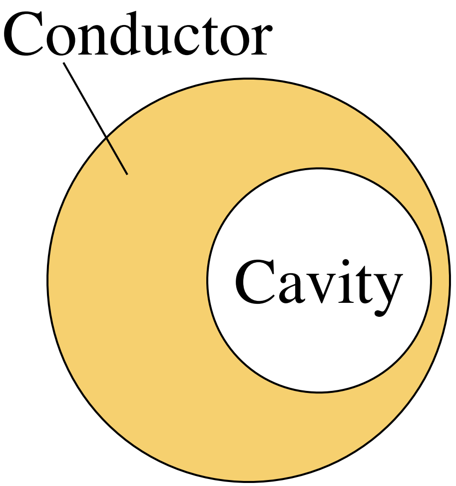
Lecture 15

PHYC 161 Fall 2016

Q23.11

A solid spherical conductor has a spherical cavity in its interior. The cavity is *not* centered on the center of the conductor. If there is a net positive charge on the conductor, the electric field in the cavity



A. points generally from the center of the conductor toward the outermost surface of the conductor.

B. points generally from the outermost surface of the conductor toward the center of the conductor.

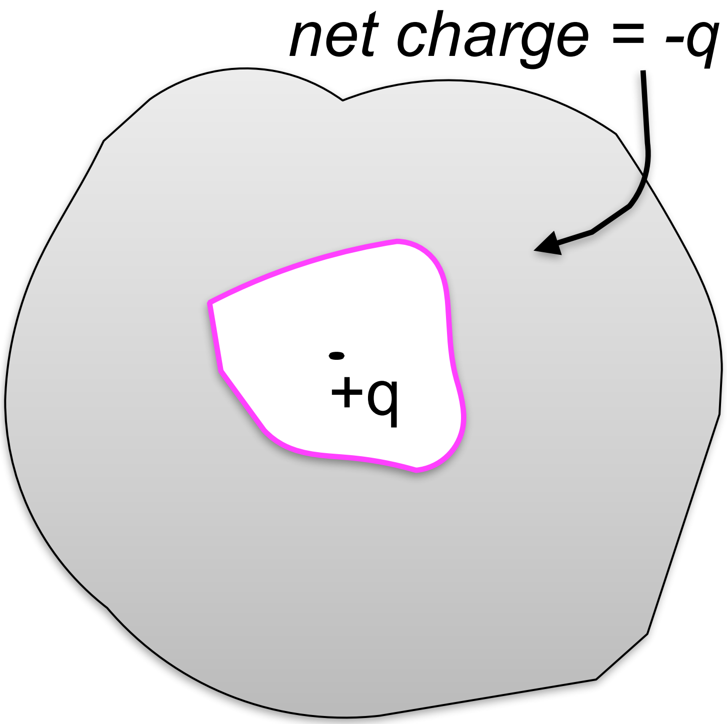
C. is uniform and nonzero.

D. is zero.

E. cannot be determined from information given.

Reading Assignment Quiz - section 22.5

- How much charge is on the outer surface of a conductor if the conductor has net charge -q and the cavity contains a charge +q?



a. zero
b. +2q
c. -q
d. -2q
e. +q

Gravitational Potential Energy

- Once again, the similarities of the gravitational force law and the electric force law bring us to review some physics from last semester.
- Remember that the gravitational potential energy was defined as:

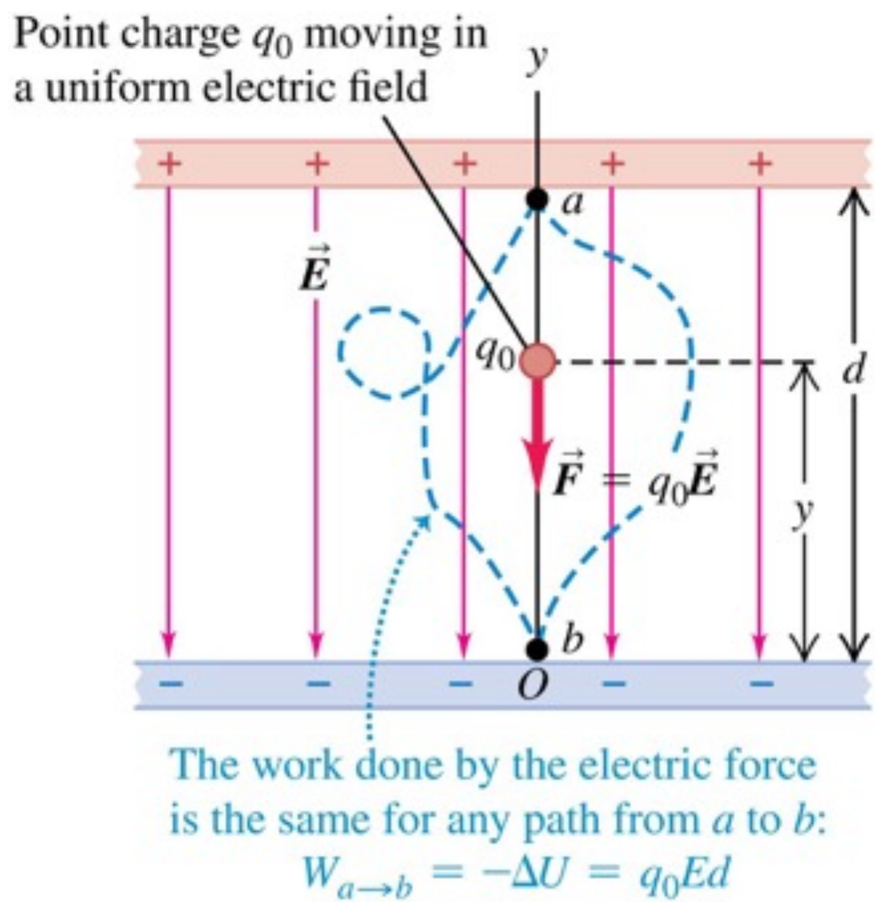
$$\Delta U_g = -W_g = -\int_1^2 \vec{F}_g \cdot d\vec{r}$$

- If you are close to the earth's surface, you can take the force to be essentially constant (=mg) and the above just gets you

$$\Delta U_g = \int_1^2 (mg)\,dy = mg\left(y_2 - y_1\right) = mgh$$

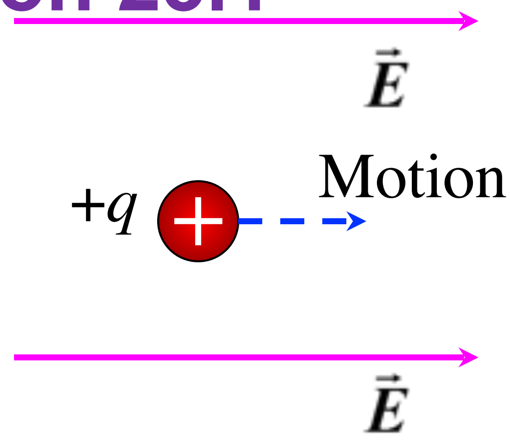
Electric potential energy in a uniform field

- In the figure, a pair of charged parallel metal plates sets up a uniform, downward electric field.
- The field exerts a downward force on a positive test charge.
- As the charge moves downward from point *a* to point *b*, the work done by the field is *independent* of the path the particle takes.



Reading Assignment Quiz - section 23.1

When a positive charge moves in the direction of the electric field,



A. the field does positive work on it and the potential energy increases.

B. the field does positive work on it and the potential energy decreases.

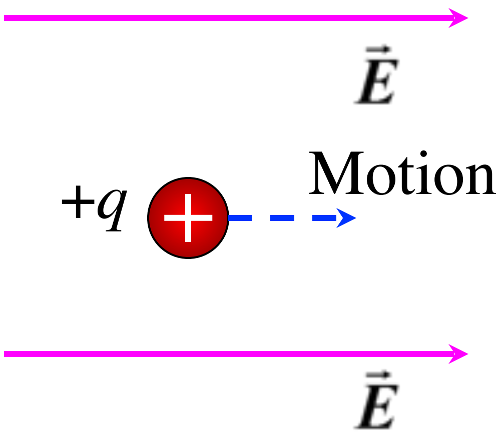
C. the field does negative work on it and the potential energy increases.

