Electric Potential Energy

A positive and a negative charge are released from rest in vacuum. They move toward each other. As they do,

A. A positive potential energy becomes more positive.
B. A positive potential energy becomes less positive.
C. A negative potential energy becomes more negative.
D. A negative potential energy becomes less negative.
E. A positive potential energy becomes a negative potential energy.

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✔ **C. A negative potential energy becomes more negative.**
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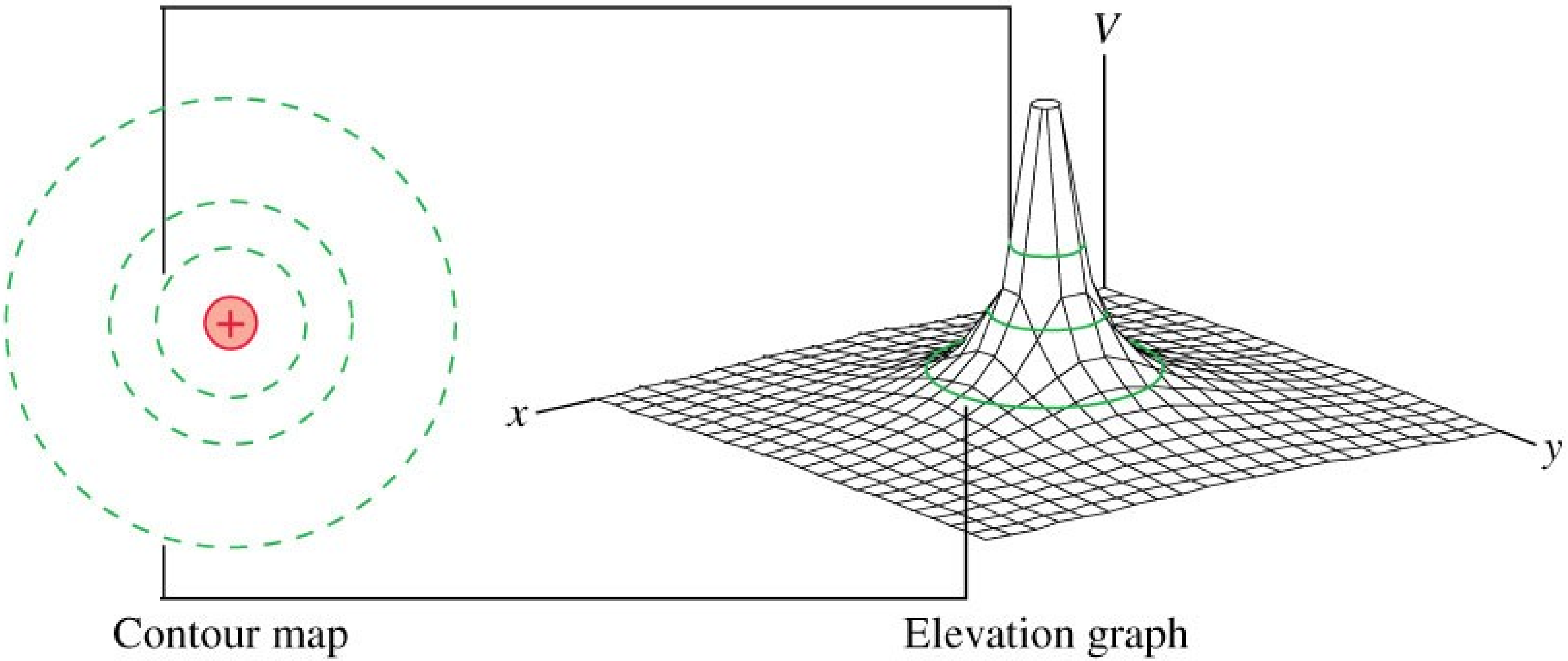
$$U_{\text{elec}} = \frac{Kq_1q_2}{r}$$

Opposite signs, so U is Negative.

U increases in magnitude as r decreases.

Electric Potential (Voltage)



Electric Potential (Voltage)

- Outside a uniformly charged sphere of radius R, the electric potential is identical to that of a point charge Q at the center:

$$V = \frac{1}{4\pi\epsilon_0}\frac{Q}{r}$$

  where $r \geq R$.

- If the potential at the surface V_0 is known, then the potential at $r \geq R$ is

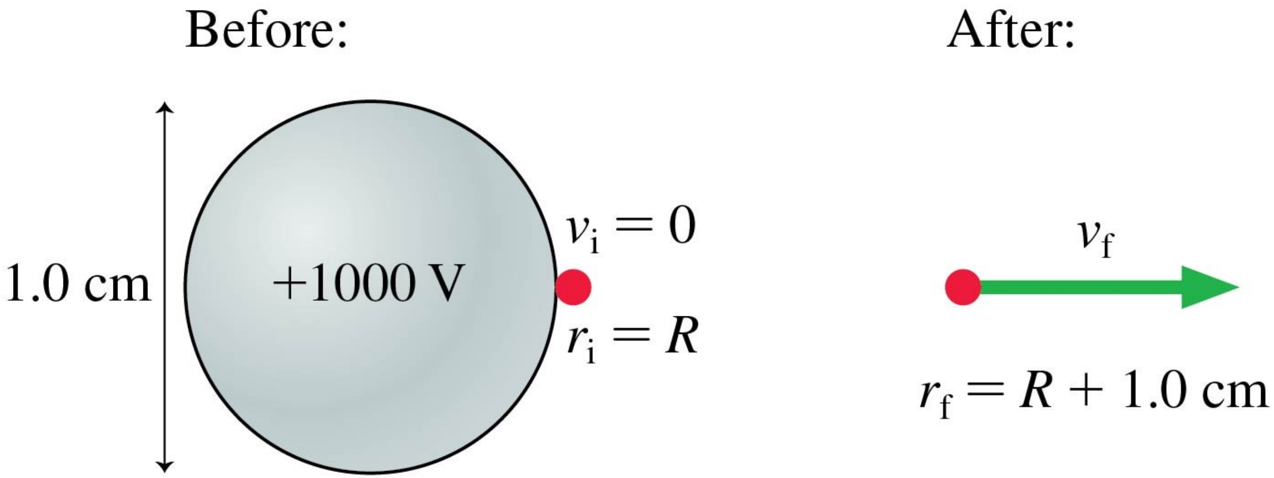
$$V = \frac{R}{r}V_0$$

Electric Potential (Voltage)

