Your questions/comments

ANNOUNCEMENTS: HW video solutions now work on byteshelf
Extra textbook practice problems on course website

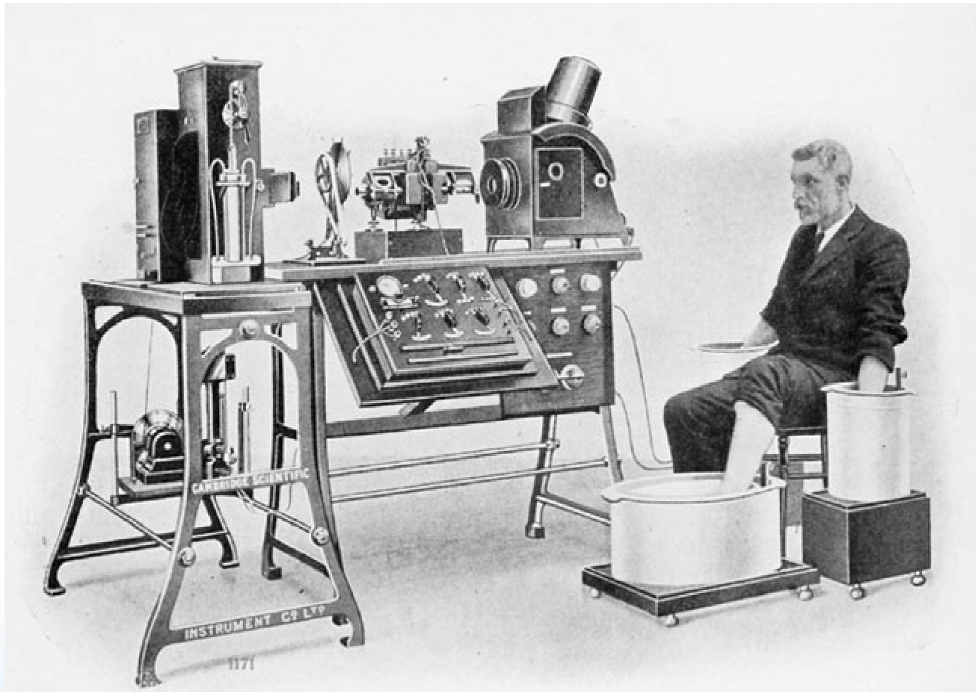
"It is hard for me to grasp the difference between the charge's electric potential and PE. The topographical map analogy is hard for me to understand. I hope your explanations and/or demos will help."

"I am honestly quite confused on this. I thought I understood it but the checkpoint really proved I had no idea what I was doing."

"I am having a hard time actually visualizing what electric potential is. I don't really understand how it is different than electric potential energy."

"I don't understand how all of the equations we've been in shown in the past 2 or 3 lectures relate to each other mathematically. A review of the equations and what they mean, starting with coulomb's law, would be extremely helpful."

"CONTOUR MAPS! THE HORRORS OF CALC 3 ARE BACK AGAIN!!!"



Phys 102 – Lecture 5

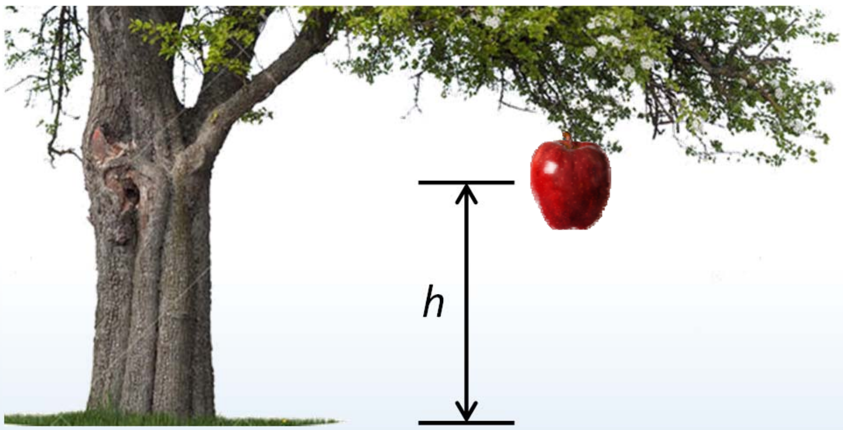
Electric potential

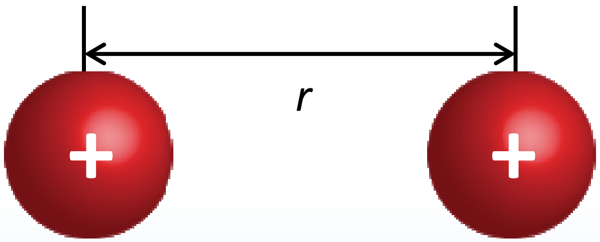
Today we will...

- Learn about the *electric potential*
- Use the principle of superposition
  - Ex: point charges
- Represent electric potential with equipotential lines
  - Relation with electric field
- Apply these concepts
  - Ex: Electrocardiogram (ECG)

Recall last time

Gravitational potential energy ⟷ Electric potential energy





Height or altitude ⟷ Electric potential

The electric potential

The electric potential is defined at a *location* in space around a charge or set of charges

Electric potential at position *P*

$$\boxed{V \equiv \frac{U_E}{q}}$$

EPE of a charge *q* at position *P*

Charge *q*

Units: J/C ≡ V ("volts")

Electric potential is a <u>*scalar*</u> (a number) NOT a vector. Signs matter!

Electric potential is 9 V higher at + end than – end

Calculation: potential in H atom

What is the magnitude of the electric potential due to the proton at the *position* of the electron?

r = 0.53 x 10^{-10} m

$$V = \frac{U_E}{q_e} = \frac{kq_p}{r} = \frac{9\times10^{9}\,\mathrm{N\cdot m^2/C^2}\cdot1.6\times10^{-19}\,C}{0.53\times10^{-10}\,\mathrm{m}} = 27.2\ \mathrm{V}$$

