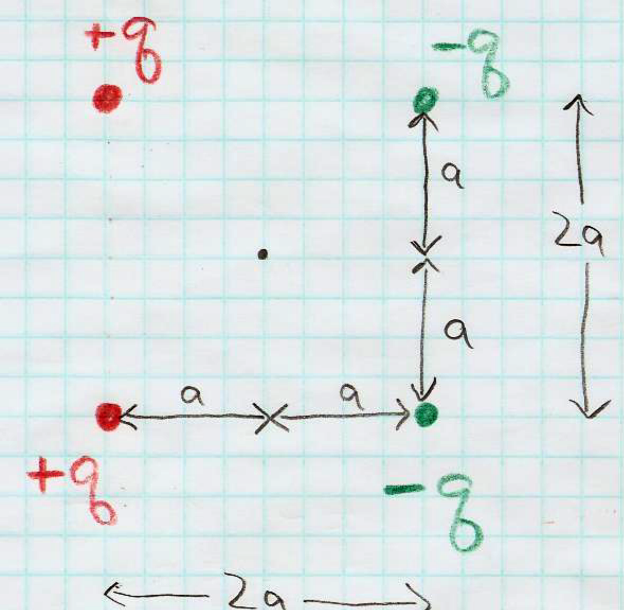
Using **superposition,** draw $\vec{E}$ at points $P_1 \ldots P_4$ if $q_2 = +2q_1$.



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.

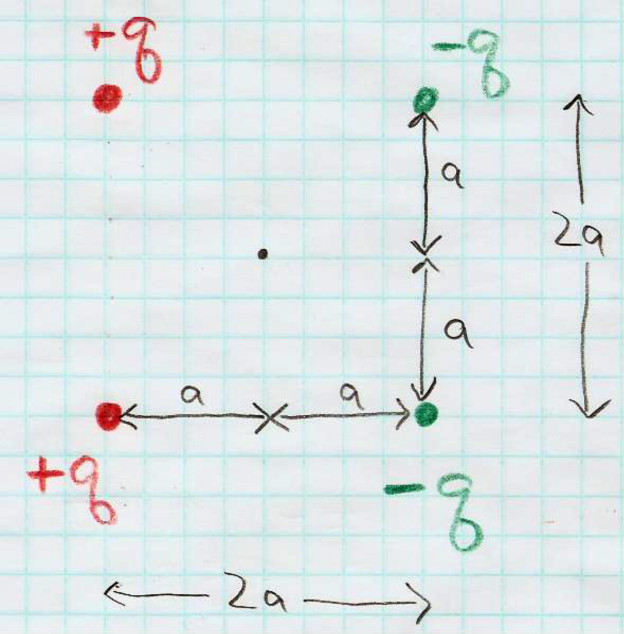


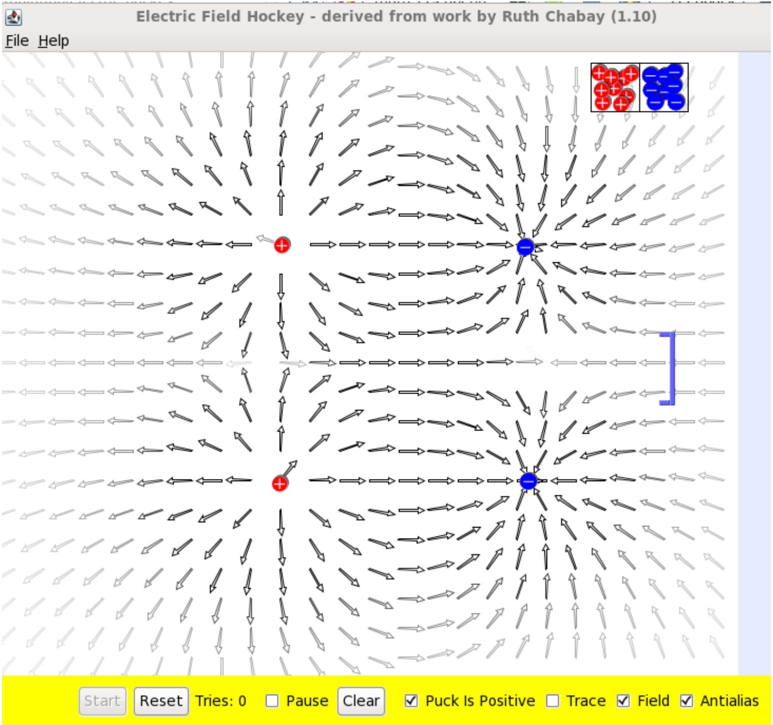
(We'll see on next page that Electric Field Hockey can draw the E field diagram for charge configurations like this.)

