Physics 222, September 7

Key Concepts:

- Electrostatic potential energy
- The electric potential
- Conductors in electrostatics
- Capacitors

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Remember Work!

Work is done by a force.

The work done by a force on an object is equal to the magnitude of the force multiplied by the distance the object moves in the direction of the force.

Notation: $\Delta W = \mathbf{F} \cdot \Delta \mathbf{r}$

In one dimension:

Work done on an object by a constant force:

$$W = F_x (x_f - x_i)$$

Work done on an object by a variable force:

$W = \Sigma_{xi}^{xf} F_x \Delta x$, as Δx becomes infinitesimally small.

Work is a scalar, a number with units.

Work can be positive or negative.

Electrostatic potential energy

An electric field E exerts a force $\mathbf{F}_{el} = q\mathbf{E}$ on a charge q.
An external force $\mathbf{F}_{ext} = -q\mathbf{E}$ can cancel the electric force.

The electric field is a conservative field.
The work done on a charge q by an external force $\mathbf{F}_{ext} = -q\mathbf{E}$ when moving it (with constant speed) in the presence of an electric field changes the electrostatic potential energy U of the charge.

Notation: $\Delta U = -q\mathbf{E}\cdot\Delta\mathbf{r}$.

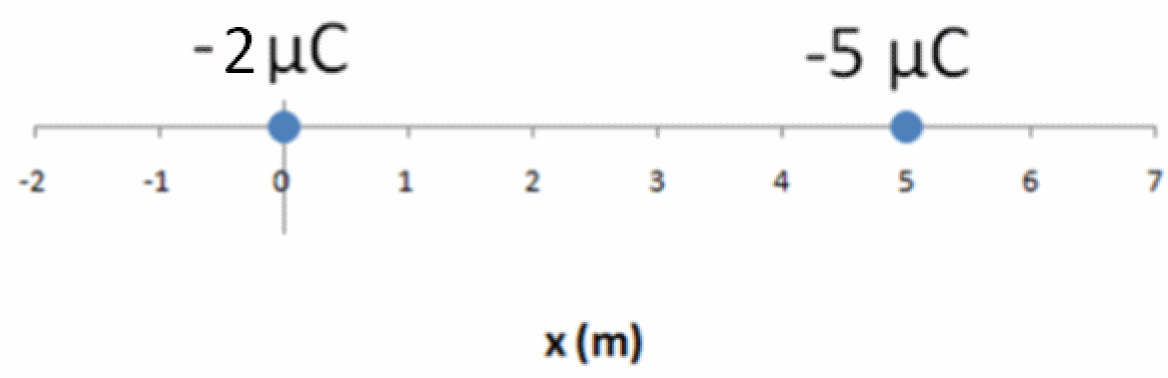
The electrostatic potential energy of a point charge q_2 when it is brought from infinity to a distance r away from another point charge q_1 is

$$U = k_e q_1 q_2/r$$

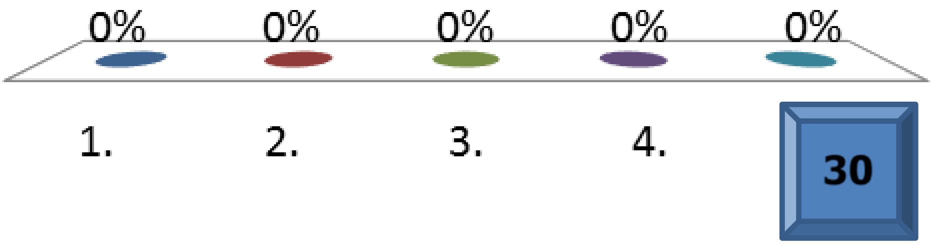
The principal of superposition holds. To find the total electrostatic potential energy of a collection of point charges, sum over all pairs.

