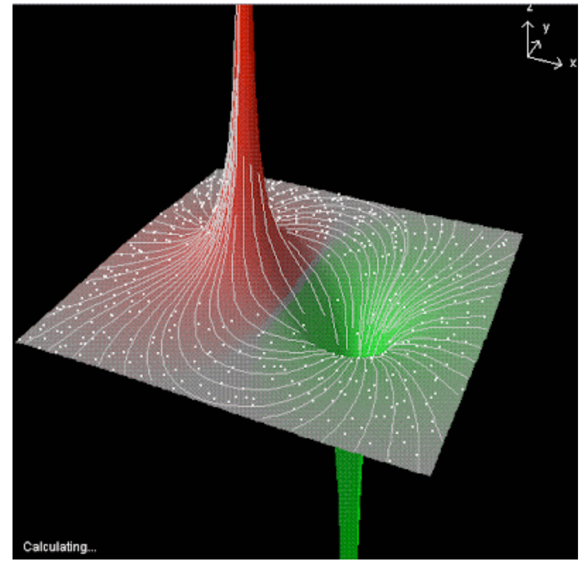
Physics 115
General Physics II



Session 19

Electric potential and conductors

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Lecture Schedule
(up to exam 2)

21-Apr	Mon	12	Specific Heats	18.4-18.6
22-Apr	Tues	13	Second Law	18.7-18.10
24-Apr	Thurs	14	Entropy	18.8-18.10
25-Apr	Fri	15	Charges	19.1-19.4
28-Apr	Mon	16	E field	19.5-19.66
29-Apr	Tues	17	Gauss law	19.7
1-May	Thurs	18	Electrical potential	20.1-20.3
2-May	Fri	19	Potential, conductors	20.4
5-May	Mon	20	Capacitors	20.5-20.6
6-May	Tues	21	Current	21.1-21.2
8-May	Thurs	22	Power, Series & Parallel Circuits	21.3-21.4
9-May	**Fri**		**EXAM 2 - Ch. 18,19,20**	

Today

Announcements

- Exam 2 is one week from today, Friday 5/9
  - Same format and procedures as last exam
  - Covers material discussed in class from Chs 18, 19, 20
  - Practice questions will posted Tuesday evening, we will review them in class Thursday

Last time

Volts

- Definition of electric potential describes only changes in V
- We can **choose** to put V=0 wherever we want – *differences* from place to place will remain the same
- Units for V are J/C: 1.0 J/C = 1.0 volt (V)
  - After Alessandro Volta (Italy, c. 1800) who invented the battery
- Note: Joules are useful for human-scale, not "micro" objects
  - For subatomic particles we use for energy units the electron-volt (eV) = energy gained by one electron charge, falling through one volt of potential difference:

$$1.0eV = (1.6\times10^{-19}C)(1V) = 1.6\times10^{-19}J$$

- Work done by E, and potential difference, for a test charge q_0 moved in the same direction as **E**:

$$W = q_0 E\Delta s$$

$$\Delta V = \frac{-W}{q_0} = -E\Delta s \rightarrow E = -\frac{\Delta V}{\Delta s}$$

This tells us:

1) Another unit for E can be volts per meter, so 1 N/C = 1 V/m.
2) E is given by the slope on a plot of V versus position