D. the field does negative work on it and the potential energy decreases.

E. the field does zero work on it and the potential energy remains constant.

A23.1

When a positive charge moves in the direction of the electric field,



A. the field does positive work on it and the potential energy increases.

B. the field does positive work on it and the potential energy decreases.

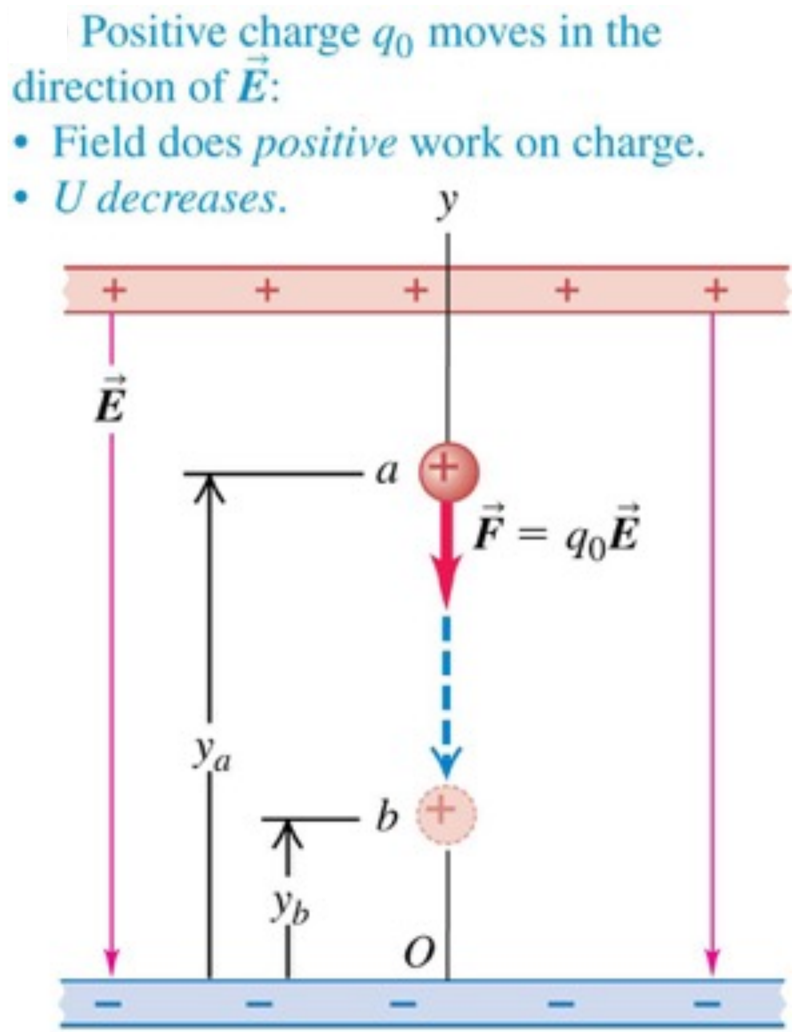
C. the field does negative work on it and the potential energy increases.

D. the field does negative work on it and the potential energy decreases.

E. the field does zero work on it and the potential energy remains constant.

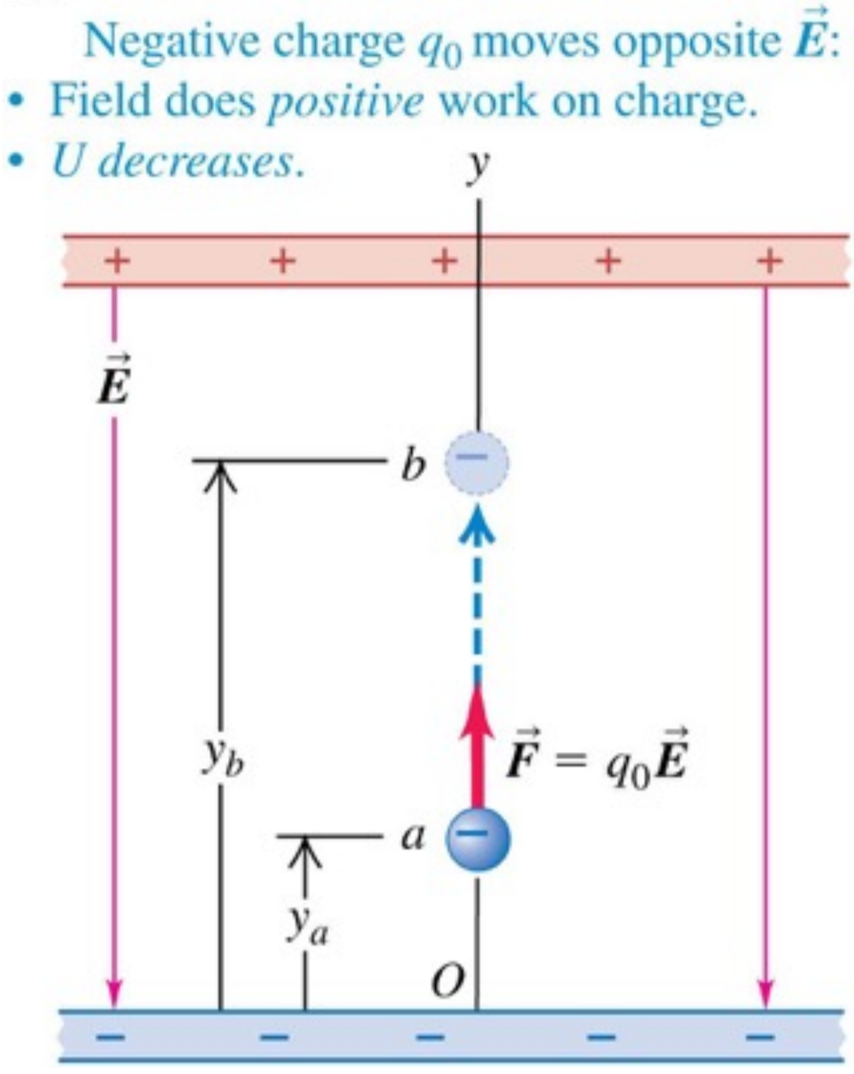
A positive charge moving in a uniform field

- If the positive charge moves in the direction of the field, the field does *positive* work on the charge.
- The potential energy *decreases*.



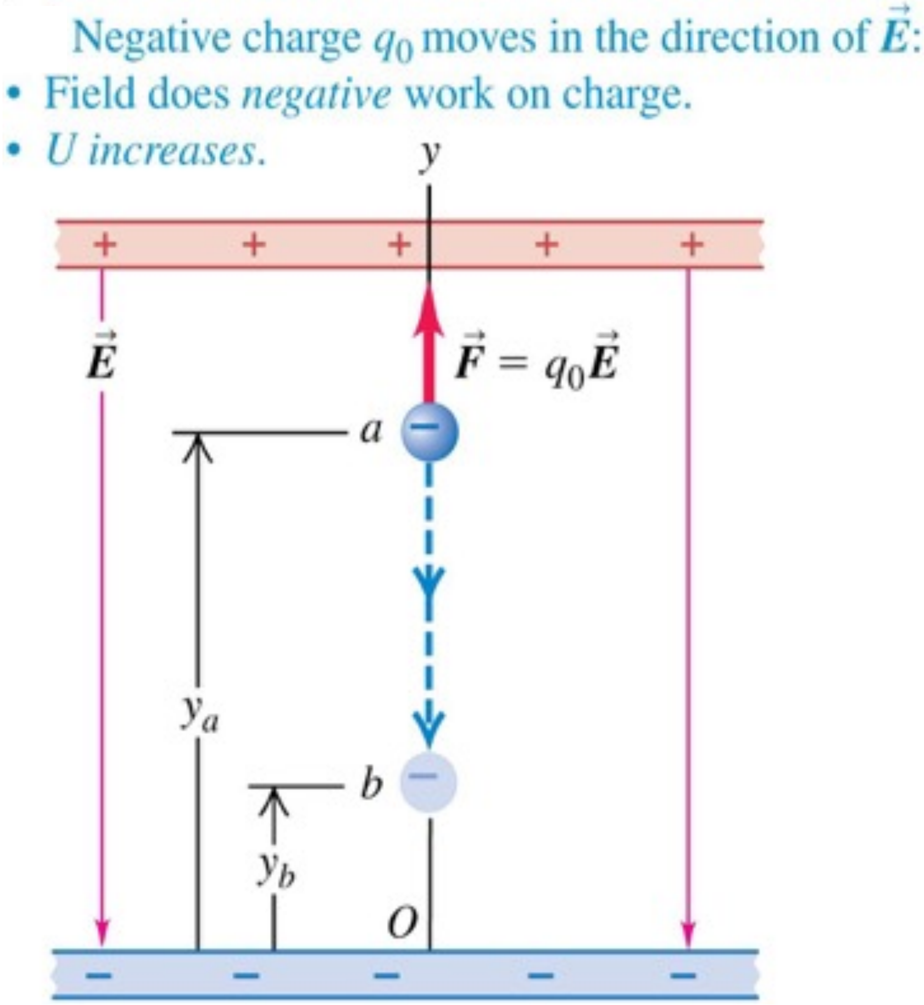
A negative charge moving in a uniform field

- If the negative charge moves opposite the direction of the field, the field does *positive* work on the charge.
- The potential energy *decreases*.