For 3 charges: $U = k_e q_1 q_2/r + k_e q_1 q_3/r + k_e q_2 q_3/r$

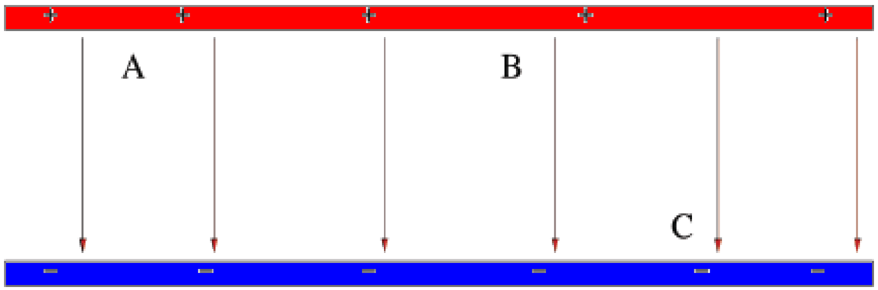
What is the electrostatic potential energy of a -5μC charge located at x = 5 m and a -2 μC charge located at the origin?



1. 0.092 J
2. 0.009 J
3. 0.018 J
4. -0.0018 J
5. $1.6 * 10^4$ J

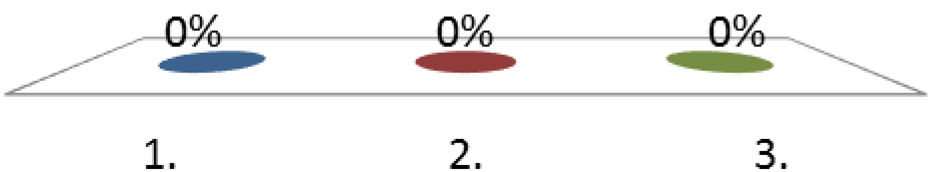


Consider a uniform electric field, for example the field inside a parallel plate capacitor, as shown. If an electron is taken from location A to location B to location C, how does its potential energy change?



Hint: $\Delta U = -q\mathbf{E}\cdot\Delta\mathbf{r}$.
$\mathbf{E}$ and $\Delta\mathbf{r}$ point in the same direction, so $\mathbf{E}\cdot\Delta\mathbf{r}$ is positive.

1. It decreases.
2. It increases.
3. It does not change.



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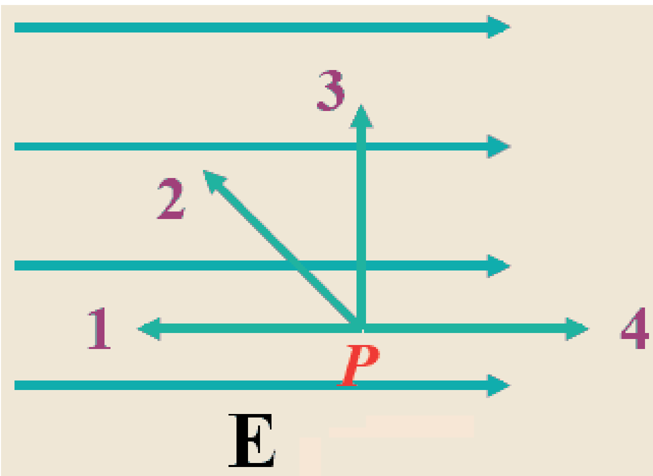
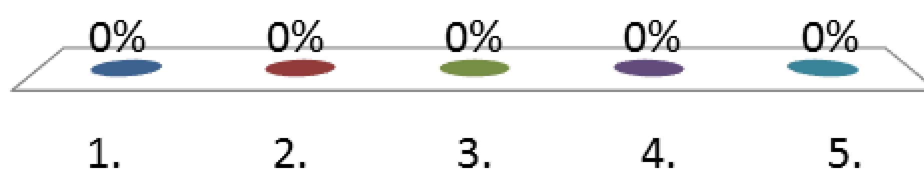
Which requires zero work, to move a positive point charge from point P to point 1, 2, 3, or 4? All those points are the same distance from P.



