Electric Potential Energy

PHY 114-01

Fall 2026

Announcements

- No homework this week.
- Midterm grades will be out by Monday next week.
- You will be able to submit a midterm reflection to get some credit back. More info available when grades are released.

Agenda

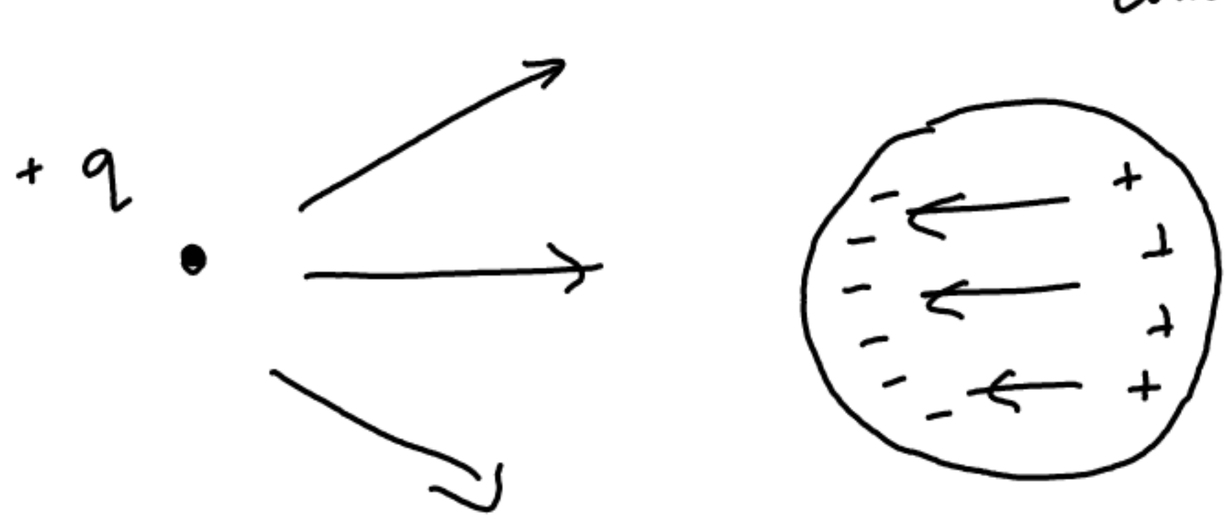
- Last time:
  - Electrostatic equilibrium
- This time:
  - Electric potential energy

Electrostatic Equilibrium in conductors

The field inside any conductor in electrostatic equilibrium

note that this ⟶ is zero.
does not include
anything not in equilibrium
($F_{net} \neq 0$)

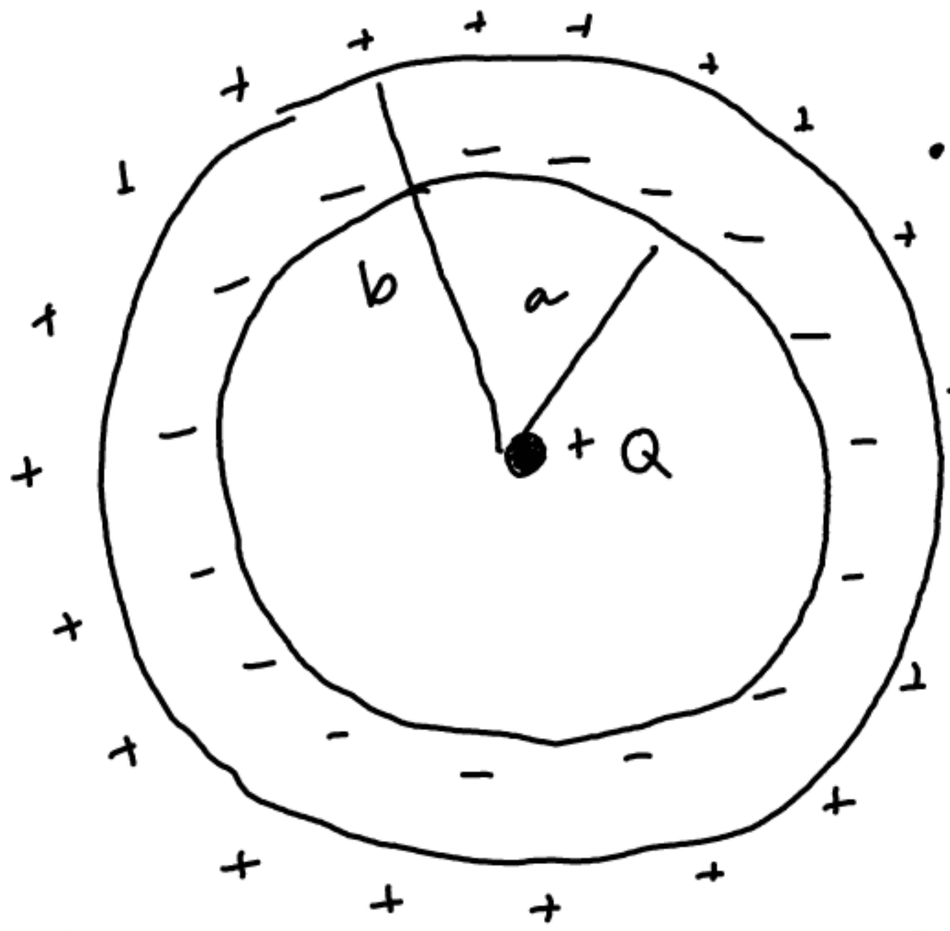
What if there's an external charge?