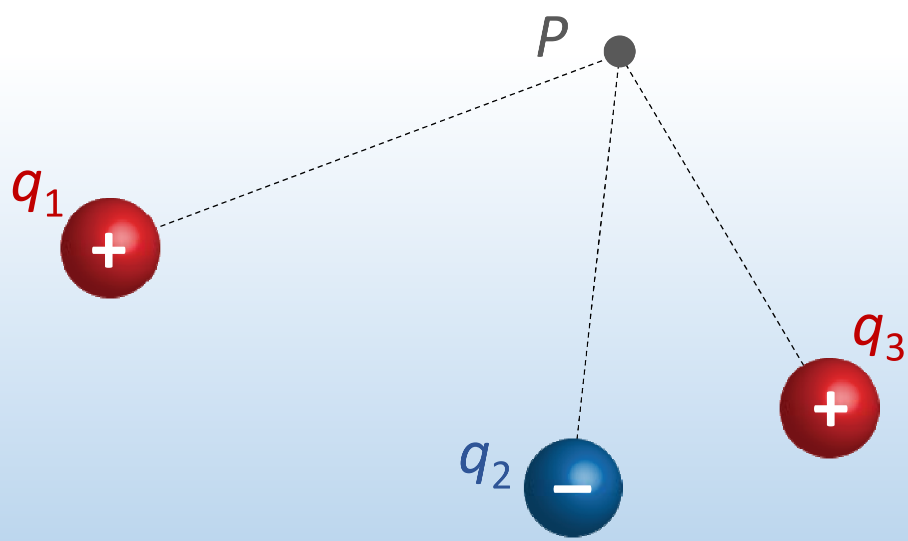
About three 9 V batteries!

Superposition principle

Total potential due to several charges = sum of individual potentials

$$V_{tot} = \sum V$$

Ex: what is the electric potential at point P due to q_1, q_2, and q_3?

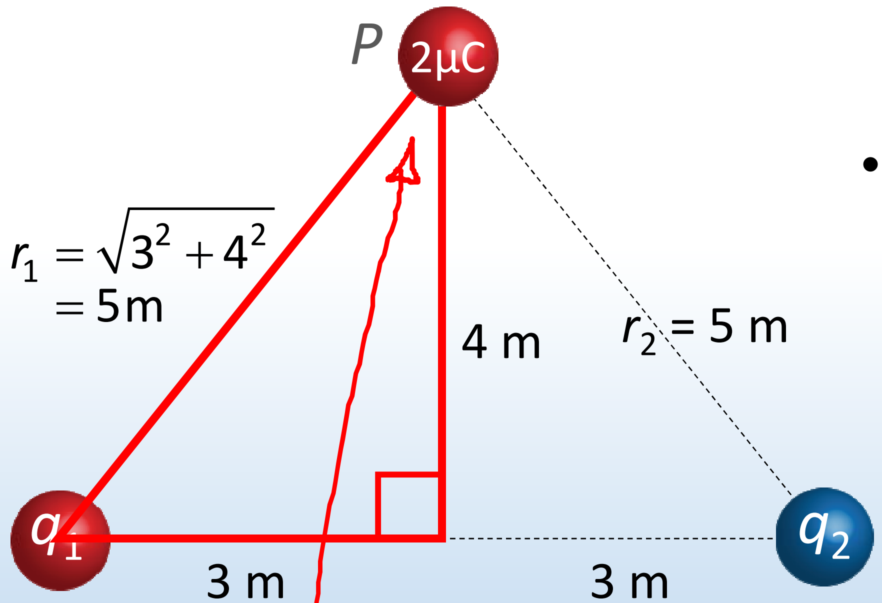


Simple addition, no vectors!
Watch for signs, though!

$$V_{tot} = V_1 + V_2 + V_3$$

Calculation: two charges

Calculate the electric potential at point *P* due to charges q_1 = +7 μC and q_2 = –3.5 μC



- Fundamental concept: Superposition

$$V_{tot} = V_1 + V_2$$

- Calculate each potential

$$V_1 = k\frac{q_1}{r_1} = 9\times10^9 \frac{(+7\times10^{-6})}{5}$$
$$= 12.6\times10^3 \text{ V}$$

$$V_2 = k\frac{q_2}{r_2} = 9\times10^9 \frac{(-3.5\times10^{-6})}{5}$$
$$= -6.3\times10^3 \text{ V}$$

Watch signs!

$$V_{tot} = \overset{= V_p}{+6.3\times10^3 \text{ V}} \checkmark$$

How much work do you do bringing a +2 μC charge from far away to point *P*?

$$W_{you} = +\Delta U = q\Delta V = q(V_p - V_\infty)$$
$$= (+2\times10^{-6})(+6.3\times10^3 - 0) = 12.6\,\text{mJ} \checkmark$$

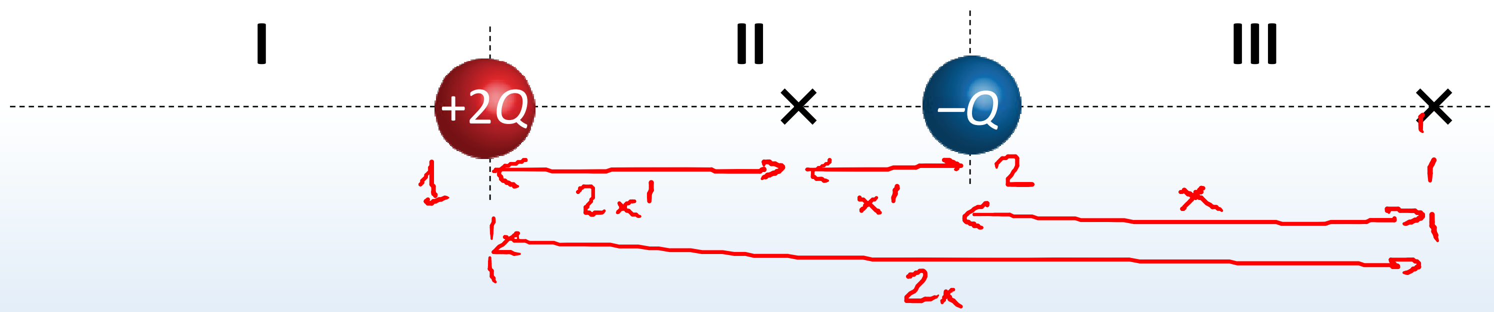
ACT: Electric potential

HW 3

$V = \frac{kq}{r}$

Two charges +2*Q* and –*Q* are placed on the *x*-axis. In which of the three regions **I**, **II**, or **III** on the *x*-axis can the electric potential be zero?