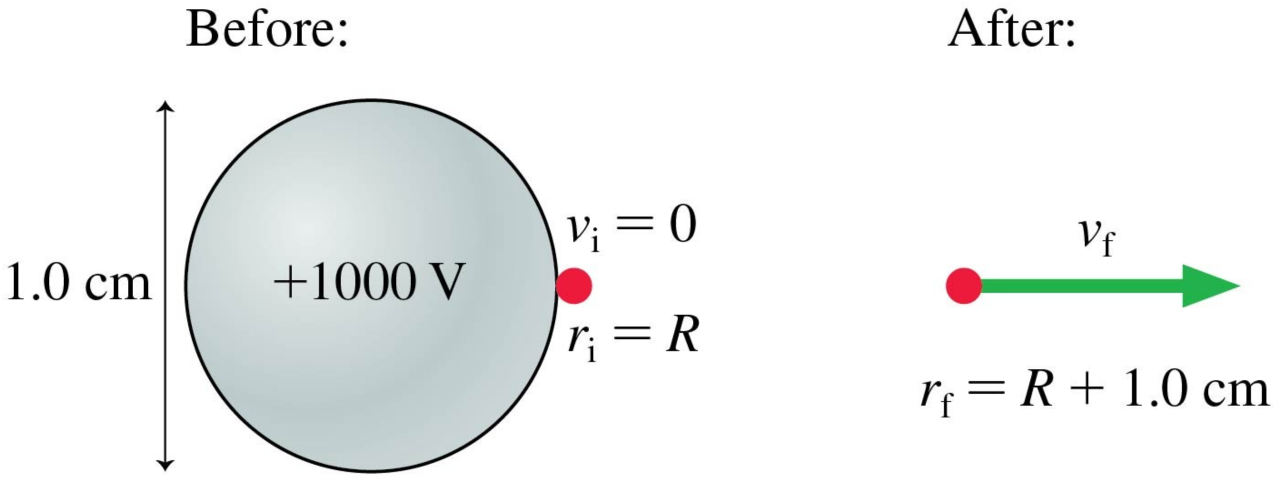
A proton is released from rest at the surface of a 1.0-cm-diameter sphere that has been charged to +1000 V.

a. What is the charge of the sphere?

b. What is the proton's speed at 1.0 cm from the sphere?



Electric Potential (Voltage)



The charge of the sphere is

$$Q = 4\pi\epsilon_0 R V_0 = 0.56 \times 10^{-9}\ \text{C} = 0.56\ \text{nC}$$

Electric Potential (Voltage)

$$\tfrac{1}{2}mv_f^2 + \frac{eR}{r_f}V_0 = \tfrac{1}{2}mv_i^2 + \frac{eR}{r_i}V_0$$

The proton starts from the surface of the sphere, $r_i = R$, with $v_i = 0$. When the proton is 1.0 cm from the *surface* of the sphere, it has $r_f = 1.0\text{ cm} + R = 1.5\text{ cm}$. Using these, we can solve for v_f:

$$v_f = \sqrt{\frac{2eV_0}{m}\left(1 - \frac{R}{r_f}\right)} = 3.6 \times 10^5\text{ m/s}$$

Electric Potential of Many Charges

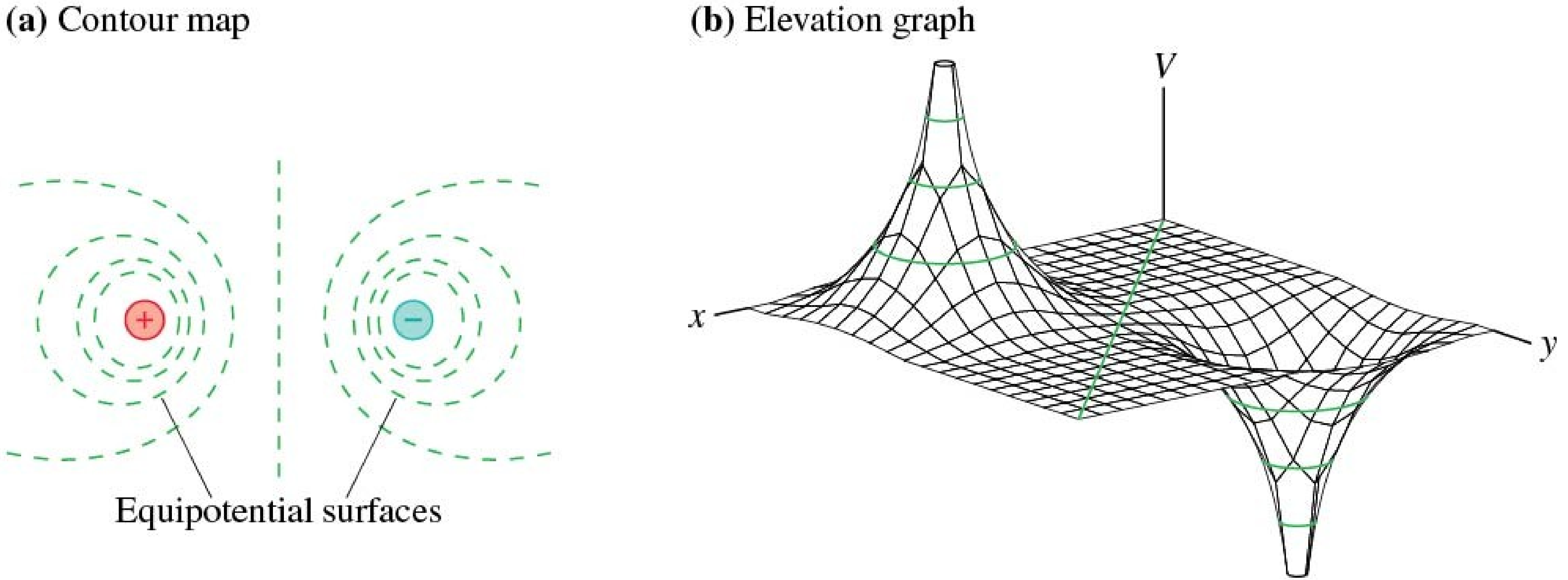
The principle of superposition.

The electric potential V at a point in space is the sum of the potentials due to each charge:

$$V = \sum_i \frac{1}{4\pi\epsilon_0} \frac{q_i}{r_i}$$

where r_i is the distance from charge q_i to the point in space where the potential is being calculated.

Electric Potential of Many Charges



Electric Potential of Many Charges

At which point or points is the electric potential zero?

