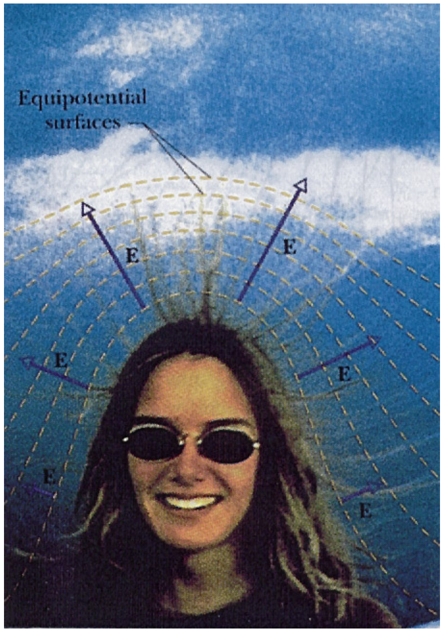
Physics 2102



Electric Potential

Electric potential energy, electric potential

Electric potential energy of a system =
= − work (against electrostatic forces) needed to needed to build the system

$$U = -W$$

Electric potential difference between two points = work per unit charge needed to move a charge between the two points:

$$\Delta V = V_f - V_i = -W/q$$

Electric potential energy, electric potential

Units : [U] = [W]=Joules;

[V]=[W/q] = Joules/C= Nm/C= Volts

[E]= N/C = Vm

1eV = work needed to move an electron through a potential difference of 1V:

$W=q\Delta V = e \times 1V$

$= 1.60\ 10^{-19}\ C \times 1J/C = 1.60\ 10^{-19}\ J$

Electric field lines and equipotential surfaces

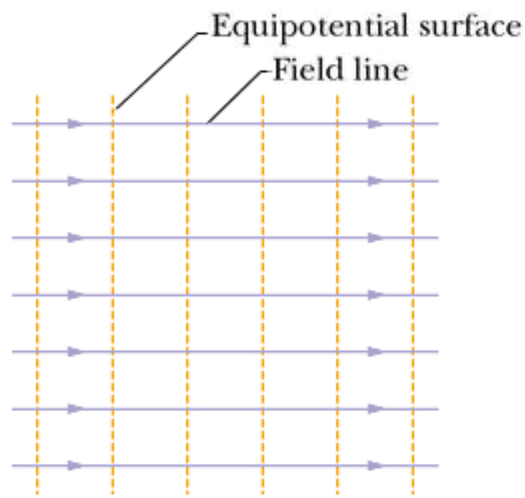
Given a charged system, we can:

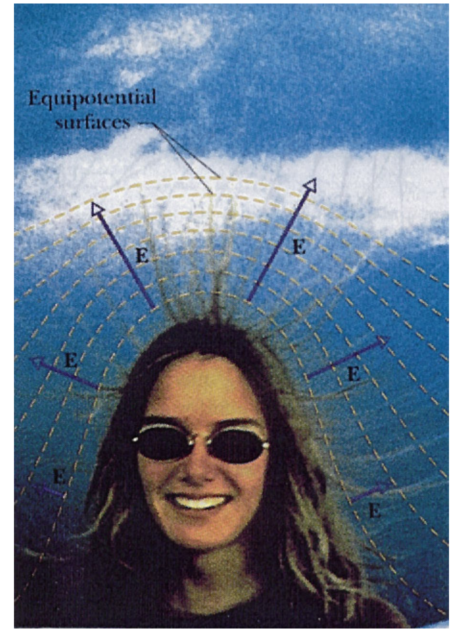
• calculate the electric field everywhere in space

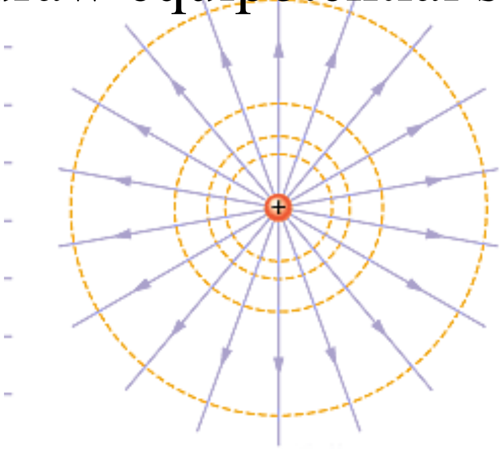
• calculate the potential difference between every point and a point where V=0