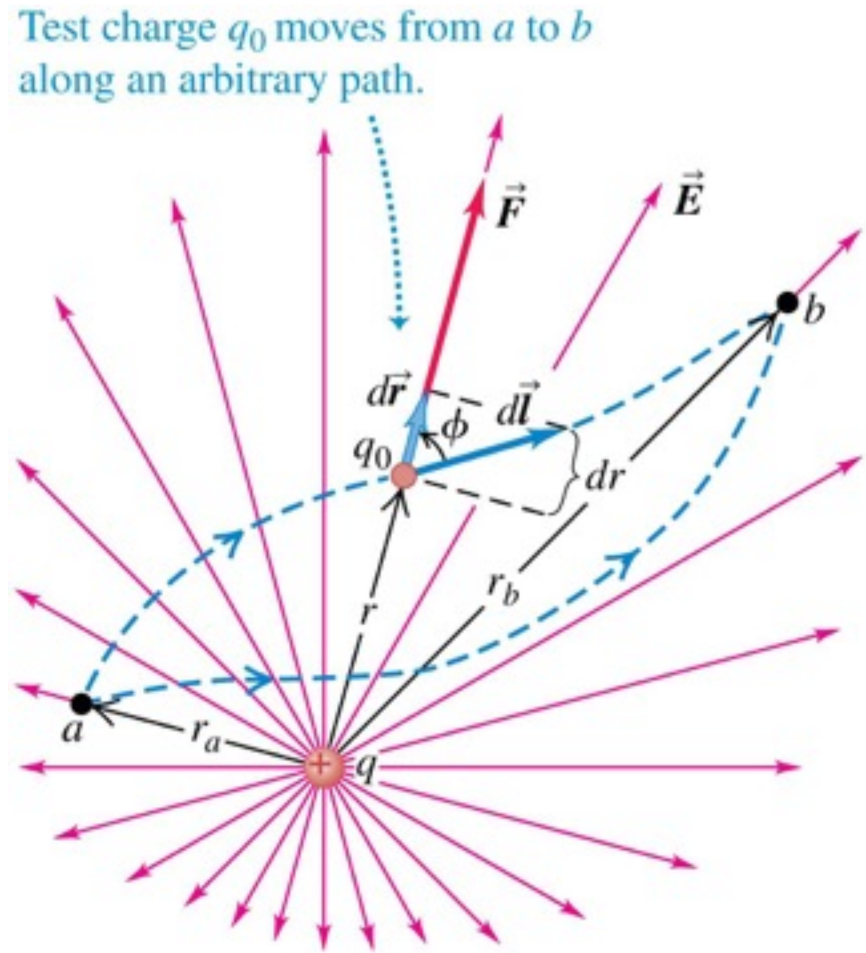
A negative charge moving in a uniform field

- If the negative charge moves in the direction of the field, the field does *negative* work on the charge.
- The potential energy *increases*.



Electric potential energy of two point charges

- The work done by the electric field of one point charge on another does not depend on the path taken.
- Therefore, the electric potential energy only depends on the distance between the charges.



Electric potential energy of two point charges

- The electric potential energy of two point charges only depends on the distance between the charges.

Electric potential energy of two point charges:

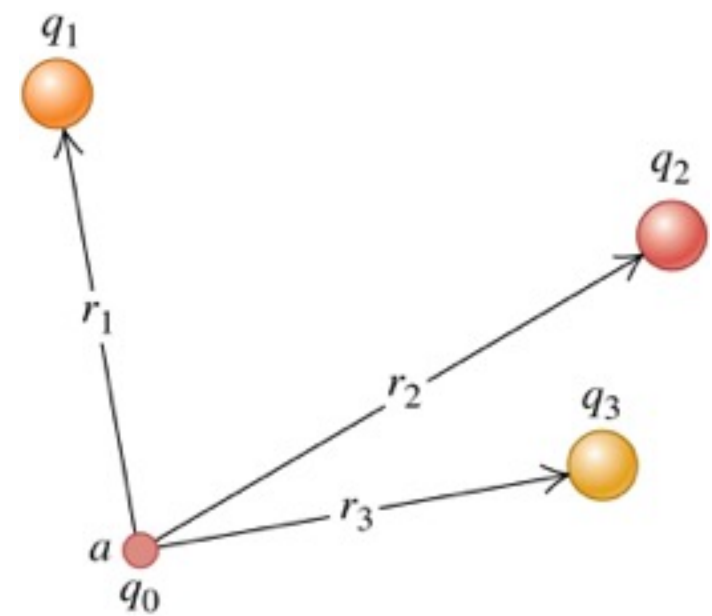
$$U = \frac{1}{4\pi\epsilon_0}\frac{qq_0}{r}$$

- U: Electric potential energy of two point charges
- $q q_0$: Values of two charges
- r: Distance between two charges
- ϵ_0: Electric constant

- This equation is valid no matter what the signs of the charges are.
- Potential energy is defined to be zero when the charges are infinitely far apart.

Electrical potential with several point charges

- The potential energy associated with q_0 depends on the other charges and their distances from q_0.
- The electric potential energy associated with q_0 is the *algebraic* sum:



Electric potential energy of point charge q_0 and collection of charges $q_1, q_2, q_3, \ldots$

$$U = \frac{q_0}{4\pi\epsilon_0}\left(\frac{q_1}{r_1} + \frac{q_2}{r_2} + \frac{q_3}{r_3} + \cdots\right) = \frac{q_0}{4\pi\epsilon_0}\sum_i \frac{q_i}{r_i}$$

Electric constant

Distances from q_0 to $q_1, q_2, q_3, \ldots$

But, this is not the TOTAL potential energy of the system!

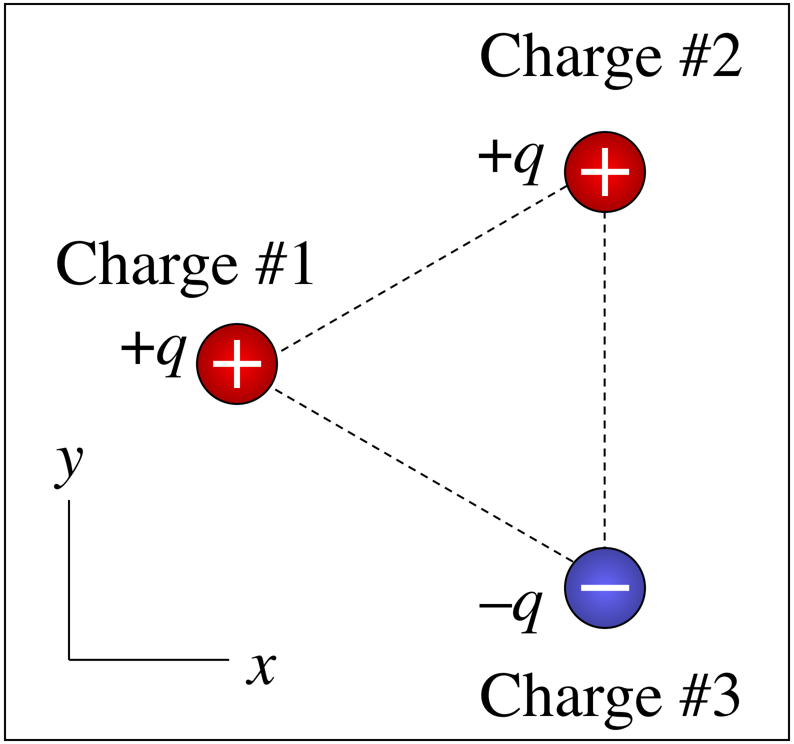
Total potential energy of the system of charges

$$U = \frac{1}{4\pi\epsilon_0} \sum_{i<j} \frac{q_i q_j}{r_{ij}}$$

Sum over all unique pairs of point charges

Q23.5

The electric potential energy of two point charges approaches zero as the two point charges move farther away from each other. If the three point charges shown here lie at the vertices of an equilateral triangle, the electric potential energy of the system of three charges is