Example: E and V in a parallel plate capacitor

- We know that between parallel plates E=const
  - So,

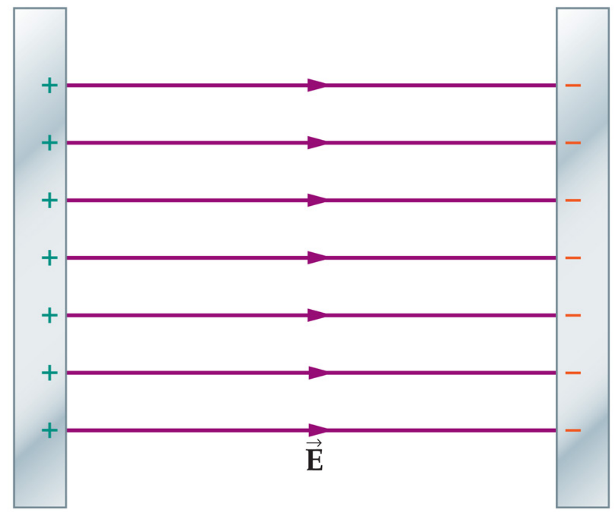
$$E = -\frac{\Delta V}{\Delta s} \rightarrow \frac{\Delta V}{\Delta s} = const$$

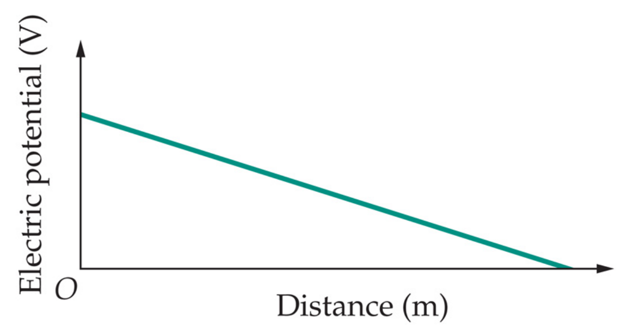
$$\Delta V = -E\Delta s$$

Slope = constant (straight line plot for V)

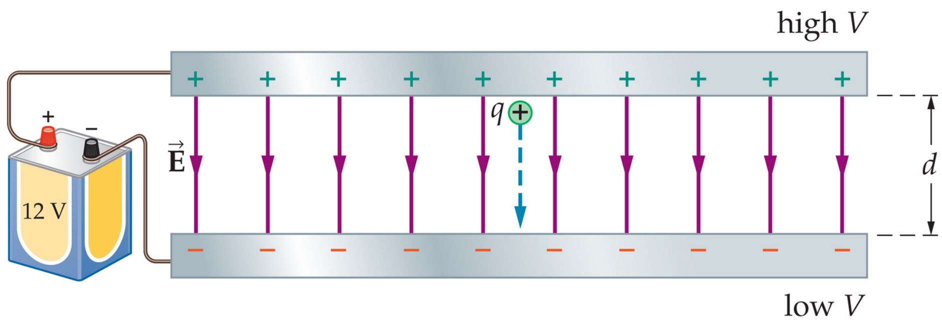
Change in V, going from + charged plate to – plate, is negative:

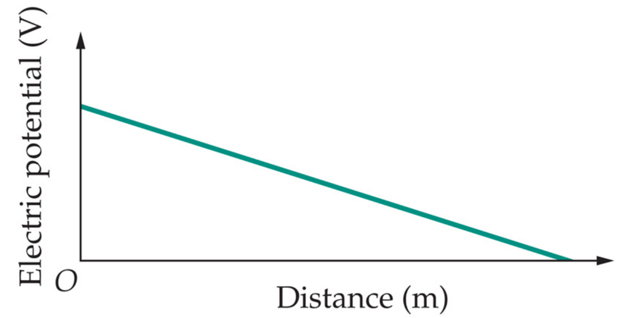
V decreases linearly from left to right across the gap





Example: charge moving between parallel plates





Example: plates 7.5mm apart are connected to a 12V battery

Battery = device that maintains a constant potential difference between its terminals (as long as its internal energy supply lasts)

V decreases linearly from top to bottom across the gap

$$E = -\frac{\Delta V}{\Delta s} = -\left(\frac{-12V}{0.0075m}\right) = 1600V/m$$

E field intensity between plates

$$\Delta U = q\Delta V = \left(10^{-6}C\right)\left(-12V\right) = -12 \times 10^{-6} J$$

Change in potential energy (in joules) of a +q *falling* from + plate to – plate, is **negative**: E field is doing work on q

What about –q moving from + charged plate to – plate? ΔU is positive: we must do work on q (apply F against the E field)
A negative charge **falls uphill** !