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

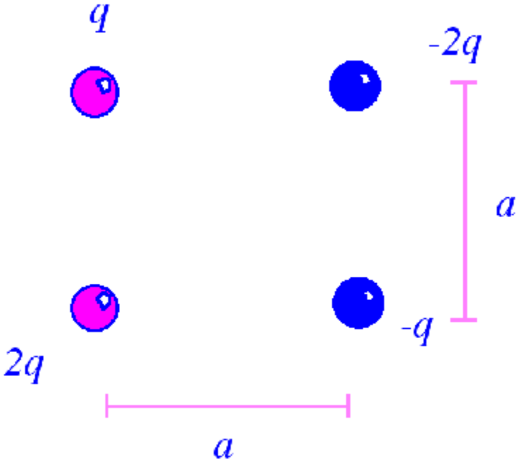
$$E_y = 0$$

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

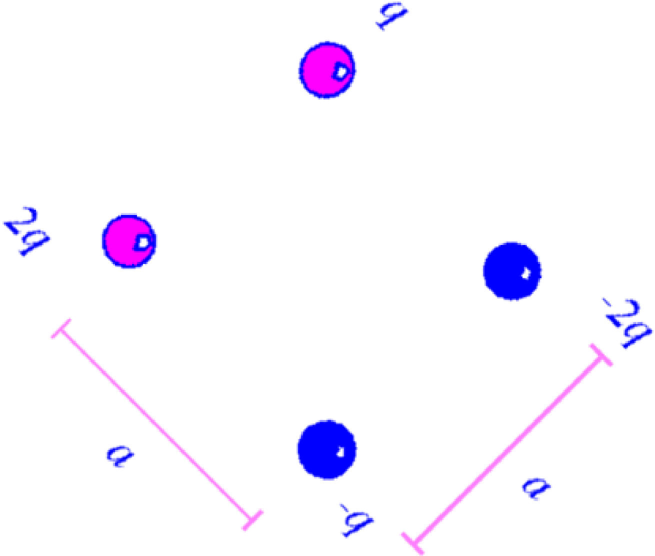



Electric Field Hockey - derived from work by Ruth Chabay (1.10)
File Help
Start Reset Tries: 0 Pause Clear Puck Is Positive Trace Field Antialias

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.



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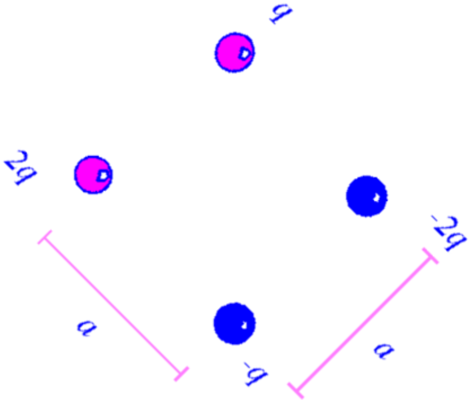
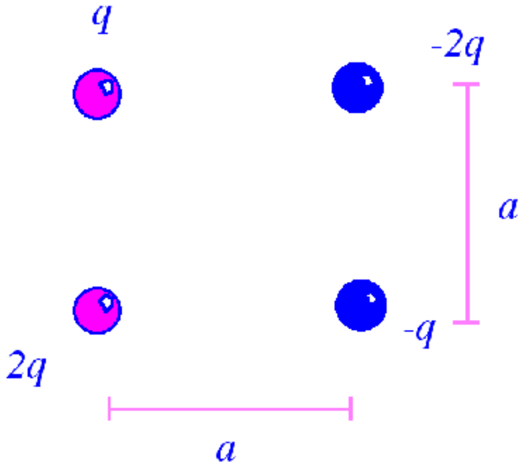


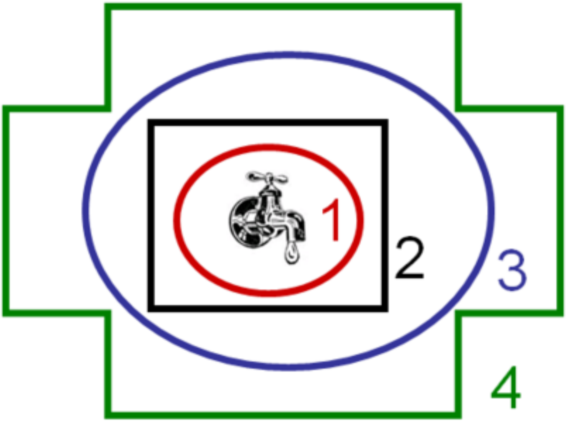
$$E_x = +4\,\frac{kq}{d^2} \qquad E_y = -2\,\frac{kq}{d^2} \qquad |E| = \sqrt{20}\,\frac{kq}{d^2} = 4\sqrt{5}\,\frac{kq}{a^2}$$