A. B. C. D.

E. More than one of these.

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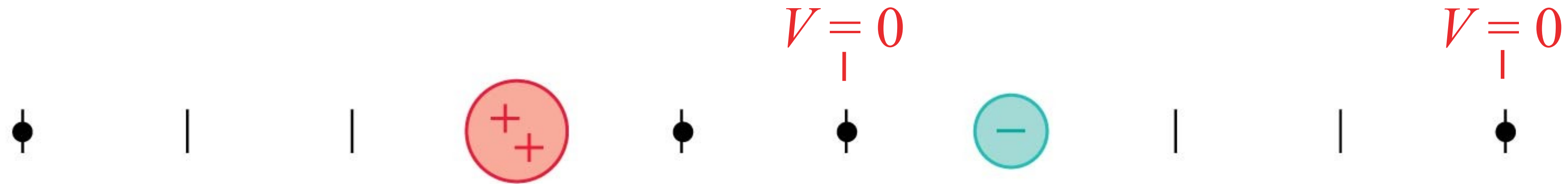
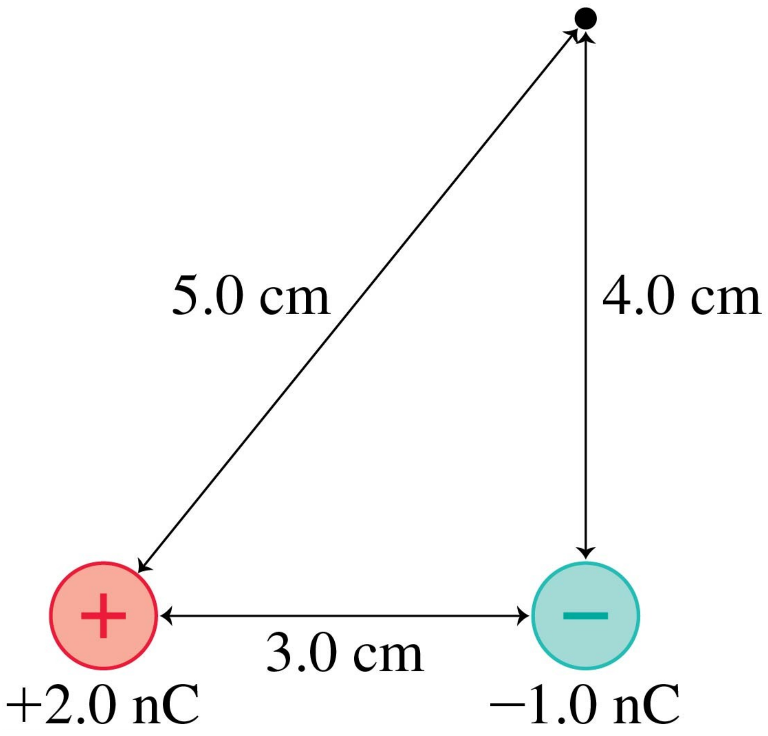


A. B. C. D.

E. More than one of these.

Electric Potential of Many Charges

Find the potential at the point.

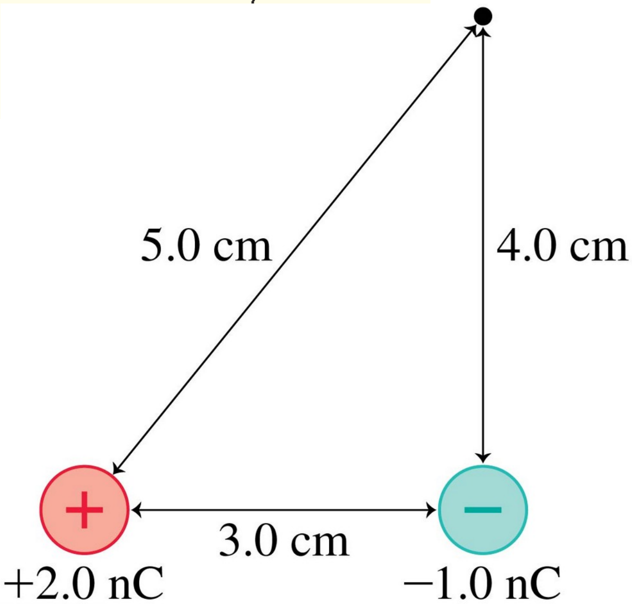


Electric Potential of Many Charges

$$V = \frac{1}{4\pi\epsilon_0}\frac{q_1}{r_1} + \frac{1}{4\pi\epsilon_0}\frac{q_2}{r_2}$$

$$= (9.0 \times 10^9\ \mathrm{N\,m^2/C^2})\left(\frac{2.0 \times 10^{-9}\ \mathrm{C}}{0.050\ \mathrm{m}} + \frac{-1.0 \times 10^{-9}\ \mathrm{C}}{0.040\ \mathrm{m}}\right)$$

$$= 135\ \mathrm{V}$$



Electric Potential and Field

Force and energy are related by

$$\Delta U = -\int_i^f \vec{F} \cdot \, d\vec{s}$$

$$\vec{F} = -\frac{dU}{ds}$$

Force per charge is field:

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

Energy per charge is voltage:

$$\Delta V = \frac{\Delta U}{q}$$

Electric Potential and Field

Force and energy are related by

$$\Delta U = -\int_i^f \vec{F} \cdot \, d\vec{s} \qquad F_s = -\frac{dU}{ds}$$

Electric field and potential are related by

$$\Delta V = -\int_i^f \vec{E} \cdot \, d\vec{s} \qquad E_s = -\frac{dV}{ds}$$

Electric Potential and Field

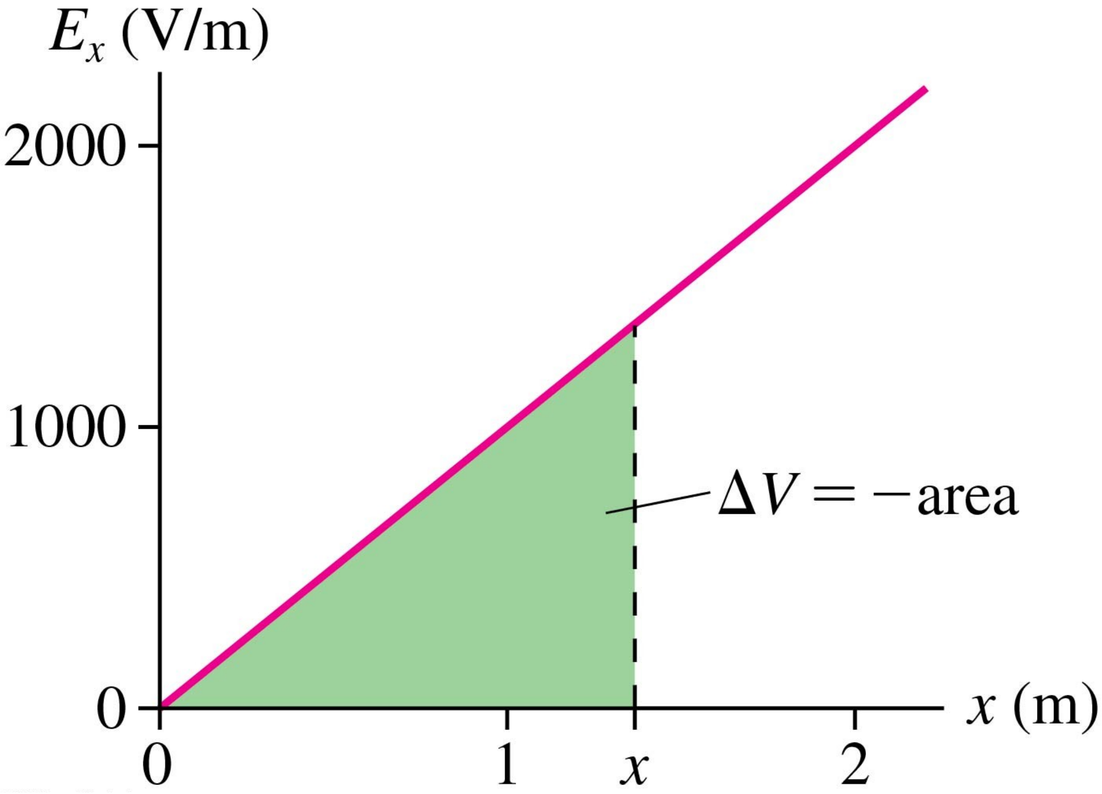
The potential difference between two points in space is