fields cancel inside the conductor!

Charge inside spherical conducting shell:

Find the field everywhere in space (all values of r)



- inner radius a
- outer radius b
- neutral shell (conducting)
- inner charge +Q
- charge −Q on inner wall
- charge +Q on outer wall

Regions to consider:

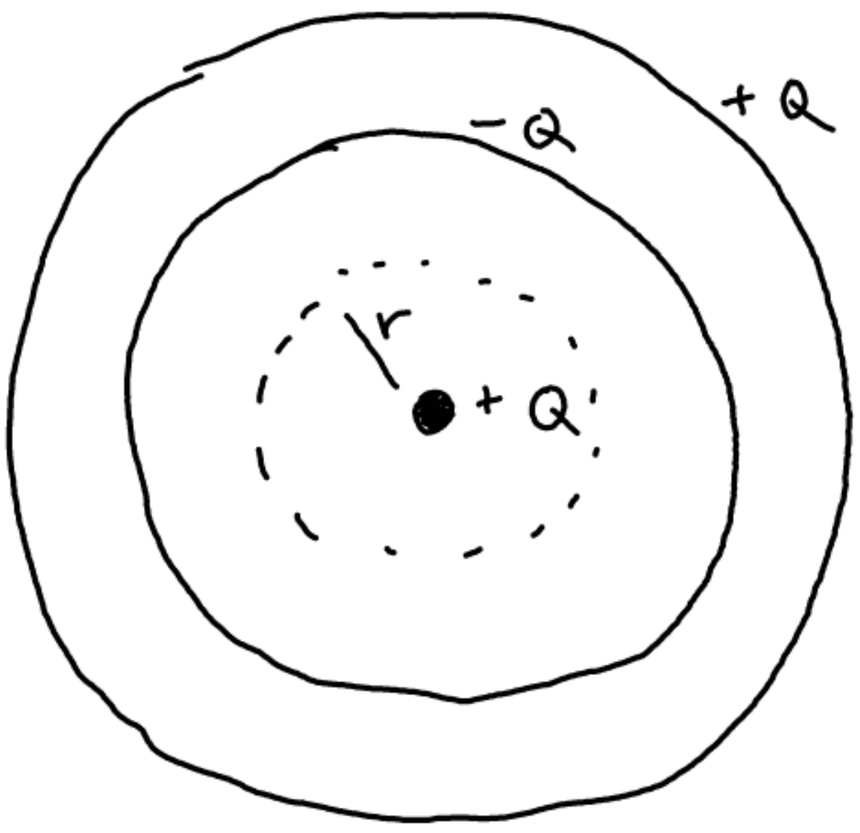
$r < a$

$a < r < b$

$r > b$

