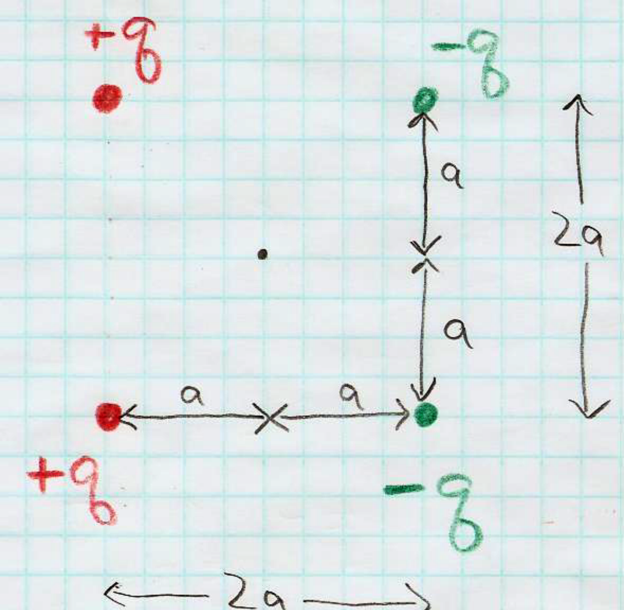
Physics 9 — Wednesday, November 28, 2018

- HW10 due Friday.
- For today, you read **Mazur** ch31 (electric circuits)
- 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.
- HW help sessions: Wed 4–6pm DRL $\boxed{\textbf{4C2}}$ (Bill), Thu 6:30–8:30pm DRL 2C8 (Grace)

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

Let's work 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.

$$\vec{E}(P) = k \sum_i \frac{Q_i}{r_{iP}^2} \hat{r}_{iP}$$

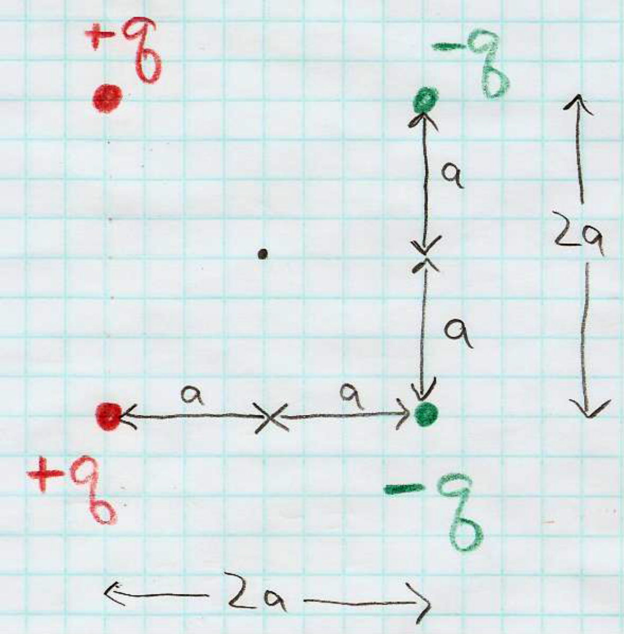


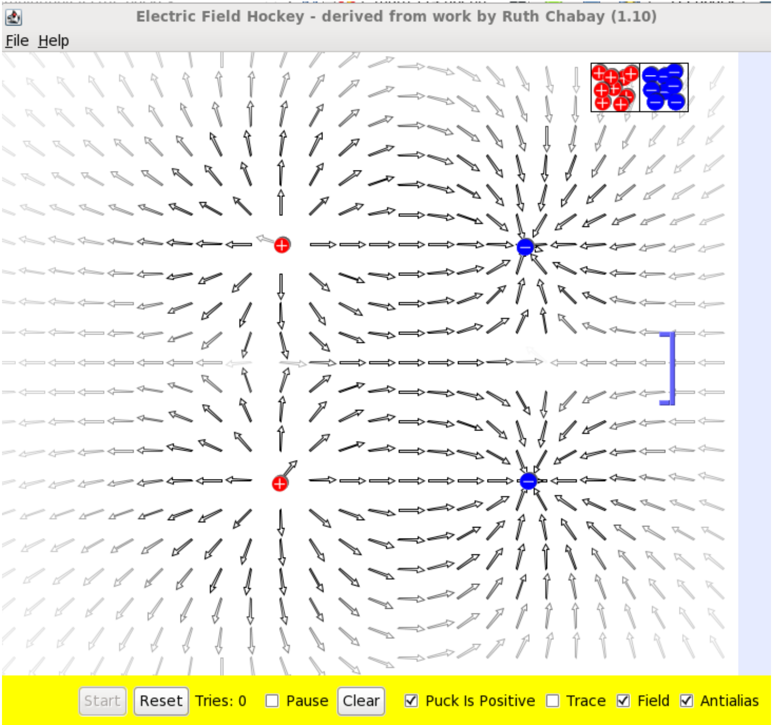
(We'll see on next page that Electric Field Hockey can draw the E field diagram for charge configurations like this.)