Electric Force is "conservative"

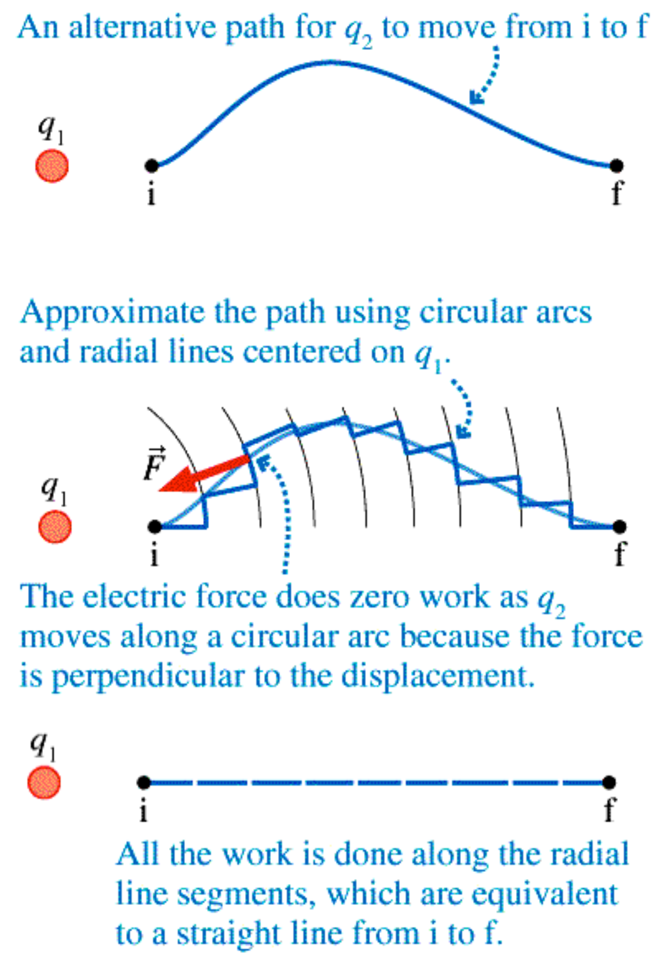
Like gravity, ***E*** force conserves net energy KE + PE

The energy needed to move a small test charge from point *i* to point *f* is independent of the path taken.

Example: in the field of a single point charge q_1, E is constant at constant r.

So, tangential path segments involve no change in energy (because *r* is constant on them).

- Any path can be approximated by a succession of radial and tangential segments, and the tangential segments do not contribute to energy gained or lost.
- What remains = a straight line path from initial to final radial position of the moving charge
- Net work will be the same for all possible paths between i and f.
- Same as with gravity: W depends only on initial and final altitude, not path



Conservation laws and motion of charged objects

- "Electrostatic force is conservative" means energy is conserved
  - If a charged object $+q_0$ moves from location A to B in an E field,

$$U + K = const \rightarrow U_A + K_A = U_B + K_B$$

$$q_0 V_A + (1/2)mv_A^2 = q_0 V_B + (1/2)mv_B^2$$

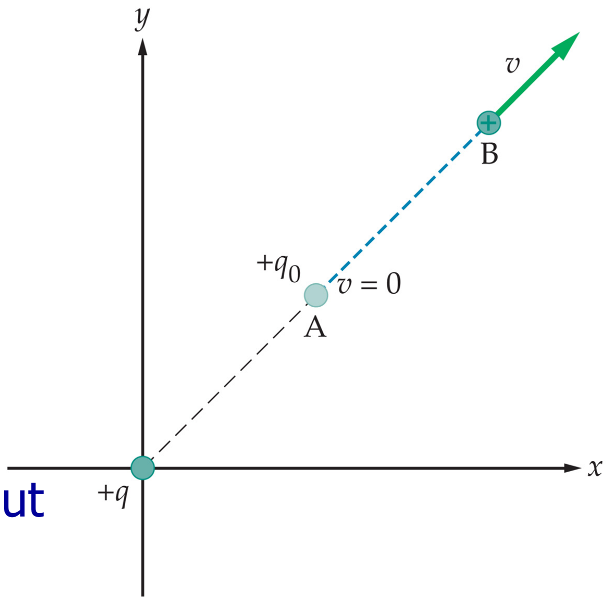
$$(1/2)mv_B^2 = q_0\left(V_A - V_B\right) + (1/2)mv_A^2$$