1. P → 1
2. P → 2
3. P → 3
4. P → 4
5. All require the same amount of work.



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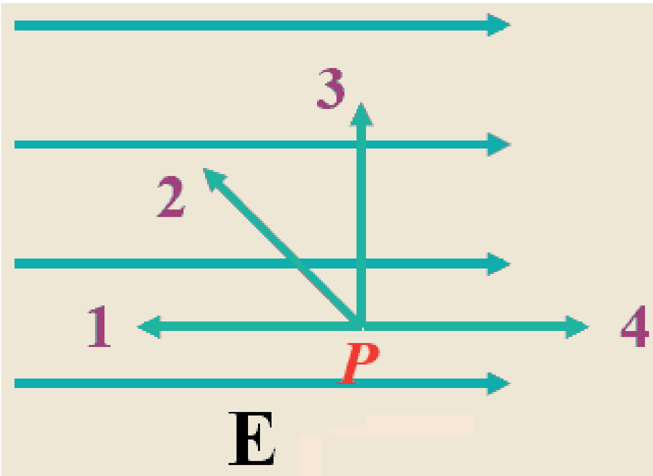
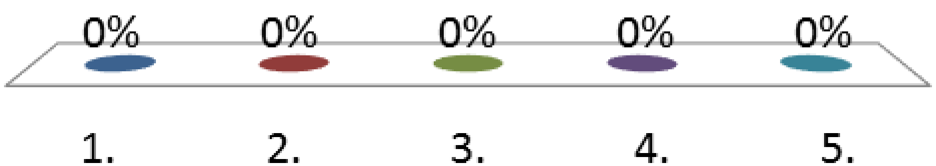
Which requires the most positive work done by an external force, to move a positive point charge from point P to point 1, 2, 3, or 4? All those points are the same distance from P.



1. P → 1
2. P → 2
3. P → 3
4. P → 4
5. All require the same amount of work.



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Electrostatic potential

Potential difference or voltage ΔV:

$$\Delta V = \Delta U/q$$

The voltage between two points is the change in the electrostatic potential energy of a test point charge q when it moves between those points, divided by q.

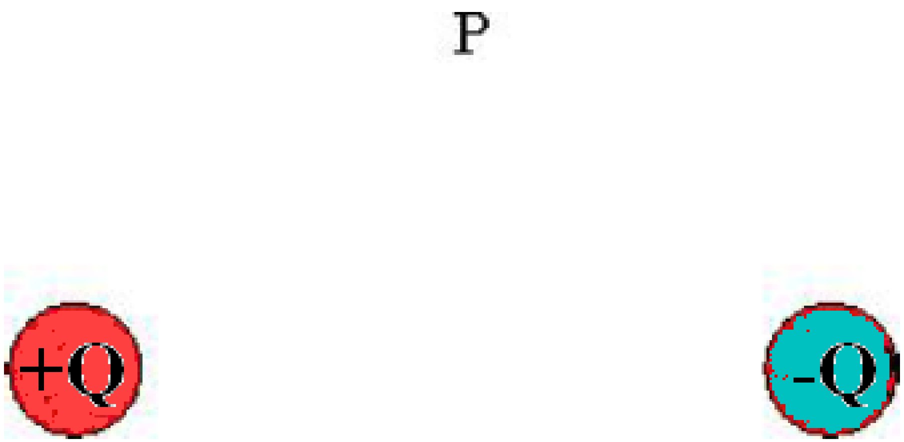
Units: Volt (V) = Joule/Coulomb (J/C).

The potential of a point charge q' a distance r away from the charge:

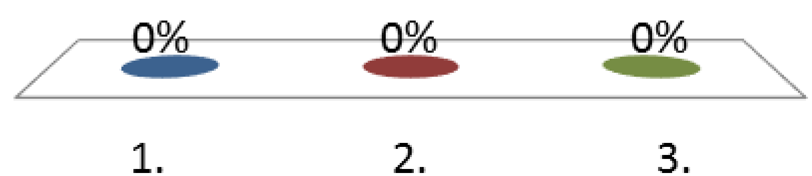
$$V(\mathbf{r}) = q'/(4\pi\varepsilon_0 r) = k_e q'/r.$$

The potential $V(\mathbf{r})$ is a scalar. It only depends on the position $\mathbf{r}$.
Potential due to many source: $V(\mathbf{r}) = V_1(\mathbf{r}) + V_2(\mathbf{r}) + V_3(\mathbf{r}) + \ldots$
We add numbers (with units), not vectors.

