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The Greatest Science Communication Competition...Ever!

PHAS Undergrad Slammers will explain complex science topics WITHOUT Academic slides or language....in 5 minutes! Can they do it????

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Tuesday March 12th, 5:30-7:30pm in HENN 200

Email: outreach@phas.ubc.ca

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Science Slam

PHYSICS ASTRONOMY

UBC

Q: What do you think about the midterm?

A. Too easy
B. Easy
C. About right
D. Difficult
E. Too difficult

Lecture 21.

Electric potential.

Finding V from known $\vec{E}$.

- Potential energy of a pair of point charges separated by a distance r is (assuming $U = 0$ when they are infinitely far apart):

$$U = \frac{k\,Q_1 Q_2}{r}$$

V_{Q_2}

- We can define the electric potential due to Q_1 at distance r from it as

$$V = \frac{U}{Q_2} = \frac{k\,Q_1}{r}$$

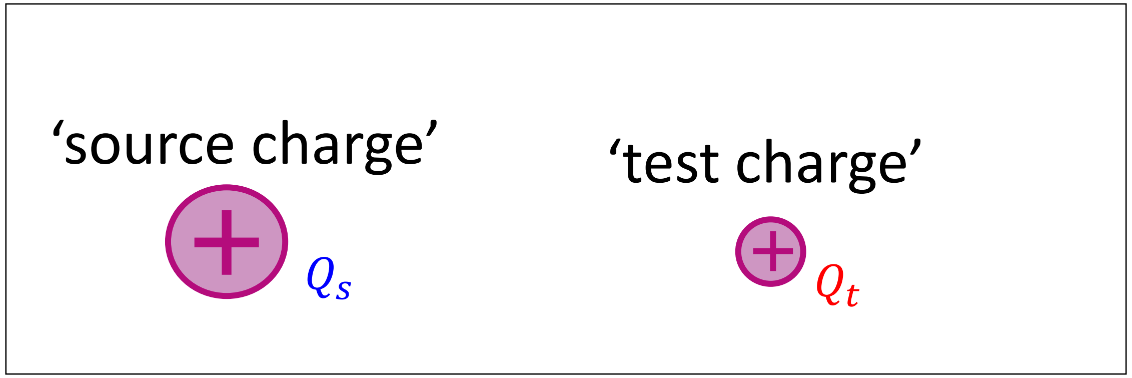
Hence, electric potential simply is electric potential energy per unit charge.

Electric force and electric field:

$$\vec{F} = K\,\frac{Q_t Q_s \hat{r}}{r^2} \equiv Q_t \vec{E}$$

Force between two charges

Field generated by Q_s



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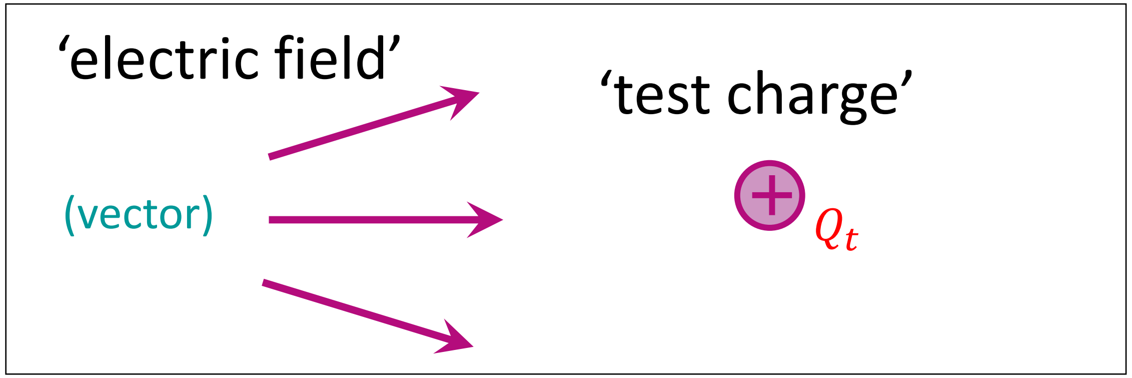
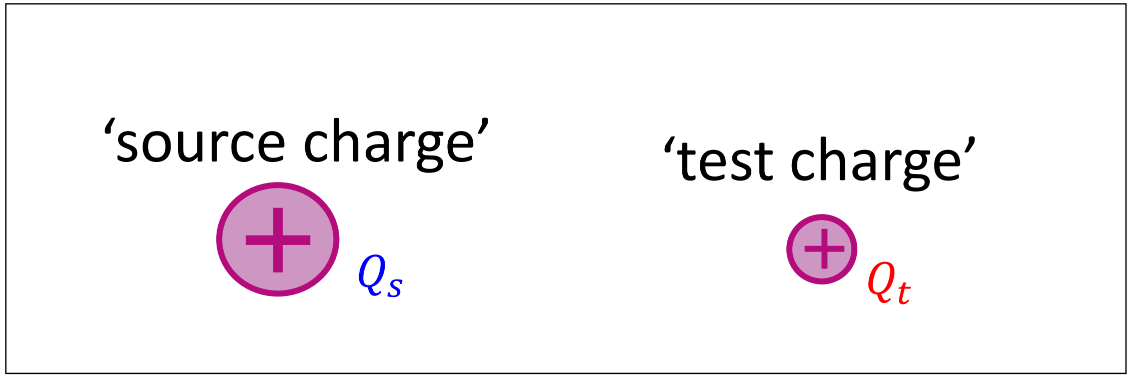


Electric potential energy and electric potential:

$$\Delta U = K\,\frac{Q_t Q_s}{r} \equiv Q_t \Delta V$$

Potential energy (source charge + test)

Potential generated by Q_s



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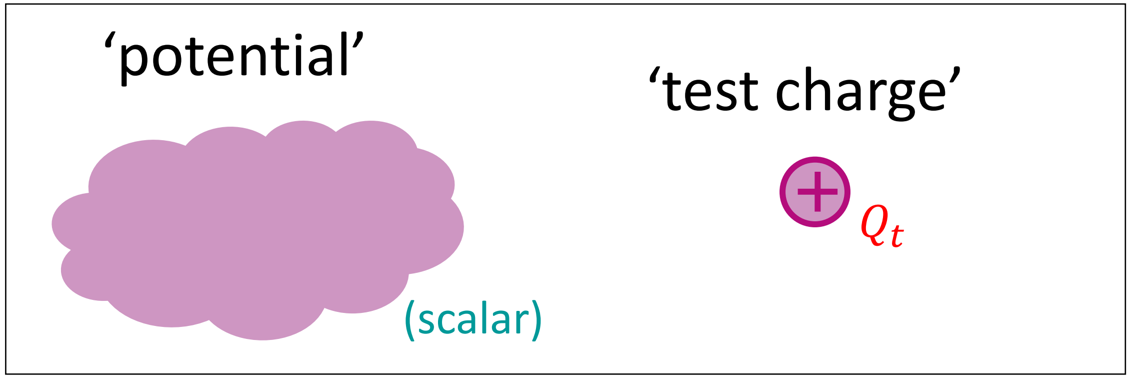


