Electric Fields, Potentials (completed)

Monday, April 25, 2016 2:14 PM

Types of Forces:

gravity, push/pull, Normal, Friction, tension, buoyancy
spring, drag, electric, magnetic, nuclear strong + weak

these underlined forces are all actually examples of the electric force.

..... No such thing as contact force
... no such thing as contact

Features of the Electric Force:

- between charges q (electrons, protons... ect.)
- decreases w/ Increased distance $\propto \frac{1}{r^2}$
- long range ... ∞ Action at a distance
- currents + circuits (dynamics)
- attract or repel (unlike gravity)
- a long range force ... action at dist.
- large vs. small ... depends
- like q's repel + unlike q's attract

What is a charge?:

- positive or negative or neutral
- comes in little bundles (quanta)
- transferable (usually electrons)
  - objects exchange q
    - ex. friction or rubbing ... literally strip e^-
    - when one objects gains e^-, the other losses

Three pith balls are suspended from thin threads. Various objects are then rubbed against other objects (nylon against silk, glass against polyester, etc.) and each of the pith balls is brought in contact with one of these objects. It is found that pith balls 1 and 2 repel each other and that pith balls 2 and 3 repel each other. From this we can conclude that

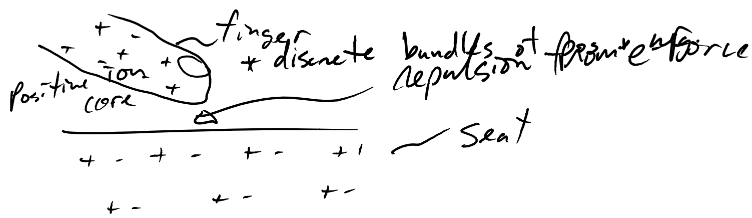
1. **1 and 3 carry charges of opposite sign.**
2. **1 and 3 carry charges of equal sign.**
3. **all three carry charges of the same sign.**
4. **one of the objects carries no charge.**
5. **we need to do more experiments to determine if the signs of the charges are similar or not.**

$$\left.\begin{array}{l} 1 + 2 \text{ like } q\text{'s} \\ 2 + 3 \text{ like } q\text{'s} \end{array}\right\} 1+2+3 \text{ like } q\text{'s}$$

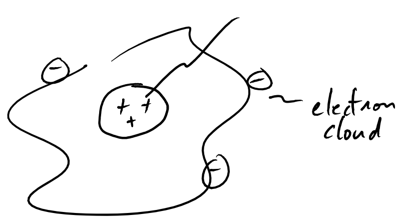
Large or Small?:

- E-force is much (40 times in mag.) greater than force of gravity
  - ex. at atomic level $F^E >> F^G$ ... 40 orders
- But.... largly ignored at celestial scale.
  b/c large objects are relatively neutral
- Does E-force matter on macro scale?

Yes!



Microscopic Model of Charge and Matter:



→ 3 protons, 3 electrons
= neutral

* Fundamental quanta of q

$e = 1.6 \times 10^{-19}$ C
& "Coulomb"
... SI unit.

Conservation of Charge:

$$Q_{tot} = N_+ e - N_- e = e(N_+ - N_-) = e(N_{protons} - N_{electrons})$$

# of neg.

practice

# of positive

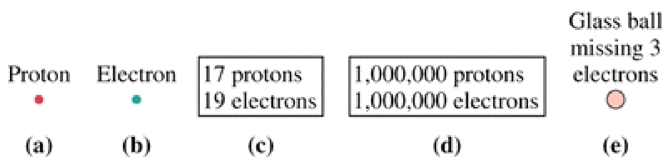
Stable Atom. ex. Lithuim $Q_{total} = 0$

if an electron is removed or Ionized, then $Q_{total} = +e$

* All matter consists of an integer multiple of e

Isolated System $\Delta Q = 0$ ← charge conservation.

Rank in order the net charges q_a to q_e of these five systems. Consider -2q less than +1q.

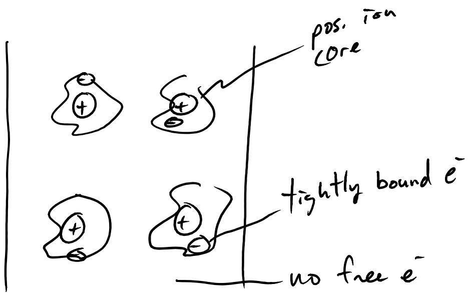


$c < b < d < a < e$

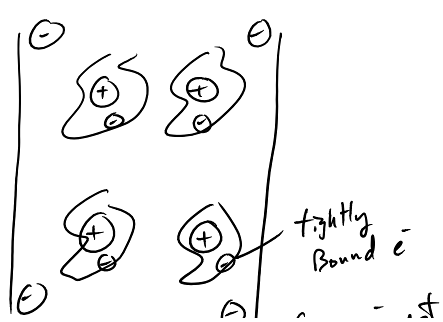
neg. ← zero → Pos.

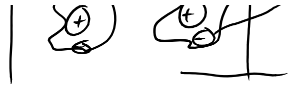
Insulators vs. Conductors vs. Semi-conductors

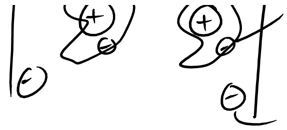
Insulator



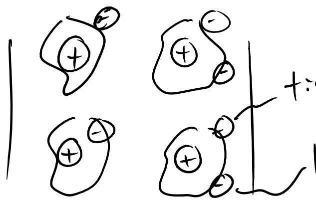
Conductor







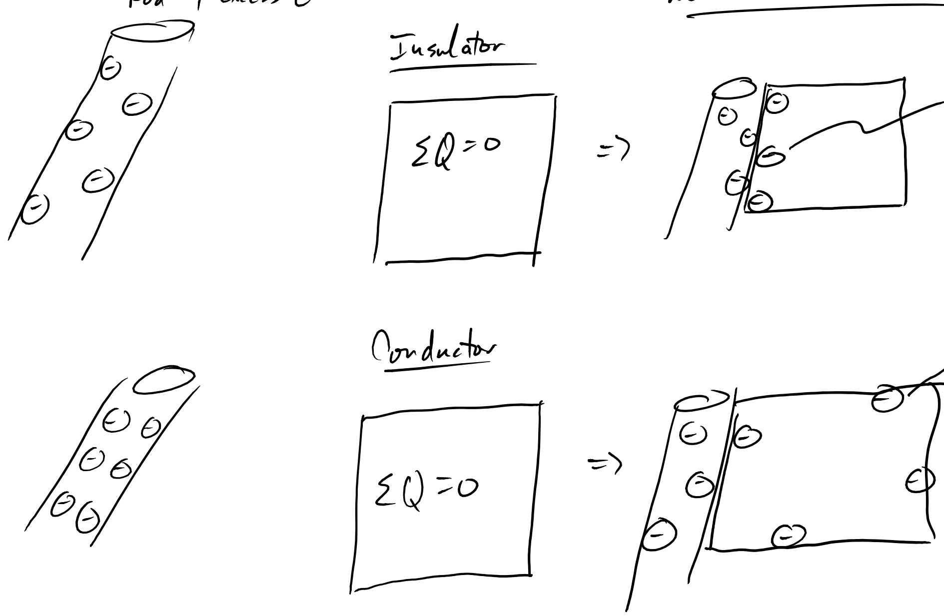
Semi conductor



Charging and Discharging

* Rub cat fur + strip charges onto an object.

ex.

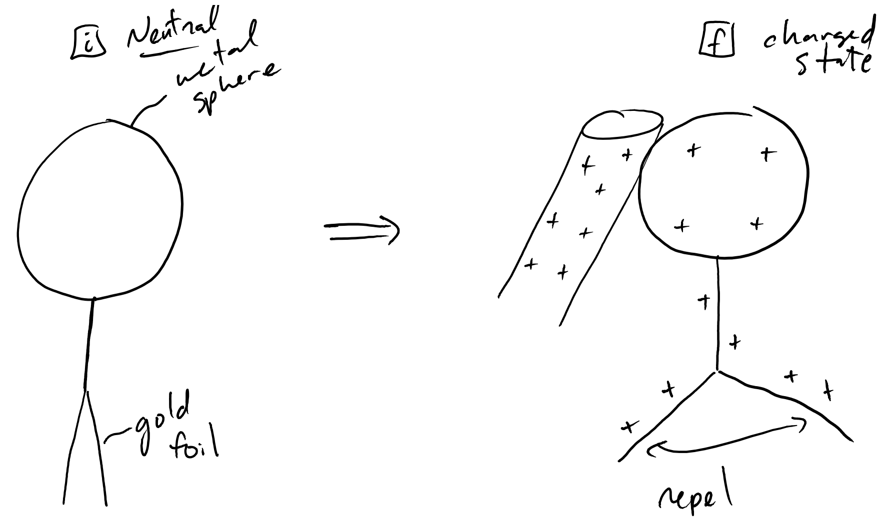


Electroscope

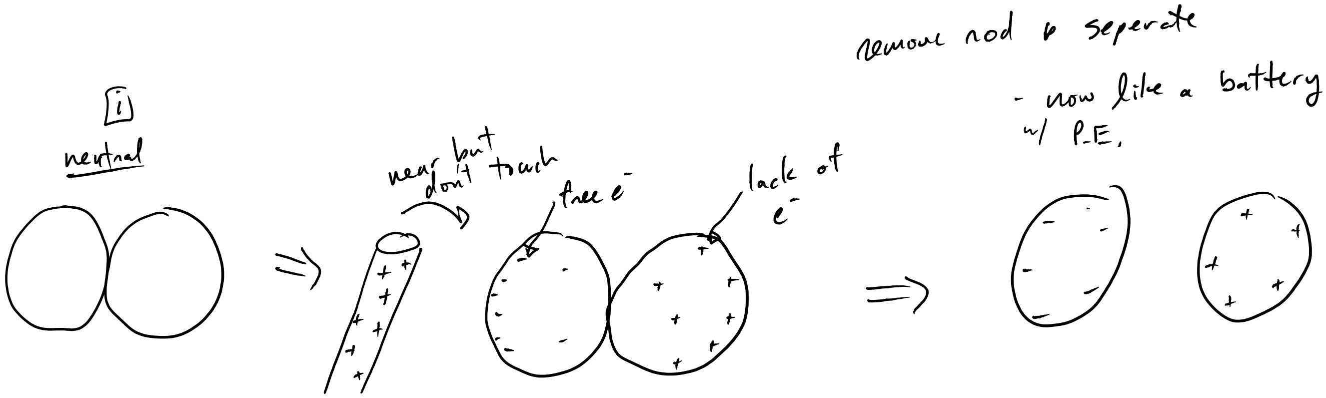
$\boxed{i}$ Neutral metal sphere

$\boxed{f}$ charged state

Electroscope

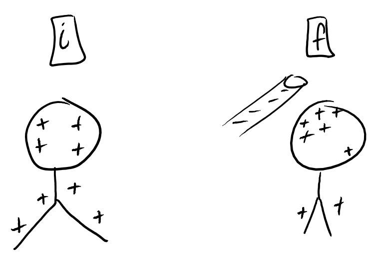


Charge by Induction: action at a distance



An electroscope is positively charged by touching it with a positive glass rod. The electroscope leaves spread apart and the glass rod is removed. Then a negatively charged plastic rod is brought close to the top of the electroscope, but it doesn't touch. What happens to the leaves?

1. **The leaves get closer together**
2. **The leaves spread further apart**
3. **The leaves don't move**
4. **One leaf moves higher, the other lower**



A rod is charged but whether or not it is net negative or positive is unknown. When the rod is brought close to a metal can, what do you expect to happen?

