Lecture 8

Electric Potential – Chapter 25

Review

- Electric Potential Energy, *U* –

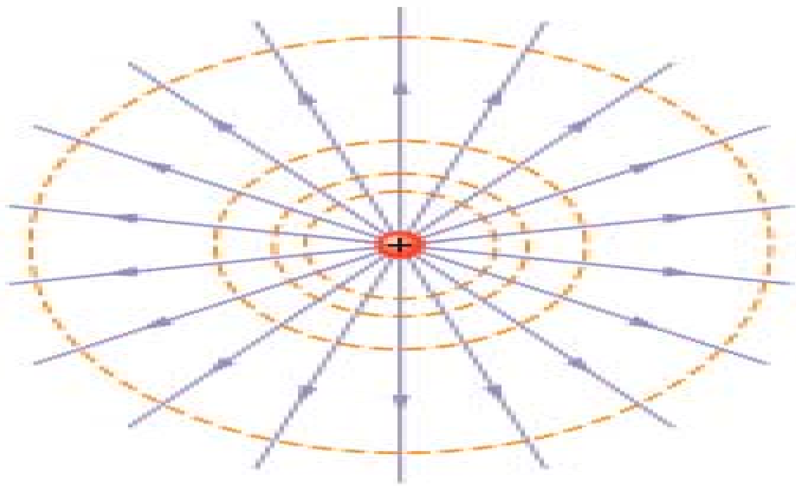
$$\Delta U = U_f - U_i = -W$$

- Electric Potential, *V* -

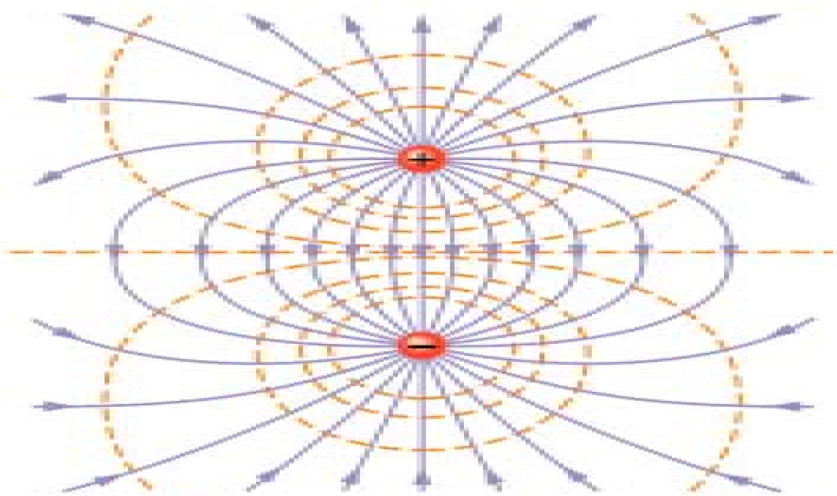
$$\Delta V = V_f - V_i = \frac{\Delta U}{q} = -\frac{W}{q}$$

- Electrostatic force is conserved, work done by force is path independent

Review



(b)



(c)

- Equipotential surface – all points are at same potential
- *E* field lines are ⊥ to the equipotential surface
- If given equipotential surfaces can draw *E* field lines

Review

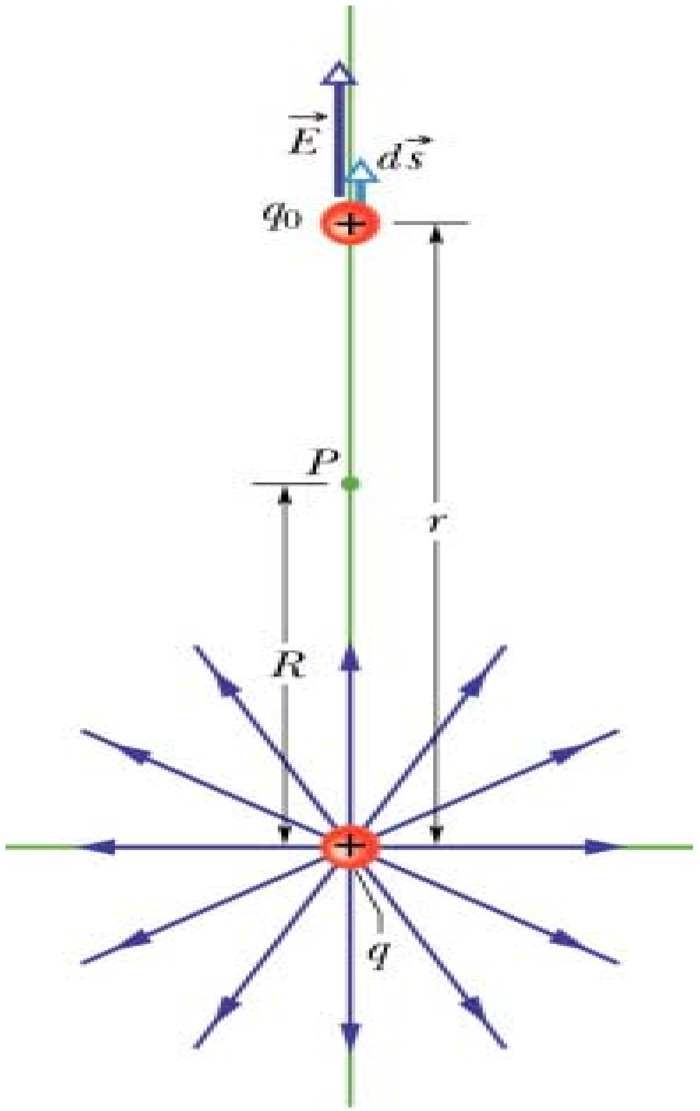
- From $$\Delta V = -\frac{W}{q}$$ and $$dW = \vec{F} \bullet d\vec{s}$$
- Derived equation for finding a potential in a *E* field
$$V_f - V_i = -\int_i^f \vec{E} \bullet d\vec{s}$$
- Potential always decreases if move along a path in the direction of the *E* field