Example: an object with charge $+q_0$, initially *at rest* at point A, in field due to charge q:

$$(1/2)mv_B^2 = q_0\left(V_A - V_B\right) + (1/2)mv_A^2$$

$$v_B^2 = 2\frac{q_0}{m}\left(V_A - V_B\right)$$

$$v_B = \sqrt{2\frac{q_0}{m}\left(V_A - V_B\right)}$$



Notice, + charge falls to a lower V, - to a higher V, but for both position B has $U = q_0\Delta V$

Notice: Info about V is *all we need to know* about E field created by q

nc.

Potential fields for point charges

- Potential = scalar field associated with vector field **E**
  - Notice: since $E = -\dfrac{\Delta V}{\Delta s}$ we can find E from variation of V
  - So a scalar field gives us complete info about a vector field!
    - How can that be? Vector has 3X information of scalar !
      - E field's behavior must be consistent with physical laws: properties are constrained by this requirement
      - Mathematicians consider many other kinds of vector fields !
- V of an isolated point charge q
  - Use calculus to get change in potential energy moving charge $+q_0$ from A to B

$$F_E = \frac{kqq_0}{r} \rightarrow \Delta U_{A-B} = U_A - U_B = kq\left(\frac{q_0}{r_A} - \frac{q_0}{r_B}\right)$$

$$V_A - V_B = \frac{\Delta U_{A-B}}{q_0} = kq\left(\frac{1}{r_A} - \frac{1}{r_B}\right)$$

We can choose to set V=0 anywhere handy
(All we care about are differences in V)
Convenient place is at $r_B = \infty$

Notice: V depends only on r :
(not a signed coordinate like x)
symmetrical around origin

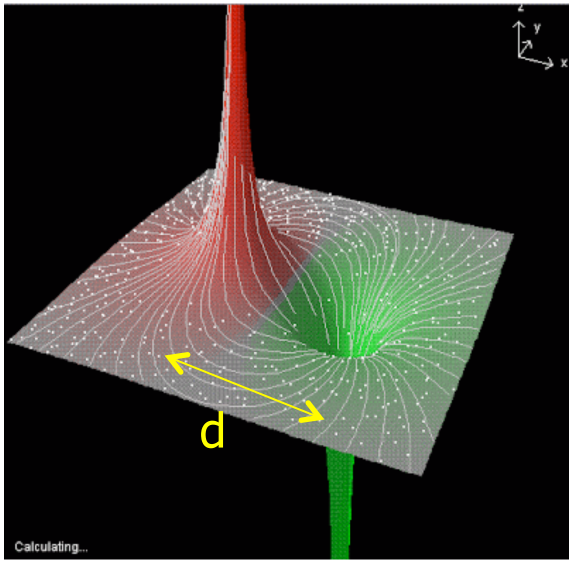
⇨ Then, for *any* location A, $V_A = \dfrac{kq}{r_A}$

Superposition principle again

- Potential at any point = sum of V due to all source q's present
  - "Test charges" are assumed tiny, negligible as field sources
  - Potentials are signed scalars, so superposition = simple sum
- Example: potential field of an electric dipole, +q and –q, distance apart is d, with + charge at x=0
  - V of a negative q is just upside-down version of +q's V

Then $V_+ = \dfrac{kq}{x}, \quad V_- = \dfrac{-kq}{(d-x)}: \quad V(x) = kq\left(\dfrac{1}{x} - \dfrac{1}{(d-x)}\right)$

Notice: for $x = d/2, \qquad V(x) = kq\left(\dfrac{1}{x} - \dfrac{1}{(d-x)}\right)$



What if we release a + test charge near x=0?
Same as releasing a ball on a surface like the one in the graph: it *rolls downhill*
(here: repelled by +q, attracted to –q)
What is E at x=0 ?
What about a negative charge?