① $r < a$ Gauss's Law

sphere around the point charge



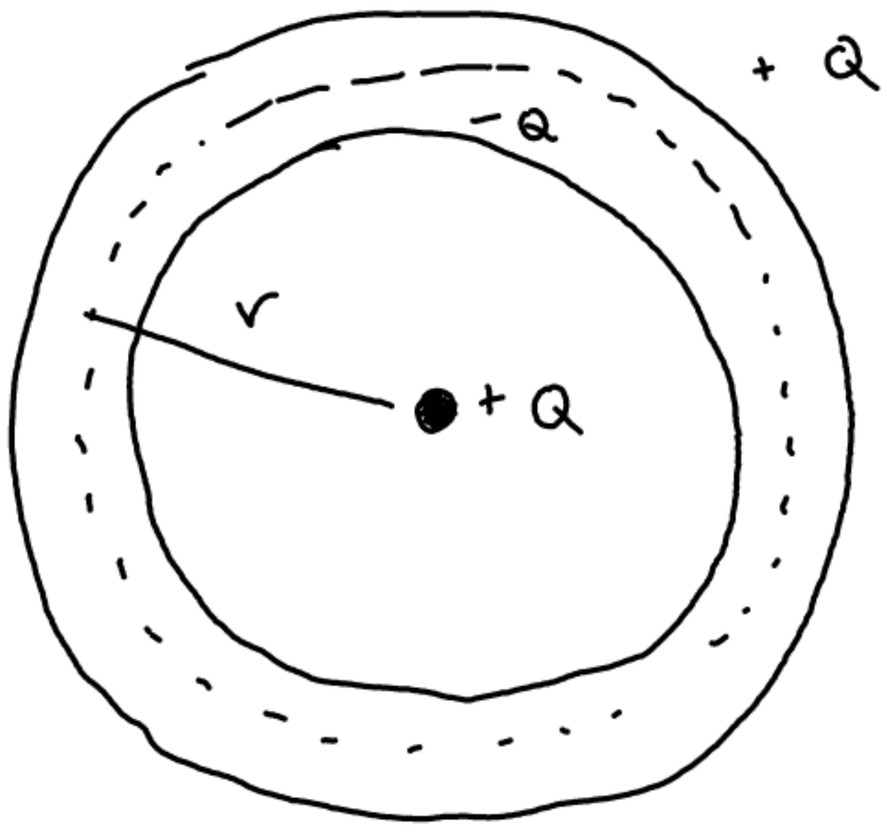
$$E \cdot A = q_{enc}/\varepsilon_0$$

$$E \cdot 4\pi r^2 = Q/\varepsilon_0$$

$$E(r) = \frac{Q}{4\pi\varepsilon_0 r^2}$$

for $r < a$

$a < r < b$



This region is inside the conductor

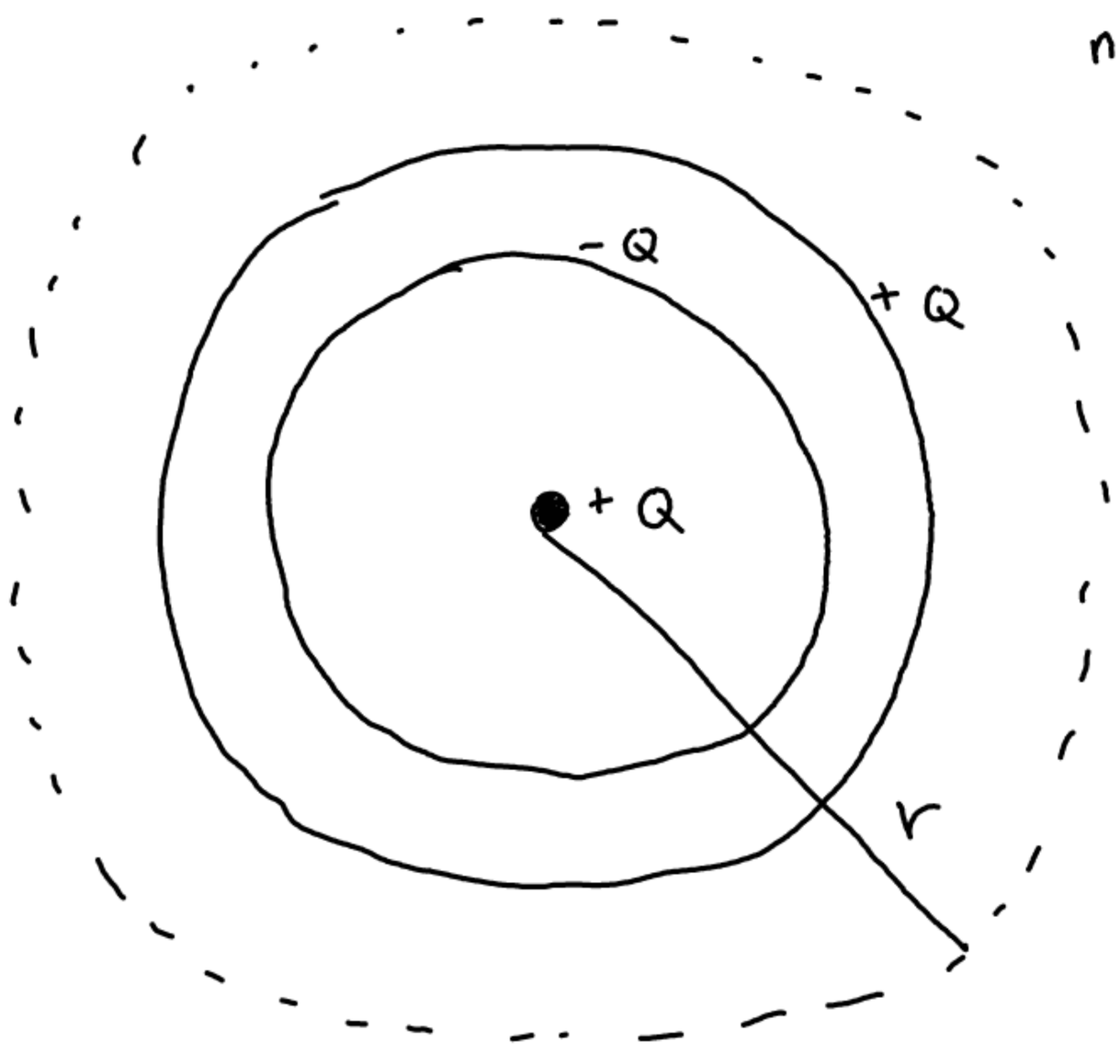
↓

$E = 0$

We can see from Gauss's Law:

$$q_{enc} = +Q + (-Q) = 0 \rightarrow E = 0$$

$r > b$



now $q_{enc} = Q - Q + Q$

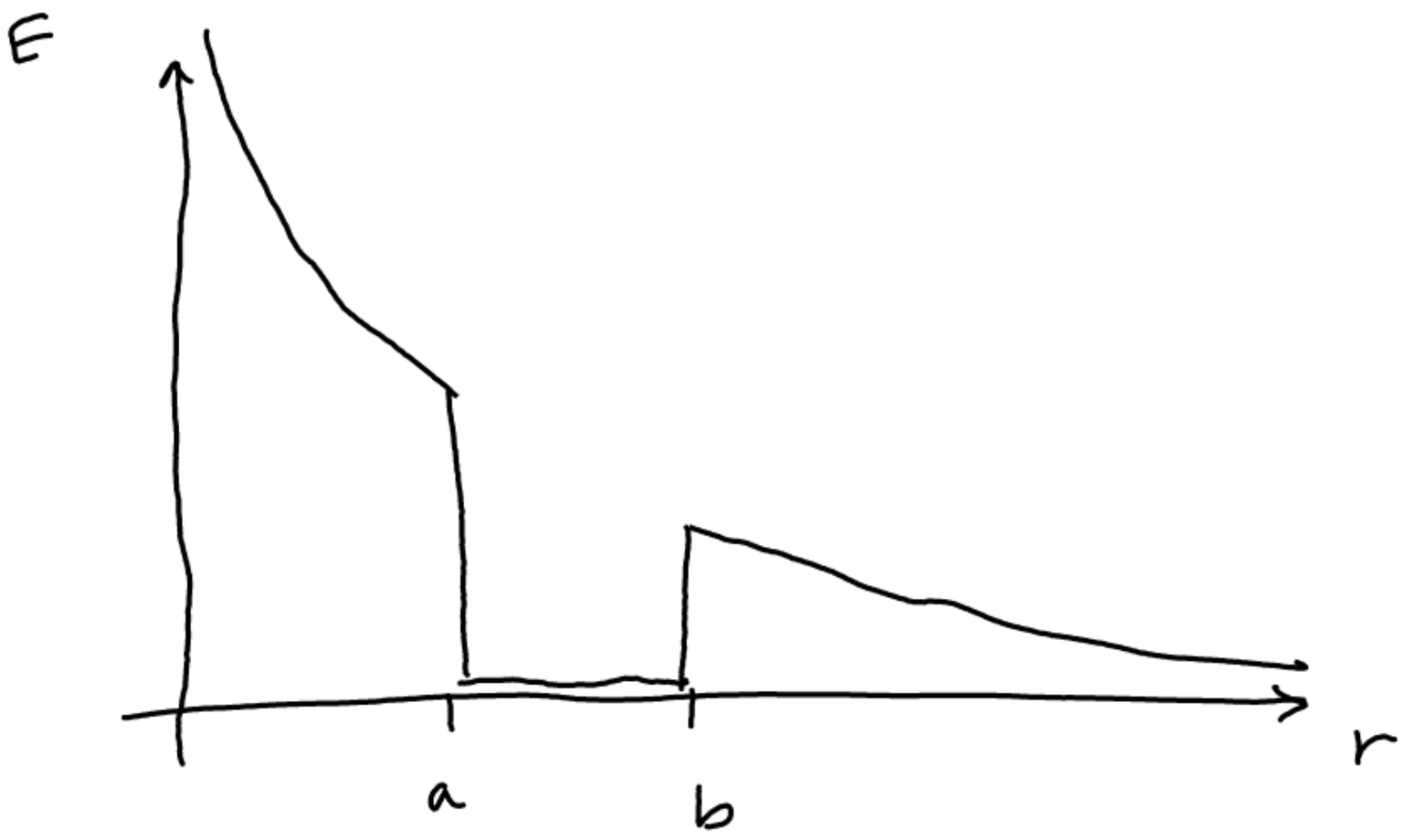
$= Q$

So we have the same form as for $r < a$:

$$E(r) = \frac{Q}{4\pi\varepsilon_0 r^2}$$

All together,

$$E(r) = \begin{cases} \dfrac{Q}{4\pi\varepsilon_0 r^2} & r < a \\ 0 & a < r < b \\ \dfrac{Q}{4\pi\varepsilon_0 r^2} & r > b \end{cases}$$



Review: potential energy

- Potential energy is related to force through WORK
  - $W_c = \int \vec{F}_c \cdot \, d\,\vec{r}$
- Work only counts if the motion is in the same direction as the force
- $W_c = -U_c$
- Work and potential energy both have units Joules (J)

$$U_c = -\int \overrightarrow{F_c} \cdot d\vec{r} \qquad \overrightarrow{F_c} = -\vec{\nabla} U_c = -\left(\frac{d}{dx}\hat{x} + \frac{d}{dy}\hat{y} + \frac{d}{dz}\hat{z}\right) U_c$$

Review: gravitational potential energy

What is the work done by gravity on a box of mass M=1kg that is moved from a position (0, 0) to (0, 5m)?

Take $g=10 m/s^2$.

A. -50 J
B. -5 J
C. 0 J
D. 5 J
E. 50 J (all colors)
F. None of the above (white card)

Review: gravitational potential energy

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Electric potential energy

- The electric force is a conservative force that looks a lot like gravitational force:

$$\overrightarrow{F_E} = \frac{kq_1q_2}{r^2}\hat{r} \qquad\qquad \overrightarrow{F_G} = \frac{-Gm_1m_2}{r^2}\hat{r}$$

- If we can write F=qE for electricity, that's the same as F=mg for near-earth gravity.