$$\Delta V = V_f - V_i = -\int_{s_i}^{s_f} E_s \, ds = -\int_i^f \vec{E} \cdot d\vec{s}$$

where s is the position along a line from point i to point f.

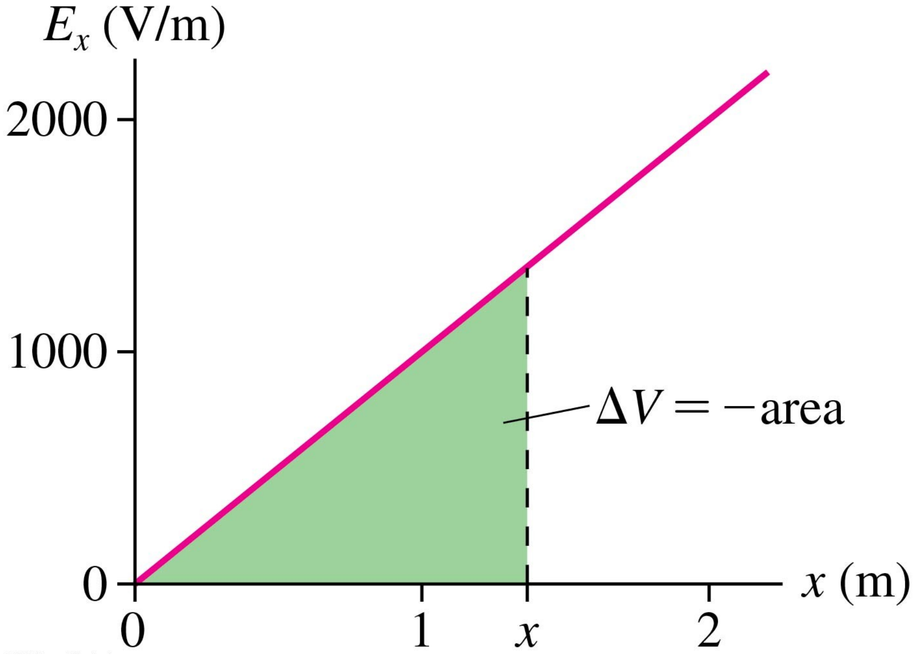
Electric Potential and Field

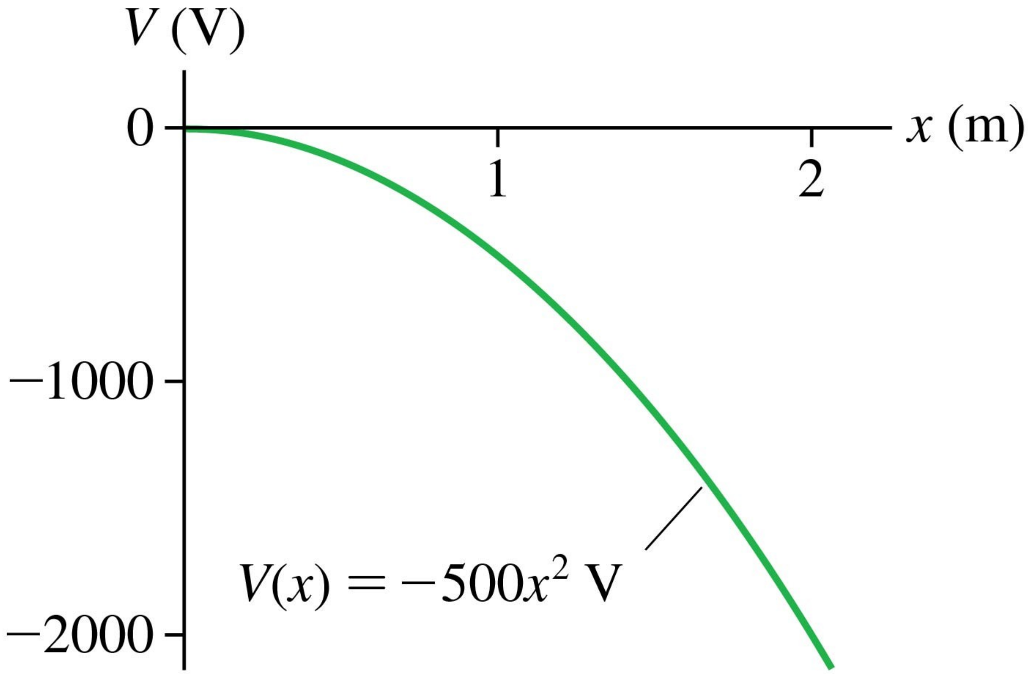
Given the electric field shown, what is the graph of the voltage?