Quiz 12

- The electric potential V in a certain region of space looks like the graph below

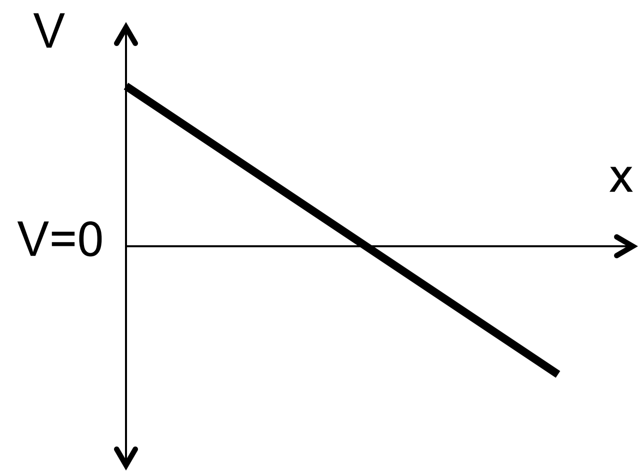
Which describes the **E** field at the place where V=0?

A. **E** points left (-x direction)

B. **E** points right (+x direction)

C. **E**=0 at that location

D. (not enough info to answer)



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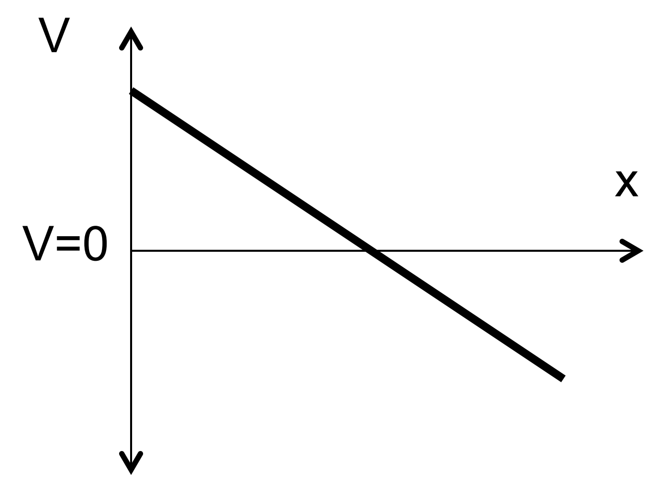