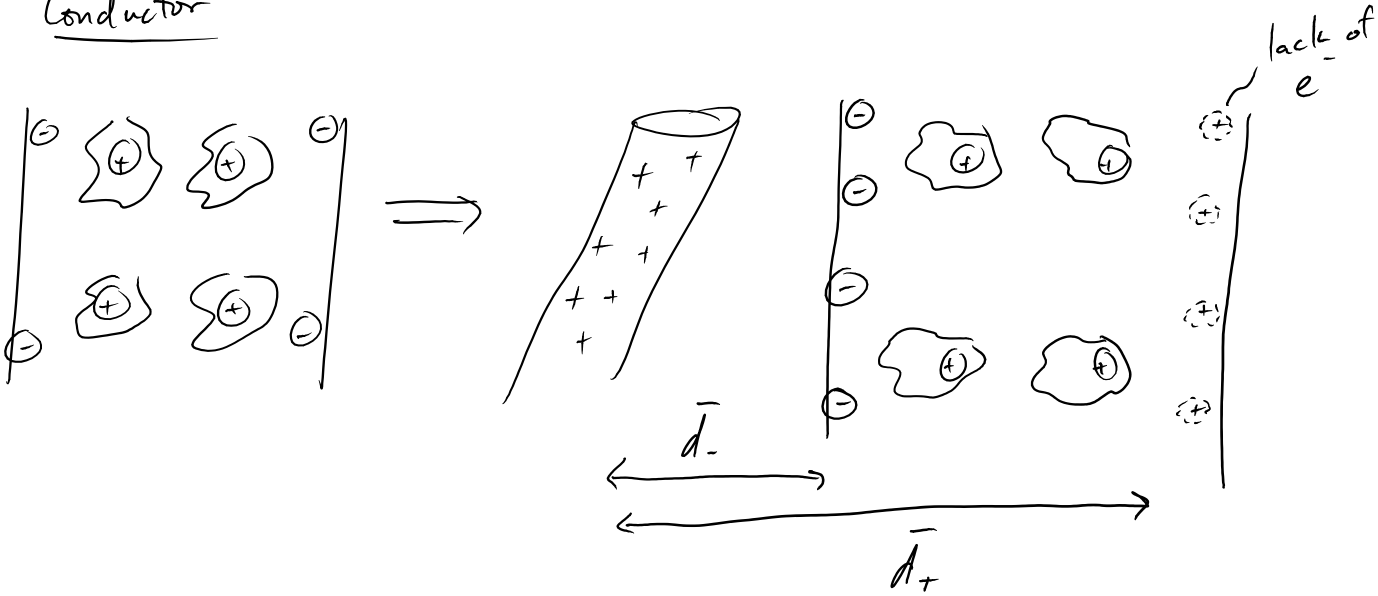
1. **Nothing**
2. **Can moves away from rod**

→ macroscale polarization

1. Nothing
2. Can moves away from rod
3. Can moves towards rod → macroscale Polarization
4. Can spontaneously combusts>

<u>Polarization</u>: charge separation

neutral <u>Conductor</u>

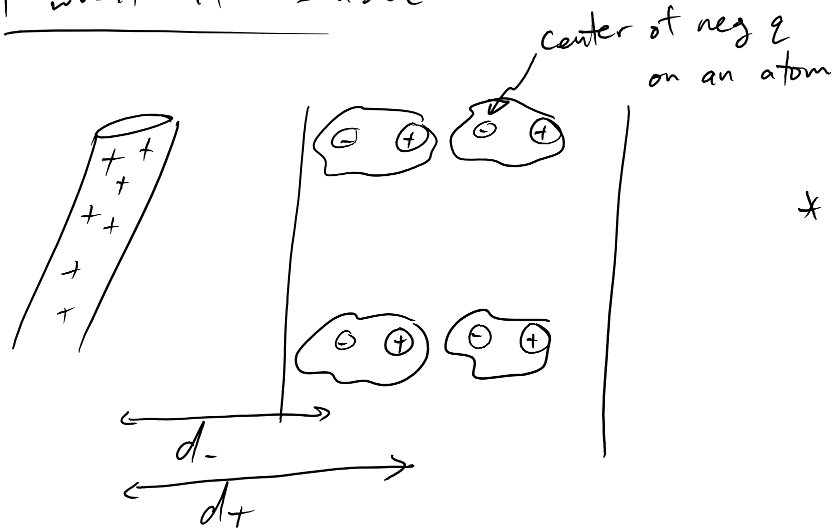


w/ $d_- < d_+$, $F_{(-)} > F_{(+)}$ → attracts

A rod is charged but whether or not it is net negative or positive is unknown. When the rod is brought close to a 2x4 piece of dry wood, what do you expect to happen?

1. Nothing
2. Wood moves away from rod
3. Wood moves towards rod → microscale Polarization
4. Wood spontaneously combust

but what if Insulator?

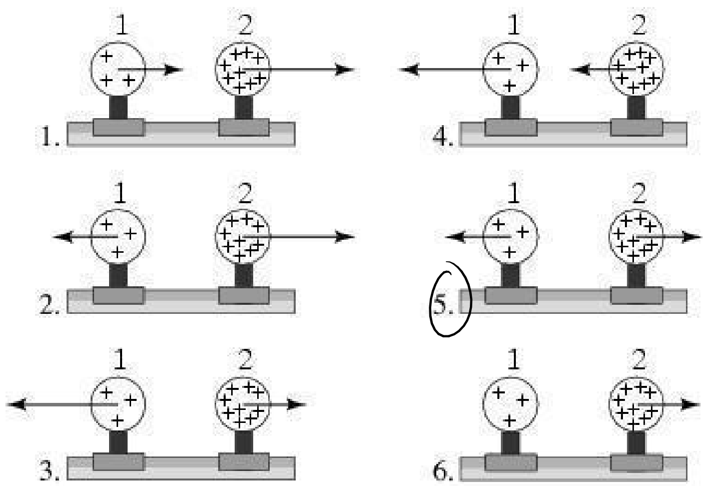


* w/ $d_- < d_+$

$F_- > F_+$

... but much smaller effect than conductor

Two uniformly charged spheres are firmly fastened to and electrically insulated from frictionless pucks on an air table. The charge on sphere 2 is three times the charge on sphere 1. Which force diagram correctly shows the magnitude and direction of the electrostatic forces?

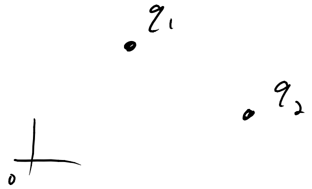


7. none of the above

* like q's repel

* Newton's 3rd Law

Coulomb's Law: Electric force between point q's

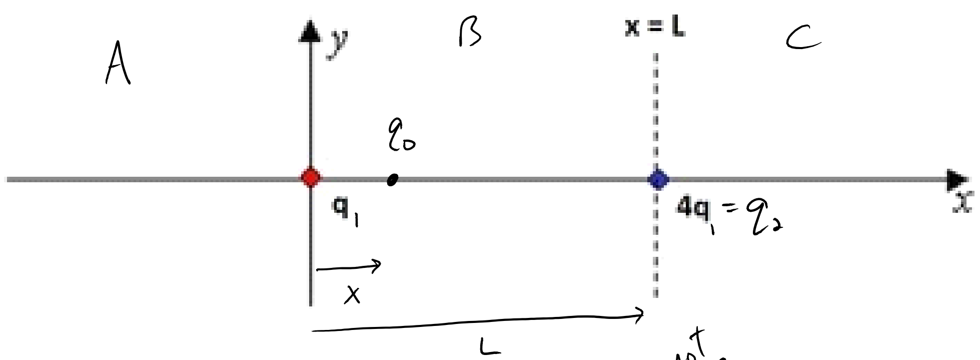


magnitude

$$|\vec{F}^E_{12}| = |\vec{F}^E_{21}| = \frac{k\,|q_1||q_2|}{\underbrace{|\Delta \vec{r}_{12}|^2}_{\text{distance between (1) + (2)}}}$$

Direction: Ad-hoc w/ FBD * like repel * unlike attract

Two point charges q and 4q are at x = 0 and x = L, respectively. A third charge is placed so that the entire three-charge system is in static equilibrium. Where is the third charge placed?



FBD($+q_0$)

$F^E_{20} \longleftarrow \bullet \longrightarrow F^E_{10}$

if $q_0(+)$ FBD(q_1) not eq.

$\bullet\!\longrightarrow F^E_{01}$

$\longrightarrow F^E_{21}$

... if $q_0(-)$ FBD(q_1) Can be In eq.

$F^E_{21} \longleftarrow \bullet \longrightarrow F^E_{01}$

What are the magnitude, sign, and x-coordinate of the third charge?

q_0 must be neg for q_1 + q_2 to be in equil.

FBD($-q_0$) $\longrightarrow \hat{x}$

$F^E_{10} \longleftarrow \bullet \longrightarrow F^E_{20}$

$$\Sigma F_x \Rightarrow +|\vec{F}^E_{20}| + \left(-|\vec{F}^E_{10}|\right) = M_0 \cancel{a_x}^{\,0}$$

$$\frac{\cancel{k}\,|q_2||\cancel{q_0}|}{(L-x)^2} - \frac{\cancel{k}\,|q_1||\cancel{q_0}|}{x^2} = 0 \Rightarrow (L-x)^2 = \frac{|q_2|}{|q_1|}x^2$$

4

$$L^2 + x^2 - 2xL - 4x^2 = 0$$

$$-3x^2 - 2xL + L^2 = 0$$ ----- quad

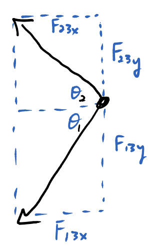
--- solve for x.

--- choose (+) value

A positively charged particle is placed along the positive *x* axis and a particle carrying a negative charge of equal magnitude is placed at equal distance from the origin along the negative *x* axis. A third particle carrying a positive charge is placed on the *y* axis. Draw an arrow to represent the direction of the vector sum of the forces exerted by 1 and 2 on 3.

Calc?

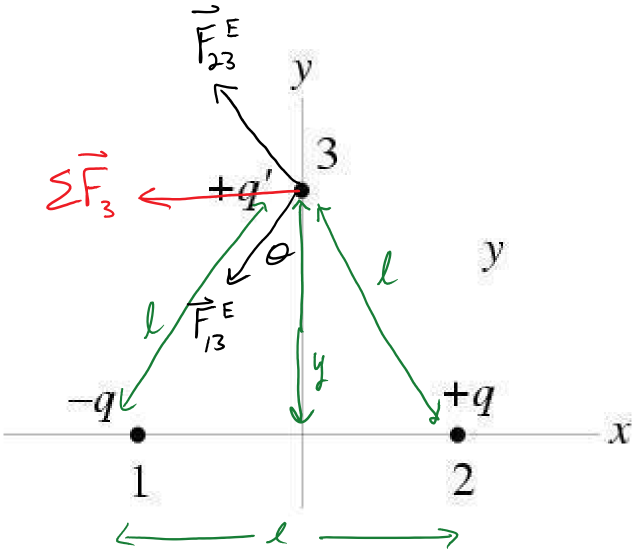
FBD(3)



$|\vec{F}_{13}| = |\vec{F}_{23}|$ + $\theta_2 = \theta_1 \equiv \theta$

$\boxed{y}$ So, $F_{23y} = -F_{13y}$ + $\Sigma F_{3y} = 0$

$\boxed{x}$ $F_{13x} = |\vec{F}_{13}| \cos\theta = F_{23x}$



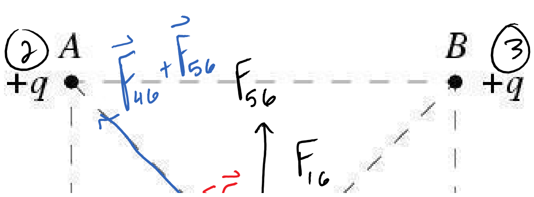
So, $\Sigma F_x \Rightarrow 2|\vec{F}_{13}| \cos\theta = m a_x$

$$2\,\frac{k|q_1||q_3|}{\ell^2} \cos\theta = m a_x$$

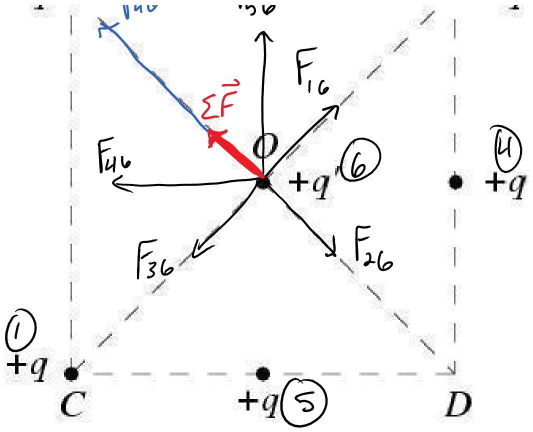
↑ but $\cos\theta$ is function of ℓ ... $\cos\theta = \frac{y}{\ell}$

$y^2 = \ell^2 - \left(\frac{\ell}{2}\right)^2 \Rightarrow \cos\theta = \frac{\sqrt{\ell^2 - \frac{\ell^2}{4}}}{\ell}$ + $\Sigma F_x = \frac{2kq^2}{\ell^2} \frac{\sqrt{\ell^2 - \frac{\ell^2}{4}}}{\ell} = m a_x$

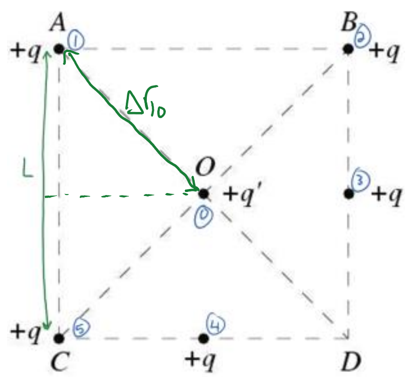
Five equally charged particles *+q* are placed on a square as illustrated. A fifth charged particle *+q'* is placed at the center *O*. What is the direction of the vector sum of the forces exerted on *q'*?