$V_{tot} = V_1 + V_2$



A. I

B. II

C. III

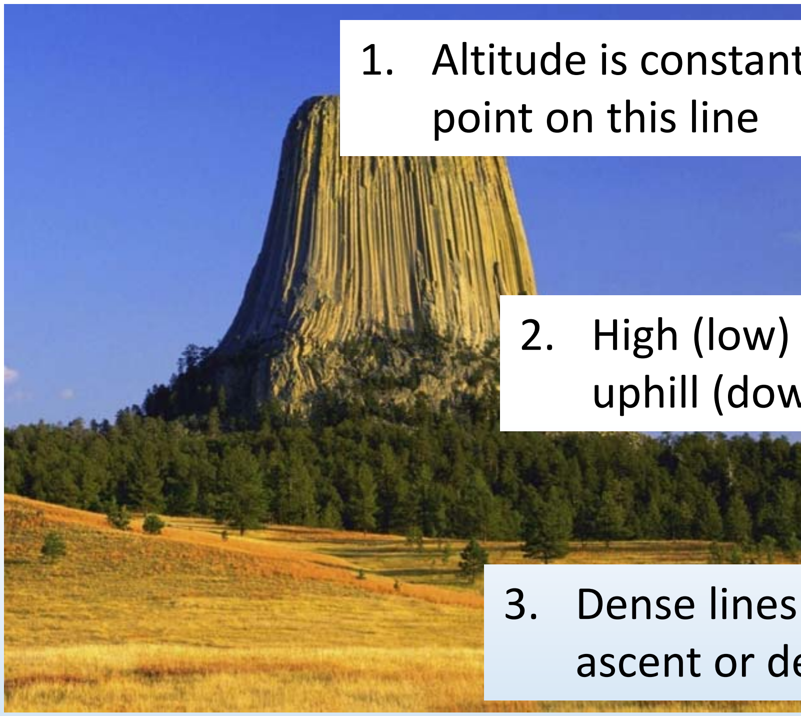
D. II and III

E. I, II, and III

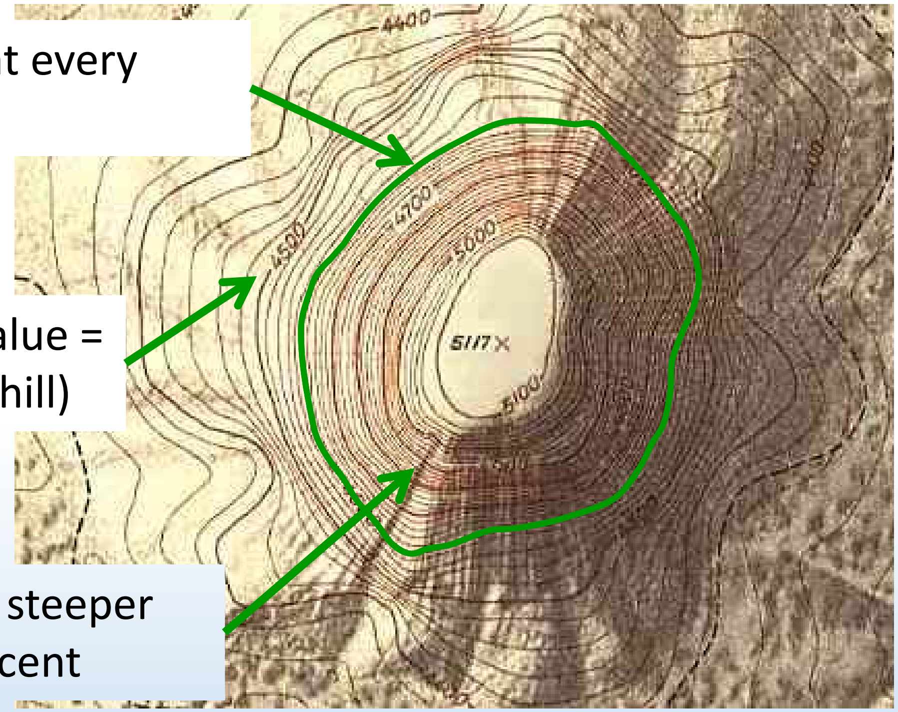
$V \propto \frac{q}{r}$ Potentials can only cancel at a point 2X as far from +2*Q* as from –*Q*

Equipotential lines

Devils tower, WY



Topographical map



1. Altitude is constant at every point on this line
2. High (low) value = uphill (downhill)
3. Dense lines = steeper ascent or descent

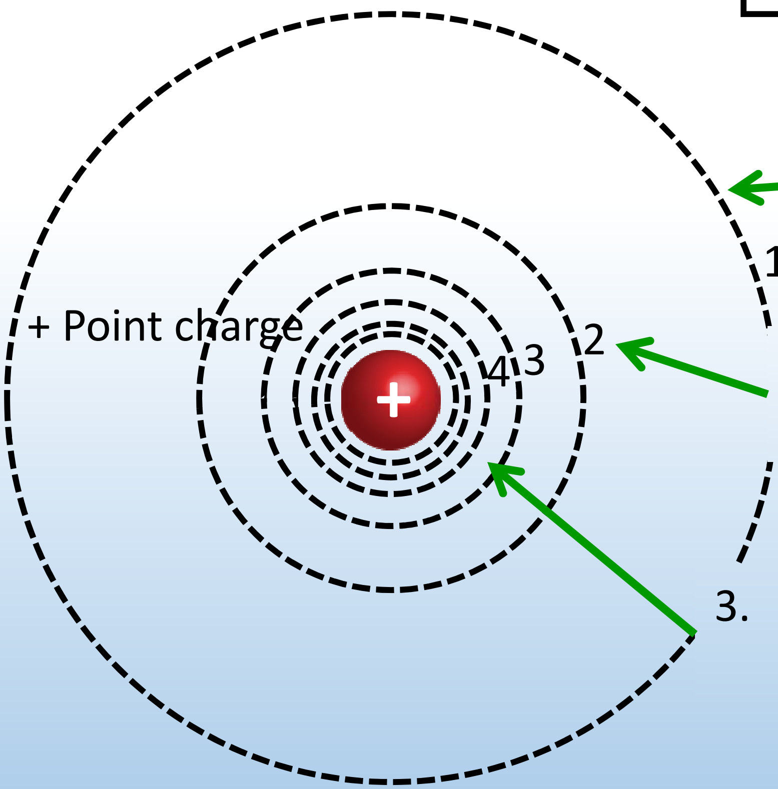
Gravitational potential energy ⟷ Electric potential energy