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

Electric Potential and Field





The Electric Potential

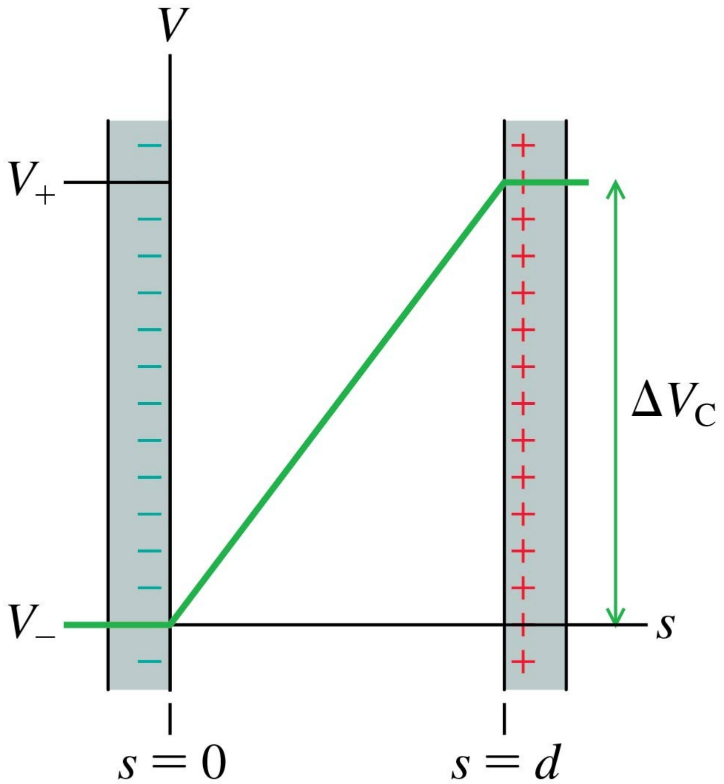
- The electric potential inside a parallel-plate capacitor is

$$V = Es \qquad \text{(electric potential inside a parallel-plate capacitor)}$$

where s **is the distance from the *negative* electrode**.

- The *potential difference* ΔV_C, or "voltage" between the two capacitor plates is

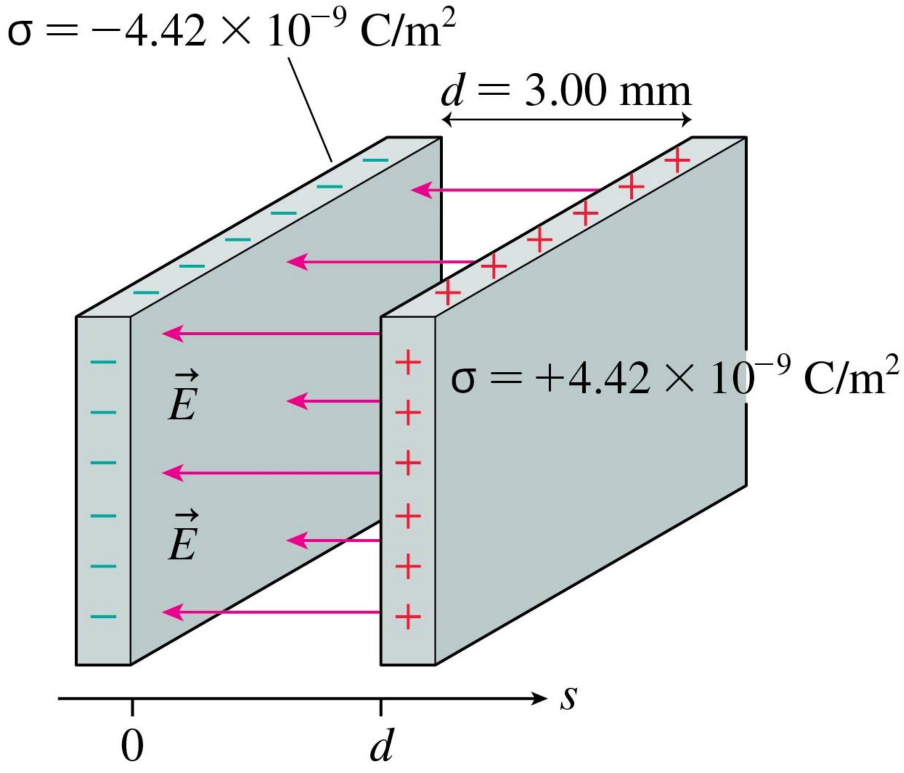
$$\Delta V_C = V_+ - V_- = Ed$$



The Electric Field Inside a Parallel-Plate Capacitor

$$\vec{E} = \frac{\sigma}{\epsilon_0}\,\hat{n}$$

$$= (500\ \text{N/C, from right to left})$$



Units of Electric Field

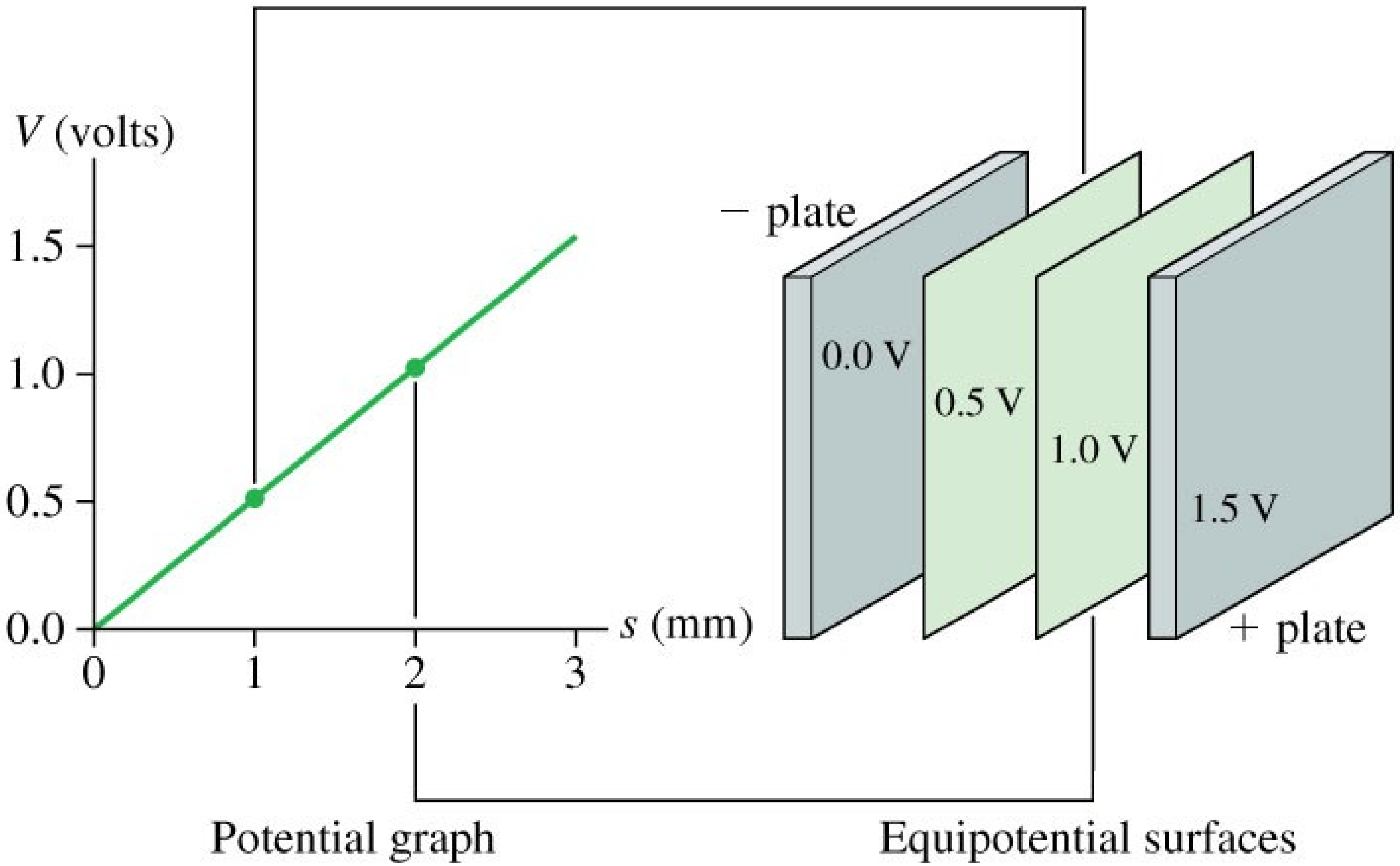
- If we know a capacitor's voltage ΔV and the distance between the plates d, then the electric field strength within the capacitor is