Electric potential energy

- If the full gravitational potential energy is

$$\overrightarrow{F_G} = \frac{-Gm_1m_2}{r^2}\hat{r} \qquad U_G = \frac{-Gm_1m_2}{r}$$

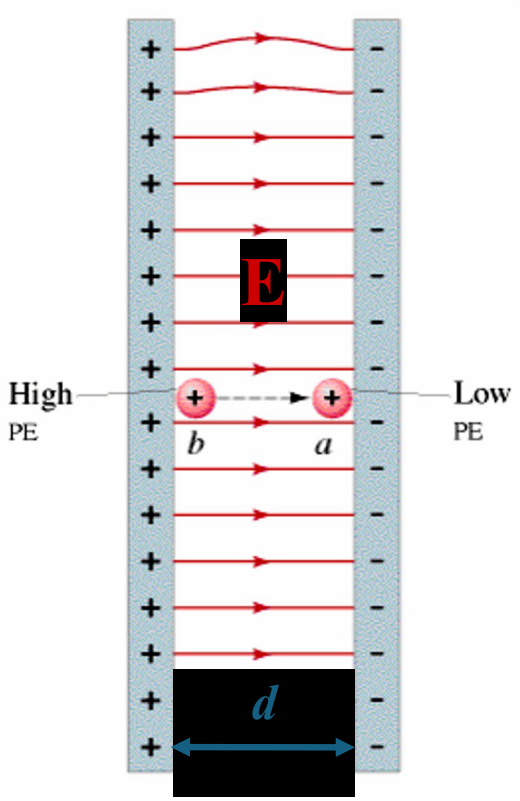
- Then what is the electric potential energy?

$$\overrightarrow{F_E} = \frac{kq_1q_2}{r^2}\hat{r} \qquad U_E = \frac{kq_1q_2}{r} = \frac{q_1q_2}{4\pi\epsilon_0 r}$$

Concept check: electric potential energy

What is the work done by the electric field E to bring the positive charge shown from point a to point b?

1. What is the force on the charge? $\vec{F} = q\vec{E}$
2. Calculate work
   1. $W_E = \int \overrightarrow{F_E} \cdot d\vec{x} = \int q\vec{E} \cdot d\vec{x}$
   2. Notice that $\vec{E}$ and $\vec{d}$ point in opposite directions
   3. $W_E = -qEd$



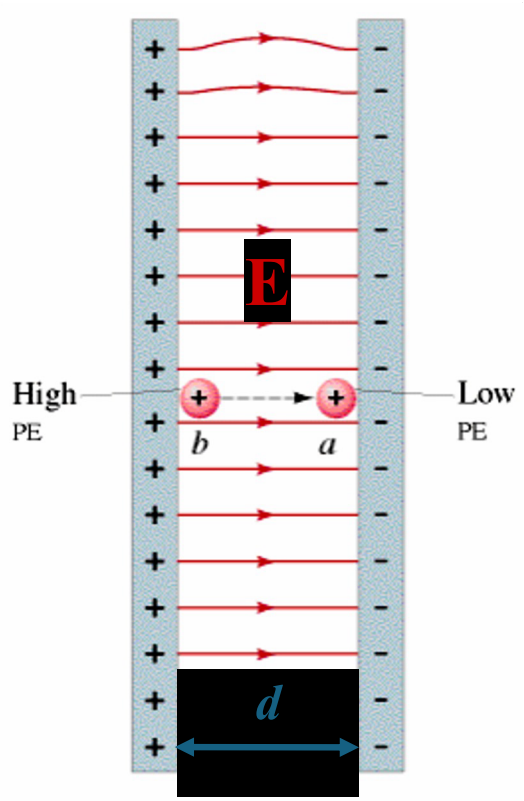
Concept check: electric potential energy

If the work done by the field was –qEd, what is the potential energy of the system?

A. -qEd

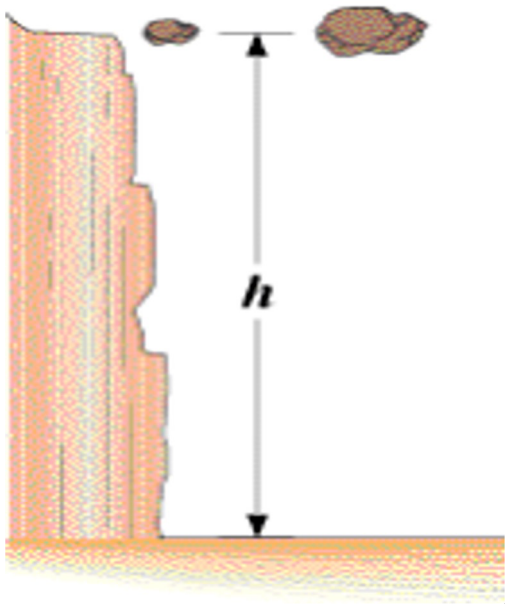
B. qEd

Relative to the initial position!