$\vec{F}_{16} = -\vec{F}_{36}$ ... cancel each other out



Which of the following are an expression for the force from q_4 on q_0, if all of the charges are equal magnitude?



$$|\vec{F}_{40}| = \frac{k|q_4||q_0|}{\Delta r_{40}^2}$$

$$= \frac{k\,q^2}{\left(\frac{L}{2}\right)^2} \quad \text{... direction } +\hat{y}$$

$$\vec{F}_{40} = \frac{4kq^2}{L^2}\langle 0,1,0\rangle$$

$\vec{F} = \frac{kq^2}{L^2}\langle 1,0,0\rangle$

$\vec{F} = \frac{4kq^2}{L^2}\langle 0,1,0\rangle$

$\vec{F} = \frac{4kq^2}{L^2}\langle -1,0,0\rangle$

$\vec{F} = \frac{kq^2}{L^2}\langle 0,1,0\rangle$

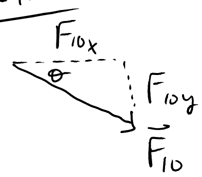
$\vec{F} = \frac{4kq^2}{L^2}\langle \frac{\sqrt{2}}{2},\frac{\sqrt{2}}{2},0\rangle$

$\vec{F} = \frac{2kq^2}{L^2}\langle \frac{\sqrt{2}}{2},-\frac{\sqrt{2}}{2},0\rangle$

Which of the following are an expression for the force from q_1 on q_0, if all of the charges are equal magnitude?

$$|\Delta r_{12}|^2 = \left(\frac{L}{2}\right)^2 + \left(\frac{L}{2}\right)^2 = 2\frac{L^2}{4} = \frac{L^2}{2}, \quad \text{so} \quad |\vec{F}_{10}| = \frac{2kq^2}{L^2}$$

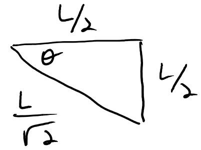
direction



$$F_{10x} = |\vec{F}_{10}|\cos\theta$$

$$F_{10y} = -|\vec{F}_{10}|\sin\theta$$

use Geometry for $\cos\theta$ & $\sin\theta$



$$\cos\theta = \frac{L/2}{L/\sqrt{2}} = \frac{\sqrt{2}}{2}$$

$$\sin\theta = \text{" "} = \frac{\sqrt{2}}{2}$$

So $$\vec{F}_{10} = \frac{2kq^2}{L^2}\left\langle \frac{\sqrt{2}}{2}, -\frac{\sqrt{2}}{2}, 0\right\rangle$$

Take 1 min to discuss what an electric field is with your neighbor and then provide one word to describe it.

The Electric Field

features:

* generated by charged objects

Philosophy

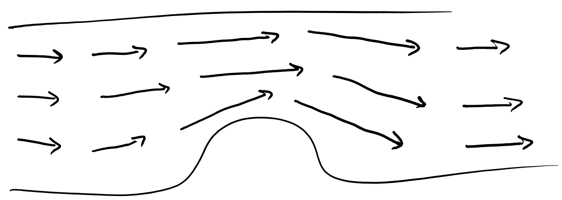
* alters space around q effecting Interactions

Practice

* map everywhere in space
  * Vector field map ... huh? (x, y, z) } every point in space has 3 #'s values, one for each component

ex. Velocity vector field

River



* if calc. $\vec{E}_q$ ← (e-field from some charge q)

then $\vec{F}_{q_0} = q_0 \vec{E}_q$ ← $\vec{E}(x,y,z)$

some other charge q_0 "test charge"

* what if more than one charge creating field.

add by principle of superposition → $\vec{E}_{tot} = \sum \vec{E}_i$ → $\underbrace{\vec{F}_{q_0} = q_0 \vec{E}_{tot}}$

Force on q_0 is equal to q_0 times net E-field from everything else

* Warning*... Vector addition

You are given a charged "test" particle to map out the electric field of a charged object. To correctly determine the object's electric field, you need to know

1. **the magnitude and sign of the charge on the test particle.**
2. **the magnitude and sign of the charge on the object.**
3. **only the sign of the charge on the test particle.**
4. **All of the above.**
5. **None of the above.**

$$\vec{E} = \frac{\vec{F}_0}{q_0} \Rightarrow \vec{F}_0 = q_0 \vec{E}$$

test force on test q_0

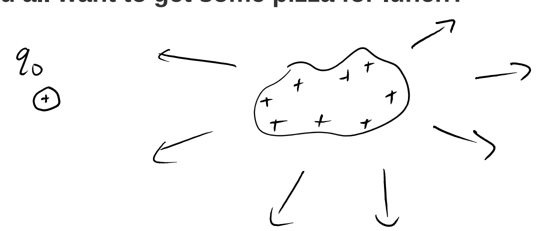
E-field of charged object

The electric field at a certain location is given by the electrostatic force per unit charge that is exerted on a charged particle at that location. So, after measuring the force on the test particle, you must divide this force by the magnitude of the charge on the test particle to obtain the force per unit charge. The sign is also important because it determines the direction of the force exerted by the object on the particle. Only if the particle is *positively* charged does the direction of the force coincide with that of the electric field (by definition).

Three students are discussing the magnitude of the test charge on a probe used for measures the electric field from charge distributions. Which of the statements do you like?

1. **"I think the test charge on the probe should be quite large so that the response is much greater and thus can be measured more accurately"**
2. **"My only problem with that is that if you have a lot of charge on your test probe, it will affect the charges on the object that are creating the very field you're trying to measure and thus ruin your measurement"**
3. **"But if the charge is too small than you may not be able to get a reliable measurement, I mean as the test charge decreases, so does the response to the field"**
4. **"You all want to get some pizza for lunch?"**

All are good statements

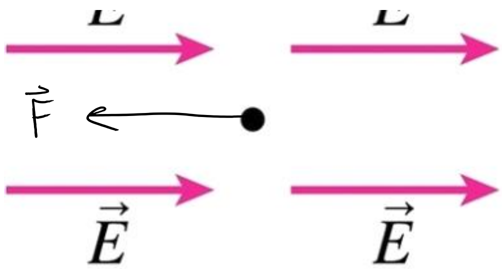


As q_0 gets closer it will repel q's more + distort the charge configuration you wished to measure the E-field of.

An electron is placed at the position marked by the dot. Draw a vector to represent the direction of the force on the charge.

$\vec{F}_0 = q_0 \vec{E}$

if q_0 (−), then $\vec{F}$ points

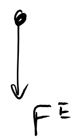


if q_0 (−), then $\vec{F}$ points In opposite direction as $\vec{E}$

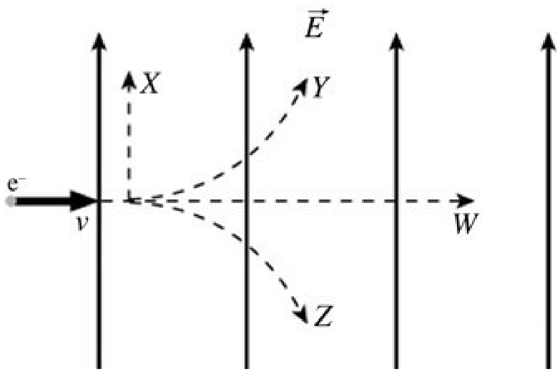
An electron is initially moving to the right when it enters a uniform electric field directed upwards. Which trajectory shown below will the electron follow?

1. **trajectory Y**
2. **trajectory W**
3. **trajectory X**
4. **trajectory Z**

FBD (e^-)



so $\vec{a}$ is downward



An electron enters a region from the left (moving right with velocity v) Which of the two E fields shown would produce the observed parabolic motion (dashed curve)?

1. **only I**
2. **only II**
3. **both I and II.**
4. **Neither I nor II**
5. **I have no idea**

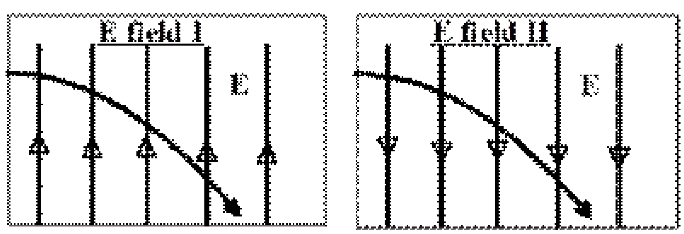
$\vec{a}$ is downward

so $\Sigma\vec{F}$ must be

w/ $\vec{F}_0 = q_0\vec{E}$

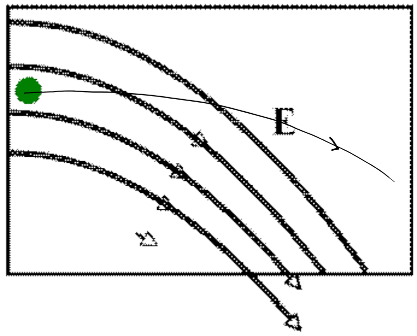
+ q_0 (−)

$\vec{F}$ + $\vec{E}$ point in opposite directions



A proton starts at rest at the green spot. How will it move?

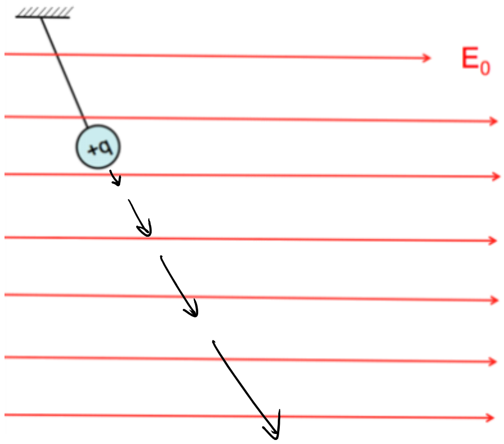
1. Stays at rest
2. Follows a path between the field lines
3. It moves to the right, curving downward but ultimately crossing a field line

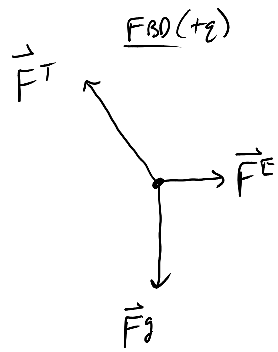


Field Lines determine force, not velocity.
The momentum gained early to the right

Objects do not have to follow field lines. The field lines show FORCE, not VELOCITY! Think of the inertia of the green proton carrying it to right, past some lines, as it picks up speed and then begins slowly to cur downwards.

Draw a free body diagram for the positively charged hanging object shown below.





If the string is cut, sketch a qualitatively correct trajectory of the object afterwards.

if $F^T \to 0$, $\Sigma \vec{F}$ ↘, so, $\vec{a}$ is down + to right

An object having a mass of 10.0 g and a charge of 8.00 x 10^{-5} C is placed in a uniform electric field E (no gravitational field) where E_x = 3.00 x 10^3 N/C, E_y = -600 N/C, and E_z = 100 N/C. What is the acceleration on the object?