A. positive.

B. negative.

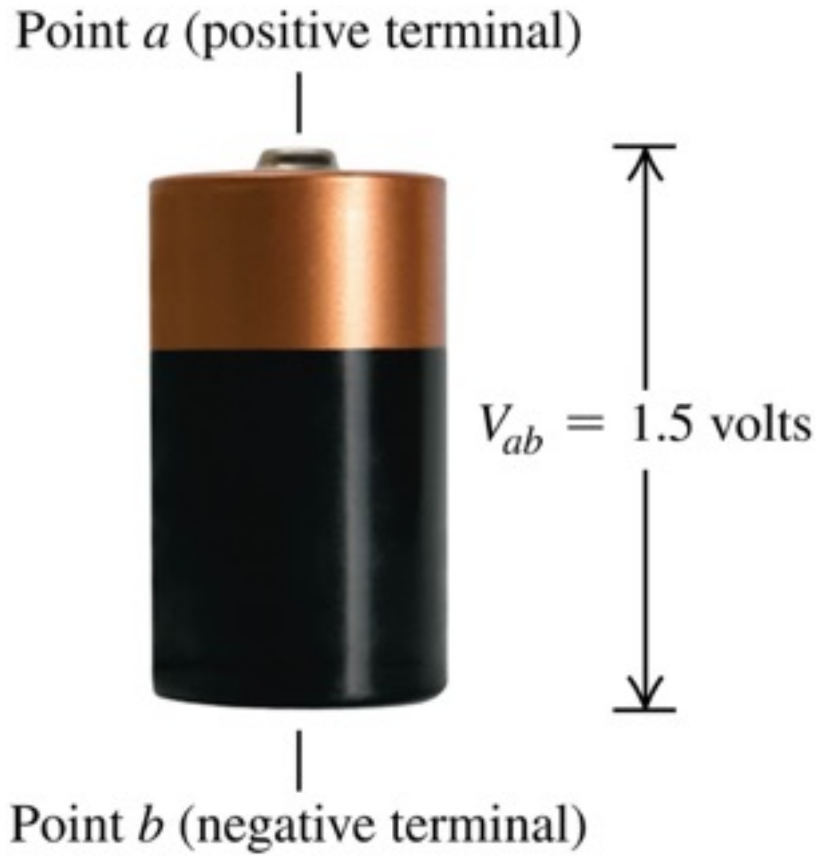
C. zero.

D. either positive or negative.

E. either positive, negative, or zero.

Electric potential

- **Potential** is *potential energy per unit charge*.
- The potential of *a* with respect to *b* ($V_{ab} = V_a - V_b$) equals the work done by the electric force when a *unit* charge moves from *a* to *b*.



Electric potential

- The potential due to a single point charge is:

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

Electric potential due to a point charge (V); Value of point charge (q); Distance from point charge to where potential is measured (r); Electric constant (ϵ_0)

- Like electric field, potential is independent of the test charge that we use to define it.

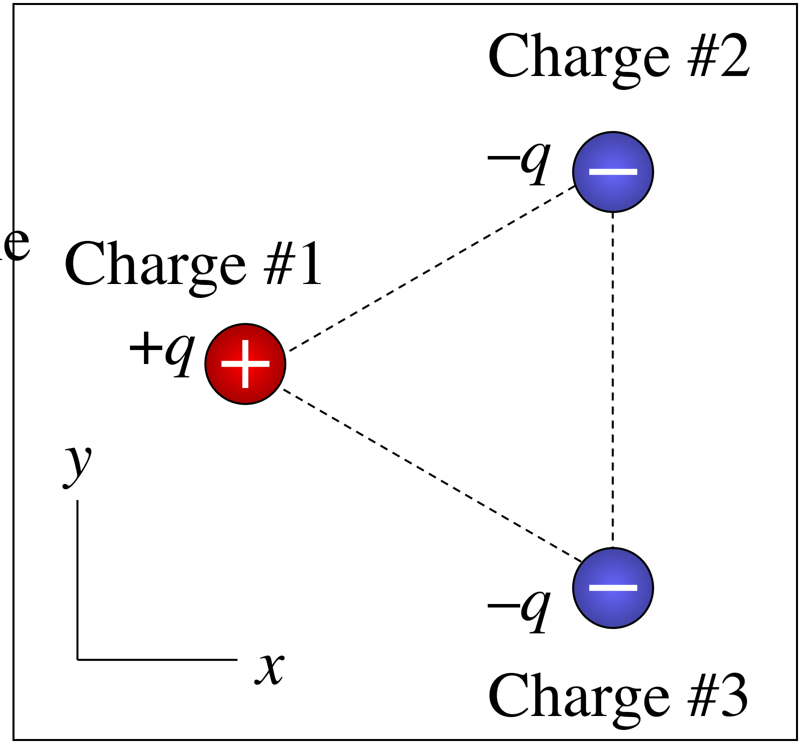
- For a collection of point charges:

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

Electric potential due to a collection of point charges (V); Value of *i*th point charge (q_i); Distance from *i*th point charge to where potential is measured (r_i); Electric constant (ϵ_0)

Q23.8

The electric potential due to a point charge approaches zero as you move farther away from the charge. If the three point charges shown here lie at the vertices of an equilateral triangle, the electric potential at the center of the triangle is



A. positive.

B. negative.

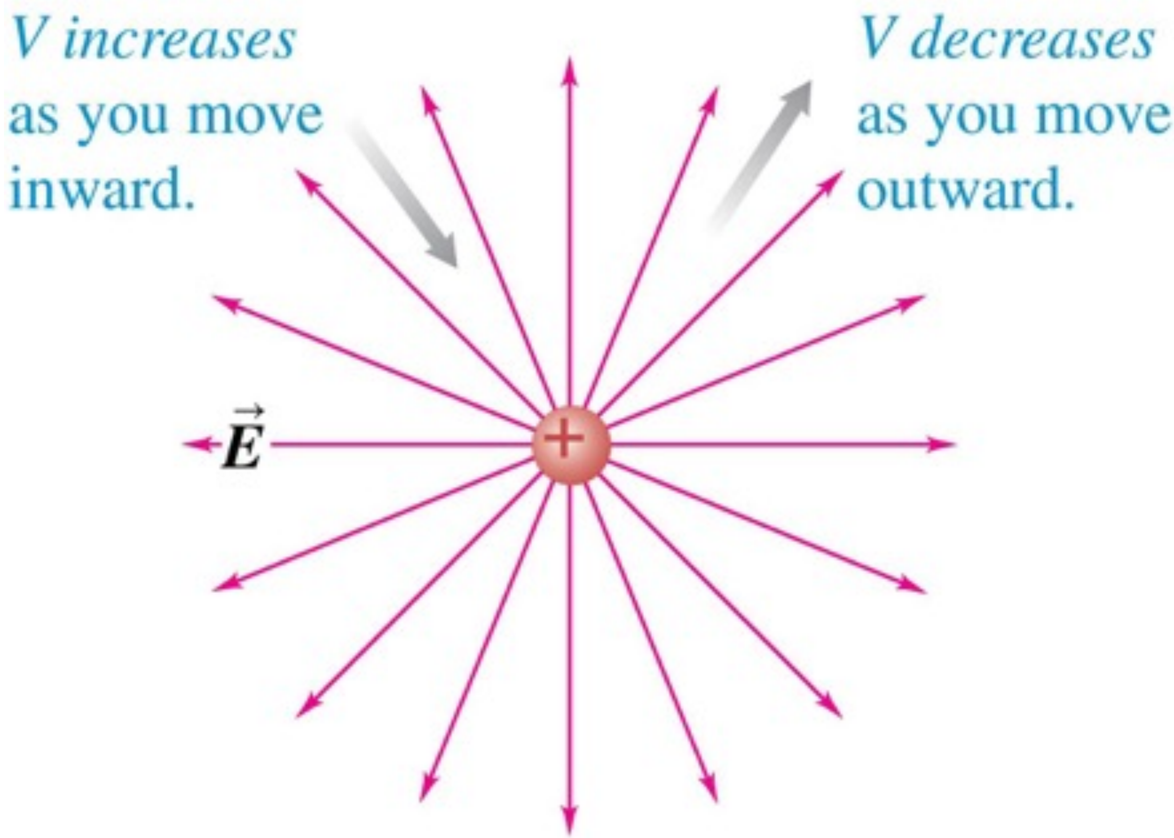
C. zero.