Electric potential: Motivation

- When we using the concept of electric potential (V), we are doing the same trick that we did when we have been introducing electric field;

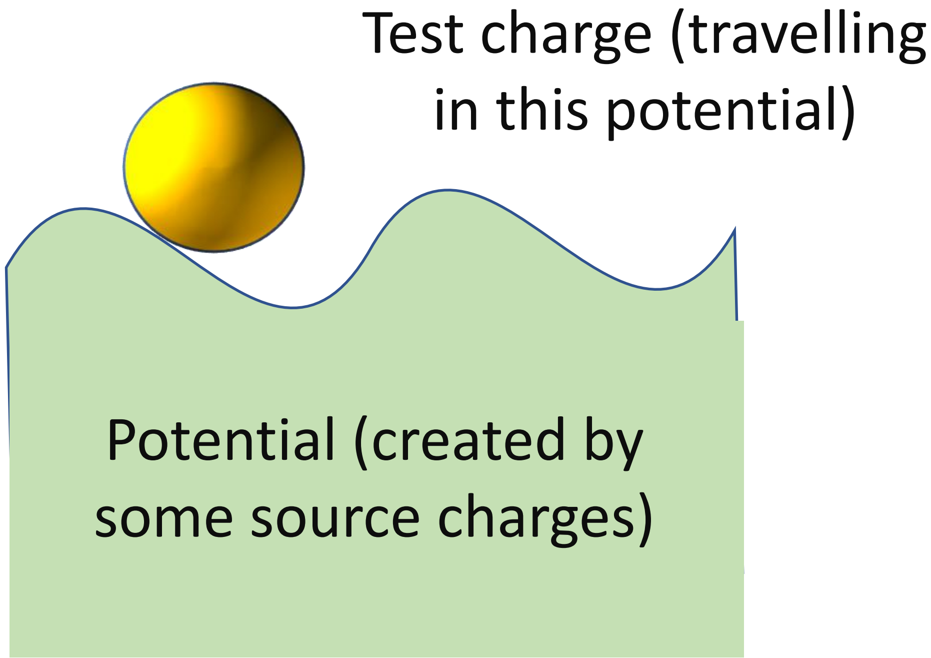
- Namely, we mentally split the Universe of electric charges into two distinct communities: one "community" creates electric field ("source charges"), the other "community" is acted by it ("test charges").

- Hence, we will be dealing with two types of problems (as well as we did with E-field):

    - ➢ There are such-and-such source charges. Which electric potential do they create?

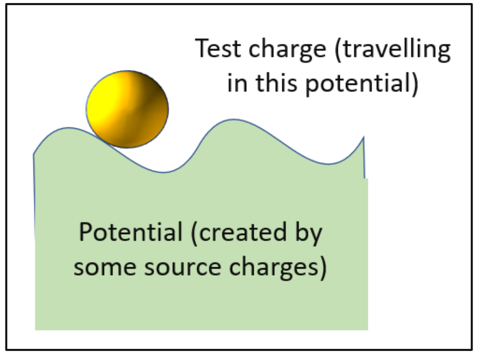
    - ➢ There is such-and-such electric potential (created by some source charges that we know about only due to the electric potential that they create). A test charge is placed in this potential. What will happen to it?

Electric potential: Visualization tool



- Electric potential for charged particles is similar to a landscape for hikers. However, there is an important difference between the two: hikers are all alike (kind of), while charged particles can be charged positively or negatively.
- The behavior of a (test) charge in an electric potential depends on the sign of that charge.

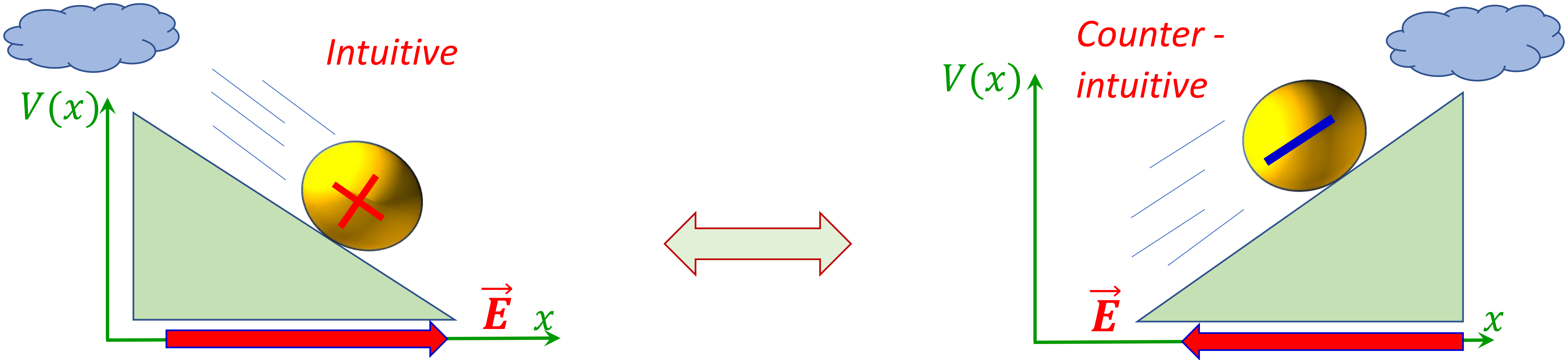
Electric potential: Visualization tool



- You can imagine potential as a landscape in which a charge travels.
- (!) Very soon we will learn that this “landscape” always has a slope in the direction of electric field!
- The slope of $V(x)$ determines what test charges do when placed in the electric potential:

- Positive charge:
  - downhill = accelerates = loses U_e
  - uphill = slows down = acquires U_e