Height or altitude ⟷ Electric potential

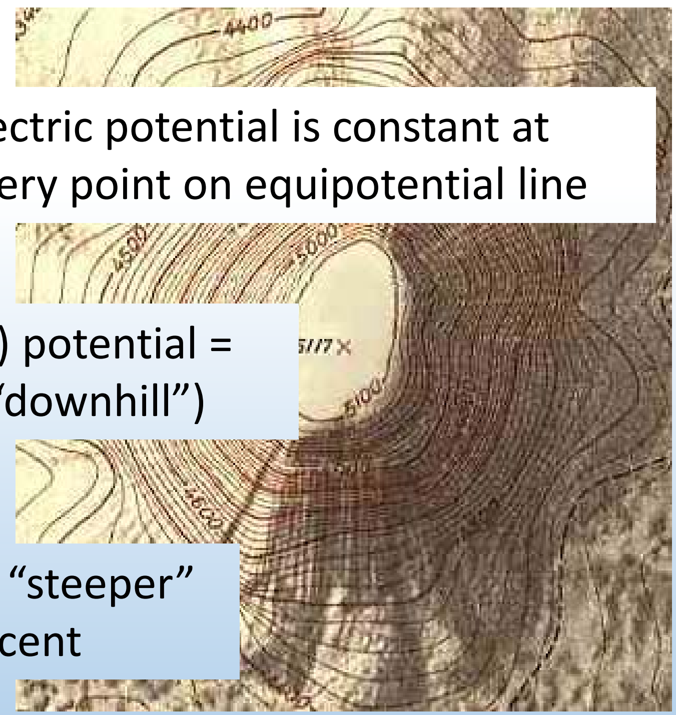
Electric potential for a charge

Equipotential lines represent electric potential in space graphically

$$\boxed{V = \frac{kq}{r}}$$



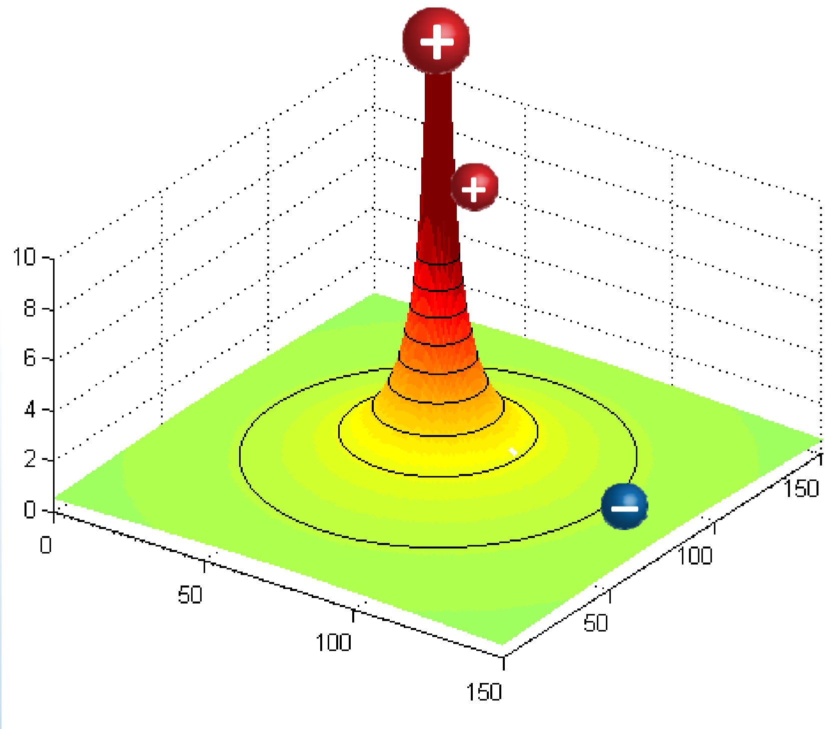
1. Electric potential is constant at every point on equipotential line
2. High (low) potential = "uphill" ("downhill")
3. Dense lines = "steeper" ascent or descent



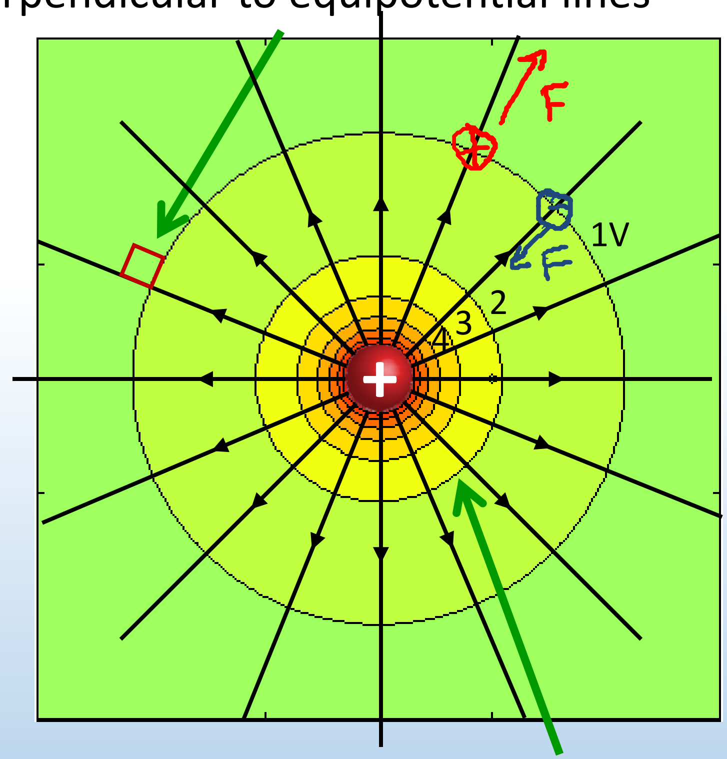
Lab 1

Equipotential & electric field lines

Equipotentials & electric field lines are geometrically related



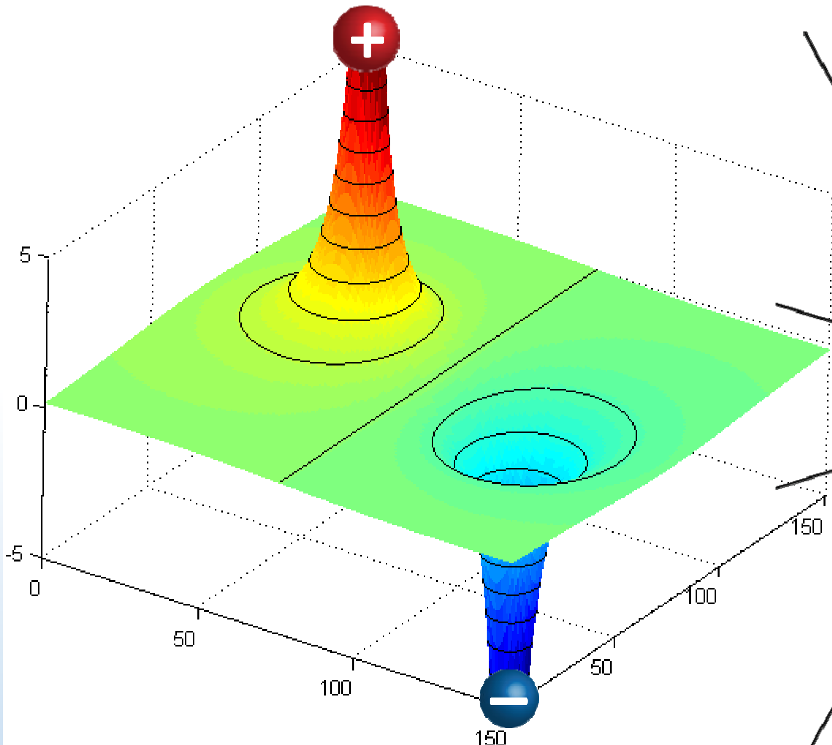
1. Electric field points "downhill", perpendicular to equipotential lines