1. < 12, -6.2, 0.8 > m/s^2
2. < 8.2, -6.2, -1.6 > m/s^2
3. < 1.2, -4.2, 2.8 > m/s^2
4. < 24, -3.8, 0.2 > m/s^2
5. < 24, -4.8, 0.8 > m/s^2

$\Sigma \vec{F} = m\vec{a} \Rightarrow q\vec{E} = m\vec{a}$

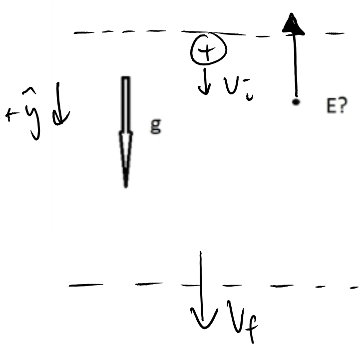
Brute force

$\vec{a} = \frac{q}{m}\vec{E} = \frac{8\times10^{-5}\,C}{0.01\,kg}\langle 3\times10^{3}, -600, 100\rangle \frac{N}{C}$

or process of elimination ... $+\hat{x}$, $-\hat{y}$, $+\hat{z}$

& $|x_{comp}| = 6\,|z_{comp}|$

A 10 g ball is charged to 8 x 10^{-5} C and dropped into a vertical electric and gravitational field (g = 10 m/s^2). The ball enters the field region traveling downward at 4 m/s and leaves it traveling at 16 m/s, taking 6 s to travel the region. Draw vector representing the direction of the electric field?

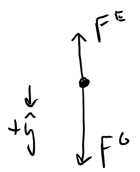


if free-fall & $\Delta t = 6s$

then $V_f = V_i + g\Delta t \Rightarrow V_f = 64\,m/s$

... not that fast so E-force must point opposite gravity

What is the magnitude of the electric field the ball traveled through? Answer in Newton's per Coulomb.



(i) $\Sigma F_y \Rightarrow mg - qE = ma_y$

need $a_y \Rightarrow$

K	uK
$V_i = 4\,m/s$	Δy
$V_f = 16\,m/s$	a_y

(ii) $a_y = \frac{V_f - V_i}{\Delta t}$

$\Delta t = 6s$

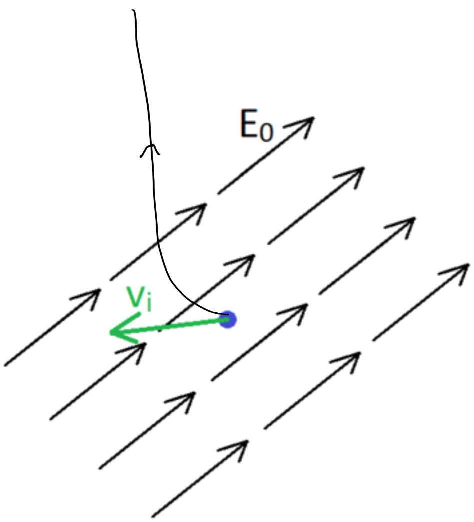
$a_y = 2\,m/s^2$

Now (i) $E = \dfrac{m(g - a_y)}{q} = \underline{1000\,\frac{N}{C}}$

Δy? $\Delta y = V_{iy}\Delta t + \frac{1}{2}a_y \Delta t^2$

$= (4)(6) + \frac{1}{\cancel{2}}(\cancel{2})(6)^2 = 60\,m$

A proton, with initial velocity v_i, is placed at the position marked by the dot. Sketch the trajectory of the charge in this field.



$\vec{F}_{q_0} = q_0 \vec{E}$, w/ $q_0 = +e$

$\vec{F}$ & $\vec{E}$ (& $\vec{a}$) point in same direction

An electron is placed in a constant electric field given by:

$\vec{E} =< -E_{0x}, E_{0y}, -E_{0z} >$

An electron is placed in a constant electric field given by:

$$\vec{E} = < -E_{0x}, E_{0y}, -E_{0z} >$$

what is the acceleration of the electron?

(a) $-\frac{e}{m_e} < E_{0x}, E_{0y}, E_{0z} >$

(b) $\frac{e}{m_e} < E_{0x}, E_{0y}, E_{0z} >$

(c) $\frac{e}{m_e} < -E_{0x}, E_{0y}, -E_{0z} >$

(d) $-\frac{e}{m_e} < -E_{0x}, E_{0y}, -E_{0z} >$

(e) $-\frac{e}{m_e} < E_{0x}, -E_{0y}, E_{0z} >$

$\Sigma \vec{F} = m\vec{a}$, $\Sigma \vec{F} = \vec{F}^E = q_0 \vec{E}$

$q_0 = -e$

$-e\vec{E} = m\vec{a}$

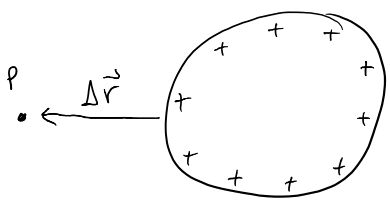
$\vec{a} = -\frac{e}{m}\vec{E}$

$|\vec{E}| = \frac{k|q|}{|\Delta\vec{r}|^2}$

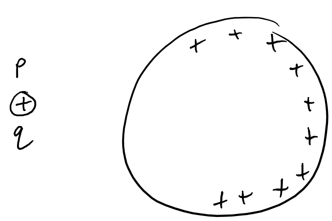
You wish to determine the electric field at a point near a positively charged metal sphere. You do so by bringing a small positive test charge q_0, to this point and measure the force F_0 on it. F_0/q_0 will be _________________ the electric field as it was at that point before the test charge was present.

1. less than
2. greater than
3. equal to

Before



After



Electric Field from a point q

$k = \frac{1}{4\pi\varepsilon_0} = \text{const.}$

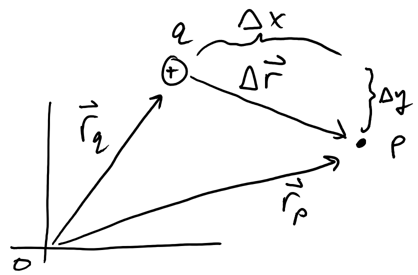
$$\vec{E}_q(\vec{r}_p) = \frac{kq}{|\Delta\vec{r}|^2}\,\Delta\hat{r}$$

("delta r hat")

* a unit vector.... has mag. 1

* gives direction

points from q
to point of interest p



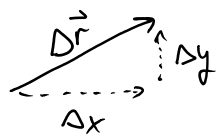
Recall vector addition (sub)

$\vec{r}_q + \Delta\vec{r} = \vec{r}_P \Rightarrow \Delta\vec{r} = \vec{r}_P - \vec{r}_q$

$$\Delta\vec{r} = \langle \underbrace{x_P - x_q}_{\Delta x},\ \underbrace{y_P - y_q}_{\Delta y},\ \underbrace{z_P - z_q}_{\Delta z} \rangle$$

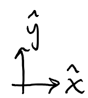
$$\Delta\hat{r} = \left\langle \frac{\Delta x}{|\Delta\vec{r}|},\ \frac{\Delta y}{|\Delta\vec{r}|},\ \frac{\Delta z}{|\Delta\vec{r}|} \right\rangle$$

ex.



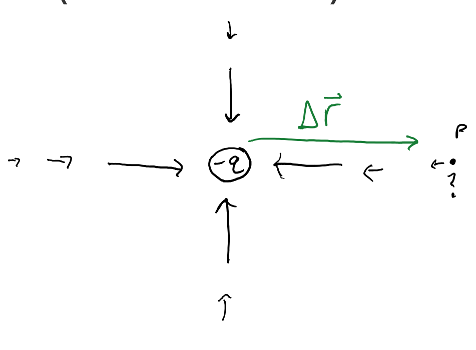
$$= \left\langle \frac{\Delta x}{\sqrt{\Delta x^2 + \Delta y^2 + \Delta z^2}},\ \frac{\Delta y}{\sqrt{\Delta x^2 + \Delta y^2 + \Delta z^2}},\ \frac{\Delta z}{\sqrt{\Delta x^2 + \Delta y^2 + \Delta z^2}} \right\rangle$$

$$\vec{E} = \underbrace{\frac{kq}{|\Delta\vec{r}|^2}}_{\text{Mag}}\ \underbrace{\Delta\hat{r}}_{\text{direction}}$$



Calculate the magnitude and direction of the electric field at a point P which is 30 cm to the right of a point charge q = -3 x 10^{-6} C. (K = 8.99 x 10^{9} N m^2/C^2)

1. **300,000 N/C, to the right**
2. **300,000 N/C, to the left**
3. **20,000 N/C, to the left**
4. **20,000 N/C, to the right**
5. **9,000 N/C, to the left**
6. **9,000 N/C, to the right**



$$|\vec{E}| = \frac{k|q|}{|\Delta\vec{r}|^2} = 300{,}000\ \frac{N}{C}$$

$$\Delta\hat{r} = \left\langle \frac{\Delta x}{\sqrt{\Delta x^2 + \Delta y^2}},\ \frac{\Delta y}{\sqrt{\Delta x^2 + \Delta y^2}} \right\rangle$$

$$\vec{E} = \frac{k(-3 \times 10^{-6}\,C)}{(.3)^2} \left\langle \frac{.3}{.3},\ \frac{0}{.3} \right\rangle$$

$$\vec{E} = \langle -300{,}000,\ 0 \rangle\ \frac{N}{C}$$

A positive charge q_0 = 2 x 10^{-6} C is placed at point P which is 30 cm in the positive direction from a point charge q = -3 x 10^{-6} C. What is the force on this positive charge q_0?

1. **<6, 0, 0> N**

$$\vec{F}_{q_x} = q_0\,\vec{E}$$

2. <-6, 0, 0> N
3. <0.6, 0, 0> N
4. <-0.6, 0, 0> N

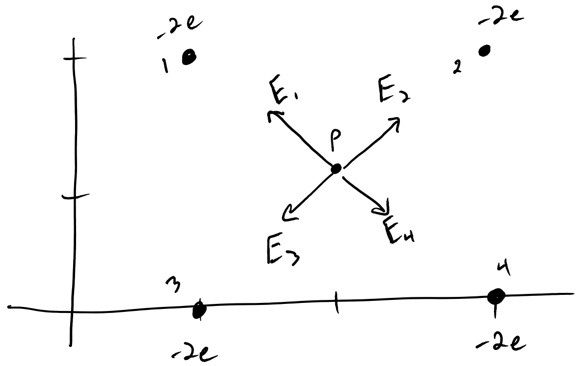
$= 2\times10^{-6}\cancel{C}\,\langle -300{,}000, 0\rangle \frac{N}{\cancel{C}}$

Four charges, all of which are q = - 2e are placed at the following coordinates:

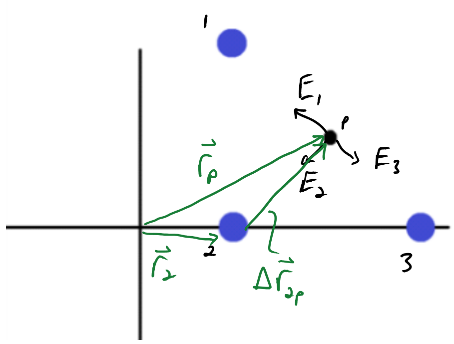
<3,2,0>, <1,2,0>, <1,0,0>, <3,0,0>

What is the electric field at point <2,1,0>?

1. < 0, 0, 0 > N/C
2. < 1/√2, 1/√2, 0, 0 > N/C
3. < -1/√2, -1/√2, 0, 0 > N/C
4. < -1/√2, 1/√2, 0, 0 > N/C
5. < 1/√2, -1/√2, 0, 0 > N/C



Consider the charge distribution (blue dots) shown below. If all the charges have a value -e, what is the direction of the electric field at the point marked with the black dot?