- Negative charge:
  - uphill = accelerates = loses U_e
  - downhill = slows down = acquires U_e



Electric potential created by a point charge

Sign of the source charge(s) determines the sign of the potential:

$$U = \frac{K\, q_1^{(\pm)} q_2^{(\pm)}}{r}$$

$$V = \frac{U}{q_2^{(\pm)}} = \frac{K q_1^{(\pm)}}{r}$$

$$(q_1^{(\pm)} = q_{\text{source}})$$

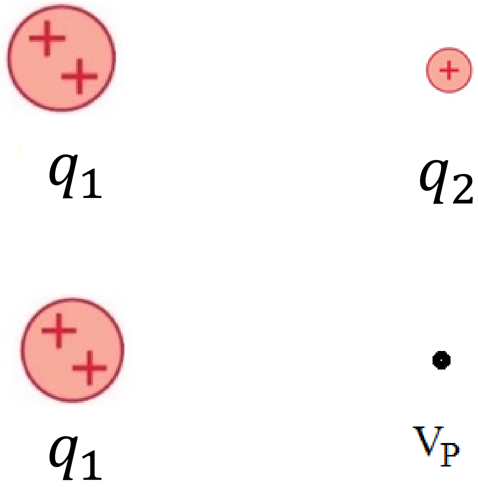
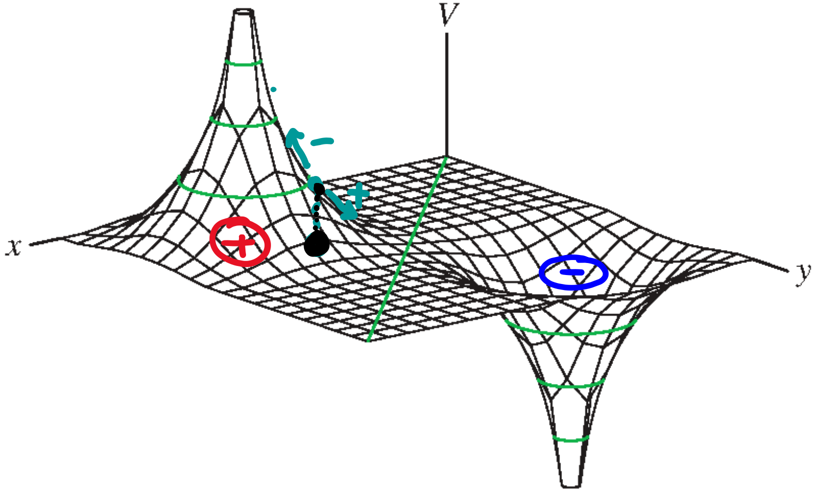


FIGURE 25.28 The electric potential of an electric dipole.

(b) Elevation graph



"Hills and craters"

Note: in this plot the physical space is two-dimensional: (x, y). The z-axis shows the magnitude of the potential as function of x and y coordinates of the source charges: $V(x, y)$.

Electric potential created by a collection of point charges

Q: What is the potential at point P?