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) $1 > 2 > 3 > 4$

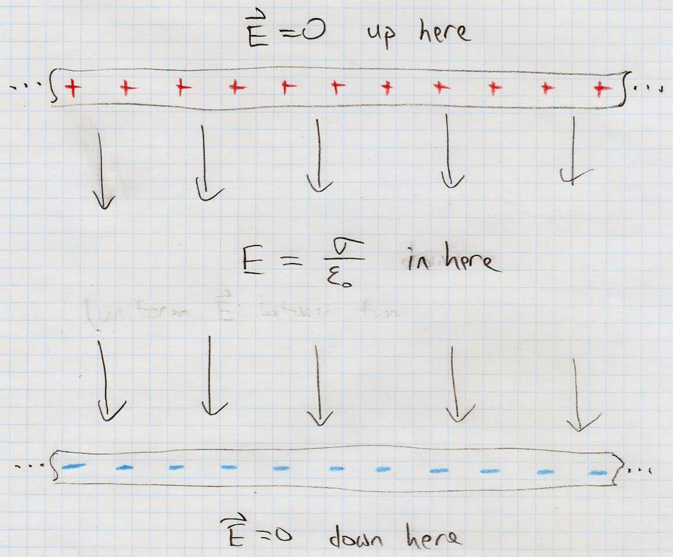
(B) $1 = 2 > 3 > 4$

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

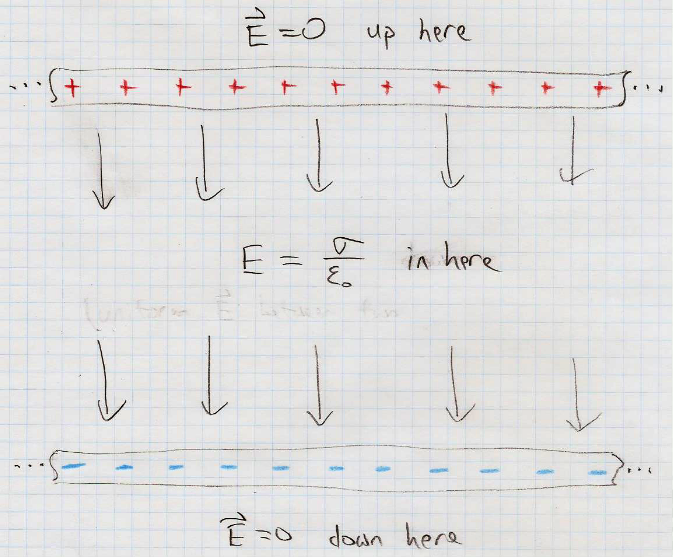
(D) $4 > 3 > 2 > 1$

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

(F) none of the above

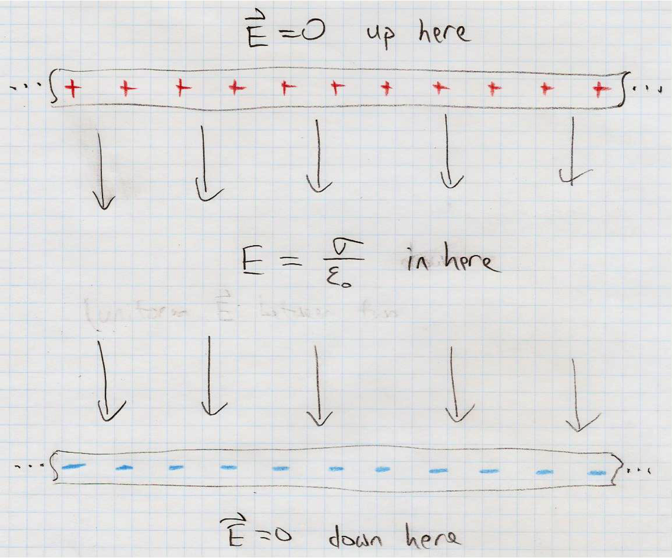


The most commonly used way to create a uniform electric field is to use the area between two large, parallel, oppositely-charged planes of uniform charge-per-unit-area, $\sigma = Q/A$.