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

$$E_y = 0$$

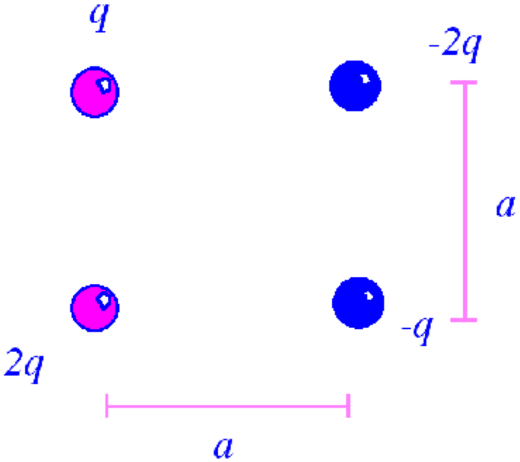
$$\vec{E} = \sqrt{2}\,\frac{kq}{a^2}\,\hat{i}$$



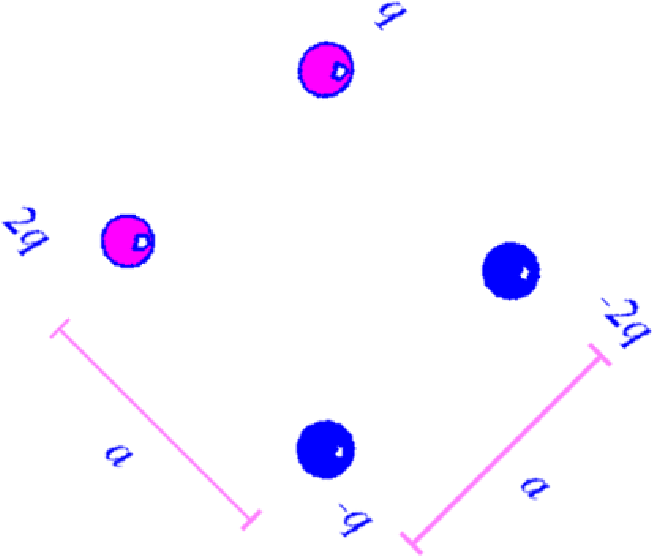


Electric Field Hockey - derived from work by Ruth Chabay (1.10)
File Help
Start
Reset
Tries: 0
Pause
Clear
Puck Is Positive
Trace
Field
Antialias