• draw electric field lines

• draw equipotential surfaces







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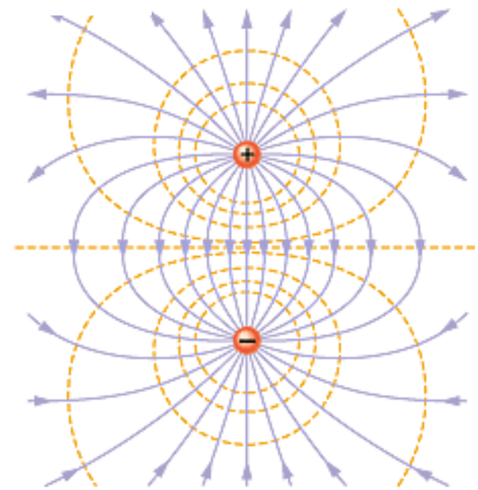


(c)

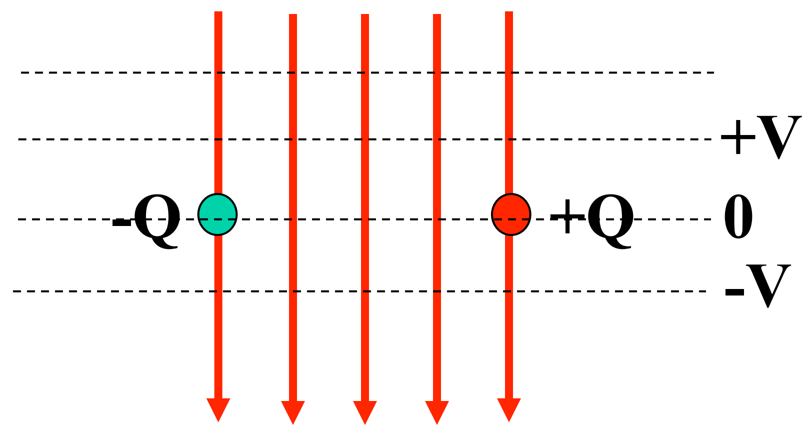
Equipotential Surfaces & Electric Field

- In a uniform electric field E, equipotentials are PLANES.
- Electric field points towards lower potential.
- In a gravitational field, a free mass moves from high to low potential. In an electric field, which of the following is true?

(a) Positive charge moves to lower V, negative charge moves to higher V

(b) Positive charge moves to higher V, negative charge moves to lower V

(c) All charge moves to lower V.



Note: all charges freely move to regions of lower potential ENERGY! Don't confuse potential with potential energy!

Electric Potential of a Point Charge

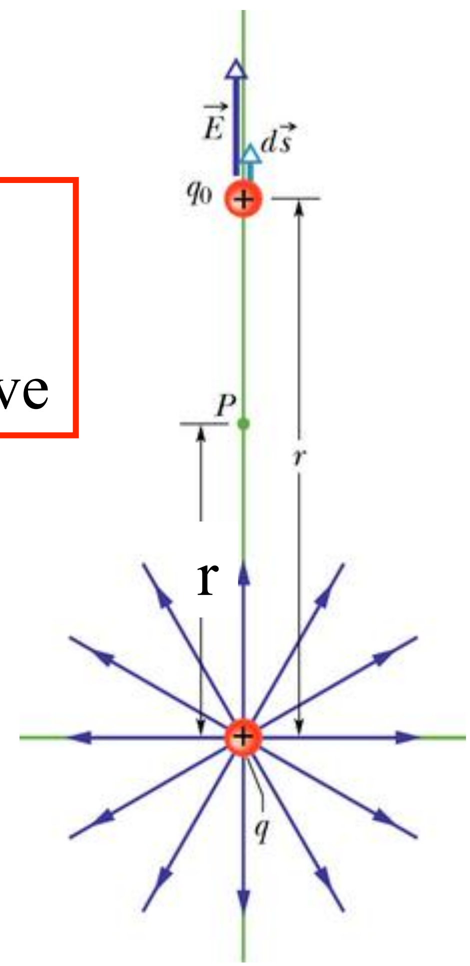
Potential = V = "Work you have to do to bring +1 C from infinity to distance r away from a point charge Q"

$$V = -W/q = -\int_{\infty}^{r} \vec{F} \cdot d\vec{s} \,/\, q$$

$$= \int_{\infty}^{r} \vec{E} \cdot d\vec{s} = \int_{\infty}^{r} E\, ds$$

$$= \int_{\infty}^{r} \frac{kQ}{r^2} dr \quad = -\left[-k\frac{Q}{R} \right]_{\infty}^{r} = k\frac{Q}{r}$$