Location P is equidistant from the two charges of an electric dipole. The voltage at P is



1. positive.
2. negative.
3. zero.



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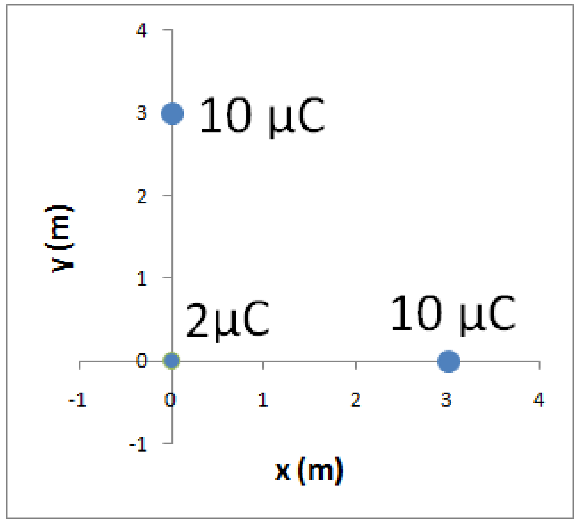
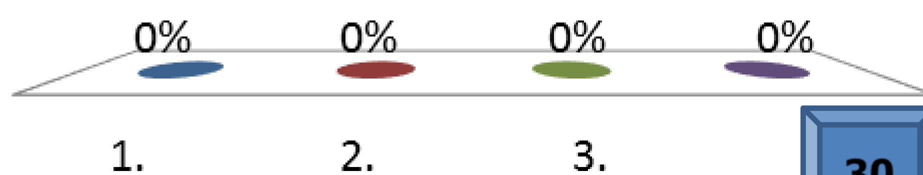
Two 10 μC charges are located at (x, y) = (0, 3m) and (3 m, 0), respectively. What is the potential due to those two charges at the location of the 2 μC charge at the origin?



1. $3*10^4$ V
2. $6*10^4$ V
3. $4.2*10^4$ V
4. $6*10^{-2}$ V



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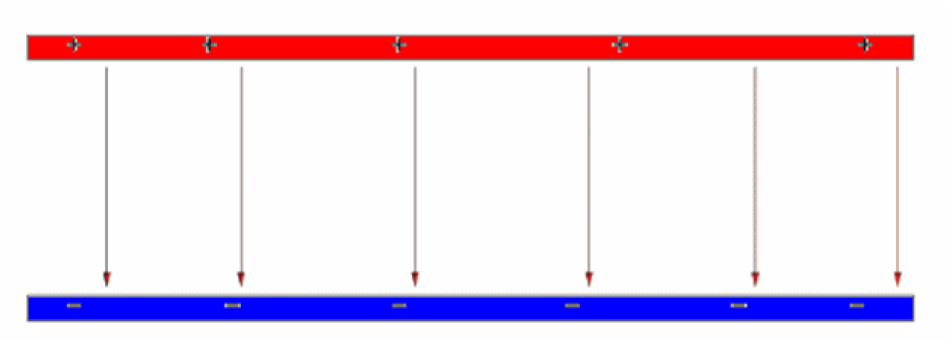
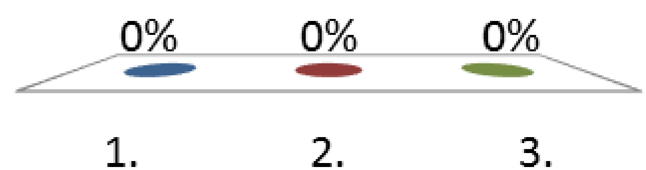
Assume that the potential difference between the positive and negative plate is 100 V. A proton travels from the positive to the negative plate.