$\vec{E}_1 + \vec{E}_3$ cancel since $q_1 = q_3$ + $\Delta\vec{r}_{1p} = -\Delta\vec{r}_{3p}$

So $\sum\vec{E} = \cancel{\vec{E}_1} + \vec{E}_2 + \cancel{\vec{E}_3}$, $\vec{E}_2$ ↙

Calc $\sum\vec{E}$? ... need $\Delta\vec{r}_{2p}$ + $\Delta\hat{r}_{2p}$

Using # from above

$\Delta\vec{r}_{2p} = \langle \Delta x_{2p}, \Delta y_{2p}, \Delta z_{2p}\rangle = \langle +1, +1, 0\rangle$, so $|\Delta\vec{r}_{2p}| = \sqrt{2}$

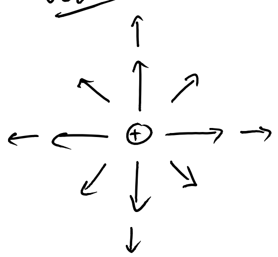
+ $\Delta\hat{r}_{2p} = \left\langle \frac{\Delta x_{2p}}{|\Delta\vec{r}|}, \frac{\Delta y}{|\Delta\vec{r}|}, '' \right\rangle = \left\langle \frac{1}{\sqrt{2}}, \frac{1}{\sqrt{2}}, 0\right\rangle$

Put together $\vec{E}_2(p) = \frac{k(-e)}{2}\left\langle \frac{1}{\sqrt{2}}, \frac{1}{\sqrt{2}}, 0\right\rangle$

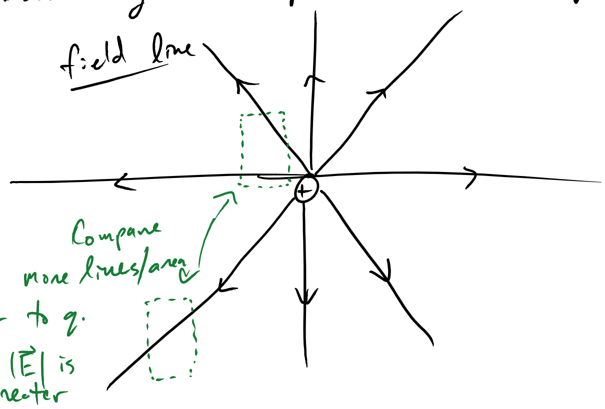
Note that sign of q w/ $\Delta\hat{r}$ gets direction correct.... in $-\hat{x}$ + $-\hat{y}$ dir.

Vector fields vs. field lines .... they both represent same thing.

vector



field line



Compare

+ more lines/area closer to q.

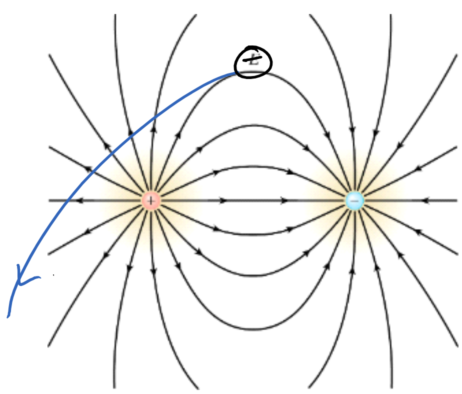
... so $|\vec{E}|$ is greater

* arrow defines direction

* lines per Area (Volume) represent mag.

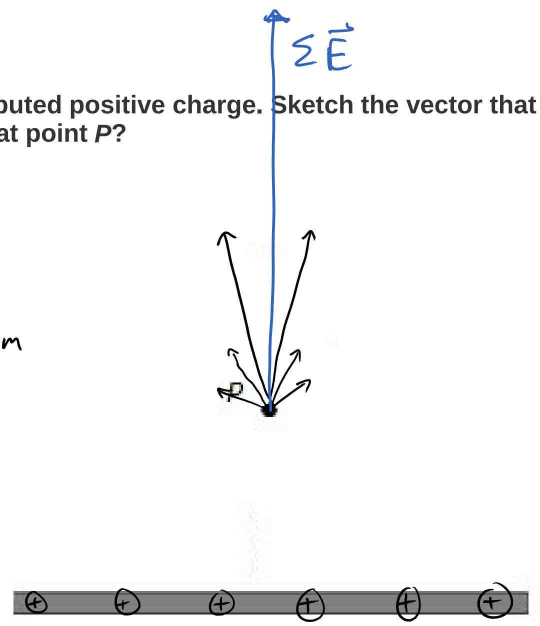
Consider a field line pattern like the one below. Suppose a negatively charged particle is released from rest from a point on one of the field lines near the top of the diagram. After release, the particle moves

1. along the same direction as the field line.
2. along the field line, but in the opposite direction.
3. straight toward the negatively charged particle.
4. straight toward the positively charged particle.
5. along some other trajectory.



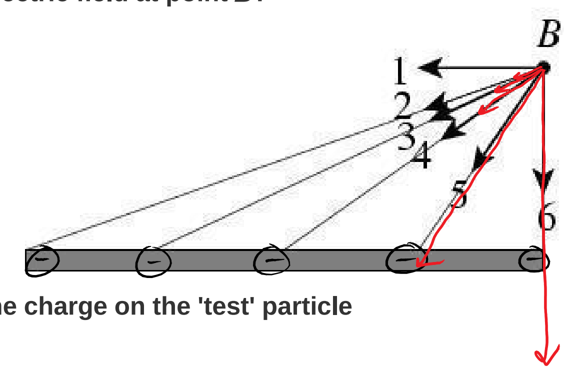
Consider a short rod carrying a uniformly distributed positive charge. Sketch the vector that represents the direction of the net electric field at point *P*?

* near flat plate of q
the E-field is approx uniform



Consider a short rod carrying a uniformly distributed negative charge. Which vector most closely represents the direction of the electric field at point *B*?

1. Vector 1
2. Vector 2
3. Vector 3
4. Vector 4
5. Vector 5
6. Vector 6
7. The answer depends on the sign of the charge on the 'test' particle



Match the charge distribution with the nature of how the electric field changes as a function of distance from the object.

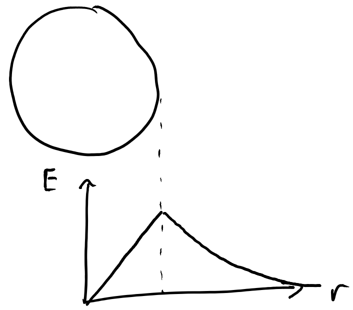
A. point charge
B. infinite line charge
C. infinite sheet of charge
D. inside a uniform spherical distribution of charge

1. increases linearly with r from center
2. independent of r
3. like 1 over r
4. like 1 over r squared

$\boxed{\text{"D"D}}$ $\propto \frac{1}{r^2}$ point particle

$\boxed{1D}$ $\propto \frac{1}{r^1}$ line

$\boxed{2D}$ $\propto \frac{1}{r^0}$ sheet

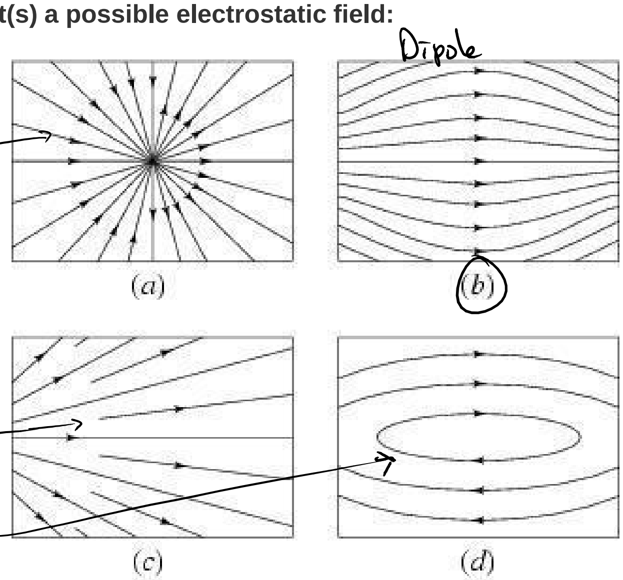


Consider the four field patterns shown. Assuming there are no charges in the regions shown, which of the patterns represent(s) a possible electrostatic field:

1. (*a*)
2. (*b*)
3. (*b*) and (*d*)
4. (*a*) and (*c*)
5. (*b*) and (c)
6. Some other combination
7. None of the above

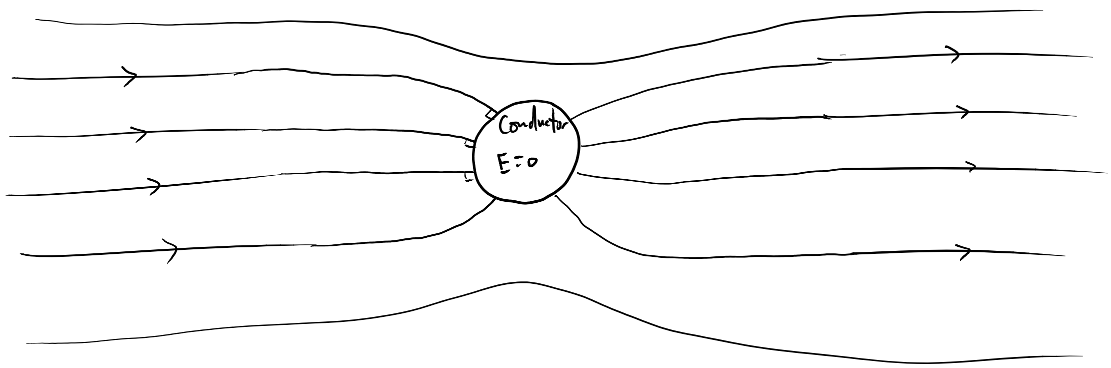
different directions?

field lines start & stop @ charges



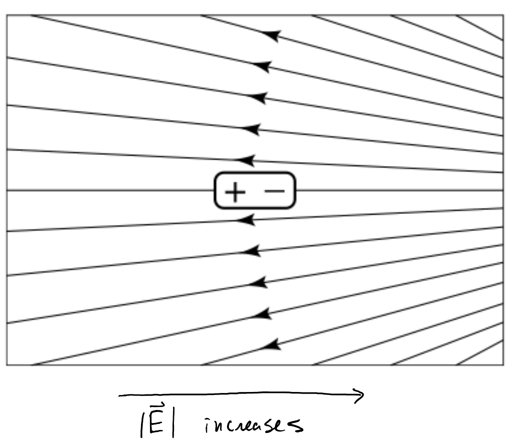
Which of the following statements are true regarding the electric field in or around a conductor.

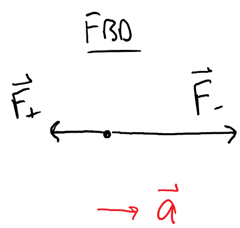
1. The E field is zero inside a conductor
2. The E field is never zero inside a conductor
3. The E field is zero inside a conductor so long as no current flows through the conductor.
4. On the outside surface of a conductor the E field lines are parallel to the surface of the conductor.
5. Outside of a conductor the E field lines are perpendicular to the surface of the conductor.
6. On the outside surface of a conductor the E field lines can take any angle with respect to the conductor.



Consider the electrically neutral dipole in an external field shown below. In which direction is the dipole accelerated?

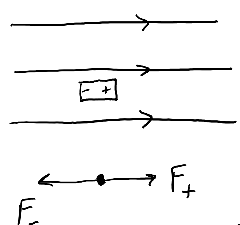
$\vec{F} = q\vec{E}$





Does a neutral object experience a force in an electric field?

1. No
2. Only in a uniform electric field
3. Only in a non-uniform electric field
4. In any electric field because the field polarizes the object



... if E is uniform then $\Sigma\vec{F} = 0$

3. Only in a non-uniform electric field
4. In any electric field because the field polarizes the object

uniform then $\Sigma \vec{F} = 0$

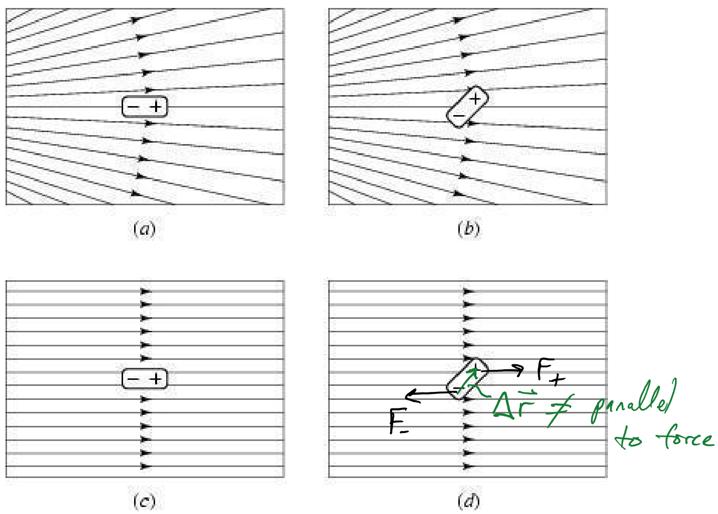
polarizes then field gradient causes net force

An electrically neutral dipole is placed in an external field. In which situation is the net force on the dipole zero but not the net torque?