D. either positive or negative.

E. either positive, negative, or zero.

Finding electric potential from the electric field

- If you move in the direction of the electric field, the electric potential *decreases*, but if you move opposite the field, the potential *increases*.



Electric potential and electric field

- Moving with the direction of the electric field means moving in the direction of decreasing V, and vice versa.
- To move a unit charge slowly against the electric force, we must apply an external force per unit charge equal and opposite to the electric force per unit charge.
- The electric force per unit charge is the electric field.
- The potential difference $V_a - V_b$ equals the work done per unit charge by this external force to move a unit charge from b to a:

$$V_a - V_b = -\int_b^a \vec{E} \cdot d\vec{l}$$

- The unit of electric field can be expressed as 1 N/C = 1 V/m.

The electron volt

- When a particle with charge q moves from a point where the potential is V_b to a point where it is V_a, the change in the potential energy U is

$$U_a - \mathrm{U}_b = q(V_a - V_b)$$

- If charge q equals the magnitude e of the electron charge, and the potential difference is 1 V, the change in energy is defined as one electron volt (eV):

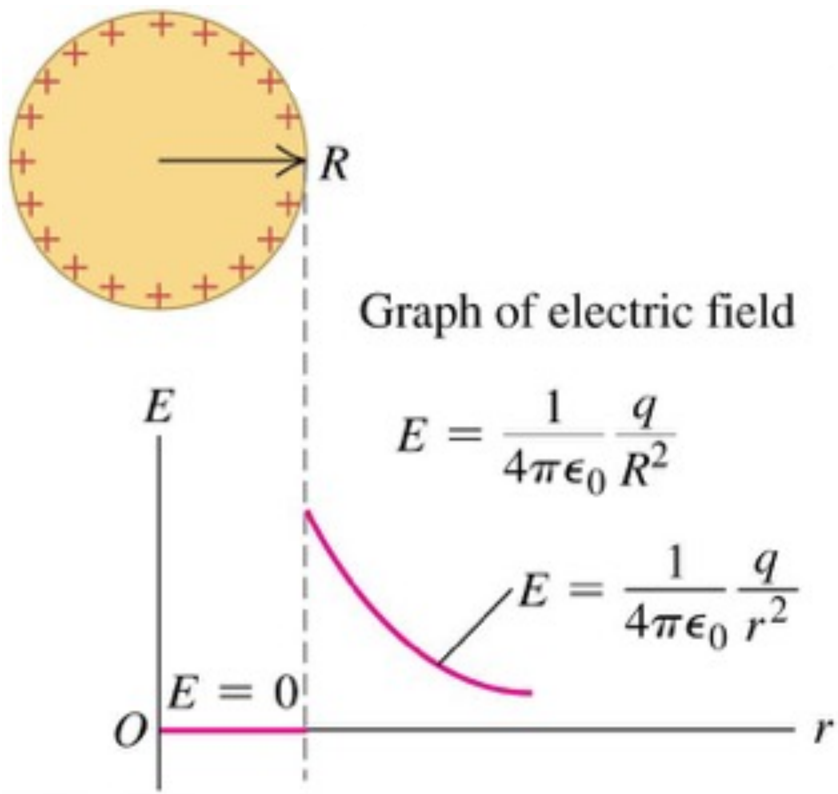
$$1\ \mathrm{eV} = 1.602 \times 10^{-19}\ \mathrm{J}$$

Electron volts and cancer radiotherapy

- One way to destroy a cancerous tumor is to aim high-energy electrons directly at it.
- Each electron has a kinetic energy of 4 to 20 MeV (1 MeV = 10^6 eV), and transfers its energy to the tumor through collisions with the tumor's atoms.
- Electrons in this energy range can penetrate only a few centimeters into a patient, which makes them useful for treating superficial tumors, such as those on the skin or lips.

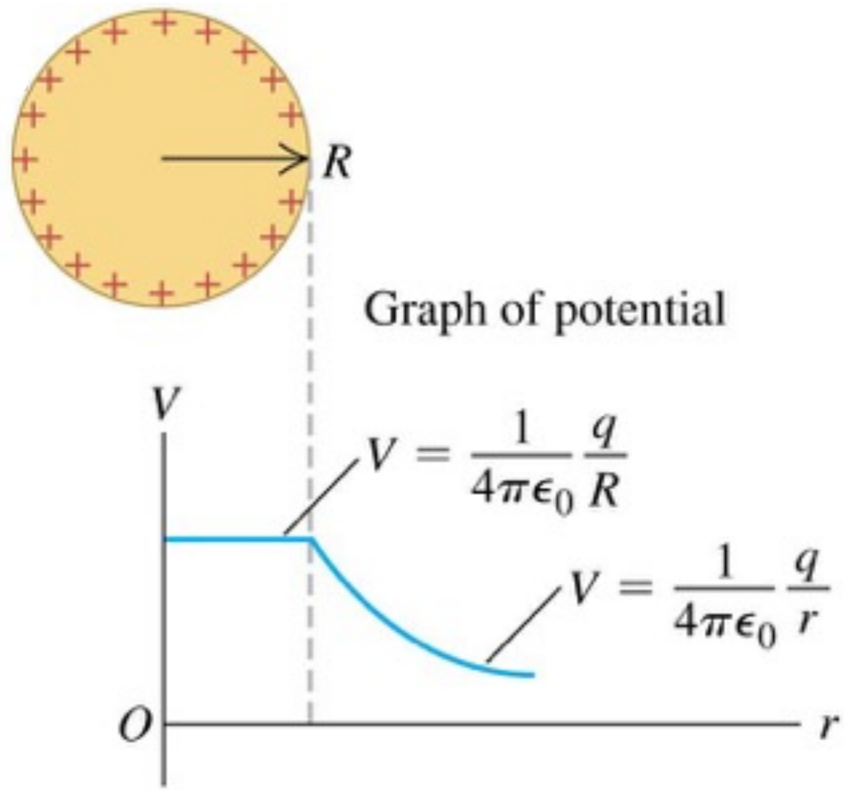
Electric potential and field of a charged conductor

- A solid conducting sphere of radius R has a total charge q.
- The electric field *inside* the sphere is zero everywhere.



Electric potential and field of a charged conductor

- The potential is the *same* at every point inside the sphere and is equal to its value at the surface.