Electric Potential (18)

- Derive potential V around a charged particle

$$V_f - V_i = -\int_i^f \vec{E} \bullet d\vec{s}$$

- Imagine moving a + test charge from *P* to ∞
- Path doesn't matter so choose line radially with *E*



Electric Potential (19)

- Chose path so

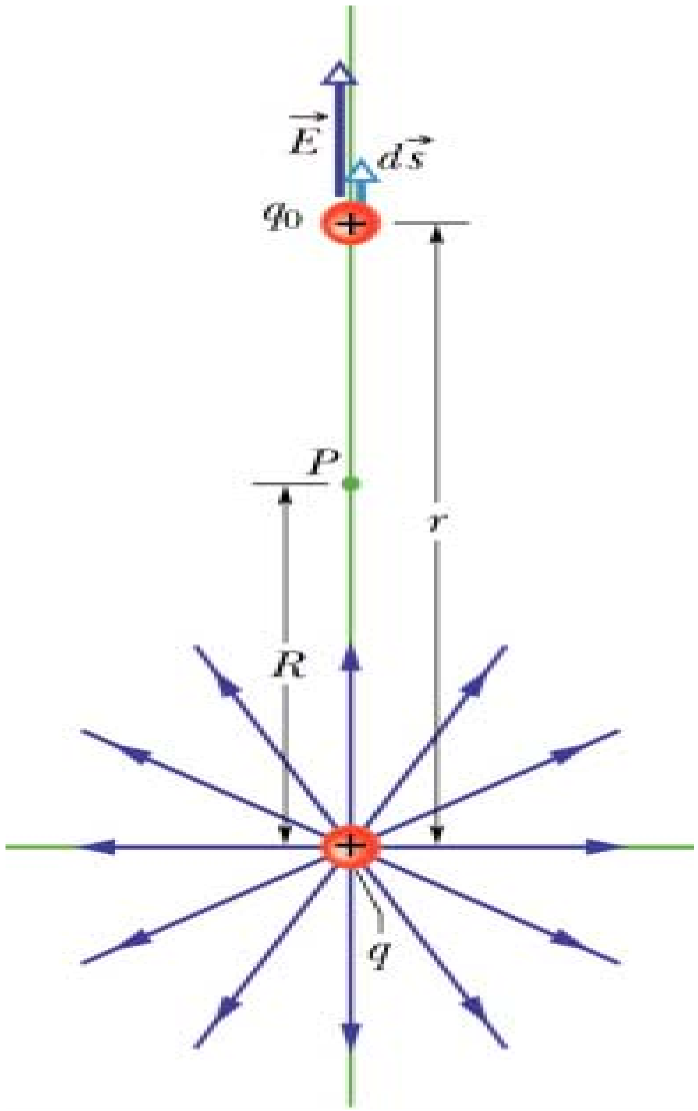
$$\vec{E} \bullet d\vec{s} = E\cos\theta ds = Eds$$