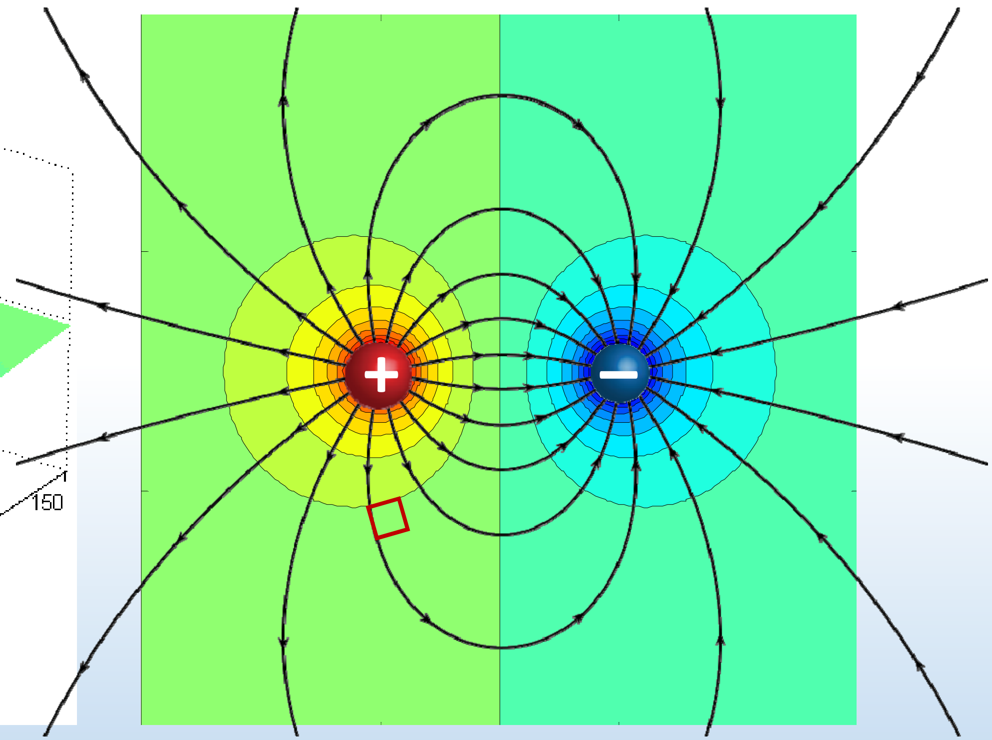


2. Dense equipotential lines = large E field

3. Positive charge moves "downhill" Negative charge moves "uphill"

Electric potential for a dipole

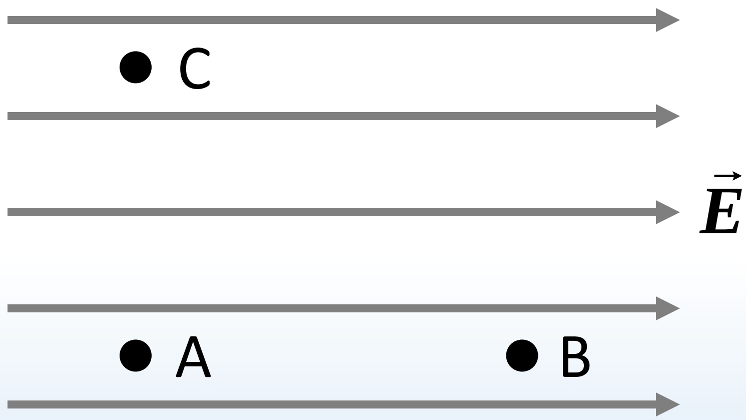


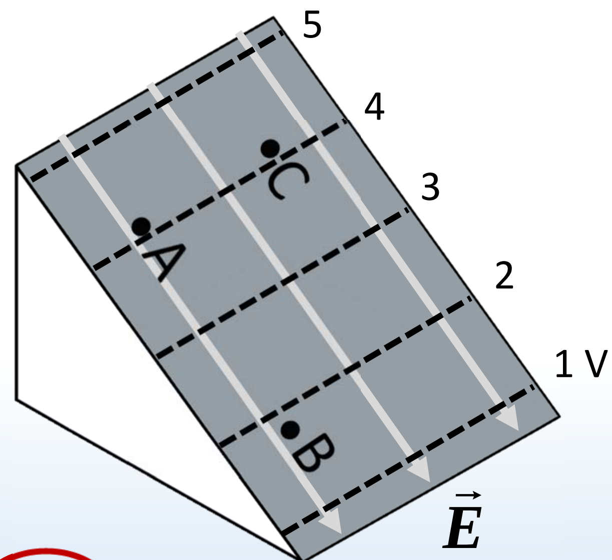


DEMO

ACT: Uniform electric field

Which diagram best represents the equipotential lines corresponding to a <u>uniform</u> *E* field pointing to the right?



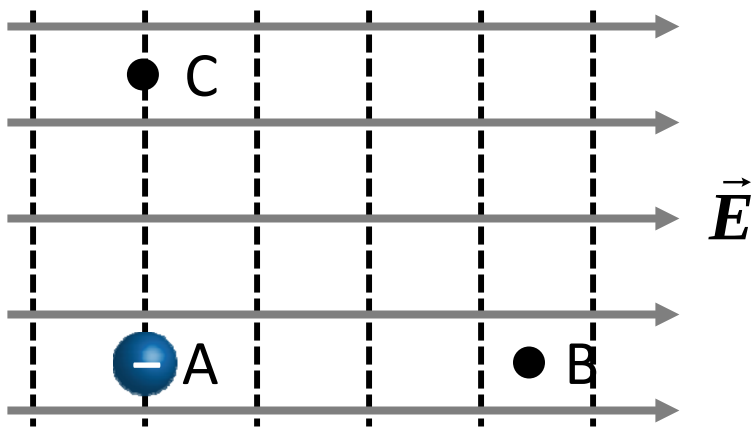


CheckPoint 1.1

46%

Electric field points “downhill”, from high to low potential

Lect. 4 Checkpoint 1.2 (Revisited)