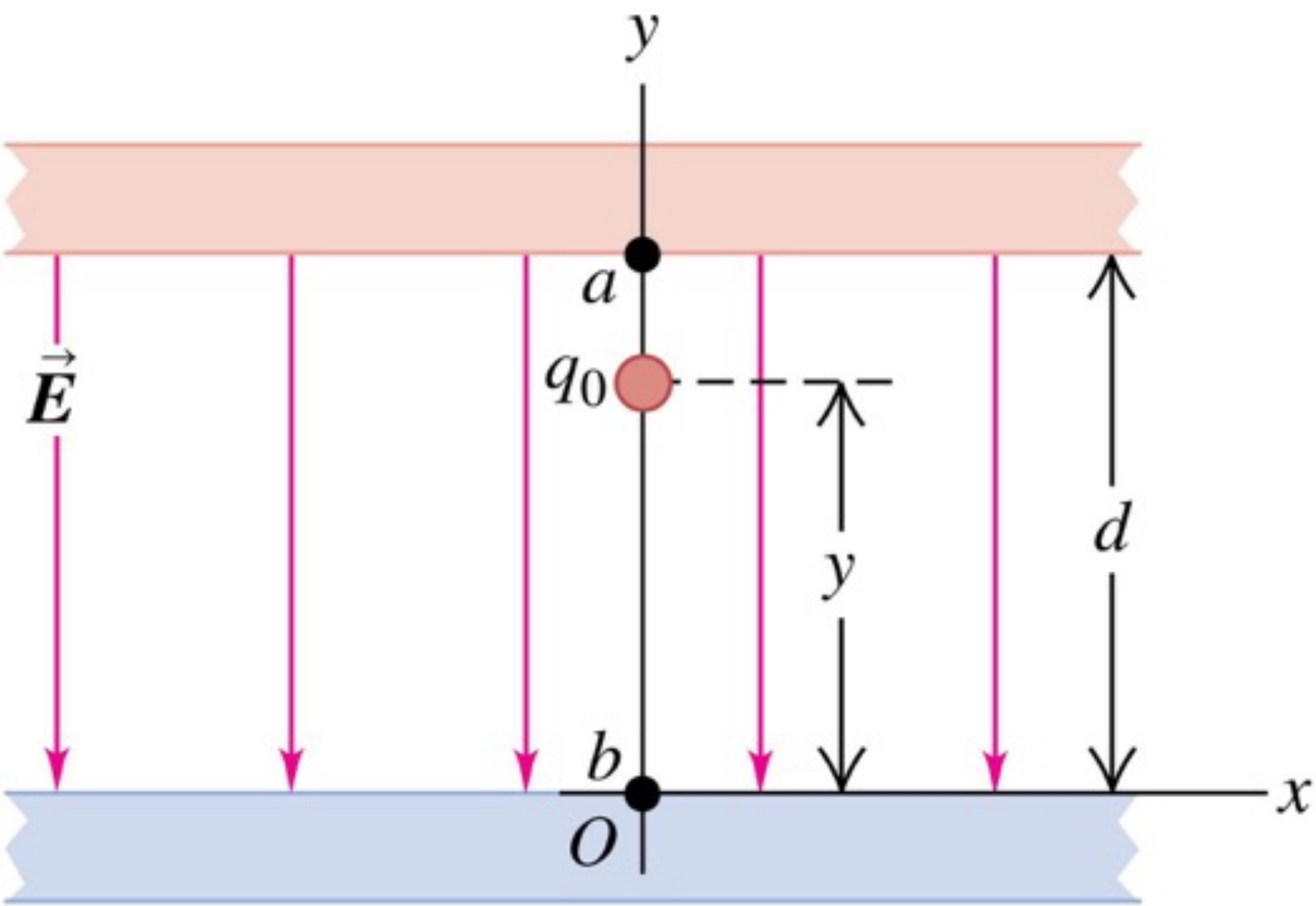


Ionization and corona discharge

- At an electric-field magnitude of about 3×10^6 V/m or greater, air molecules become ionized, and air becomes a conductor.
- For a charged conducting sphere, $V_{\text{surface}} = E_{\text{surface}} R$.
- Thus, if E_{m} is the electric-field magnitude at which air becomes conductive (known as the **dielectric strength** of air), then the maximum potential V_{m} to which a spherical conductor can be raised is $V_{\text{m}} = RE_{\text{m}}$.

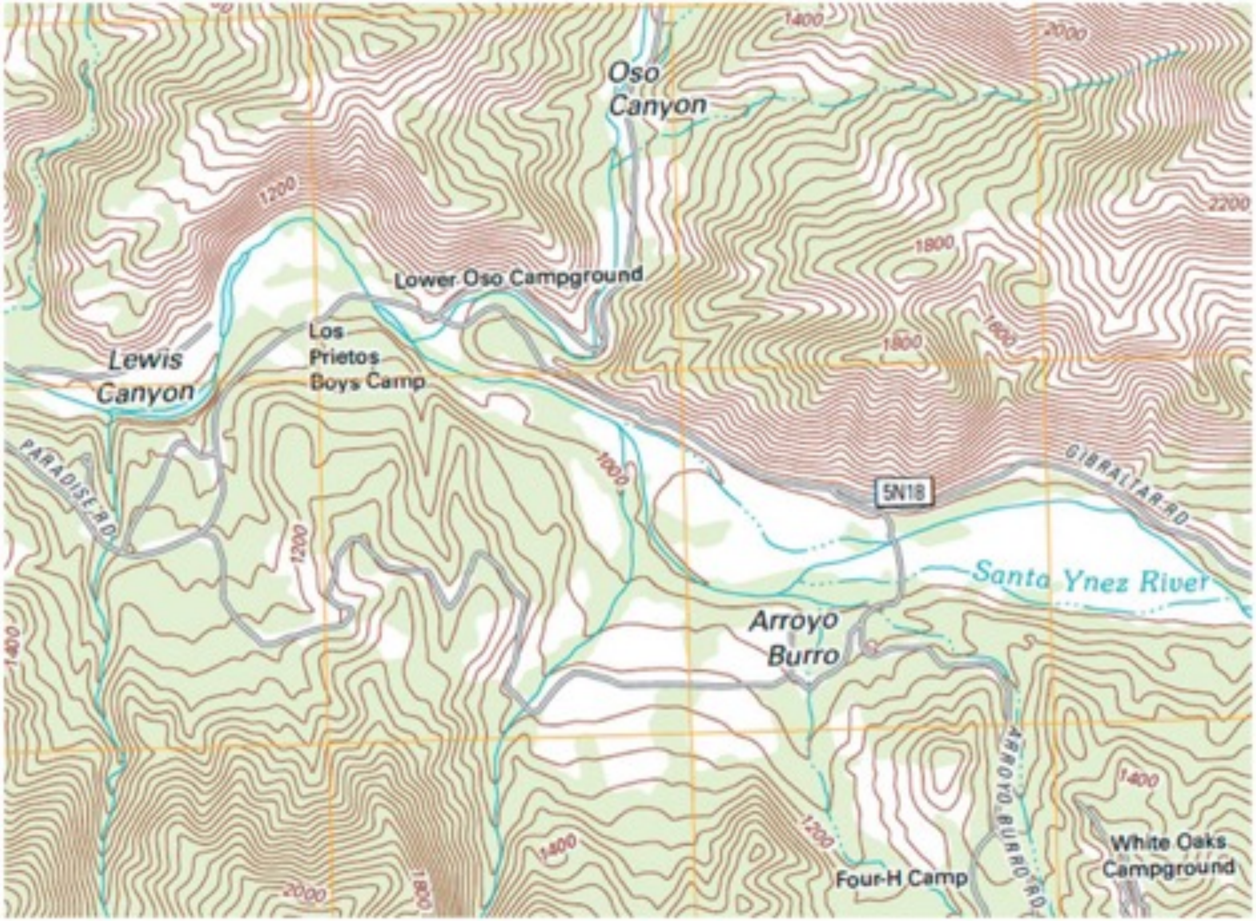
Oppositely charged parallel plates

- The potential at any height y between the two large oppositely charged parallel plates is $V = Ey$.