Because: a + charge would "roll downhill" on V plot

$E = -\Delta V/\Delta x$: notice ΔV is negative as you increase x

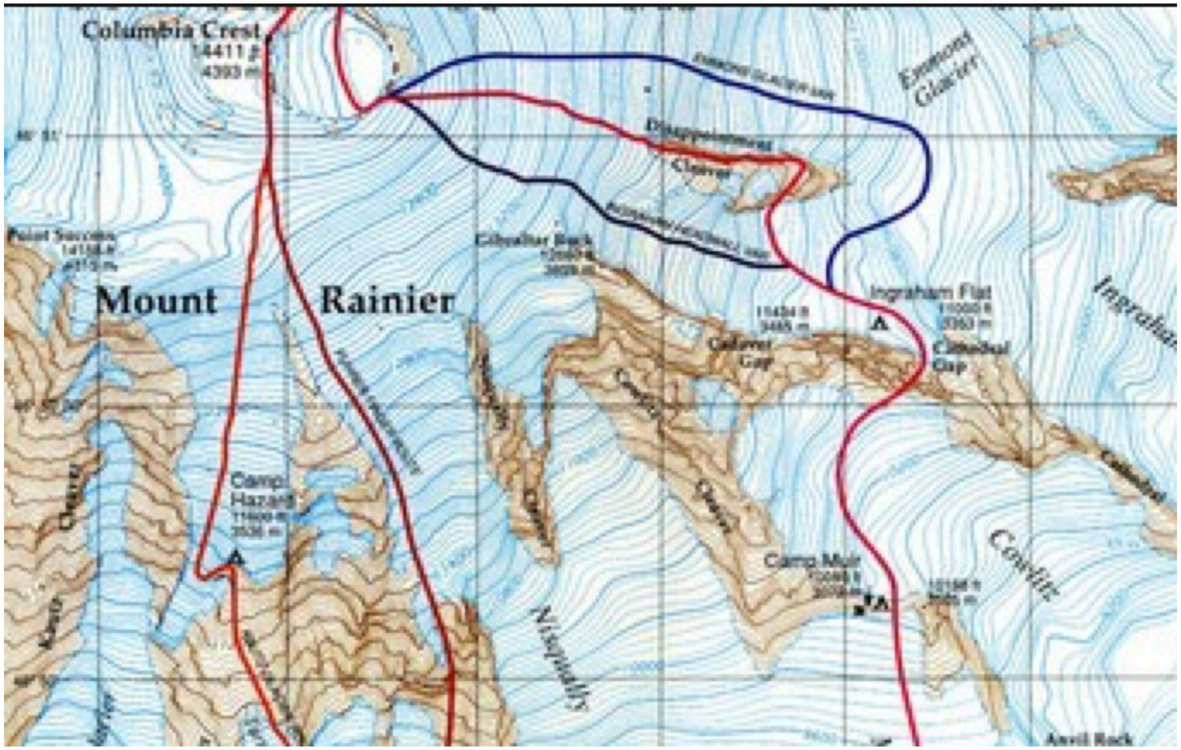
E = 0 only if V's **slope** =0

This graph shows an E field that is constant in magnitude

Equipotentials

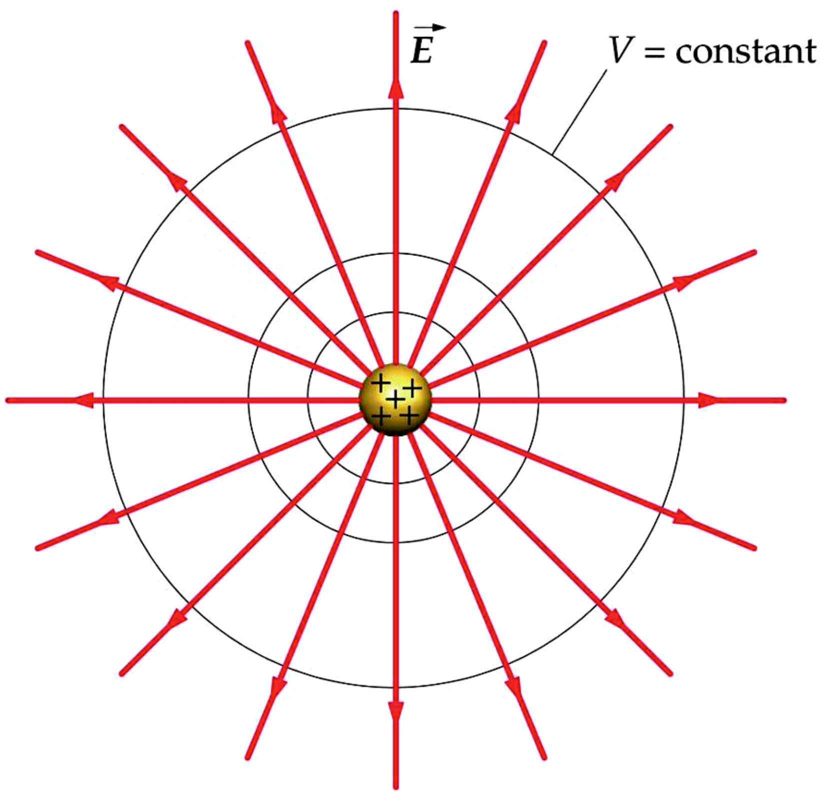
- Contour map shows lines of constant altitude
  - Walk along a contour, you do not go up or down
  - Recall: $U_g = mgy$ near surface of earth (in general $U = -\frac{GM_E}{r}m$)
  - Contours are lines of constant $U_g \rightarrow$ equipotentials