A. 0 V

B. 50 V

C. 80 V

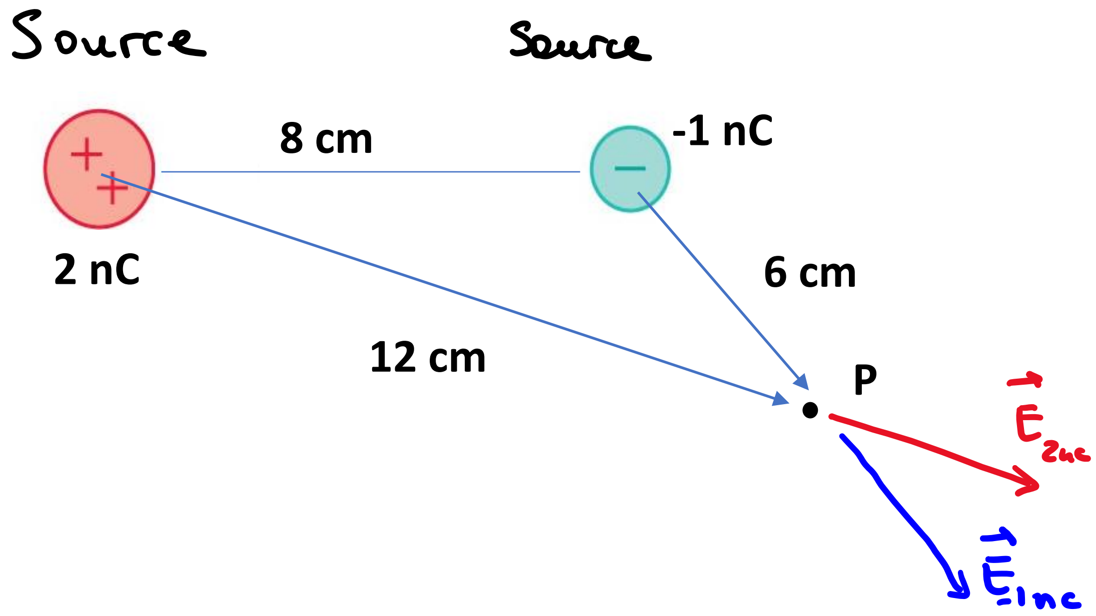
D. -50V

E. -80V

$$V_q = \frac{kq_{\pm}}{r}$$

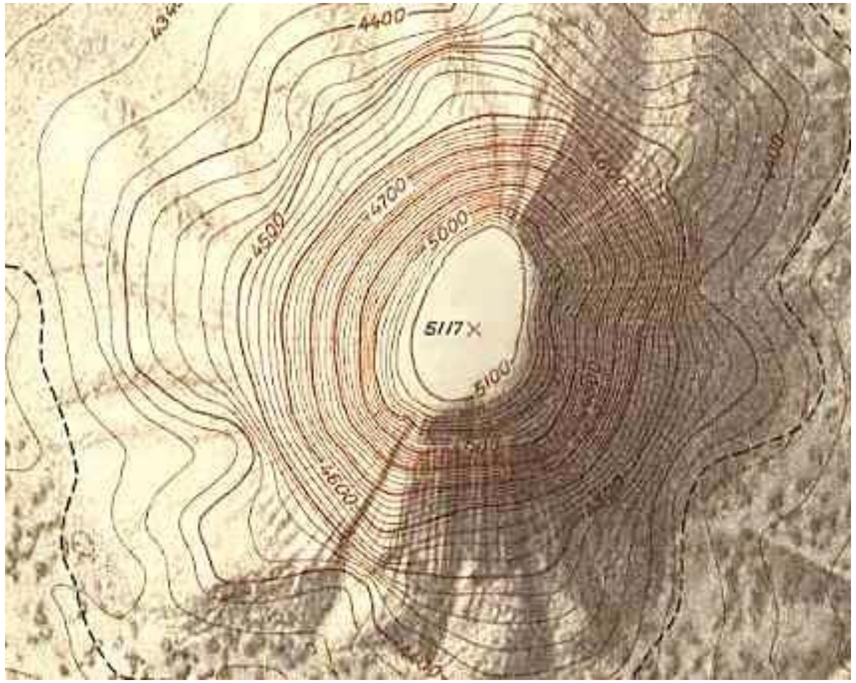
$$V_p = V_{2nC} + V_{-1nC} =$$

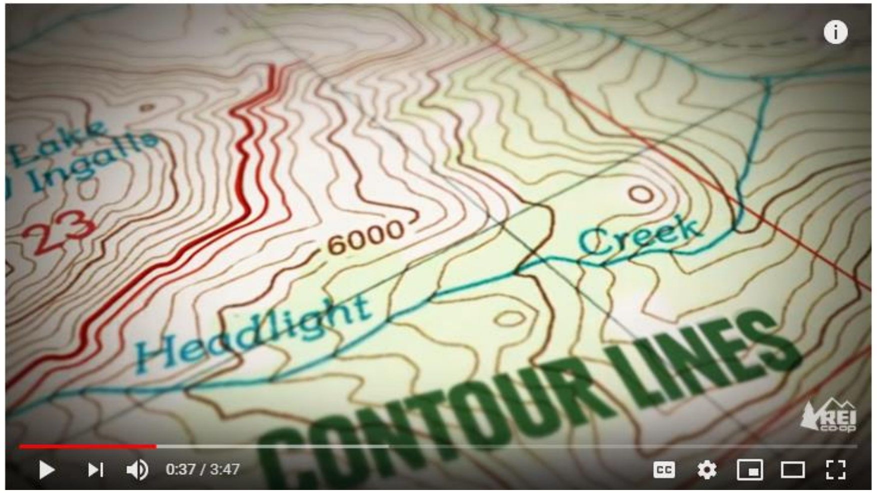
$$= \frac{k(2nC)}{12\text{ cm}} + \frac{k(-1nC)}{6\text{ cm}} = 0$$



Q: Mentally compare this calculation with the calculation you would have to do to find the electric field at point P. Which is easier?

Do you know what a topographic map is?

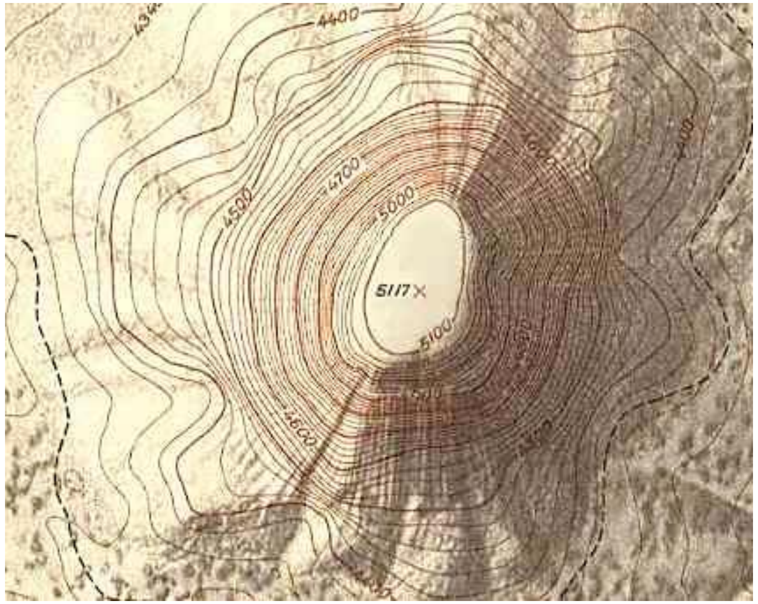


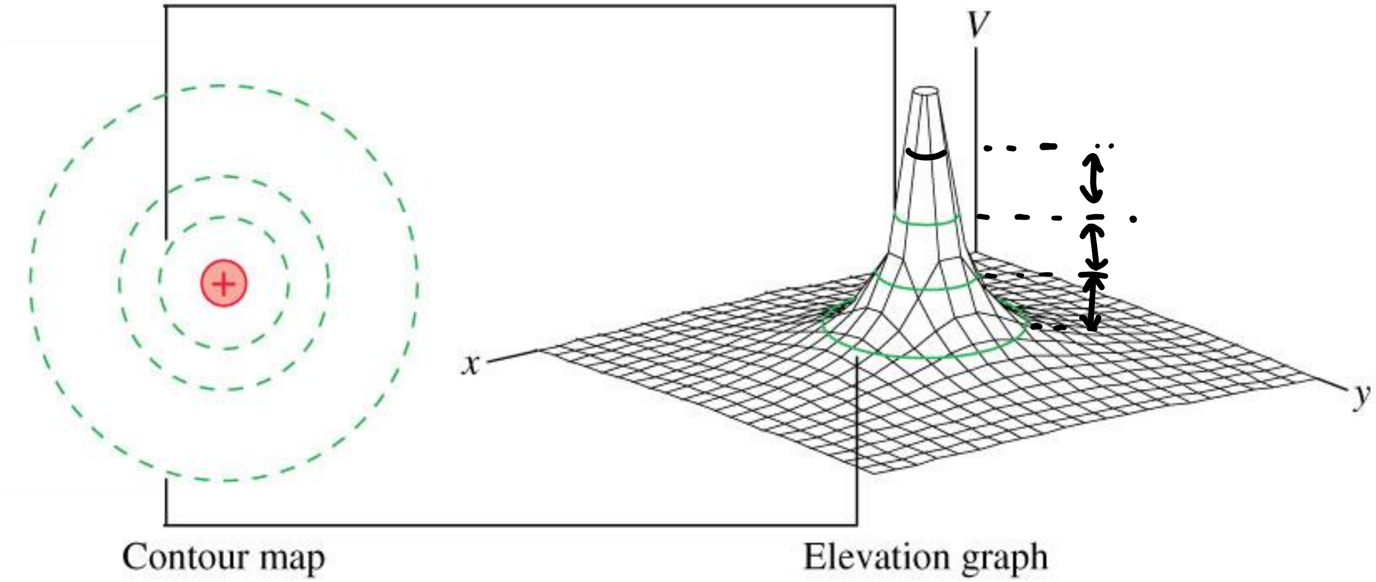


Contour lines on topographical maps connect points with the same elevation

Topo maps: https://www.youtube.com/watch?v=CoVcRxza8nI

(equipotential = lines of equivalent potential)