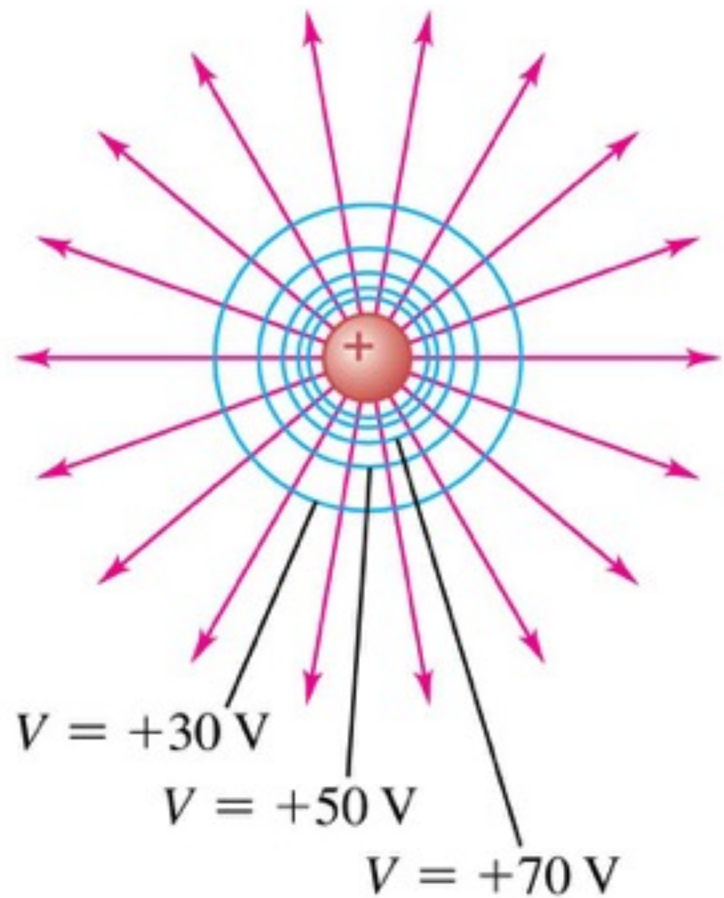
Equipotential surfaces

- Contour lines on a topographic map are curves of constant elevation and hence of constant gravitational potential energy.

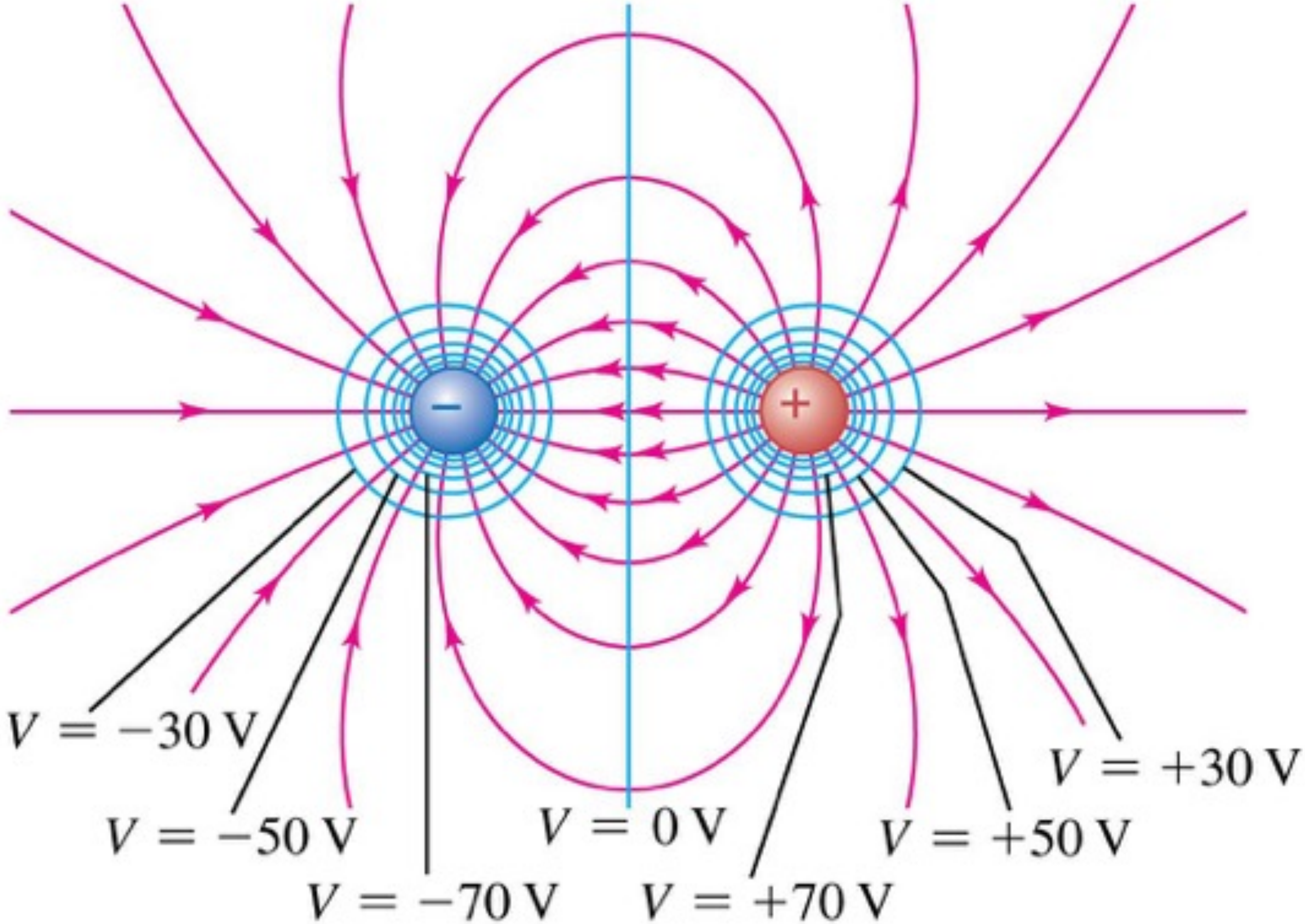


Equipotential surfaces and field lines

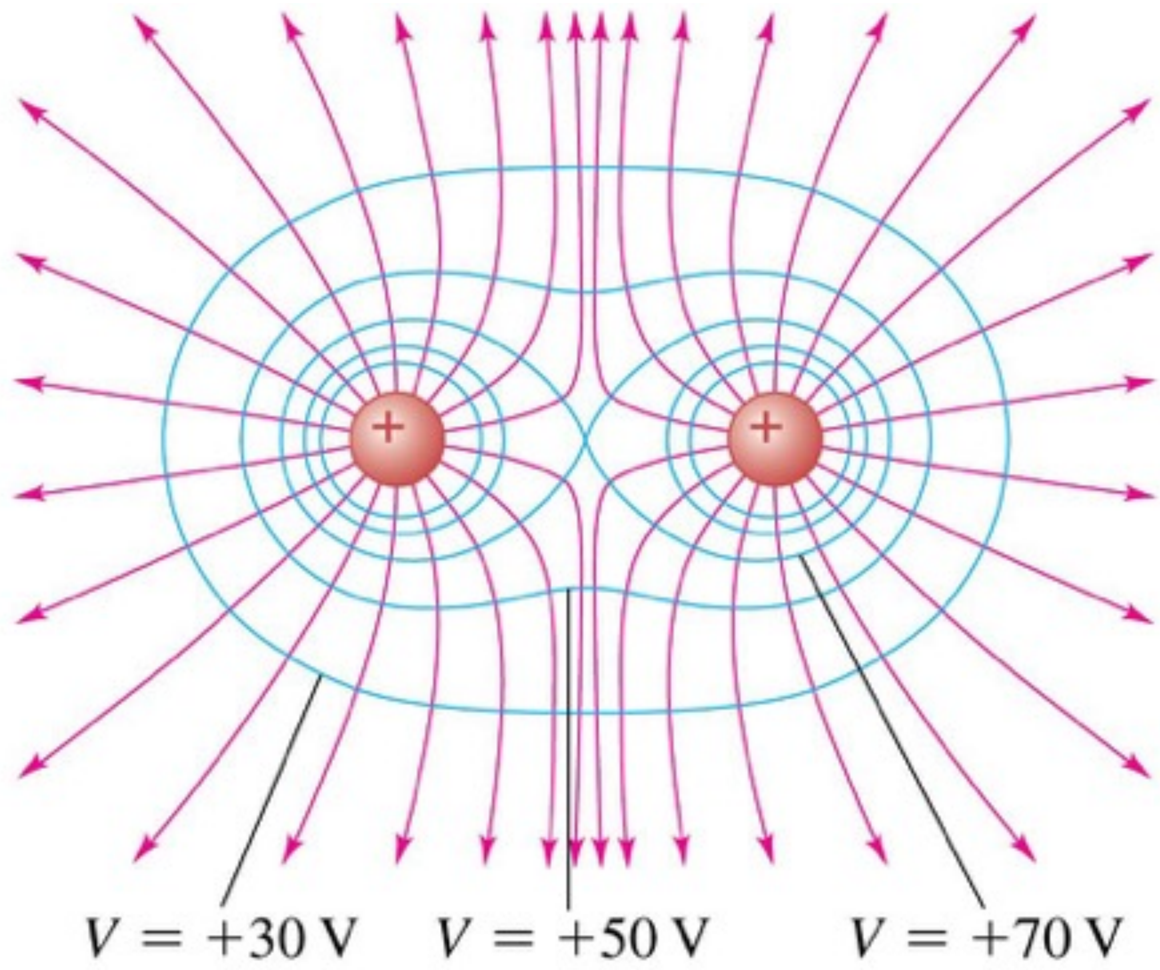
- An **equipotential surface** is a surface on which the electric potential is the same at every point.
- Field lines and equipotential surfaces are always mutually perpendicular.
- Shown are cross sections of equipotential surfaces (blue lines) and electric field lines (red lines) for a single positive charge.