Here's a trickier 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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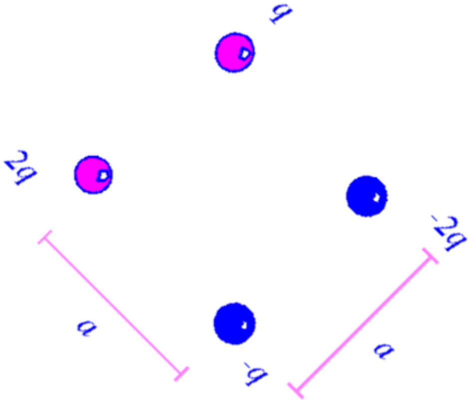
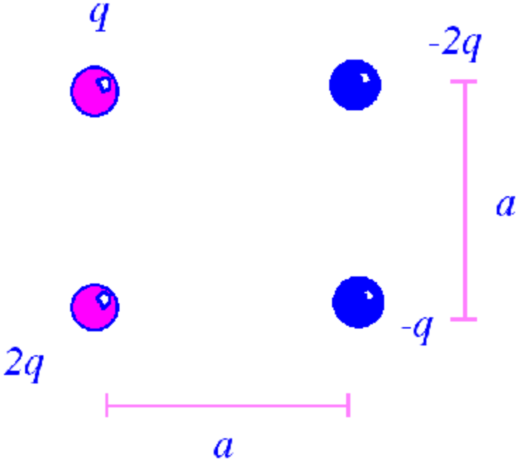
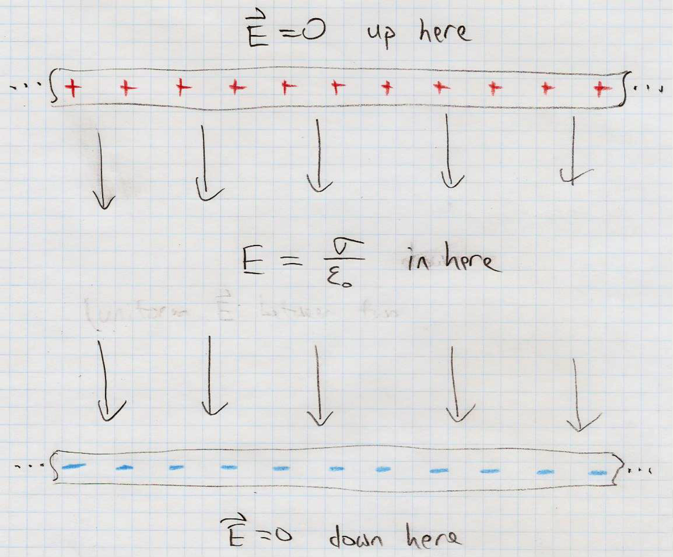


$$E_x = +4\,\frac{kq}{d^2} \qquad E_y = -2\,\frac{kq}{d^2} \qquad |E| = \sqrt{20}\,\frac{kq}{d^2} = 4\sqrt{5}\,\frac{kq}{a^2}$$

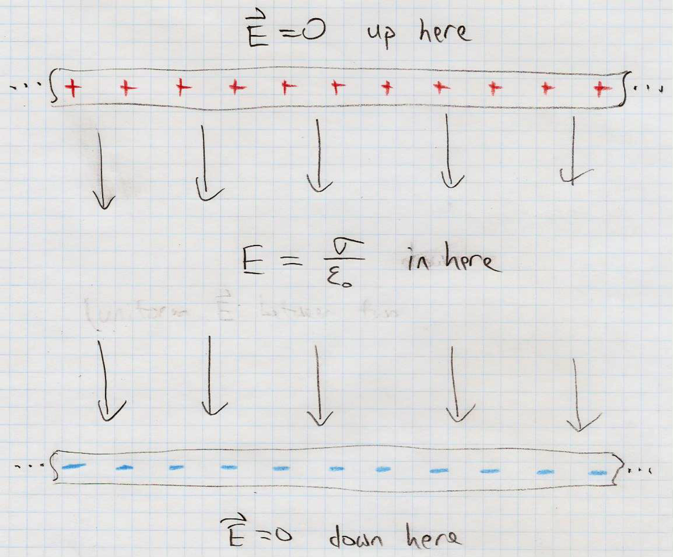
Four charged particles are arranged in a square, as shown. Find (and draw) the electric field at the center of the square. (Here was the messier solution to the original problem.)



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

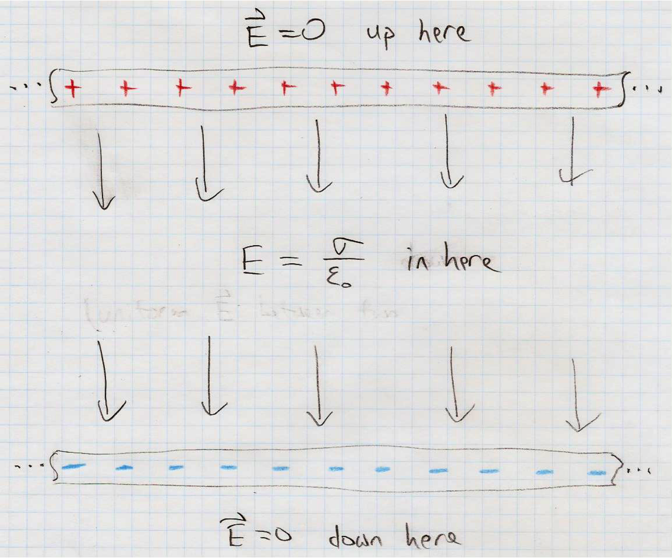


The most commonly used way to create a uniform electric field is to use the area between two large, parallel, oppositely-charged planes of uniform charge-per-unit-area, $\sigma = Q/A$.