Contour lines on topographical maps connect points with the same elevation

Equipotential lines show profiles along which the potential does not change

Five rules for everybody who draws equipotential lines or surfaces

- Equipotential lines are drawn with one and the same “step”: same potential drop between any pair of two adjacent lines
- Stronger variation of the potential (steeper slope) ↔ denser equipotential lines
- Hills correspond to positive source charges, craters – to negative source charges.

- They never intersect
- Field lines always intersect equipotential lines perpendicularly and point “downhill” (in the direction of decreasing potential)

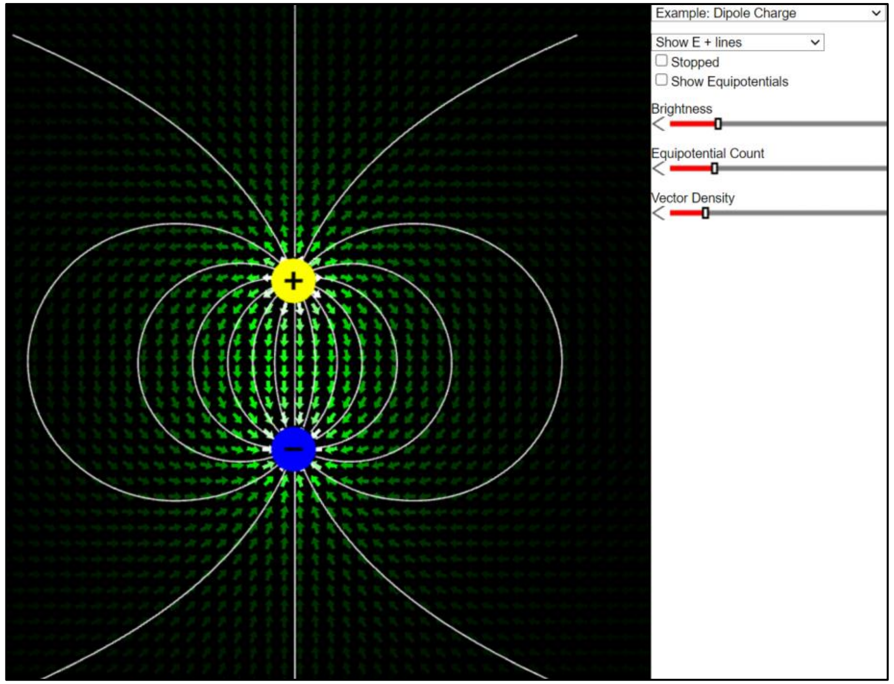
$\vec{E}$

Q: Draw equipotential lines for:

a) parallel plate capacitor,

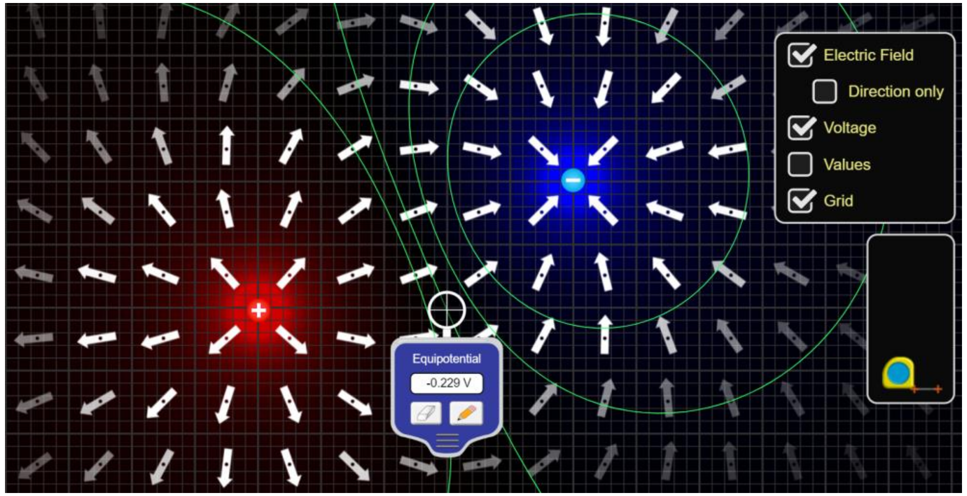
b) point charge,

c) dipole.



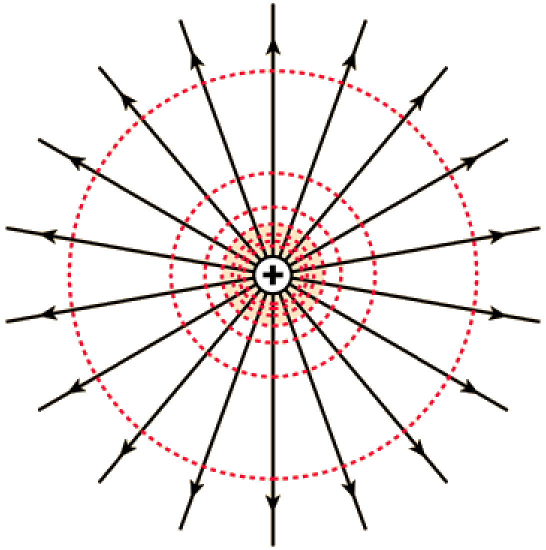
http://www.falstad.com/emstatic/

- Equipotential lines are drawn with one and the same "step": same potential drop between any pair of two adjacent lines
- Stronger variation of the potential (steeper slope) $\leftrightarrow$ denser equipotential lines
- Hills correspond to positive source charges, craters – to negative source charges.
- They never intersect.
- Field lines always intersect equipotential lines perpendicularly