Equipotential surfaces and field lines for a dipole

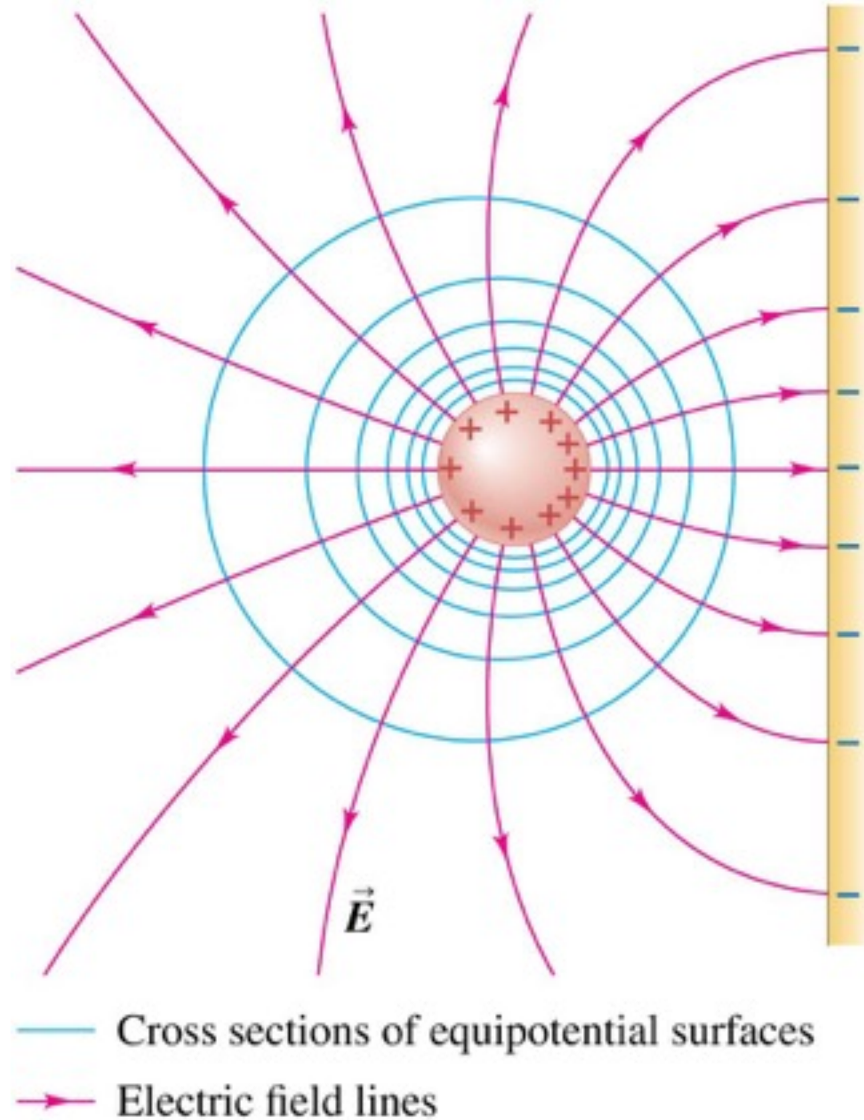


Field and potential of two equal positive charges



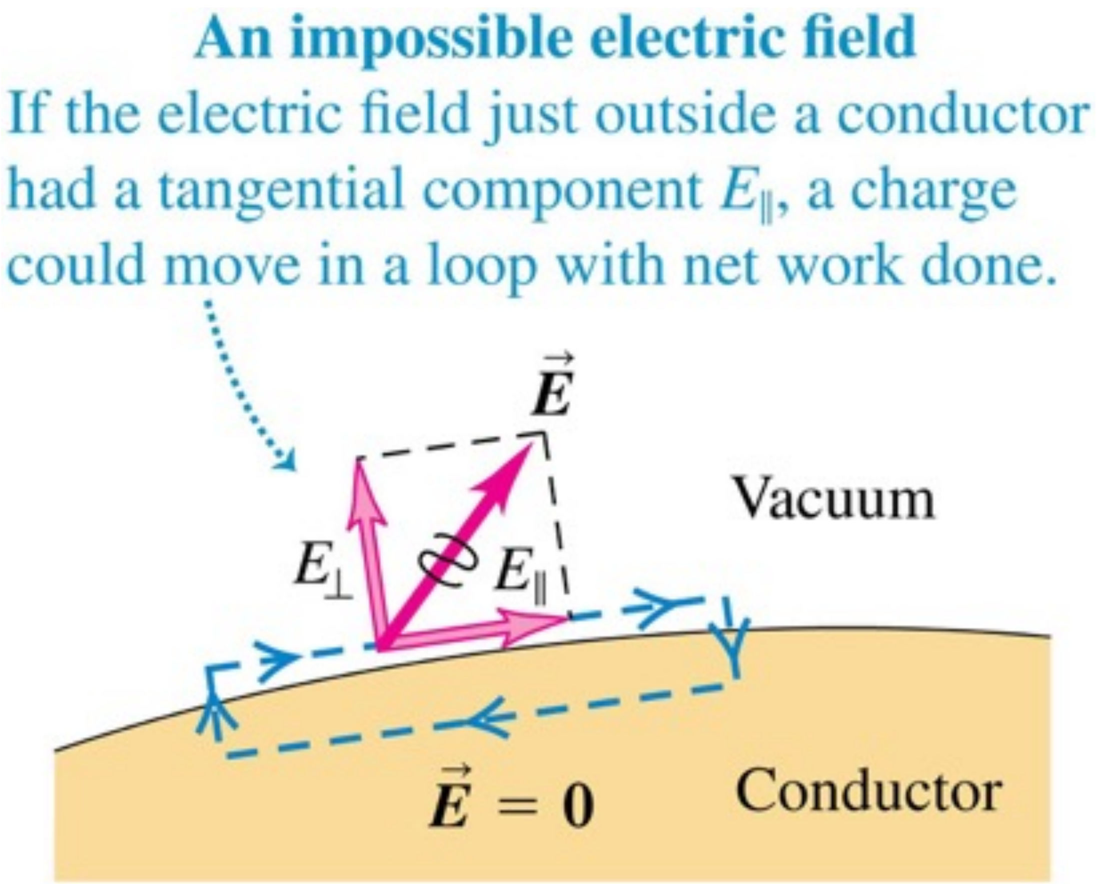
Equipotentials and conductors

- When all charges are at rest:
  - the surface of a conductor is always an equipotential surface.
  - the electric field just outside a conductor is always perpendicular to the surface.



Equipotentials and conductors

- If the electric field had a tangential component at the surface of a conductor, a net amount of work would be done on a test charge by moving it around a loop as shown here—which is impossible because the electric force is conservative.



Potential gradient

- The components of the electric field can be found by taking partial derivatives of the electric potential:

Electric field components found from potential: Each electric field component ...

$$E_x = -\frac{\partial V}{\partial x} \qquad E_y = -\frac{\partial V}{\partial y} \qquad E_z = -\frac{\partial V}{\partial z}$$

... equals the negative of the corresponding partial derivative of electric potential function V.

- The electric field is the negative gradient of the potential:

$$\vec{\boldsymbol{E}} = -\vec{\nabla} V$$