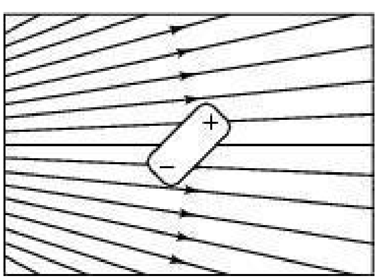
(a) + (b) $\Sigma \vec{F} \neq 0$

(c) $\Sigma \tau = 0$

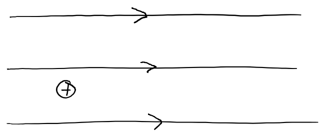
(d) $\Sigma \vec{F} = 0$, $\Sigma \tau \neq 0$



Consider the dipole in the non-uniform field shown below. The vector sum of the electrostatic forces exerted on the dipole points in which direction?



* $\Sigma \vec{F}$ to left due to non-uniform field
  + a_{com} to left.
* Wobble, b/c torque direction changes as it goes through being horizontal



Which of the following quantities are constant for a charged particle only under the influence of a uniform electric field?

1. **Position**
2. **Velocity**
3. **Acceleration**
4. **Net Force**
5. **Work per time**
6. **Work per distance**

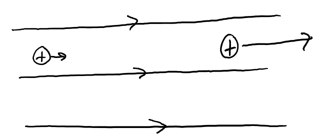
$\Sigma\vec{F} = \vec{F}^E = q\vec{E} = m\vec{a}$

if $\vec{E} = \text{const.}$ then $\Sigma\vec{F}, \vec{a}$ are const.

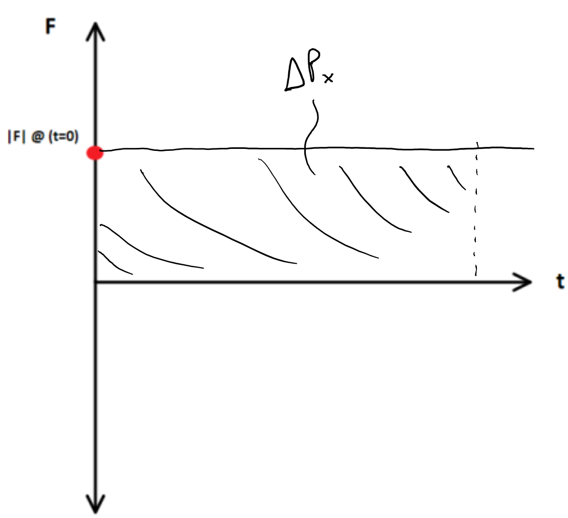
if $\Sigma F = \text{const}$

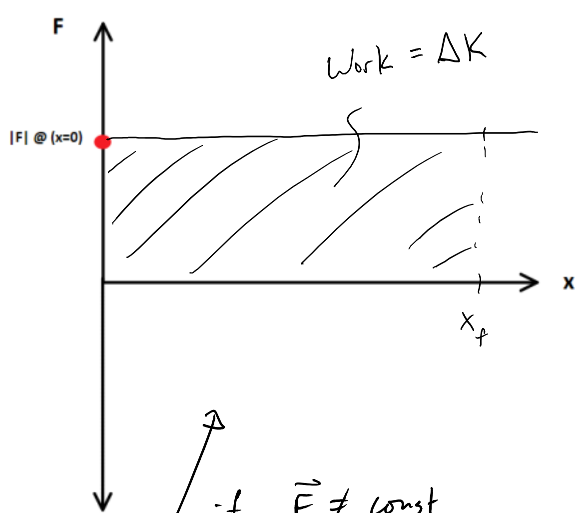
$W = \vec{F}\cdot\Delta\vec{r} = |\vec{F}||\Delta\vec{r}|\cos\theta$

$\frac{W}{|\Delta\vec{r}|} = |\vec{F}|\cos\theta$



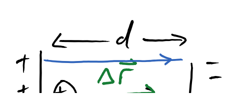
An electron is traveling in the positive x direction when it enters a uniform electric field that is parallel to the direction of its motion. The field speeds up the electron. Sketch the force as a function of time and position, starting with the moment the electron entered the field.





if $\vec{F} \neq$ const b/c $\vec{E} \neq$ Const you must use area

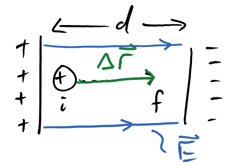
Determine whether each of the following are a vector or scalar quantity.



Determine whether each of the following are a vector or scalar quantity.

A. change in potential energy S
B. electric field V
C. work S
D. kinetic energy S
E. electric force V
F. total energy S

work + energy are scalar



if F = const $\quad W = \vec{F}\cdot\Delta\vec{r} = |\vec{F}||\Delta\vec{r}|\cos\theta$

$\Delta\vec{r}$ $\vec{F}$

recall Work-Energy $\quad W = \Delta K$, $\quad |q||\vec{E}|\, d\, \cancel{\cos\theta}^{\,1} = \frac{1}{2}m(v_f^2 - v_i^2)$

* use work to find speeds

... but Electric force is Conservative ... work only depends on initial + final locations + not path

so define Potential Energy + $W_c = -\Delta U$

Electric Potential

Define $\quad V \equiv \dfrac{U}{q_0}$

measured In Volts

Electric Potential Energy

$U = q_0 V$

some set of q's make an electric potential field (EP)

place a test charge q_0 in (EP) + get

EPE Between the two

change in P.E.

$$\boxed{\Delta U = q_0 \Delta V}$$

Which vector could represent the electric potential at point P, some distance from a charged rod?

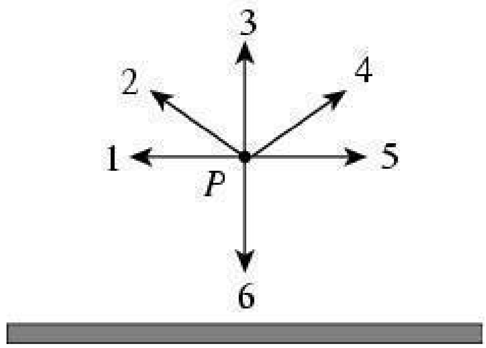
1. 1
2. 2
3. 3
4. 4
5. 5
6. 6
7. None of the above

$U = q\,V$

charge (scalar)

EPE (scalar)

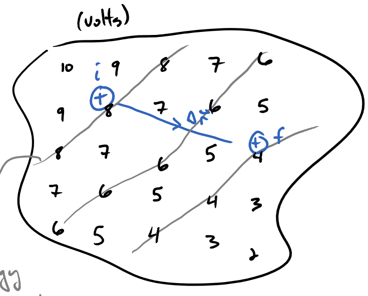
EP (scalar)



Scalar Field : map w/ a number at all points in space.

ex.

(volts)



equipotential lines

by analogy same as topo lines.

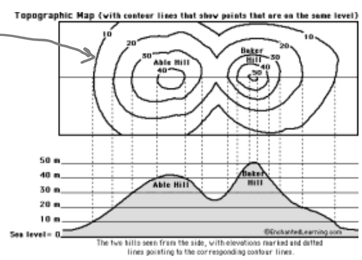
$V_i = 8\,V$, $V_f = 4\,V$

$\Delta V = -4\,V$

$+\ \Delta U^E = q_0 \Delta V = -\Delta KE$

if no other forces

Compare to topo map



scalar potential field map.

to get $\Delta U^g = mg\,\underbrace{\Delta h}$

get from topo map.

Field Philosophy

* Fields from q's exist whether or not a test q_0 is placed in the field (Electric + Potential)

* charges alter the space around them

* fields do not require interaction to be quanified.

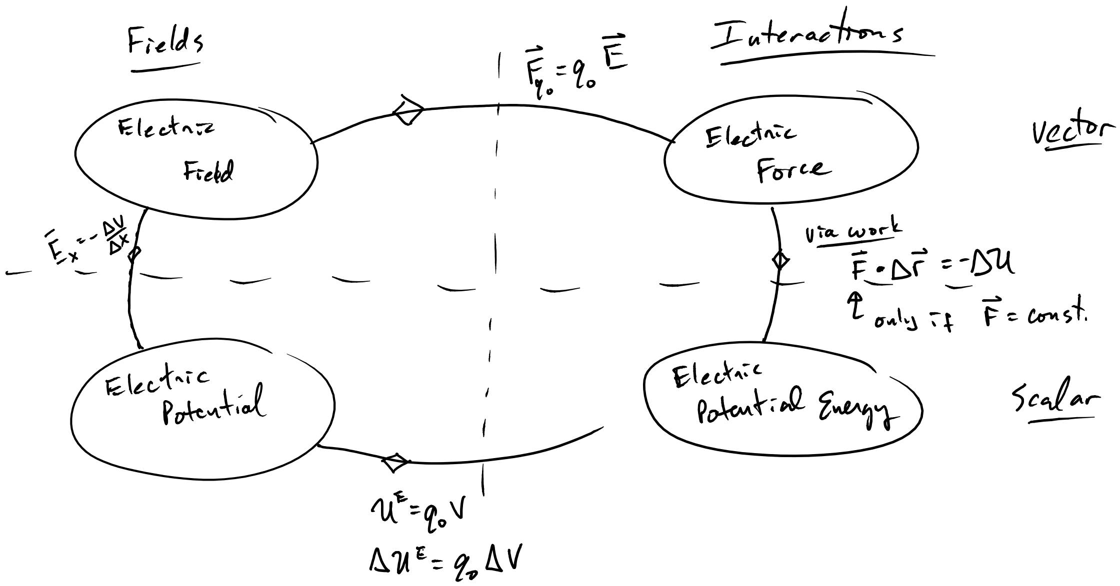
A positively charged particle is moved from *A* to *B* and it is found that the potential difference between *A* and *B*, V_{AB}, is positive. If, instead, we move a negative particle from *A* to *B*, we obtain a potential difference V_{AB}

1. of the same sign.

2. of the opposite sign.

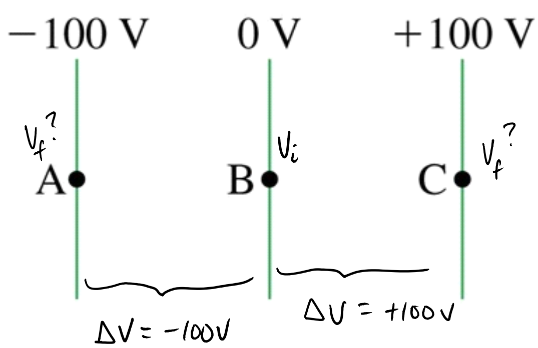
Field is independent of the charge that moves through it.

Big Picture



A proton is released from rest at point B, where the potential is 0 V. Afterward, the proton

1. **moves toward A with a steady speed**
2. **moves toward A with an increasing speed**
3. **moves toward C with a steady speed**
4. **moves toward C with an increasing speed**
5. **remains at rest at B**



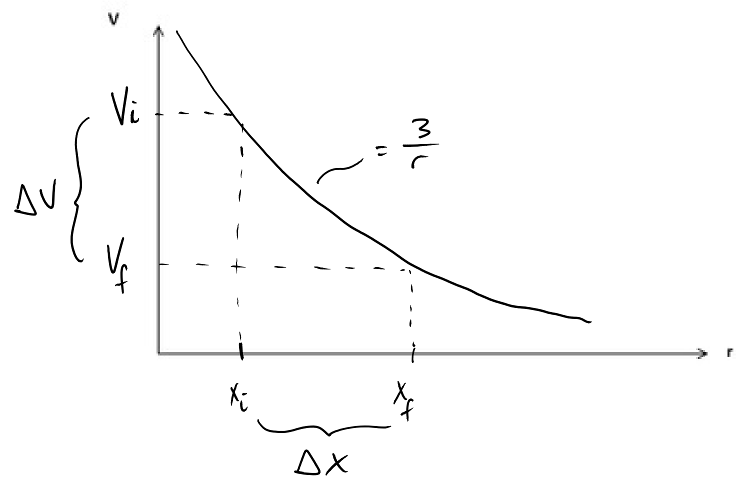
$\Delta U = q \Delta V = -\Delta K$

it will move in direction of increasing K.E.