When a negative charge is moved from A to C, it moves along an equipotential line

A. positive work

B. zero work

C. negative work

V is constant

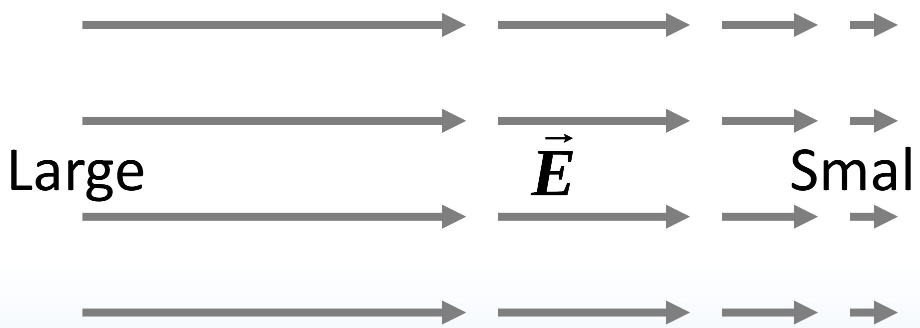
$U = qV$ is constant

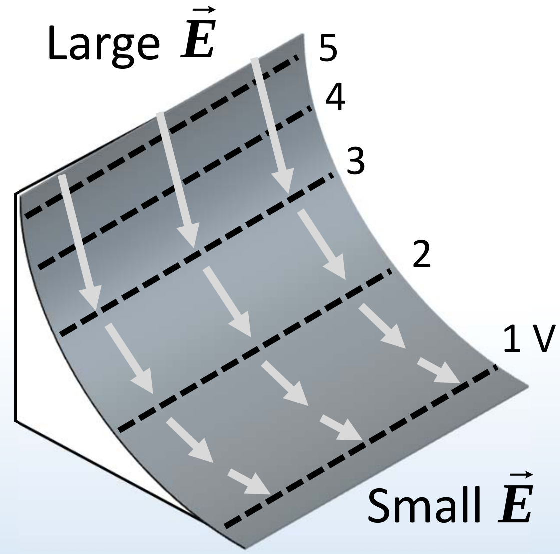
$\Delta U = 0$

$W = 0$

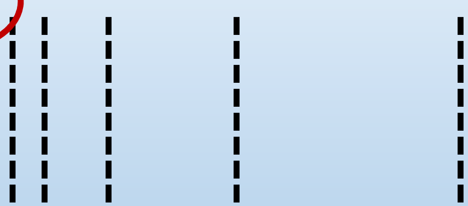
ACT: Electric field gradient

Now consider an E field that <u>decreases</u> going to the right. Which diagram best represents the equipotential lines?

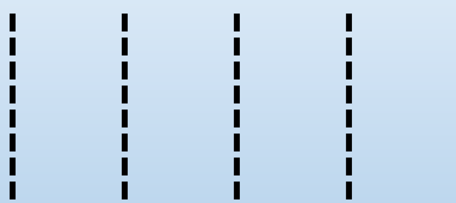




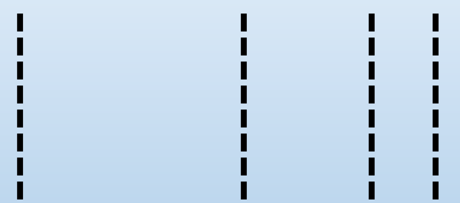
A.



B.



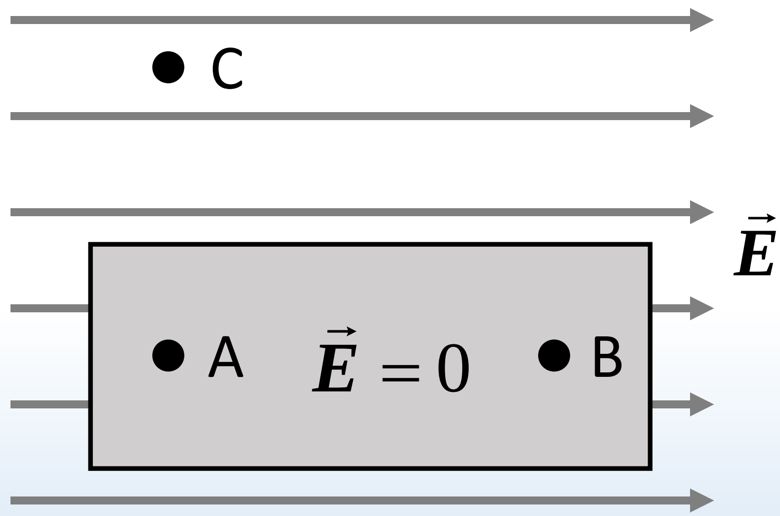
C.

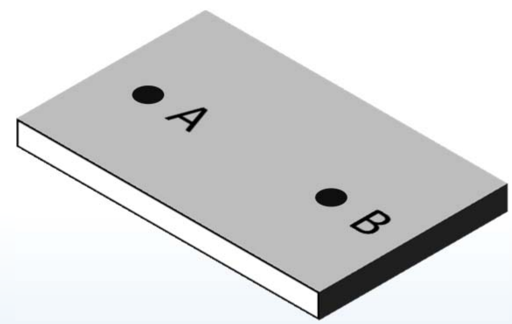


Large electric field = "steep" descent = dense equipotential lines

ACT: CheckPoint 2.1

Points A and B lie in an ideal conductor inside a uniform *E* field





The electric potential at point A is ______ at point B

7% A. Greater than
87% B. Equal to
6% C. Less than

$\vec{E} = 0$ means not "uphill" nor "downhill", but "flat"