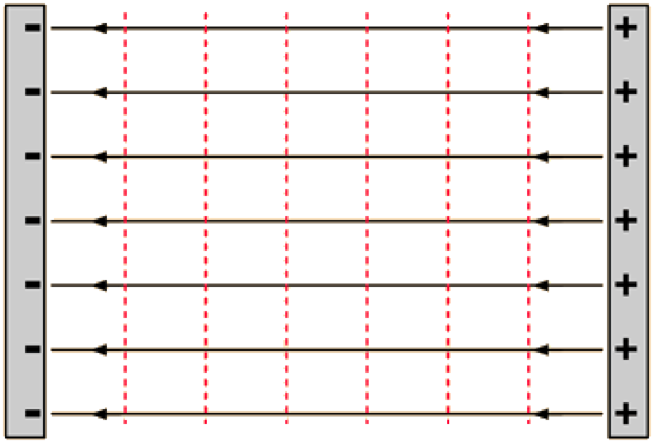


https://phet.colorado.edu/en/simulations/charges-and-fields

Answer:

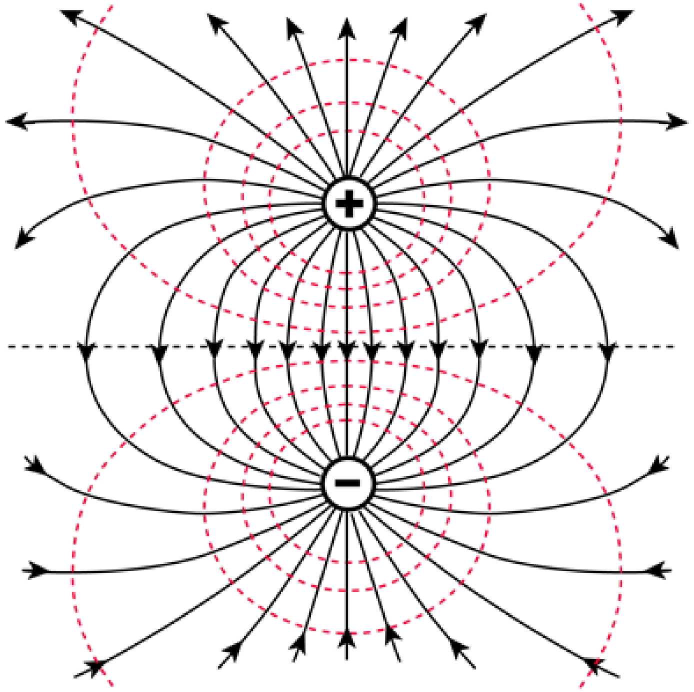


Point charge



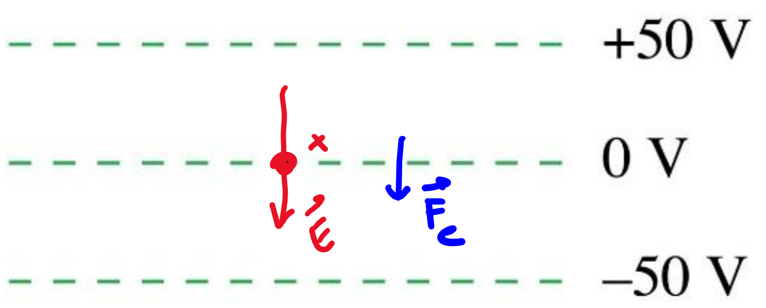
Parallel-plate capacitor

(uniform electric field)



Electric dipole

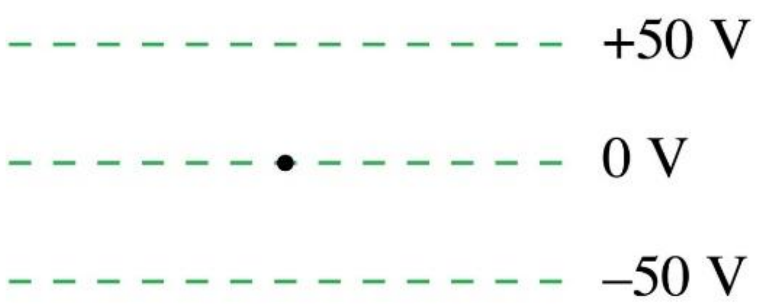
Q: A proton is released from rest at the dot, where the potential is zero volt. Afterwards, the proton



A. Remains at the dot.
B. Moves upward with steady speed.
C. Moves upward with an increasing speed.
D. Moves downward with a steady speed.
E. Moves downward with an increasing speed.

Q: A proton is released from rest at the dot, where the potential is zero volt. Afterwards, the proton

- Direction?
  - Positive charge moves “downhill” => 0 V to -50 V
- Acceleration or steady speed?
  - Energy approach: $\Delta U = q_{+}\Delta V, \quad \Delta V < 0 \quad \Rightarrow$
    $\Delta U < 0 \quad \Rightarrow \quad \Delta K > 0 \quad \Rightarrow$ accelerates.



A. Remains at the dot.

B. Moves upward with steady speed.

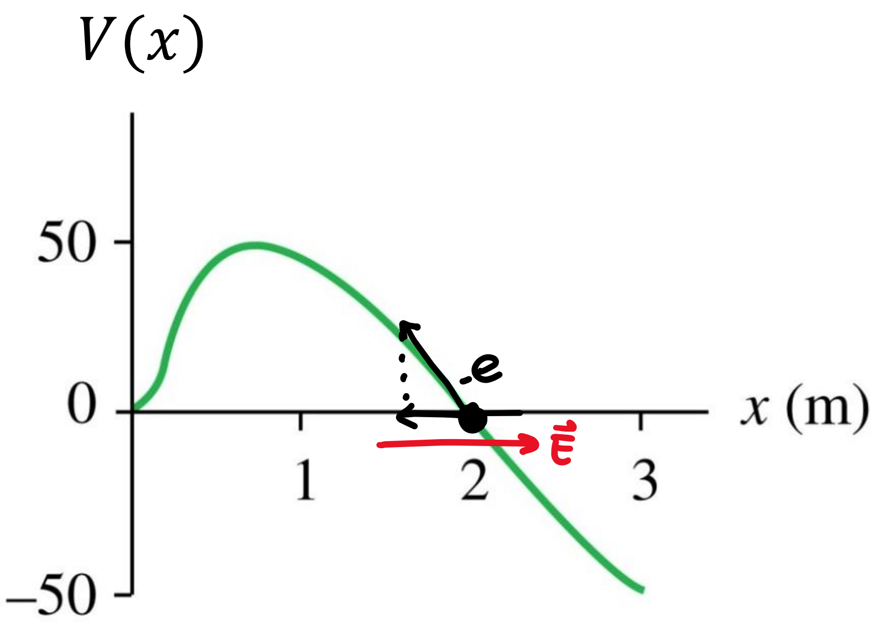
C. Moves upward with an increasing speed.