$\Delta U_{BA} (-)$, so $\Delta K_{BA} (+)$

Positive charges feel force down electric potentials (V) which is the direction of decreased U^E.

The electric potential falls off like 1/r in a region in space due to some charge distribution a distance r away. Sketch the electric potential (V) as a function of r.



If V(x) = 3/x, where x is in meters and V is in Joules per Coulomb, what is the electric potential difference between x_i = 1 m, and x_f = 3 m?

$V_i = \frac{3}{1} V$, $V_f = \frac{3}{3} V$ $\Rightarrow$ $\Delta EP \equiv \Delta V = (1-3)V = -2V$

Does a positive charge speed up or slow down if it moves from x_i = 1 m to x_f = 3 m? Assume the charge is influenced by no other forces.

1. **Speed up**
2. **Slow down**
3. **Not enough information**

* (+) q's speed up as $V \downarrow$

w/ $\sum E_i + \cancel{W_{nc}}^{0} = \sum E_f \Rightarrow \Delta U = -\Delta K$

$\underbrace{q \Delta V}_{(-)} = - \underbrace{\frac{1}{2} m (v_f^2 - v_i^2)}_{(+)}$ ---- so $\underline{v_f > v_i}$

* if q (−), slows down as $V \downarrow$

or neg q's feel force up electric potentials

b/c that decreases the U^E

A 2 kg sphere that is charged up to -1 C, moves from a region where the electric potential is 4 V to a point where it is 14 V. If the sphere was moving at an initial speed of 10 m/s, what is its final speed?

1. 9.5 m/s
2. 10.5 m/s
3. 14.0 m/s
4. 100 m/s
5. 110 m/s

$U = qV$, so $\Delta U = q\Delta V$

Energy: $\Sigma E_i + W_{nc} = \Sigma E_f \Rightarrow K_i + U_i + \cancel{W_{nc}}^{0} = K_f + U_f$

$$-\frac{1}{2}m(v_f^2 - v_i^2) = \Delta U = q\Delta V$$

$$v_f^2 = v_i^2 - \frac{2q}{m}\Delta V$$

$$= 10^2 + 10$$

$$v_f = \sqrt{110}\ m/s \approx 10.5\ m/s$$

An electron is accelerated through a 150,000 V potential difference. How much kinetic energy is gained during this process?

1. 150,000 J
2. 0.15 MeV
3. 42 kg m/s
4. 1.5 eV
5. 300,000 eV
6. 150,000 eV

$\Delta U = q\Delta V = -\Delta K \Rightarrow \Delta K = -(-e)150{,}000V = +150{,}000eV$

Non-SI Unit called electron-volts

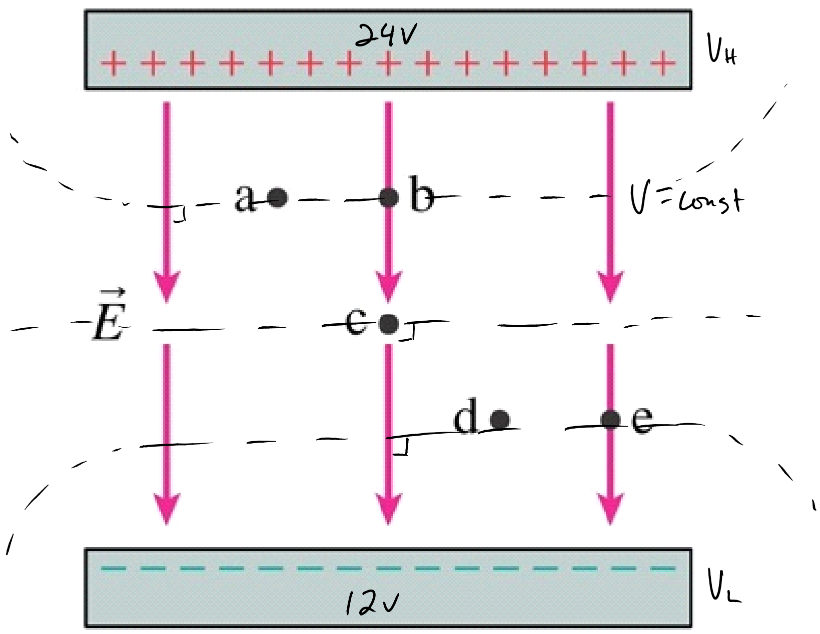
If it began from rest, what speed, in m/s, has it acquired? (m_e = 9.11 x 10^{-31} kg)

$1eV = 1.6 \times 10^{-19} J$, $\Delta K = \frac{150000eV \mid 1.6 \times 10^{-19} J}{\mid 1eV}$

$\Delta K = K_f - \cancel{K_i}^{0} = \frac{1}{2}mv^2$

$v = 2.3 \times 10^8\ m/s$ ← so fast relativistic effects are present

Rank in order, from largest to smallest, the potentials Va to Ve at the points a to e.



$V_A = V_B > V_C > V_D = V_E$

Note: * $\vec{E}$ ⊥ to equipotentials

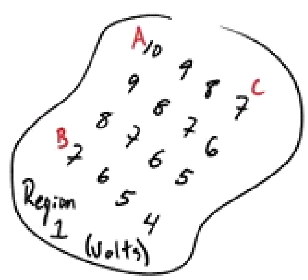
* V increases towards ⊕ q

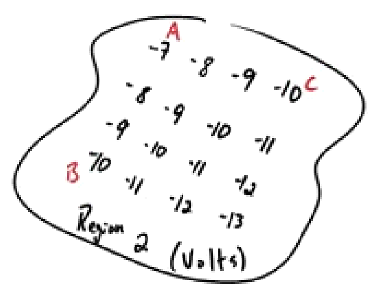
Three students are discussing the following electric potential maps of two separate regions of space. Which student do you agree with most?

1. **"I think a proton that moves from point A to B in region 1 will gain more kinetic energy than a region 2, eh"**
2. **"Cool story bro, but they are opposite potential energy gains, so one will gain kinetic energy while the other loses it"**
3. **"What huh? I don't think there is any difference between A to B in either region, or A to C for that matter foo"**

$\boxed{1}$ $\Delta V_{AB} = -3\text{ V} = \Delta V_{AC}$

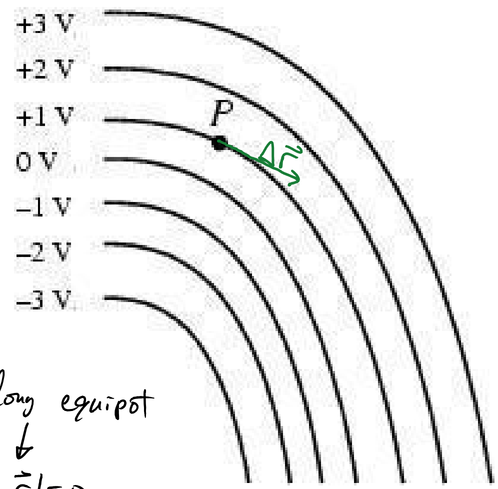
$\boxed{2}$ $\Delta V_{AB} = -10 - (-7) = -3\text{V} = \Delta V_{AC}$





A small positively charged particle is placed at point *P* in the electric field shown below. Which way should the particle be moved if no work is to be done on it as it moves?

1. **Along the 1-V equipotential**
2. **Perpendicular to the equipotential lines**
3. **You can't avoid doing work, unless you move the charge along the 0-V equipotential line**



$W = -\Delta U = -q\Delta V$

if $W=0$ ... $\Delta V = 0$

Also $W = |\vec{F}||\Delta\vec{r}|\cos\theta$

along equipot

if $W=0$ than either $|\vec{F}|=0$, $|\Delta\vec{r}|=0$

or $\cos\theta = 0$ → which means $\theta = 90°$

... so $\vec{F} \perp$ to equipotentials

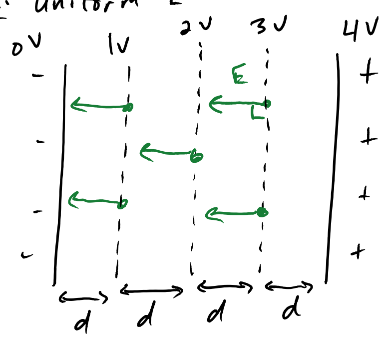
E.P. to E-field

* use equipotentials to find $\vec{E}$

Recall $E_x = -\dfrac{\Delta V}{\Delta x} \Rightarrow \vec{E} = -\left\langle \dfrac{\Delta V}{\Delta x}, \dfrac{\Delta V}{\Delta y}, \dfrac{\Delta V}{\Delta z} \right\rangle$ gradient "3D" slope.

* $|E_x| = \dfrac{|\Delta V|}{|\Delta x|}$
  * if ΔV = const between equipotentials then $|\Delta r| \downarrow$, $|E| \uparrow$
* $\vec{E}$ is $\perp$ equipotential
* $\vec{E}$ points towards decreasing V

ex. Uniform E



A solid spherical conductor is given a net nonzero charge. The electrostatic potential of the conductor is

1. largest at the center.
2. largest on the surface.
3. largest somewhere between center and surface.
4. constant throughout the volume.

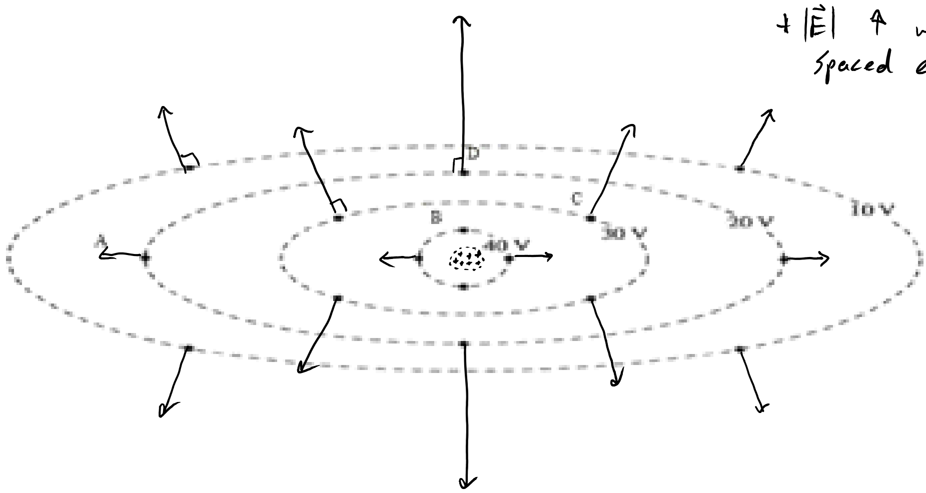
$$\bar{E}_x = \frac{\Delta V}{\Delta x}$$

w/ $|\vec{E}| = 0$ inside conductor

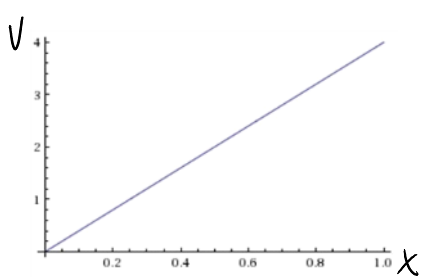
ΔV must also be zero

Sketch the electric field vectors at the points on this equipotential map.

* E ⊥ Const. V
* $|\vec{E}|$ ↑ w/ closer spaced equipotentials



The plot shows the electric potential as a function of x for some distribution of charge. Which one of the following statements concerning the electric field associated with this potential is correct?