Gravitational and Electric Potential Energy

Gravity



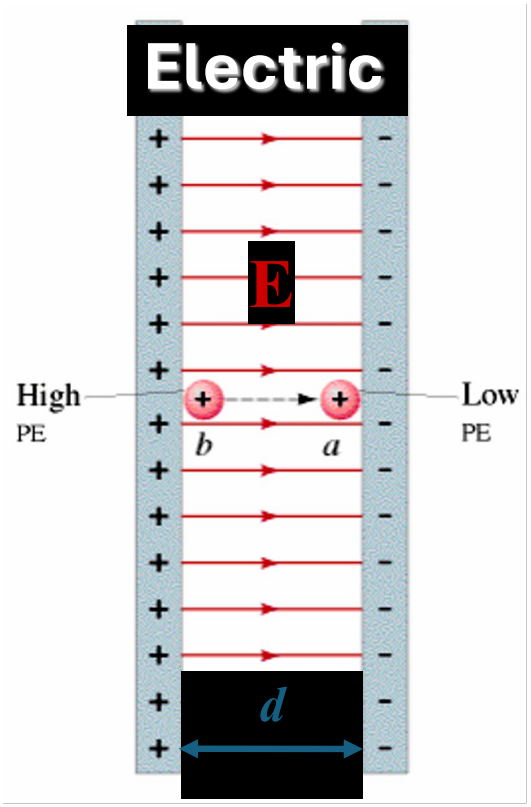
High PE

Low PE

$$U_{grav} = mgh$$

High PE

Electric

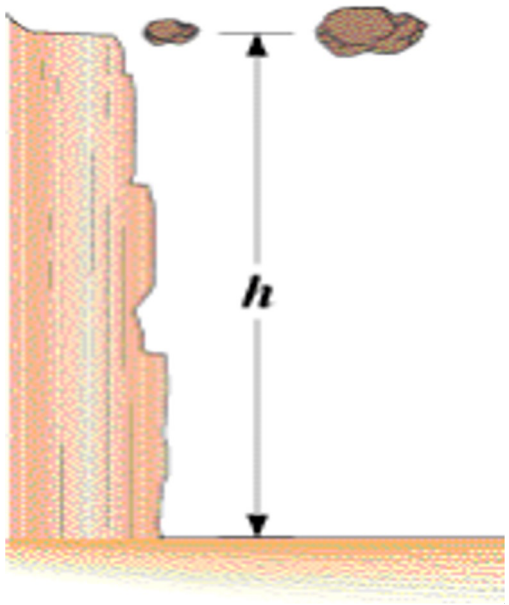


Low PE

$$U_{elec} = qEd$$

Gravitational and Electric Potential Energy

Gravity



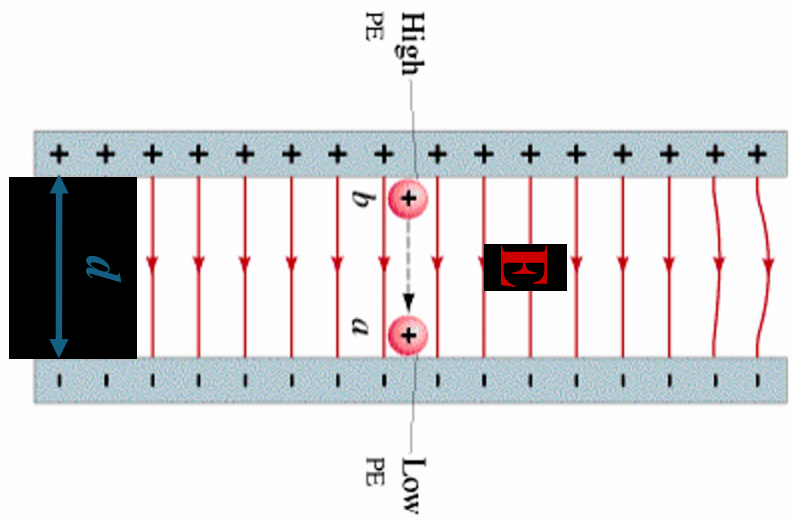
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