D. Moves downward with a steady speed.

E. Moves downward with an increasing speed.

- Very soon we will learn:
  - $\Delta V \neq 0 \quad \Rightarrow \quad \text{there is E} \quad \Rightarrow$
    $\text{there is force} \quad \Rightarrow \quad \text{charge will accelerate}$

Q: An electron is released from rest at $x = 2$ m in the potential shown. What does the electron do right after being released?



A. Stay at $x = 2$ m.

B. Move to the right ($+x$) at steady speed.

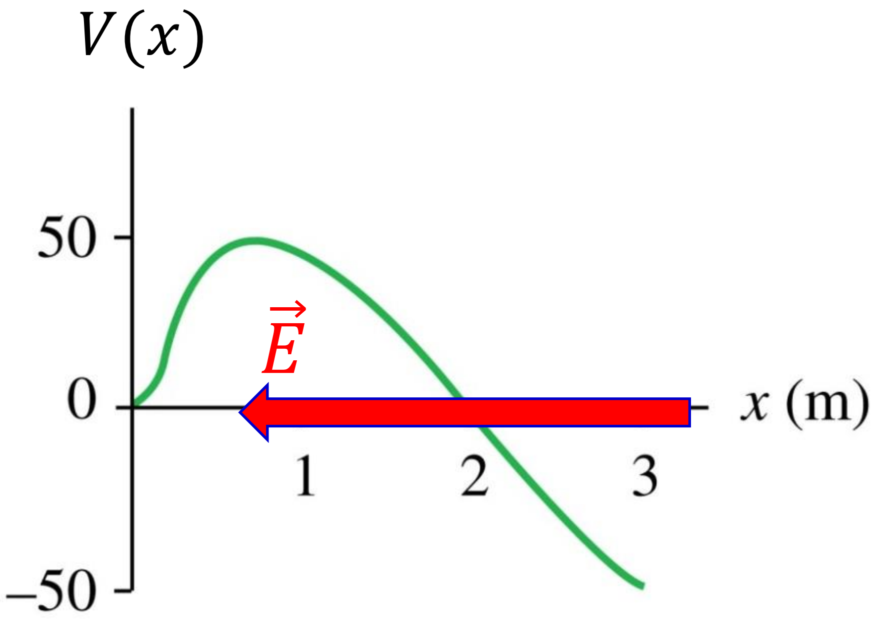
C. Move to the right with increasing speed.

D. Move to the left ($-x$) at steady speed.

E. Move to the left with increasing speed.

Show the direction of electric field at $x = 2$.

Q: An electron is released from rest at $x = 2$ m in the potential shown. What does the electron do right after being released?



A. Stay at $x = 2$ m.

B. Move to the right ($+x$) at steady speed.

C. Move to the right with increasing speed.

D. Move to the left ($-x$) at steady speed.

E. Move to the left with increasing speed.

- E-field points "downhill" => along +x => the electron will move to the left under the force $\vec{F} = (-e)\,\vec{E}$
- Force => acceleration => increasing speed

Show the direction of electric field at $x = 2$.

Connecting Electric potential and Electric field

Electric field, Electric force, Electric potential energy, Electric potential – OMG!

Q: All these quantities are inter-related. Find connections between them.

$$
\begin{tikzcd}[column sep=huge, row sep=huge]
\vec{F} \arrow[r, leftrightarrow, "\Delta U = -\int_i^f \vec{F}\cdot d\vec{s}"] \arrow[d, leftrightarrow, "\vec{F} = q_\pm \vec{E}"'] & \Delta U \arrow[d, leftrightarrow, "\Delta U = q_\pm \Delta V"] \\
\vec{E} \arrow[r, leftrightarrow, "\Delta V = -\int_i^f \vec{E}\cdot d\vec{s}"'] & \Delta V
\end{tikzcd}
$$

$$\Delta U = -W_e =$$

$$= -\underline{\vec{F}_e \cdot \Delta\vec{s}}$$

- Force $(\vec{F})$
- Field $(\vec{E})$
- Energy (U)
- Potential (V)

$$\Delta V = \frac{\Delta U}{q_\pm} = \frac{-\vec{F}\cdot\Delta\vec{s}}{q_\pm} = -\frac{\cancel{q_\pm}\,\vec{E}\cdot\Delta\vec{s}}{\cancel{q_\pm}} = -\vec{E}\cdot\Delta\vec{s}$$

$\vec{E} \Rightarrow V$: Potential difference between two points, i and f:

- If you know electric field, you can calculate the potential difference between two points by integrating $\vec{E} \cdot d\vec{s}$ on a path connecting these two points

$$\boxed{\Delta V = V_f - V_i = -\int_i^f \vec{E} \cdot d\vec{s}}$$

(2) Remember about V_i

(1) Don't forget the dot product
(integrate 'outwards', it's more convenient)

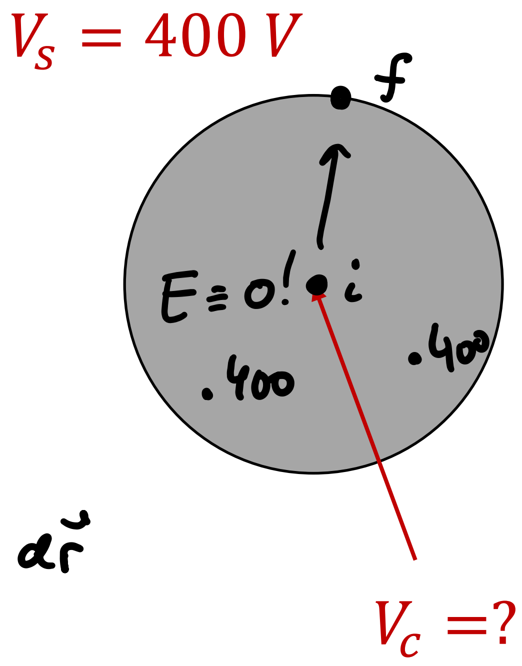
(3) …and don't forget about the minus in front of the integral!