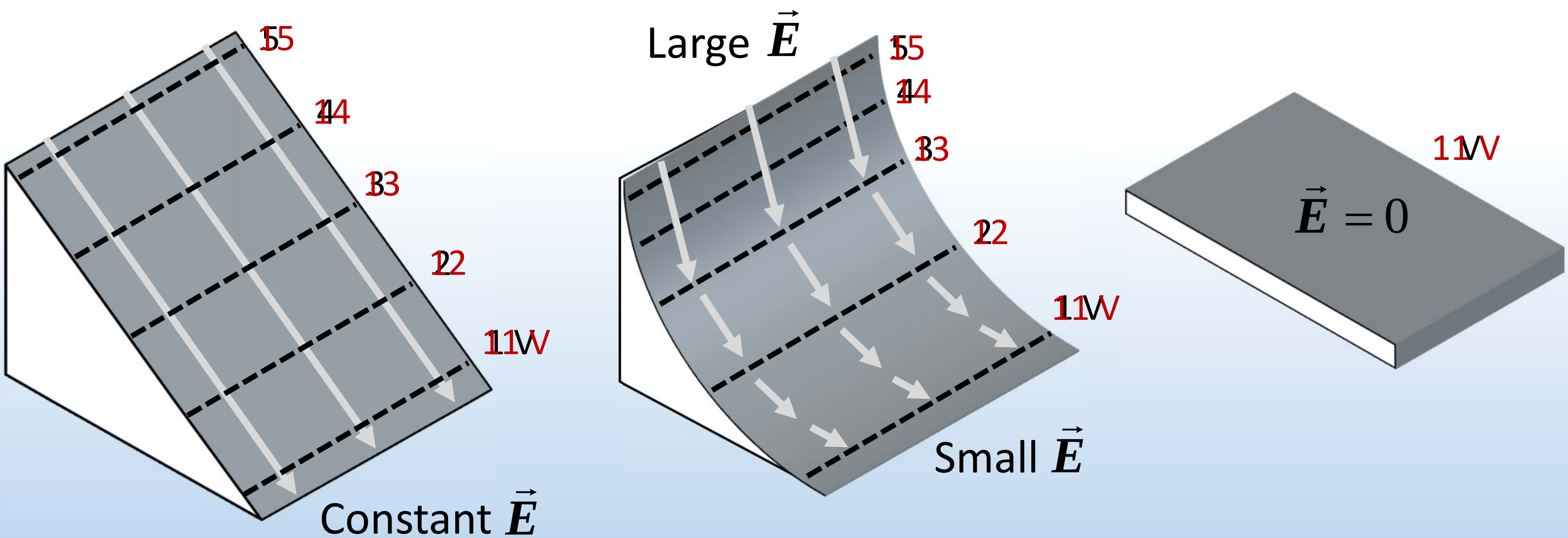
V is constant everywhere inside conductor

Note: *V* is not necessarily 0, just constant!

Electric potential difference

Note that the electric field and force depend on electric potential *difference* ΔV, NOT on electric potential V itself

"Voltage"



This will be important starting next lecture with circuits

Relationship between F, E, U_E, V

Exam 1

	Vector	Number ("scalar")
Property of interacting charges	***F*** [N] Ex: $F = k\dfrac{q_1 q_2}{r^2}$	***U_E*** [J] Ex: $U = k\dfrac{q_1 q_2}{r}$
Property of point in space	***E*** [N/C]=[V/m] Ex: $E = k\dfrac{q}{r^2}$	***V*** [J/C]=[V] Ex: $V = k\dfrac{q}{r}$

F ↔ U_E: $W_E = F\Delta r\cos\theta = -\Delta U_E$

F ↔ E: $\vec{\mathbf{E}} \equiv \vec{\mathbf{F}}/q$

U_E ↔ V: $V \equiv U_E/q$

E ↔ V: *E* points from high to low *V*

Exam 1 two weeks from Thursday!

- Points of emphasis

  Start reviewing early (cramming DOES NOT work)

  Emphasize <u>understanding concepts & problem solving, NOT memorization</u>

- Study tips

  Review concepts: pre-lectures, lecture notes, textbook, discussion summary

  Practice solving problems: old exams, extra textbook problems, ACTs, HW; starting from conceptual basis (rather than “what equation do I use”)

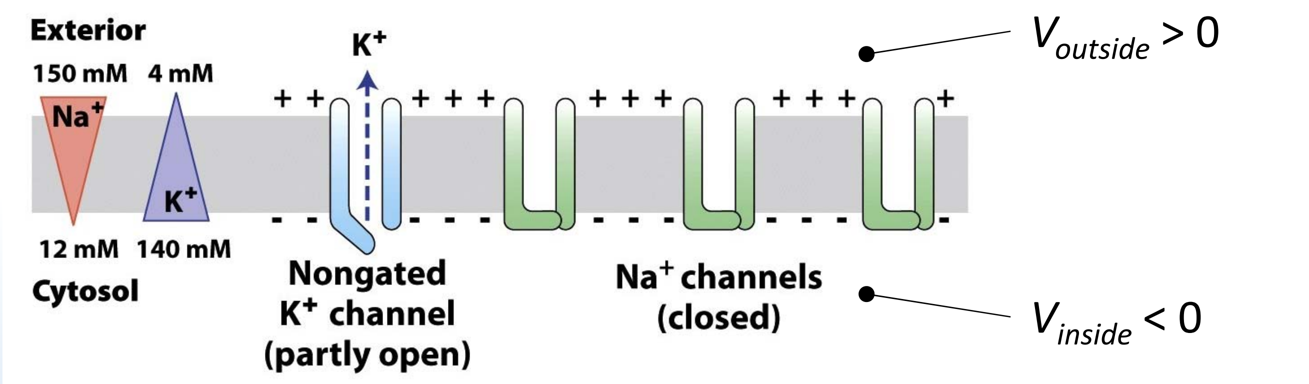
  Understand formulas: know what each symbols mean & when to use (and when NOT to use) an equation

  Ask questions: use office hours & review session to fill gaps in understanding

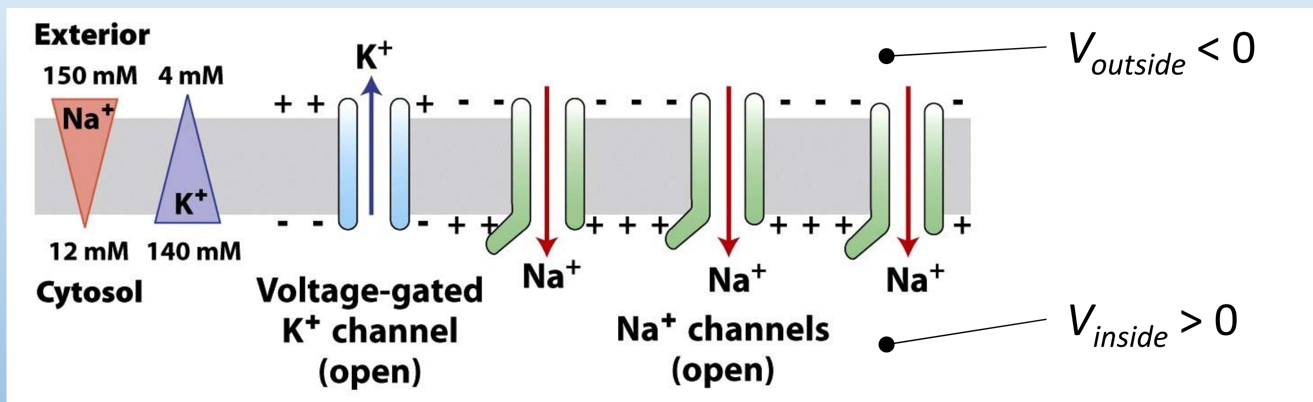
Electric potential in biology

Ion channels in cell membrane create a charge imbalance
Cells have an electric potential difference across membrane