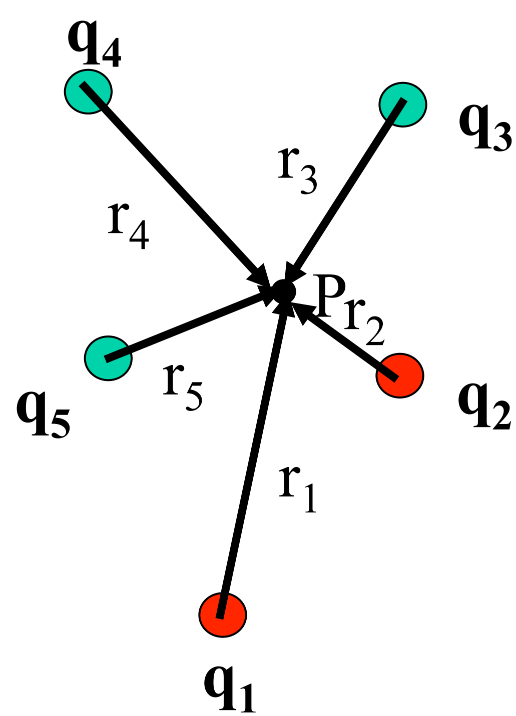
Note: if Q were a negative charge, V would be negative



Electric Potential of Many Point Charges

- Electric potential is a SCALAR
- Just calculate the potential due to each individual point charge, and add together! (Make sure you get the SIGNS correct!)

$$V = \sum_i k \frac{q_i}{r_i}$$



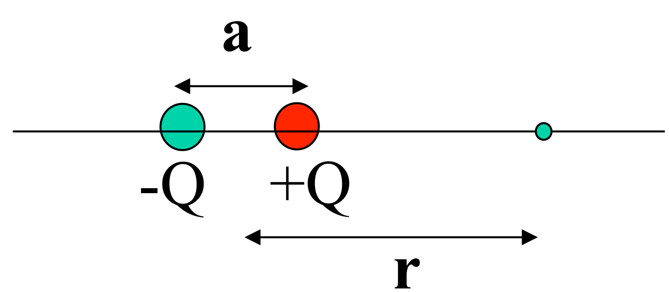
Electric Potential of a Dipole (on axis)

What is V at a point at an axial distance r away from the midpoint of a dipole (on side of positive charge)?

$$V = \frac{Q}{4\pi\varepsilon_0 (r - \frac{a}{2})} - \frac{Q}{4\pi\varepsilon_0 (r + \frac{a}{2})}$$

$$= \frac{Q}{4\pi\varepsilon_0}\left(\frac{(r + \frac{a}{2}) - (r - \frac{a}{2})}{(r - \frac{a}{2})(r + \frac{a}{2})} \right)$$

$$= \frac{Qa}{4\pi\varepsilon_0 (r^2 - \frac{a^2}{4})}$$



Far away, when r >> a:

$$V = \frac{p}{4\pi\varepsilon_0 r^2}$$

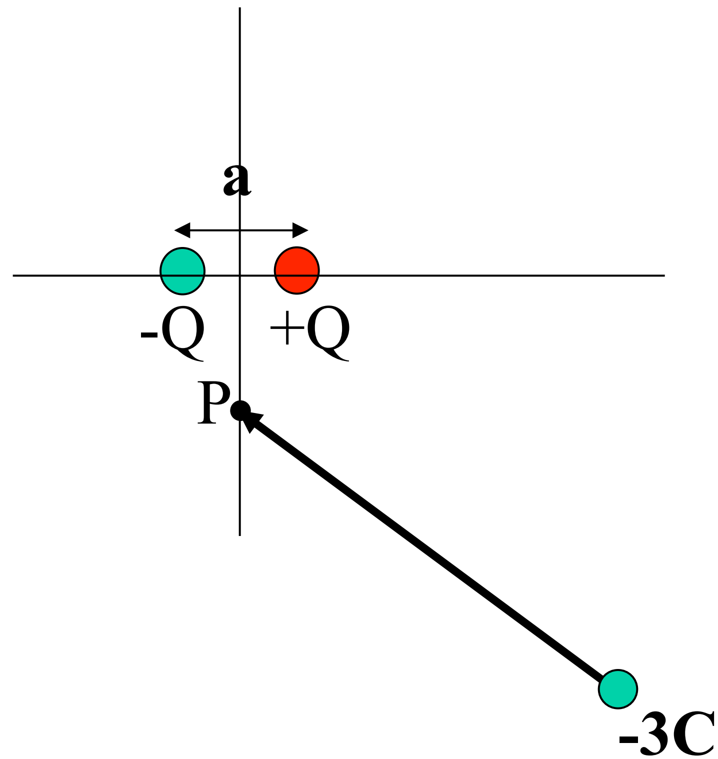
Electric Potential on Perpendicular Bisector of Dipole

You bring a charge of -3C from infinity to a point P on the perpendicular bisector of a dipole as shown. Is the work that you do:

a)Positive?

b)Negative?

c)Zero?



Electric Potential of Many Point Charges

What is the electric potential at the center of each circle?