$$E = \frac{\Delta V_C}{d}$$

- The units of electric field are volts per meter, or V/m.

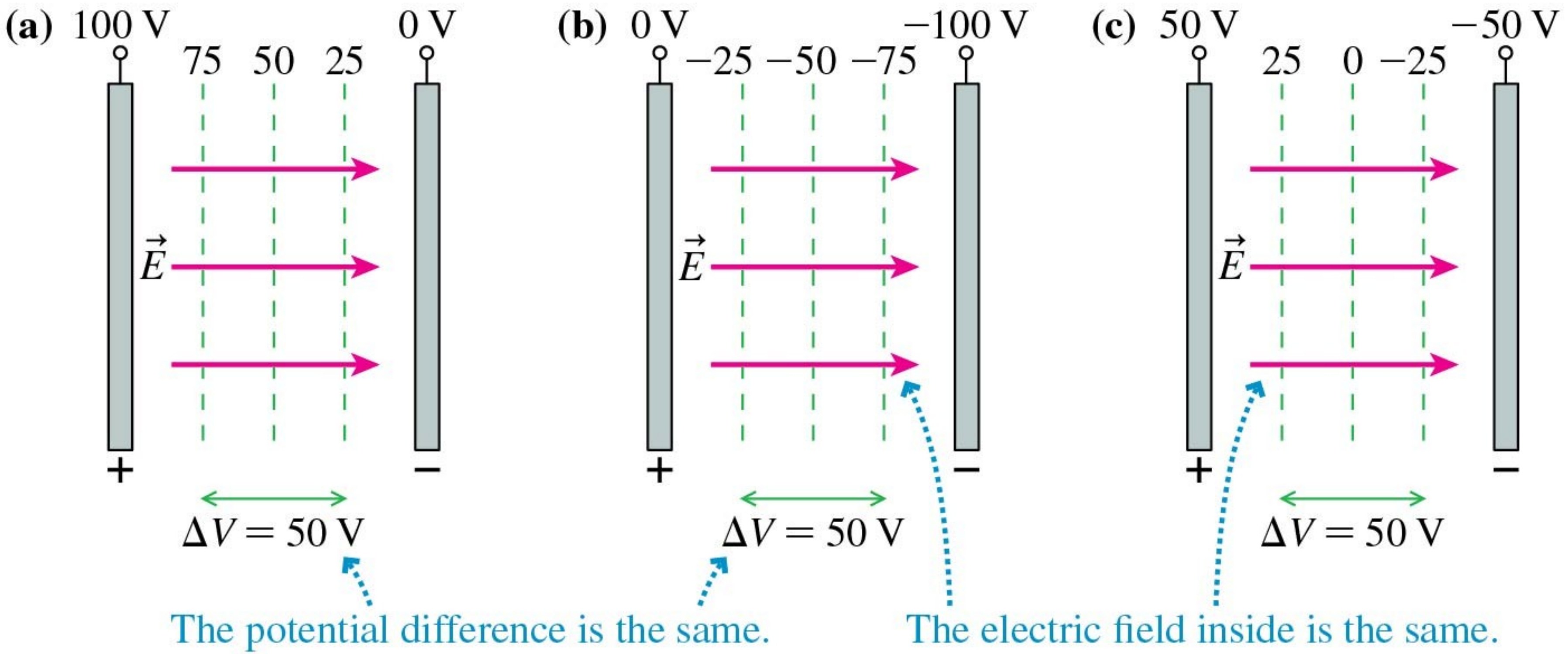
$$1 \text{ N/C} = 1 \text{ V/m}$$

The Electric Potential



The Zero Point of Electric Potential

The three contour maps below represent the *same physical situation*.