Cells at rest are *polarized*

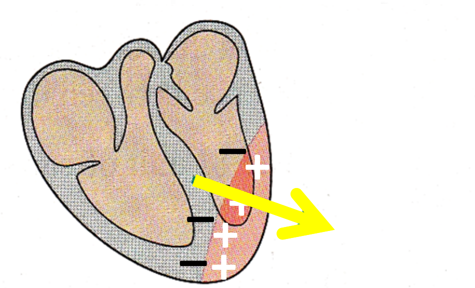


Some cell types (ex: neurons and muscle cells) *depolarize* when they fire

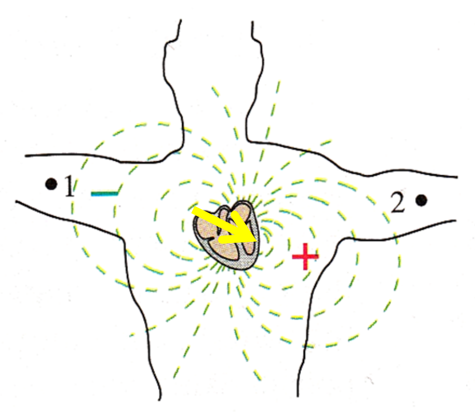


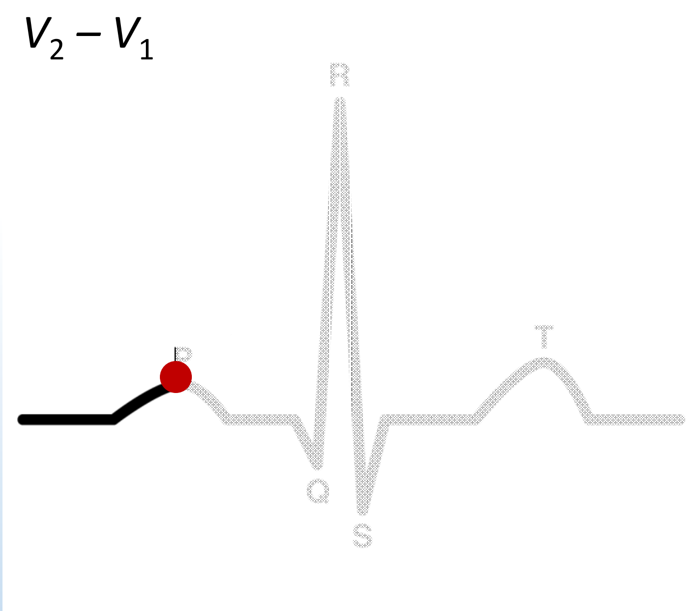
Electrocardiogram (ECG)

ECG detects electric potential difference from depolarization and polarization of cardiac tissue



Ventricular depol.



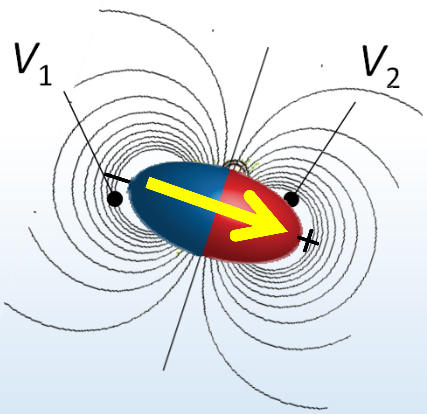


The heart behaves as time-varying electric dipole

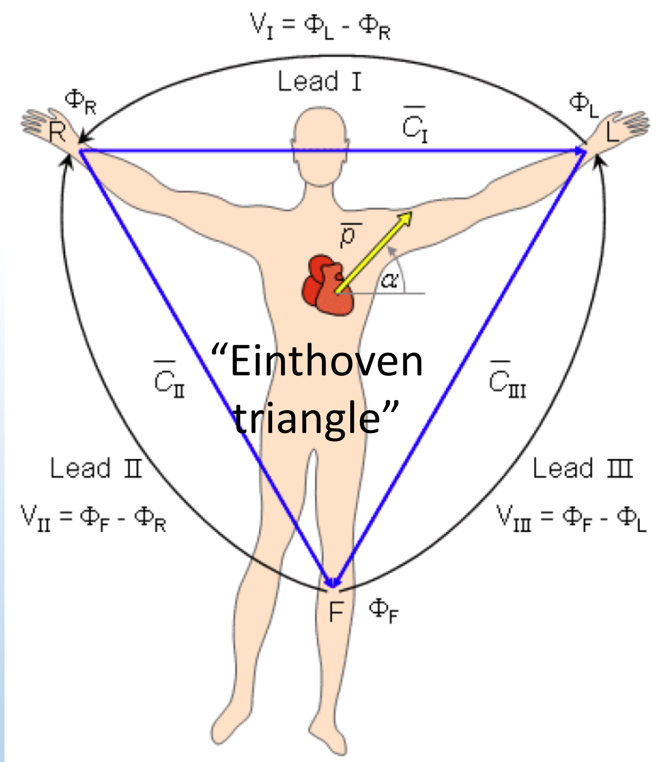
ACT: Electrocardiogram

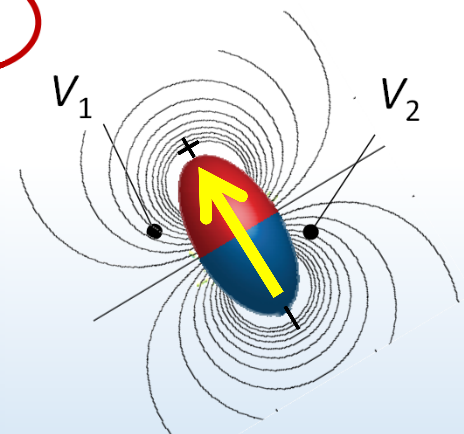
At a certain time during an ECG you measure a ***negative*** electric potential difference $V_2 - V_1$. Which diagram of the cardiac dipole could be correct?

A.



$V_2 - V_1 > 0$





$V_2 - V_1 < 0$

Usually ECG is done with 3, 6, or 12 leads
Need minimum of 3 to get dipole direction

Summary of today's lecture

- Electric potential

  Superposition & point charges $V_{tot} = \sum \frac{kq}{r}$

- Equipotential lines

  Relationship with electric field

  Ex: Uniform field, non-uniform field, conductor, ECG