Hint:
change in kinetic energy
+ change in potential energy
= 0

1. Its kinetic energy increases by $1.6*10^{-17}$ J = 100 eV.
2. Its kinetic energy decreases by $1.6*10^{-17}$ J = 100 eV.
3. Its kinetic energy does not change, only its potential energy changes.



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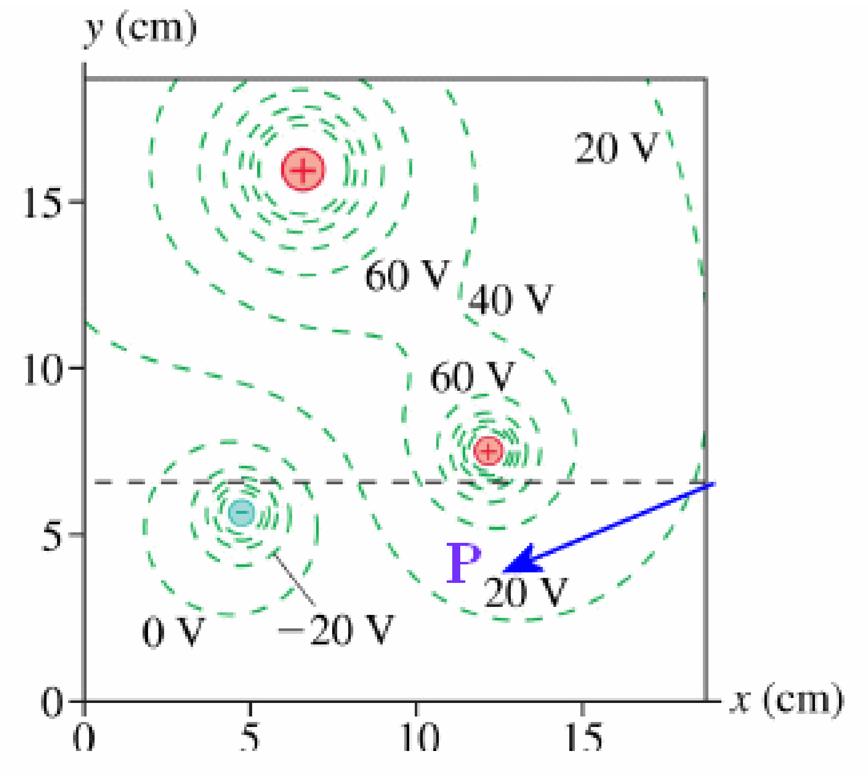
Visualizing the potential

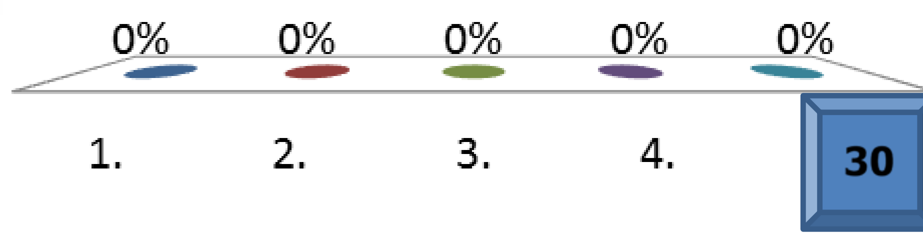
Equipotential surfaces (contour plots).

- We can describe the electric potential pictorially with **equipotential surfaces** (contour plots).
- Each surface corresponds to a different fixed value of the potential.
- Equipotential lines are lines connecting points of the same potential.
- Equipotential lines are always perpendicular to field lines, and therefore perpendicular to the force experienced by a charge in the field.
- If a charge moves along an equipotential line, no work is done; if a charge moves between equipotential lines, work is done.

The graph below shows a contour map of the equipotential surfaces due to 3 point charges. Estimate the magnitude and direction of the electric field at point P.