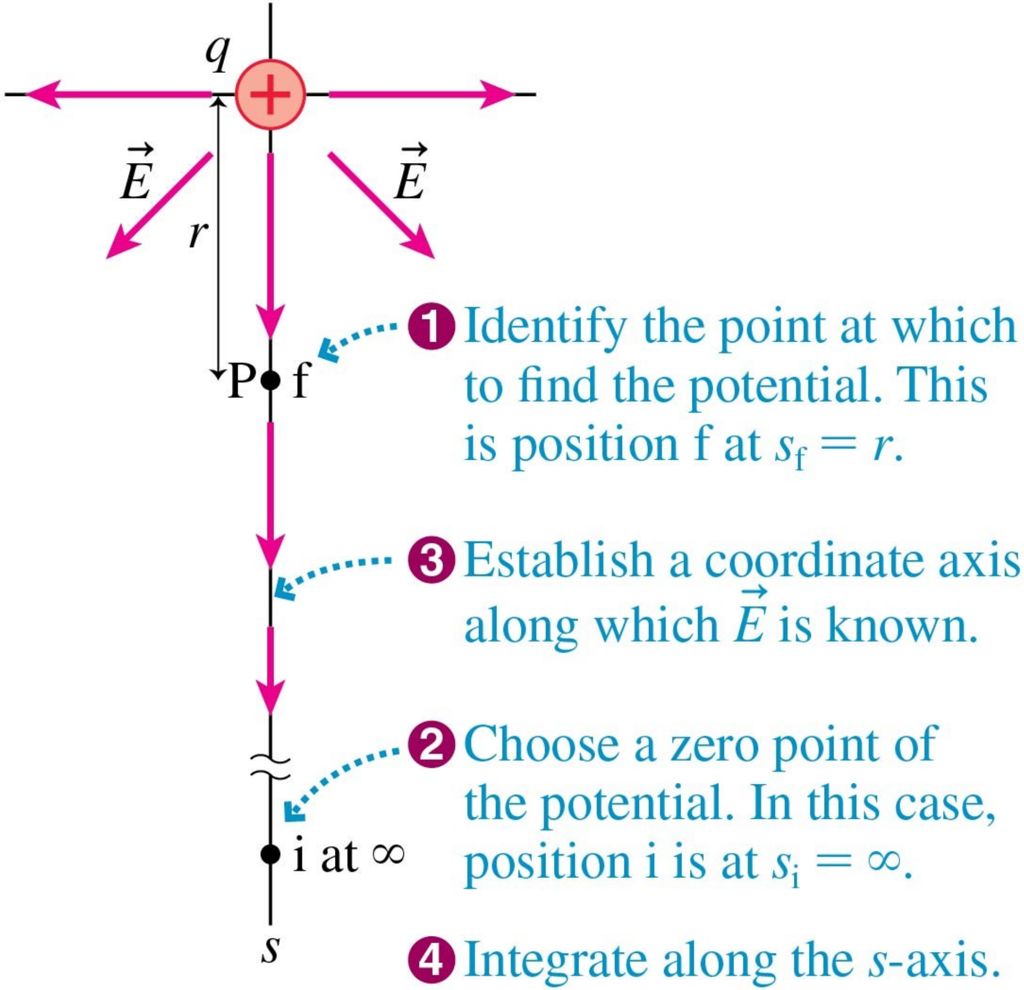


Electric Potential and Field

$$E_s = \frac{1}{4\pi\epsilon_0}\frac{q}{s^2}$$

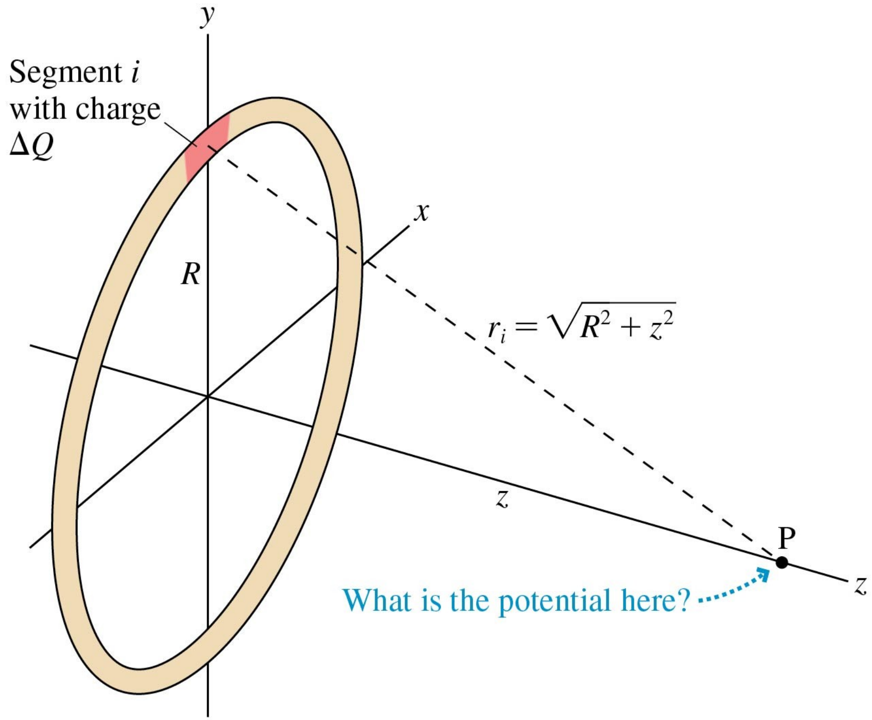
$$V(r) = V(\infty) + \frac{q}{4\pi\epsilon_0}\int_r^{\infty}\frac{ds}{s^2}$$

$$V_{\text{point charge}} = \frac{1}{4\pi\epsilon_0}\frac{q}{r}$$



Electric Potential of a Charge Distribution

A thin, uniformly charged ring of radius R has total charge Q. Find the potential at distance z on the axis of the ring.



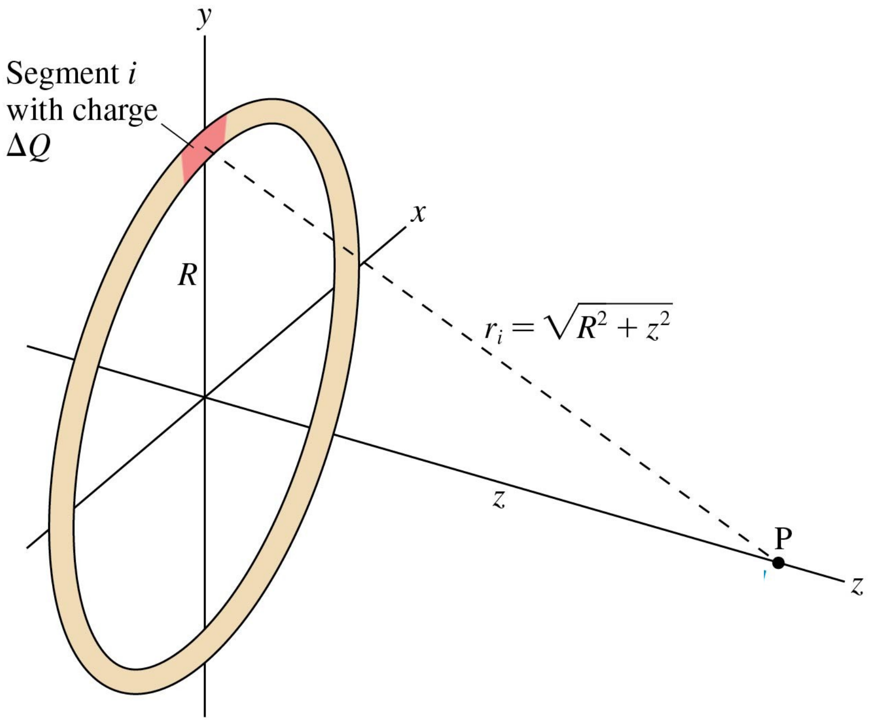
Electric Potential and Field

What is the electric field on the axis of a ring of charge?