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:

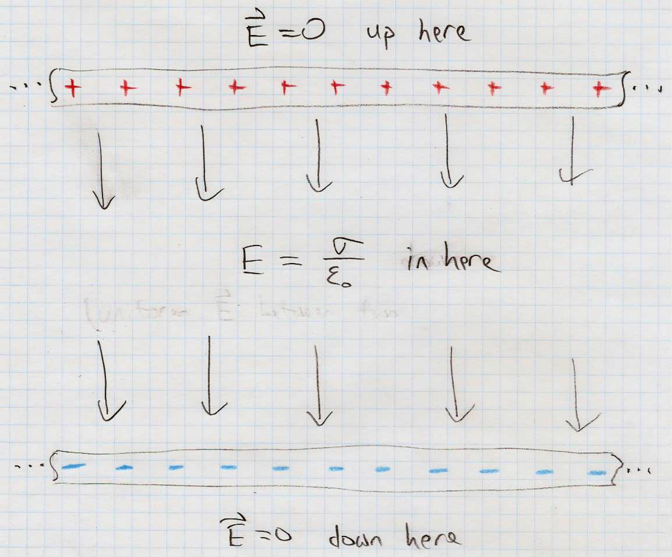


(A) positive

(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:

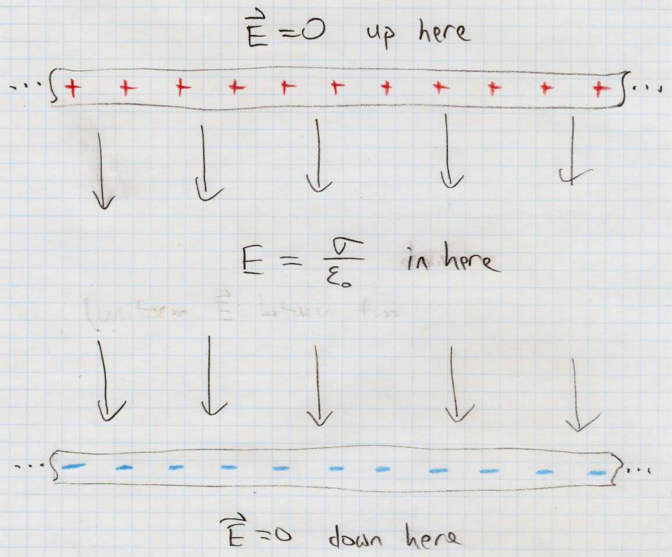


(A) positive

(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:

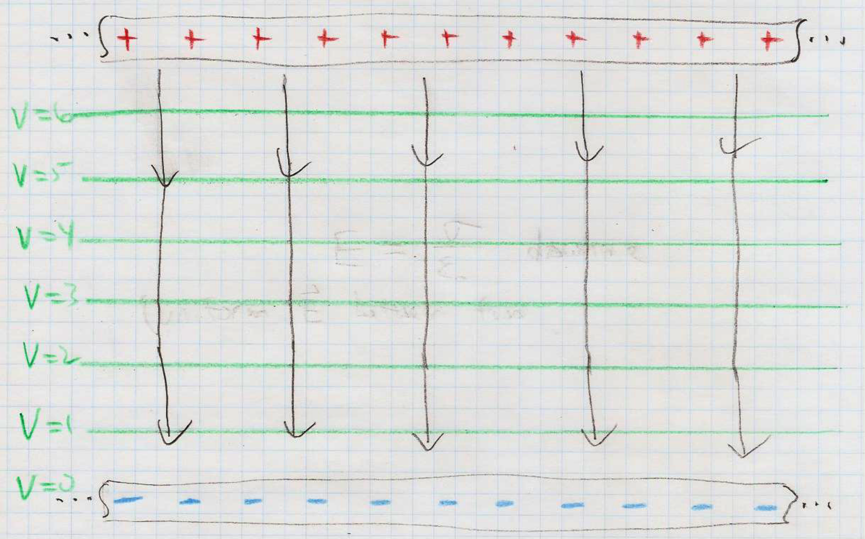


(A) positive

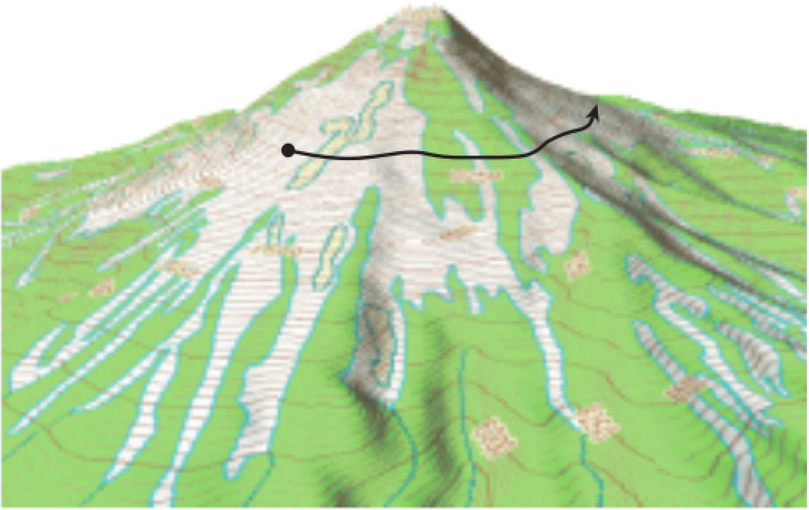
(B) negative

(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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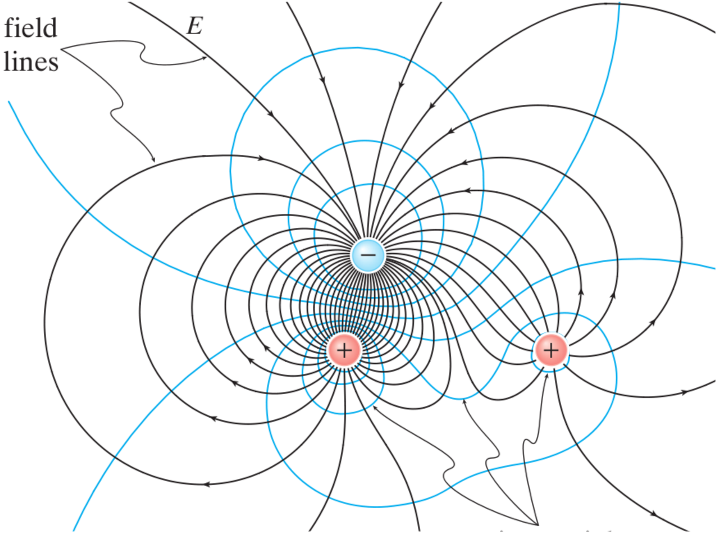
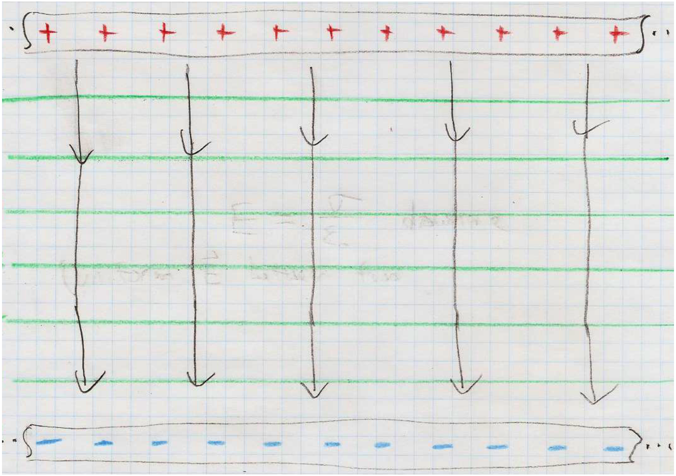


Figure 25.9 Field lines and equipotentials for three stationary charged particles.

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.

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

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

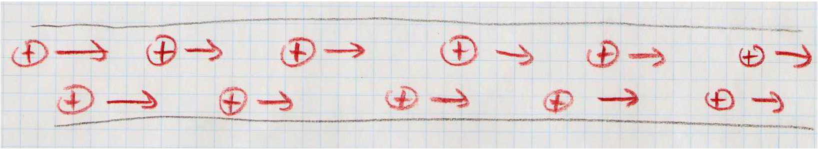
$$U^G = m\ g\ h$$

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 $\vec{E}$.