1. ~20 V/m up
2. ~800 V/m down
3. ~2000 V/m to the right
4. ~40 V/m down
5. ~1000 V/m to the left



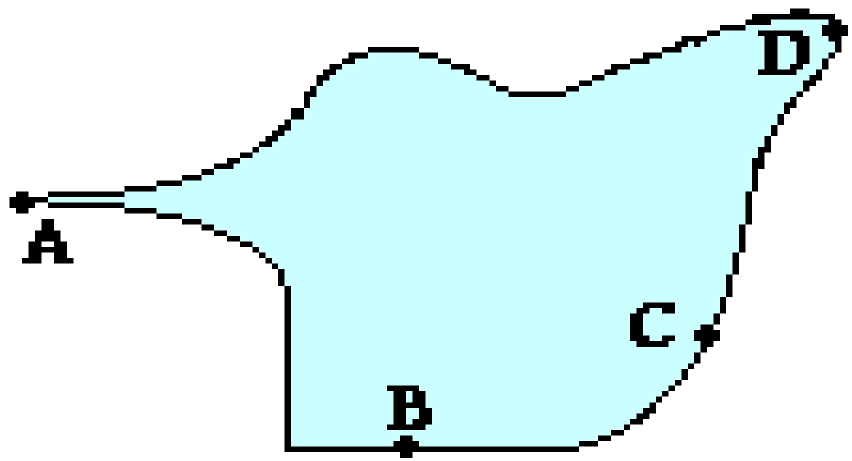
Conductors in electrostatics

In electrostatic equilibrium a conductor has the following properties.

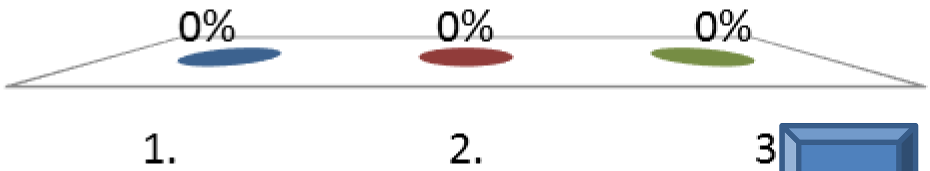
- Any excess charge resides on the surface of the conductor.
- The electric field is zero within the solid part of the conductor. The whole conductor is at the same potential.
- The electric field at the surface of the conductor is perpendicular to the surface.
- Charge accumulates, and the field is strongest on pointy parts of the conductor.

A conductor shields its interior from any outside electric fields.

A diagram of an irregularly shaped charged conductor is shown below. Four locations along the surface are labeled A, B, C, and D. Rank these locations in increasing order of the strength of the electric field just outside the surface, beginning with the smallest electric field



1. B < C < D < A
2. The field is the same everywhere just outside the surface.
3. B = C < D = A



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Capacitors

A capacitor is a device for storing separated charge.

Any two conductors separated by an insulating medium form a capacitor.

Capacitance: $C = Q/V$

Q = amount of charge separated, V = voltage across the conductors.

C depends on the geometry of the device.

Parallel plate capacitor: $C = \varepsilon A/d$

A = area of plates, d = plate separation, $\varepsilon = \kappa\varepsilon_0$,

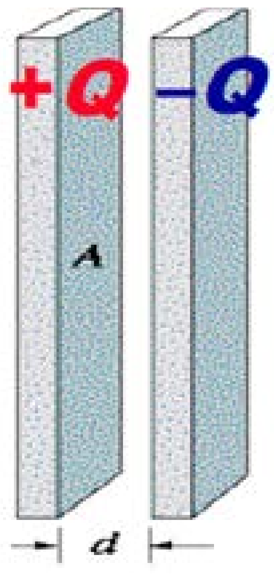
κ = dielectric constant of the material between the plates

Capacitors also store energy.

Electrostatic potential energy stored in the capacitor:

$U = (1/2)QV = (1/2)(Q^2/C) = (1/2)CV^2$

A parallel-plate capacitor initially is connected to a battery and the plates hold charge ±Q. The battery is then disconnected. If the plate spacing is now doubled, what happens?



1. the voltage decreases
2. the voltage increases
3. the charge decreases
4. the charge increases
5. both voltage and charge change