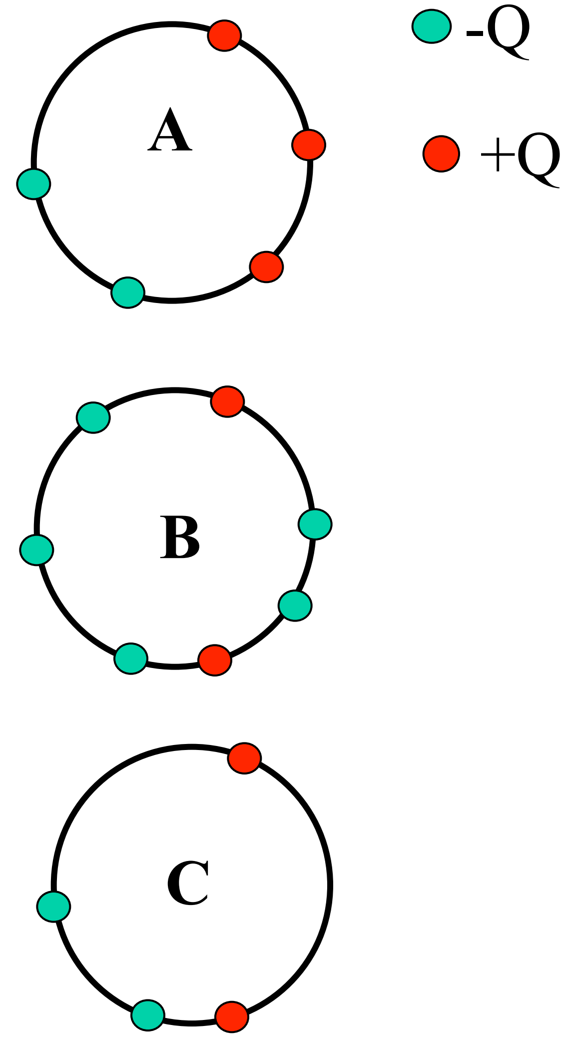
- Potential is a SCALAR
- All charges are equidistant from each center, hence contribution from each charge has same magnitude: V
- +Q has positive contribution
- -Q has negative contribution

A: -2V+3V = +V

B: -5V+2V = -3V

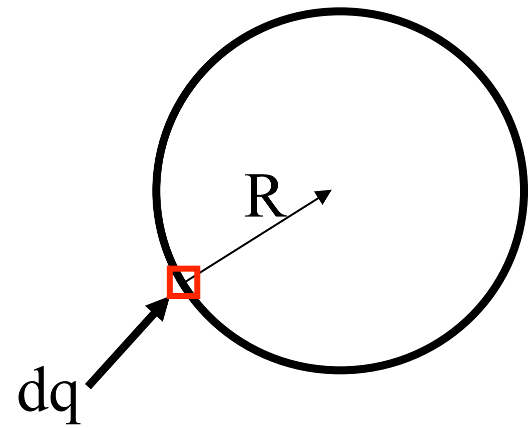
C: -2V+2V = 0

Note that the **electric field** at the center is a vector, and is NOT zero for C!



Continuous Charge Distributions

- Divide the charge distribution into differential elements
- Write down an expression for potential from a typical element -- treat as point charge
- Integrate!
- Simple example: circular rod of radius R, total charge Q; find V at center.



$$V = \int \frac{dq}{4\pi\varepsilon_0 R}$$

$$= \frac{1}{4\pi\varepsilon_0 R}\int dq = \frac{Q}{4\pi\varepsilon_0 R}$$

Potential of Continuous Charge Distribution: Example

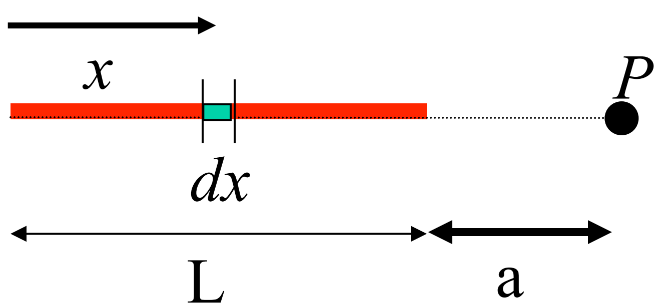
- Uniformly charged rod
- Total charge q
- Length L
- What is V at position P shown?

$$\lambda = q / L \qquad dq = \lambda\, dx$$

$$V = \int \frac{k\,dq}{r} = \int_0^L \frac{k\lambda dx}{(L + a - x)}$$

$$= k\lambda\left[-\ln(L + a - x)\right]_0^L$$

$$V = k\lambda \ln\left[\frac{L + a}{a}\right]$$



Summary:

- **Electric potential**: work needed to bring +1C from infinity; units = V
- Electric potential uniquely defined for every point in space -- independent of path!
- Electric potential is a **scalar** -- add contributions from individual point charges
- We calculated the electric potential produced:
  - by a single charge: $V=kq/r$,
  - by several charges using superposition, and
  - by a continuous distribution using integrals.