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:

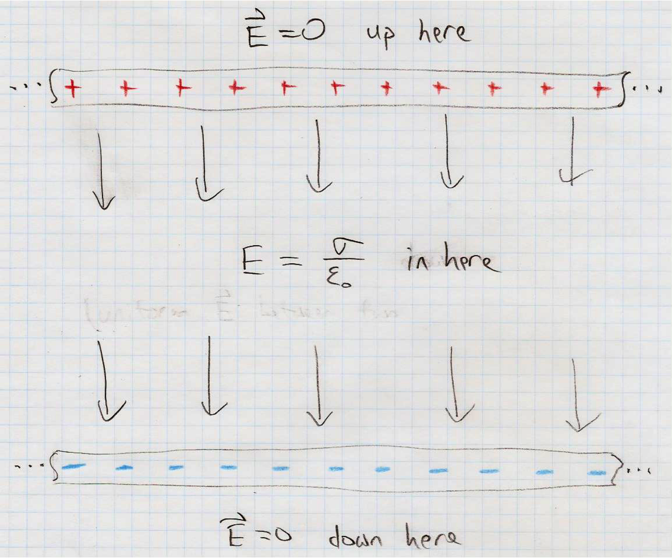


(A) positive

(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:

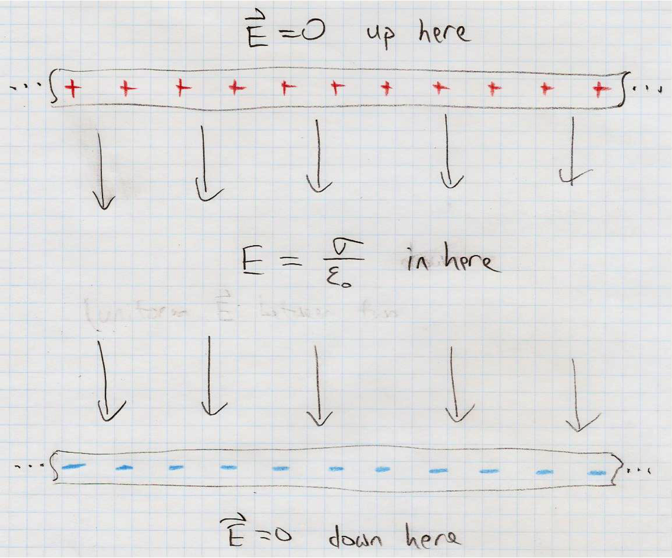


(A) positive

(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:

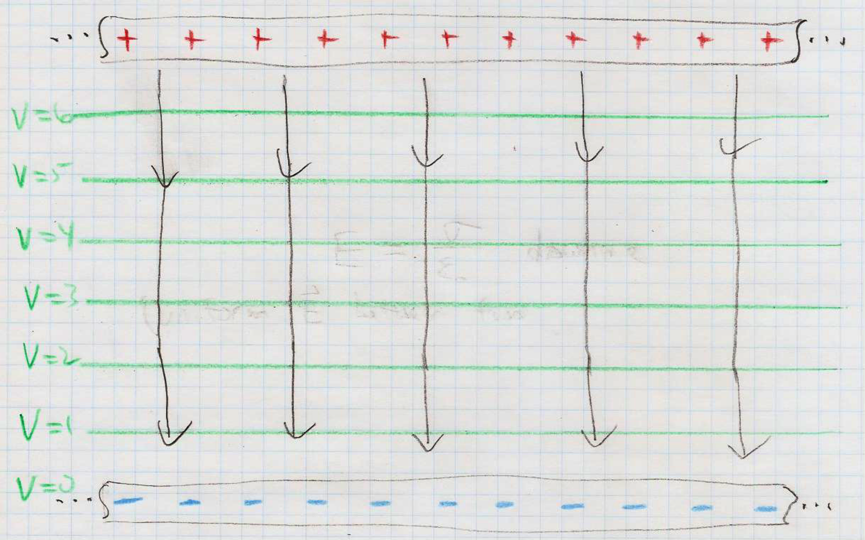


(A) positive

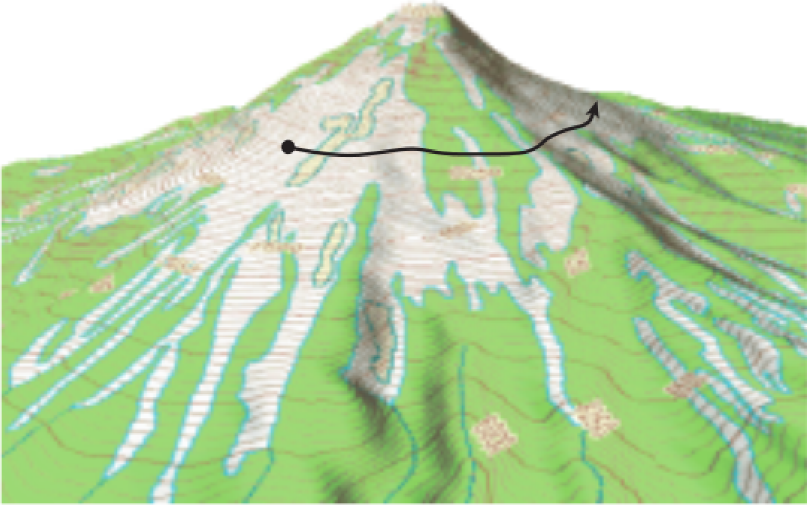
(B) negative

(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.

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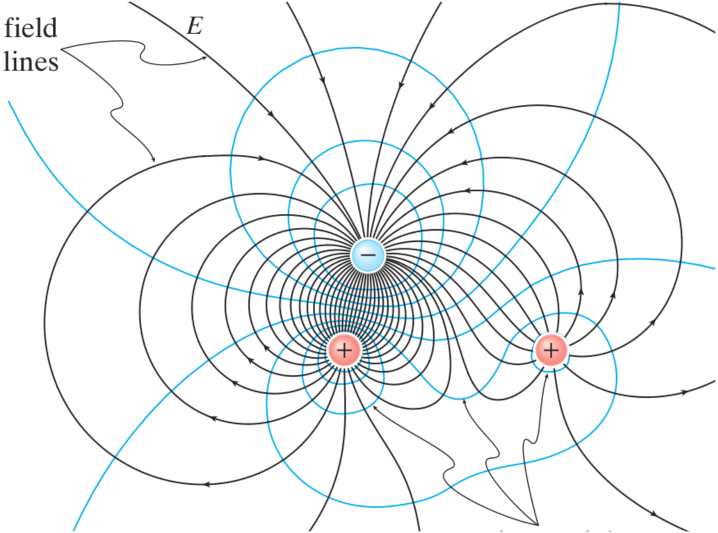
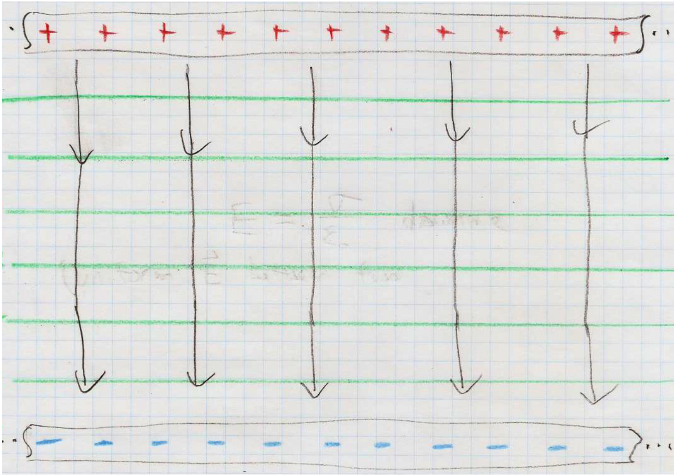


Figure 25.9 Field lines and equipotentials for three stationary charged particles.

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

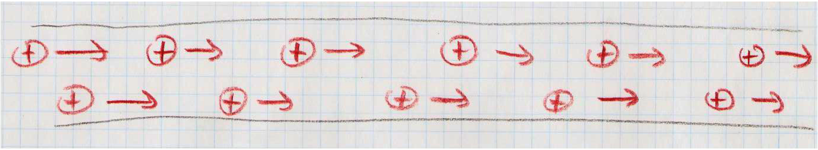
$$U^G = m\ g\ h$$

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 $\vec{E}$.

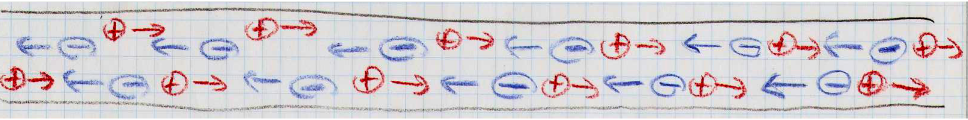


Inside a wire, positively charged particles are moving to the right. What is the direction of the electric current (symbol I, unit = ampere, or “amp”) ?

(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

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