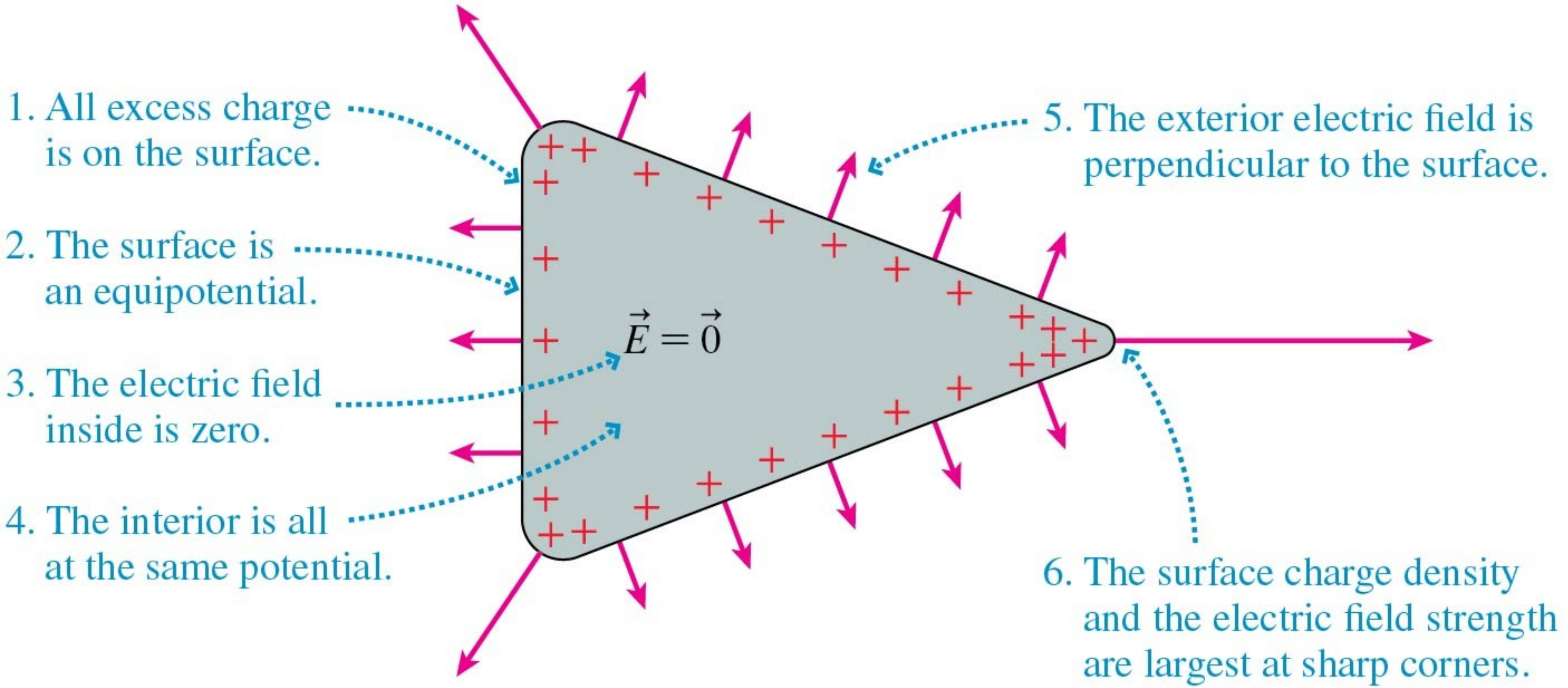
$$V_{\text{ring}} = \frac{1}{4\pi\epsilon_0}\frac{Q}{\sqrt{z^2+R^2}}$$

$$E_z = -\frac{dV}{dz} = -\frac{d}{dz}\left(\frac{1}{4\pi\epsilon_0}\frac{Q}{\sqrt{z^2+R^2}}\right)$$

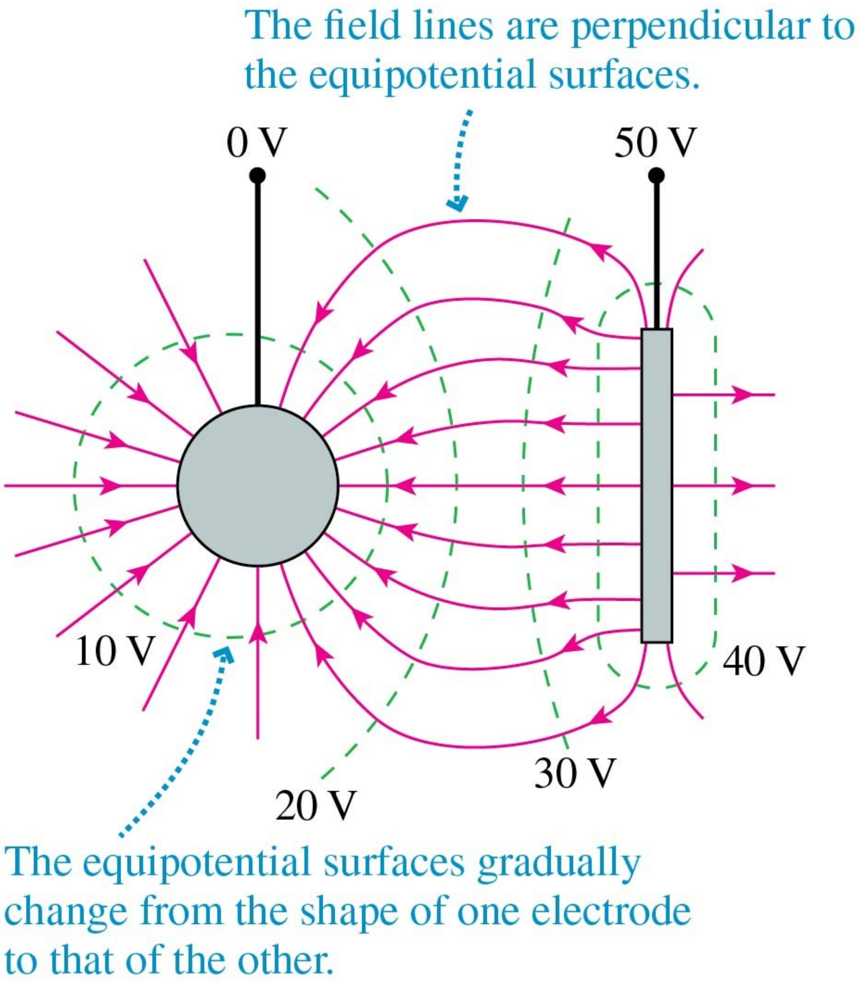
$$= \frac{1}{4\pi\epsilon_0}\frac{zQ}{(z^2+R^2)^{3/2}}$$



Electric Potential and Conductors



Electric Potential and Conductors



Since a conductor surface must be an equipotential, the equipotential surfaces close to each electrode roughly match the shape of the electrode.

Electric Potential and Conductors

Metal wires are attached to the terminals of a 3 V battery. What is the potential difference between points 1 and 2?

A. 6 V
✔B. 3 V
C. 0 V
D. Undefined.
E. Not enough information to tell.