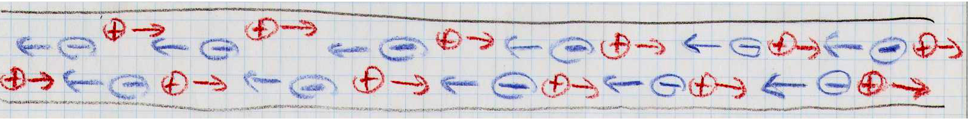


Inside a wire, positively charged particles are moving to the right. What is the direction of the electric current (symbol I, unit = ampere, or "amp") ?

(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

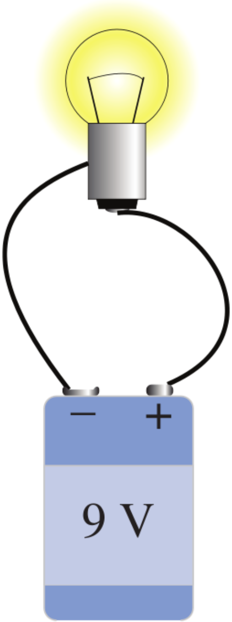
(C) zero

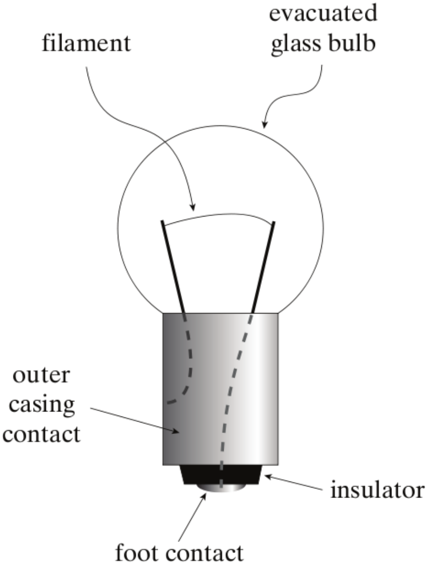
- Working with one or two other people, take one bare flashlight bulb, one new **D**-size battery, and one piece of wire.
- Find four different ways to connect these three objects together such that the bulb lights up.
- What is the key to making the bulb light up?

Alternatively (your choice) if you have your computer with you, you and your neighbor(s) can build a "virtual" circuit by going to this web link:

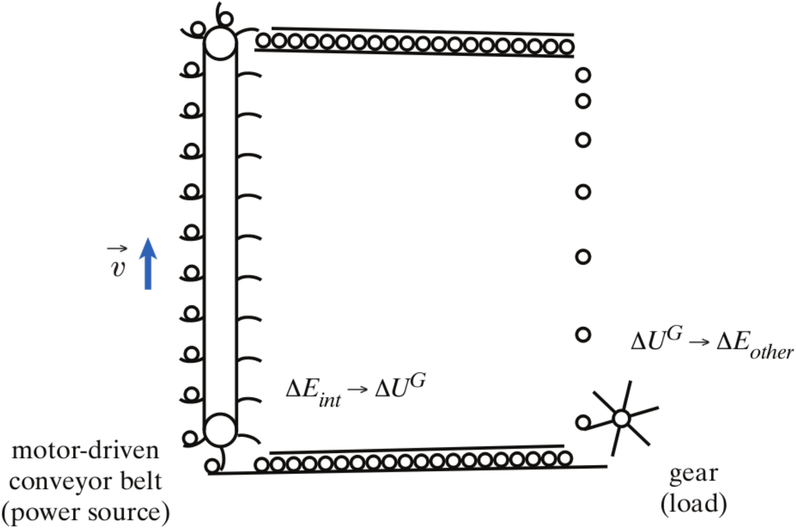
`https://phet.colorado.edu/sims/html/circuit-construction-kit-dc/latest/circuit-construction-kit-dc_en.html`

If that's hard to type, just go to `https://phet.colorado.edu` and then click "play with simulations" then "physics" then "electricity, magnets & circuits" then "circuit construction kit: DC" then "intro."