$V = ?$ $\qquad \vec{E} \to V$ $\qquad Q$

Q: A metal sphere carries a charge of 5×10^{-9} C. Its surface is at a potential of 400 V, relative to the potential far away. What is the potential at the center of the sphere ?

$$\Delta V = V_f - V_i = -\int_i^f \vec{E} \cdot d\vec{s}$$

$$400 - V_c = -\int 0 = 0$$



$d\vec{s} = d\vec{r}$

A. −400 V

B. 400 V

C. 2×10^{-6} V

D. 0

E. Need to know the radius R

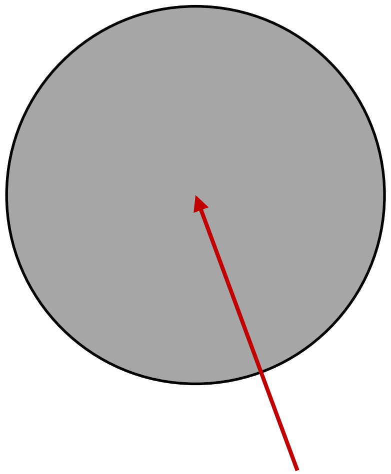
$$V_c = 400$$

Q: A metal sphere carries a charge of 5×10^{-9} C. Its surface is at a potential of 400 V, relative to the potential far away. What is the potential at the center of the sphere ?

- Recall the properties of conductors: $E = 0$ everywhere inside the conductor
- $\Delta V = V_s - V_c = -\int_{r=0}^{r=R} \vec{E} \cdot d\vec{s} = 0$ since $E \equiv 0$ =>
- $V_s = V_c$

So if V = 400 V on the surface, then V = 400 V everywhere inside the sphere!

$V_s = 400\ V$



$V_c = ?$

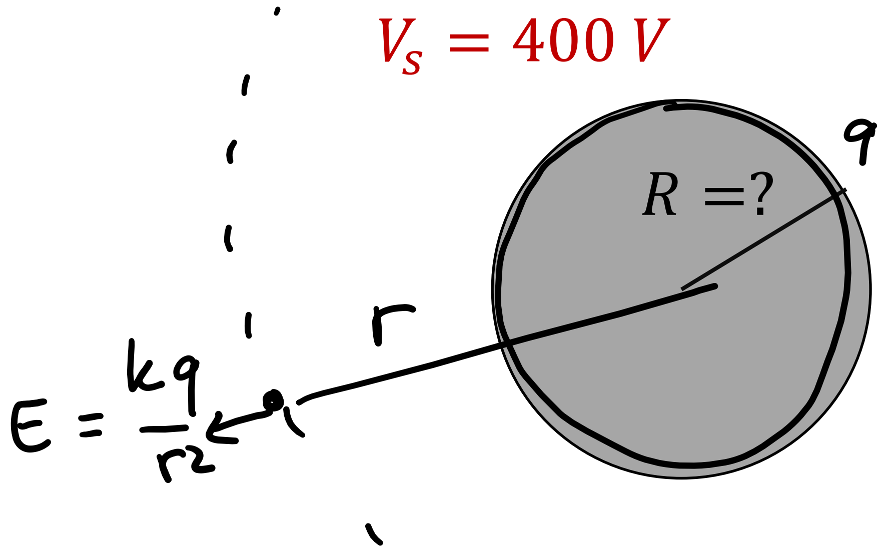
A. −400 V
B. 400 V
C. 2×10^{-6} V
D. 0
E. Need to know the radius R

In general, V is continuous

In equilibrium, the whole conductor is under the same potential. Always.

Q: A metal sphere carries a charge of 5×10^{-9} C. Its surface is at a potential of 400 V, relative to the potential far away. What is the radius of the sphere ?

$$\Delta V = V_f - V_i = -\int_i^f \vec{E} \cdot d\vec{s}$$



A. 1.5 m
B. 0.9 m
C. 0.23 m
D. 0.11 m
E. 0.05 m

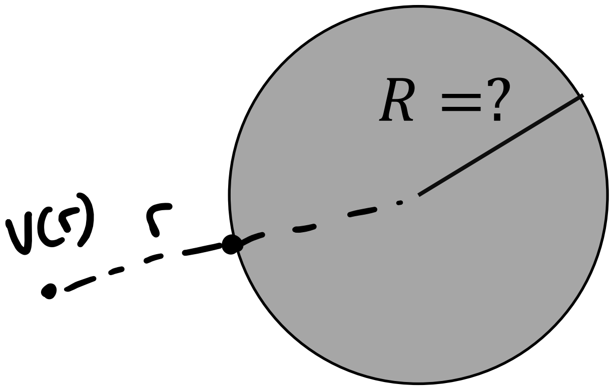
Q: A metal sphere carries a charge of 5×10^{-9} C. Its surface is at a potential of 400 V, relative to the potential far away. What is the radius of the sphere ?

- We can find the potential outside the sphere as:

$$\Delta V = V_\infty - V(r) = -\int_{r=r}^{r=\infty} \vec{E} \cdot d\vec{s}$$

$V_\infty = 0$

$V_s = 400\ V$



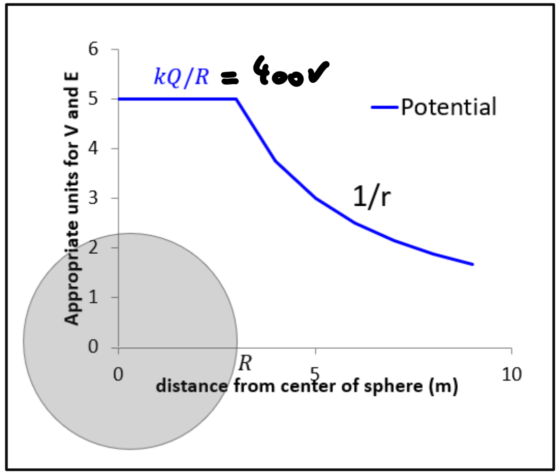
- From Gauss's law we know that the electric field outside the sphere is the same as for a point charge =>

$$V_{\text{sphere}}(r > R) = \frac{kQ}{r}$$

at r = R

A. 1.5 m
B. 0.9 m
C. 0.23 m
D. 0.11 m
E. 0.05 m

$$V_{\text{sphere}}(r < R) = 400\ V \equiv \frac{kQ}{R}$$



...and we know that potential is continuous!

$$V_{\text{sphere}}(r = R) = \frac{kQ}{R} = 400\ V \quad \Rightarrow \quad R = 0.11\ m$$