(Which direction is path of steepest descent?)



Electric field equipotentials

- In the E field of a point charge, $V(r) = \dfrac{kq}{r}$
  - Equipotentials = points with same r: circles
  - Spacing of equipotentials with equal ΔV: $V_A - V_B = kq\left(\dfrac{1}{r_A} - \dfrac{1}{r_B}\right)$



Example: map for q=1 microC
we want ΔV=10V
Choose V=0 at r=infinity

$$V(r) = \frac{\left(9\times10^9\ \mathrm{V\cdot m/C}\right)\left(10^{-6}C\right)}{r}$$

$$= \frac{\left(9\times10^3\ \mathrm{V\cdot m}\right)}{r}$$

$$r(V) = \frac{\left(9\times10^3\ \mathrm{V\cdot m}\right)}{V}$$

$$V = 1000V \Rightarrow 9m$$

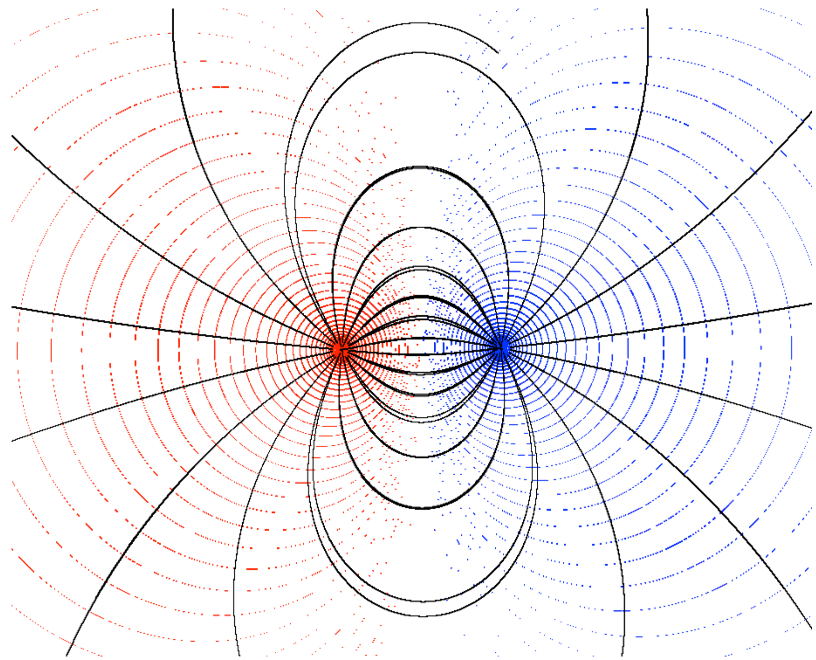
$$V = 2000V \Rightarrow 4.5m$$

$$V = 3000V \Rightarrow 3m$$

$$V = 4000V \Rightarrow 2.25m$$

Rules for Equipotentials

1. Equipotentials ***never*** intersect other equipotentials. (Why?)
2. The surface of any static conductor is an equipotential surface. The conductor volume is all at the ***same*** potential.
3. Field line cross equipotential surfaces ***at right angles***. (Why?)
4. Close equipotentials indicate a strong electric field.



5. The potential V decreases in the direction in which the electric field E points, i.e., energetically "downhill".
6. For any system with a net charge, equipotential surfaces become spheres at very large distances ("looks like" a point charge).