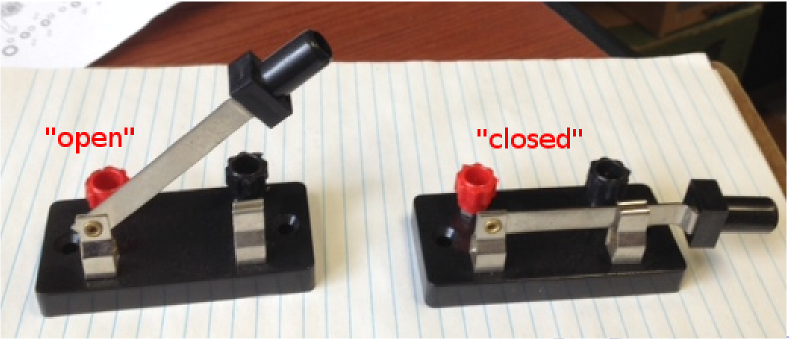
(By the way what is the emf (or “voltage”) of a D-cell battery? It’s much less than 9 volts.)

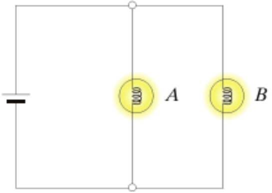


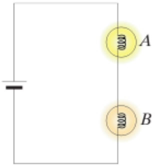
What in this diagram is analogous to the bulb? Wires? Battery? Voltage? What does a ball represent?

- Now (for convenience) use sockets to hold the bulb and the battery, and again light the bulb.
- Do you see where the sockets make their connections to the battery and the bulb?

- Next, add a switch, so that "closing" (connecting) the switch lights the bulb and "opening" (unconnecting) the switch switches off the bulb. Once it works, sketch a circuit diagram.





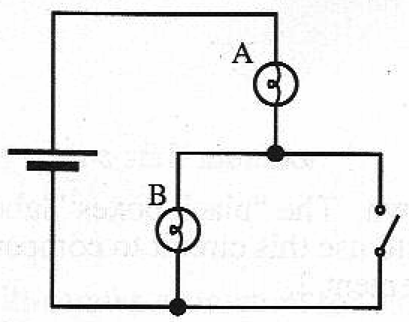


Which circuit diagram shows two bulbs connected in series? In parallel? [Click (A)=left diagram, (B)=right diagram.]

- In which case is the potential difference across bulb A equal to the potential difference across bulb B (even if the two bulbs are not identical)?
- In which case does the same current flow through both bulbs (even if the two bulbs are not identical)?

- Try wiring the two bulbs in series: how does the brightness of each bulb compare with the single-bulb circuit?
- Next try wiring the two bulbs in parallel: now how does the brightness of each bulb compare with the single-bulb circuit?
- How can you wire a 2nd battery to make the light less wimpy?

If you were to build this circuit, when would bulb A be brighter?

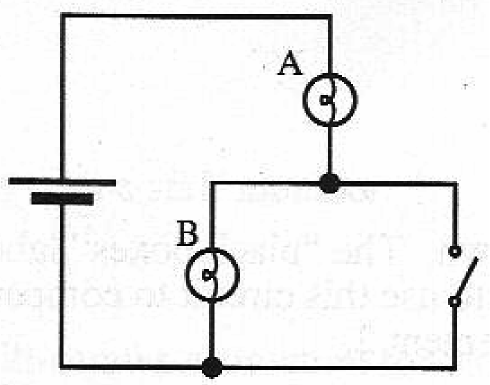


(A) A is brighter when the switch is open

(B) A is brighter when the switch is closed

(C) A is the same brightness in both cases

How does the resistance of bulb B compare with the resistance of a **closed** switch? (A circuit diagram usually shows a switch in its open position, as this one does.)