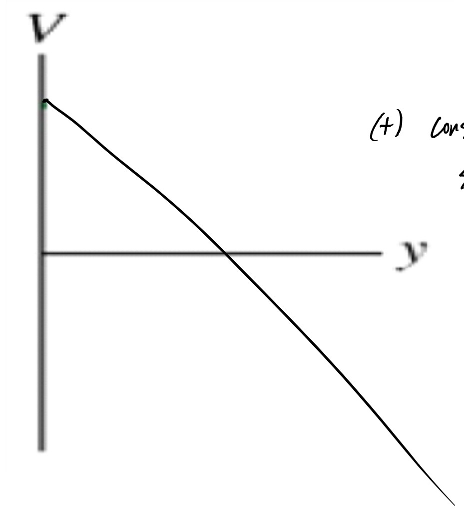


1. increases linearly and points in the positive x-direction.
2. increases linearly and points in the negative x-direction.
3. is uniform in the x-direction and points in the positive x-direction.
4. is uniform in the x-direction and points in the negative x-direction.
5. has zero x component.

$$E_x = -\frac{\Delta V}{\Delta X}$$

Constant (+) slope

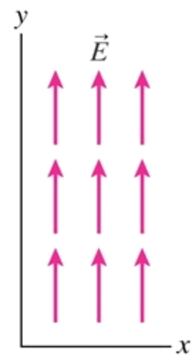
Sketch the voltage as a function of *y* for the electric field shown.



$E_y = -\frac{\Delta V_y}{\Delta y}$

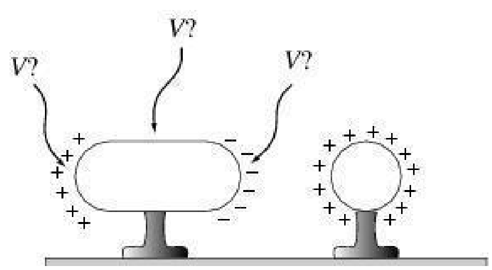
(+) constant.

so slope must be negative const



A charged object is brought near an uncharged metal object. Negative charges accumulate on the side of the uncharged object nearest to the charged sphere, positive charges on the opposite side. On the uncharged metal object, the potential is

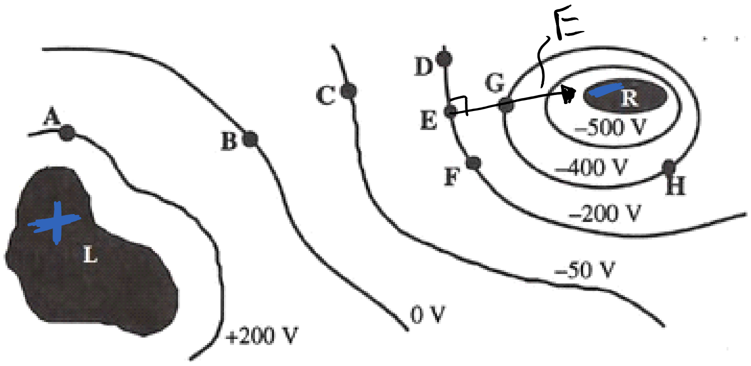
1. **largest on the positive side.**
2. **largest on the negative side.**
3. **largest in the middle.**
4. **the same everywhere.**



$E_x = -\frac{\Delta V}{\Delta x}$

$E_x = 0$, so $\Delta V = 0$

A set of equipotential surfaces has been mapped out for a charge distribution on two conductors, L and R.



Which conductor is positively charged?

Voltage increases towards (+)

so L

What is the magnitude of the potential difference between points A and H?

$|V_A - V_H| = |200 - (-400)| = 600\,V$

At which point would an electron have the greatest potential energy?

$U = qV$

(−)

H

What is the direction of the electric field at point E?

* towards decreasing V
* $\perp$ to equipotentials

towards G

At which point would a charged particle feel the strongest magnitude force?

where $|\vec{E}|$ greatest

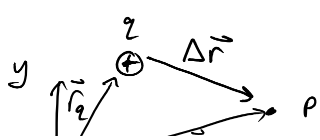
so where equipotentials are most closely spaced

H

Electric Potential from a point charge

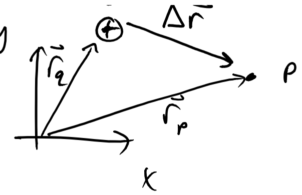
* Define zero of V @ $r = \infty$

$$V(P) = \frac{kq}{|\Delta \vec{r}|}$$



$$V(p) = \frac{kq}{|\Delta \vec{r}|}$$

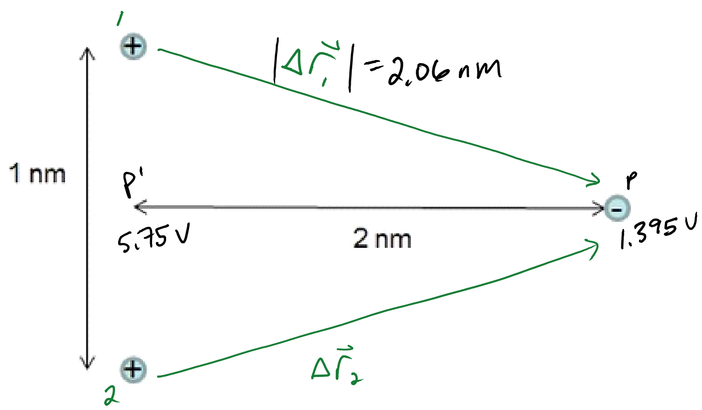
distance between q + point p



How about from multiple q's

$$V_{tot}(p) = \sum_i V_i(p) = V_1(p) + V_2(p) + \dots$$

An electron is 2 nm away from a line that connects two protons that are 1 nm apart. The electron lies along the perpendicular bisector to the line between the protons. (e = 1.60 x 10^{-19} C, k = 8.99 x 10^{9} N·m^2/C^2)



What is the electric potential at the location of the electron from the protons?

$$V(p) = V_1(p) + V_2(p) = 2V_1(p)$$

same q + dist.

$$= \frac{2k(+e)}{2.06 \times 10^{-9}\,m} = 1.395\ V$$

What is the electric potential energy of the electron interacting with the protons?

$$U = qV \Rightarrow U_e = eV = -1.395\,eV$$
$$= -2.23 \times 10^{-19}\ J$$

Which point does the electron have a higher electric potential energy, between the protons or 2 nm away along the perpendicular bisector?

1. **Between the protons**
2. **2 nm away along the bisector**
3. **They are the same**

$V \uparrow$ towards $(+)$ q's

w/ $U = -eV$, $U_e \downarrow$ " " " "

What is the magnitude of the electric potential energy difference, of the electron interacting with the protons, between the location 2 nm away on the bisector vs. directly between the two protons?

$$V_{p'} = \frac{2ke}{0.5 \times 10^{-9}\,m} = 5.754\ V$$

so $|\Delta U_{p'p}| = |e(V_{p'} - V_p)|$

$$= 4.359\ eV$$

$$= 6.97 \times 10^{-19}\ J$$

If an electron was to be fired along the perpendicular bisector away from the protons, what initial speed would it need to just momentarily come to rest at a distance 2 nm away from the line adjoining the two protons? m_e = 9.11x10^{-31} kg

$$\sum E_i + \cancel{W_{nc}}^{\,0} = \sum E_f \quad \Rightarrow \quad K_i + U_i = \cancel{K_f}^{\,0} + U_f$$

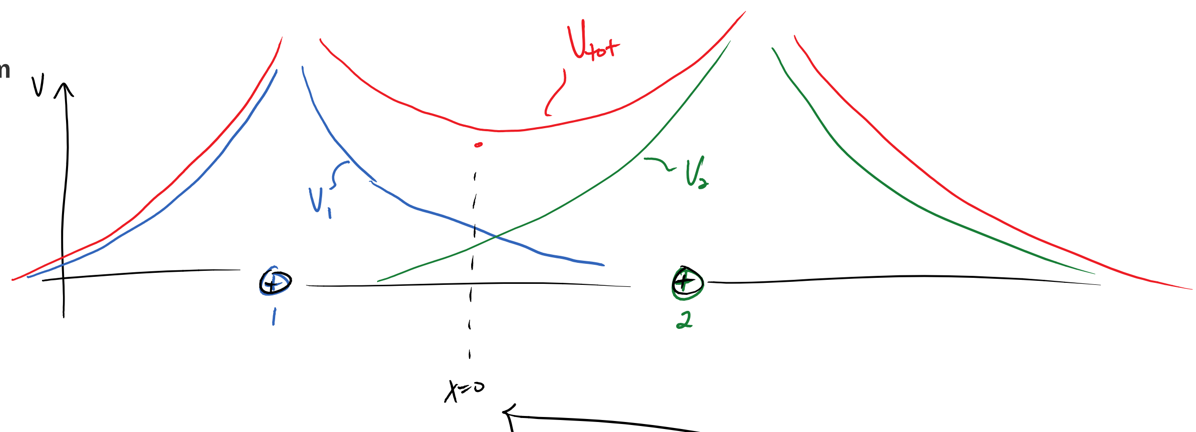
$$\frac{1}{2} m v_i^2 = -e\underbrace{(V_f - V_i)}_{6.97\times10^{-19}\,J}$$

$$v_i = 1.24\times10^{6}\ m/s$$

Two positive charges are located on the x-axis at a location x = 1 nm and x = -1 nm. What location(s) is the electric potential from those charges zero?

1. x = 0 nm
2. x = - 2 nm
3. x = ±∞
4. x = 4 nm

$V = \frac{kq}{r}$



Can a region of space have zero electric field and a non-zero electric potential?

1. Yes
2. No

$$E_x = -\frac{\Delta V}{\Delta x}$$ if slope of $V(x) = 0$ but not $V(x)$

look @ $x = 0$

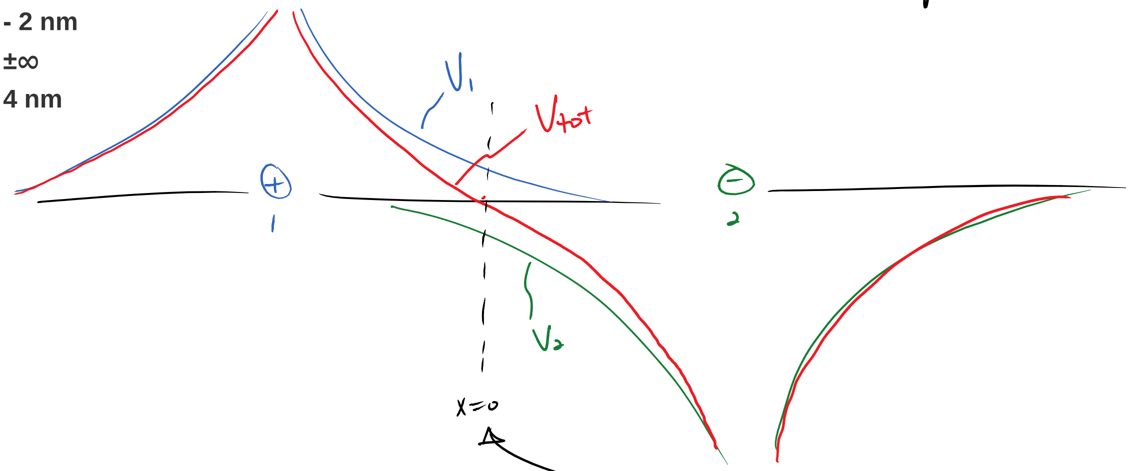
$V_{tot} > 0$

but $\frac{\Delta V}{dx} = 0$

A negative charge is located on the x-axis at a location x = -1 nm, while a positive is at x = +1 nm. What location(s) is the electric potential from those charges zero?

$V = \frac{kq}{r}$

1. x = 0 nm
2. x = - 2 nm
3. x = ±∞
4. x = 4 nm



Can a region of space have a non-zero electric field and zero electric potential?

1. Yes
2. No

$E_x = -\frac{\Delta V}{\Delta x}$ ... if slope of $V(x) \neq 0$

but $V(x) = 0$

look @ $x=0$

$V_{tot} = 0$

but $\frac{\Delta V}{\Delta x} \neq 0$