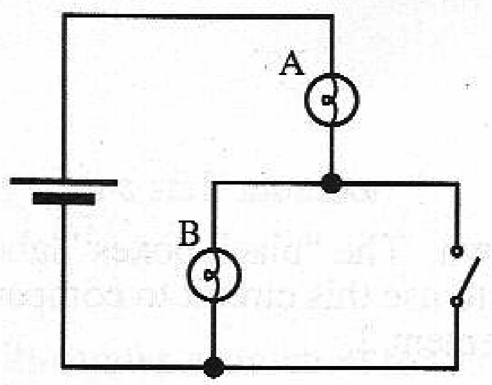


(A) a closed switch has much smaller resistance than bulb B

(B) a closed switch has much larger resistance than bulb B

(C) the resistance of a closed switch is similar to the resistance of bulb B

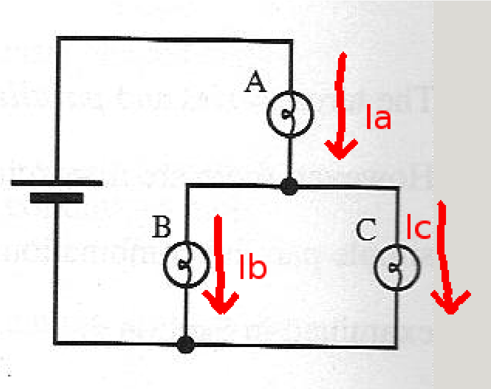
By the way, what is the resistance of an **open** switch? (Is it very easy or is it very difficult for current to flow through an open switch?)



(A) an open switch has a very small resistance, effectively "zero"

(B) an open switch has a very large resistance, effectively "infinite"

What relationship between I_a, I_b, and I_c does the **junction rule** (a.k.a. "Kirchoff's current rule") allow us to write down?



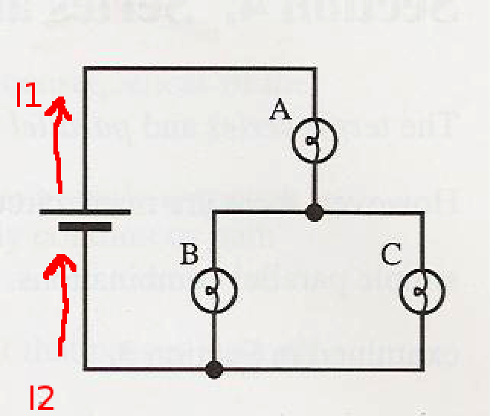
(A) $I_a + I_b = I_c$

(B) $I_a = I_b + I_c$

(C) $I_a = I_b - I_c$

(D) $I_a + I_b + I_c = 0$

In the steady state, how does the current I_1 flowing out of the battery compare with the current I_2 flowing back into the battery?



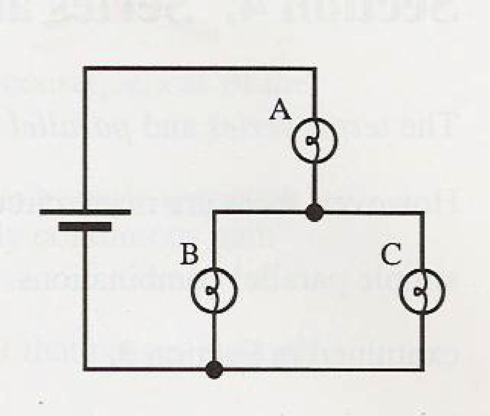
(A) They are equal.

(B) I_1 is bigger, because the current is "used up" by the light bulbs.

(C) They should have the same magnitude, but I_2 should be flowing downward instead.

(D) You can't tell, because there is a junction where the 3 bulbs meet.

Predict the relative brightness for the three bulbs (assuming the bulbs are identical). (Once you predict, feel free to try it!)



(A) $A < B < C$

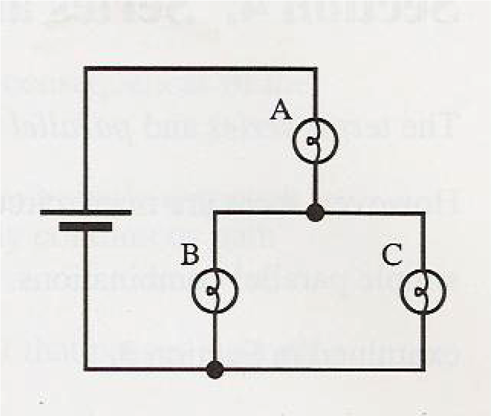
(B) $A < B = C$

(C) $A = B = C$

(D) $A > B = C$

(E) $A > B > C$

You just predicted $A > B = C$ when all 3 bulbs are present. Now predict what will happen to the brightness of bulbs A and B if bulb C is unscrewed. (Once you predict, feel free to try it.)



(A) A and B will both become brighter.

(B) A and B will both become dimmer.

(C) A will become brighter, and B will become dimmer.

(D) A will become dimmer, and B will become brighter.

(E) The brightness of A and B will not change.

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