- Using radial path, rewrite

$$ds = dr$$

- Use limits for *i* = R and *f* = ∞

$$V_\infty - V_R = -\int_R^\infty Edr$$



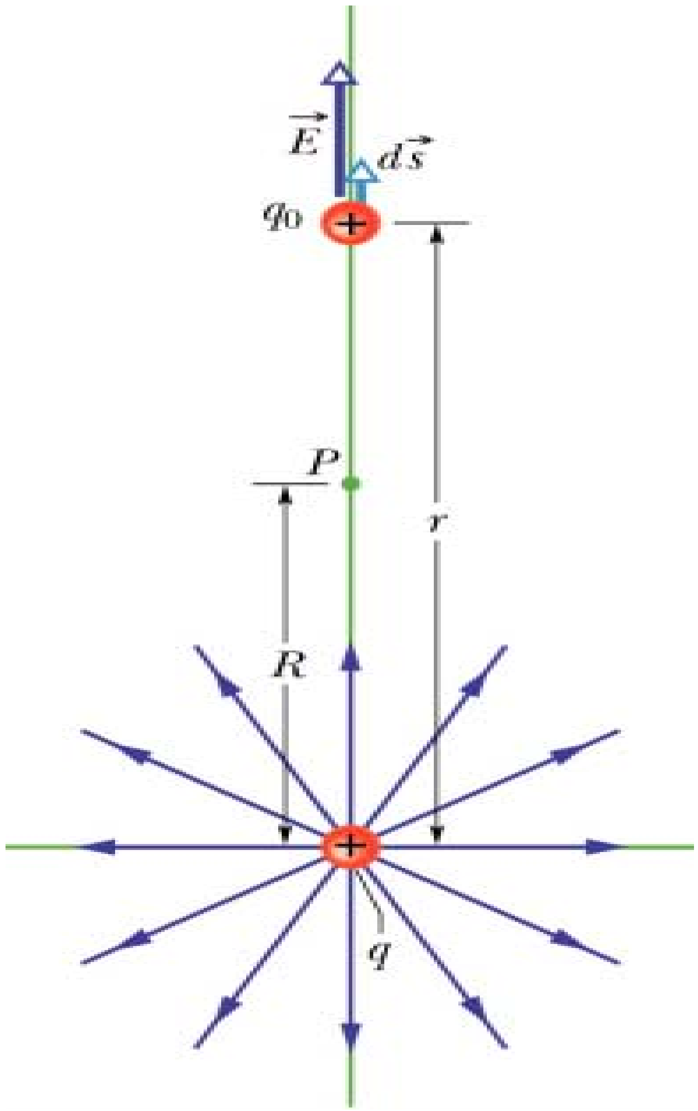
Electric Potential (20)

- Use E for point charge

$$E = k\frac{q}{r^2}$$

- Define $V_\infty = 0$

$$0 - V = -kq\int_R^\infty \frac{1}{r^2}\,dr$$



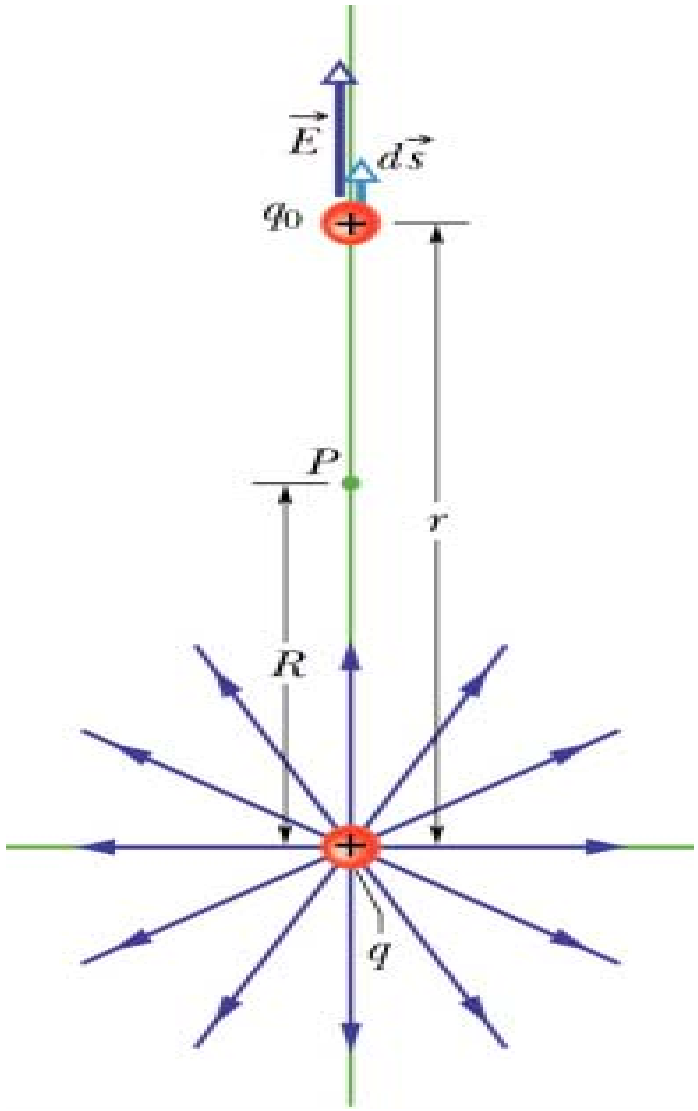
Electric Potential (21)

- Finish integral

$$0 - V = kq\left[\frac{1}{r}\right]_R^{\infty} = -k\frac{q}{R}$$

- Letting *R* become any distance *r* from particle

$$V = k\frac{q}{r}$$



Electric Potential (22)

$$V = k\frac{q}{r}$$

- Sign of V is same sign as q
  - + charge produces $+V$
  - - charge produces $-V$
- V gets larger as r gets smaller
  - In fact $V = \infty$ when $r = 0$ (on top of charge)
- From shell theorem this holds outside or on external surface of a spherical charge distribution

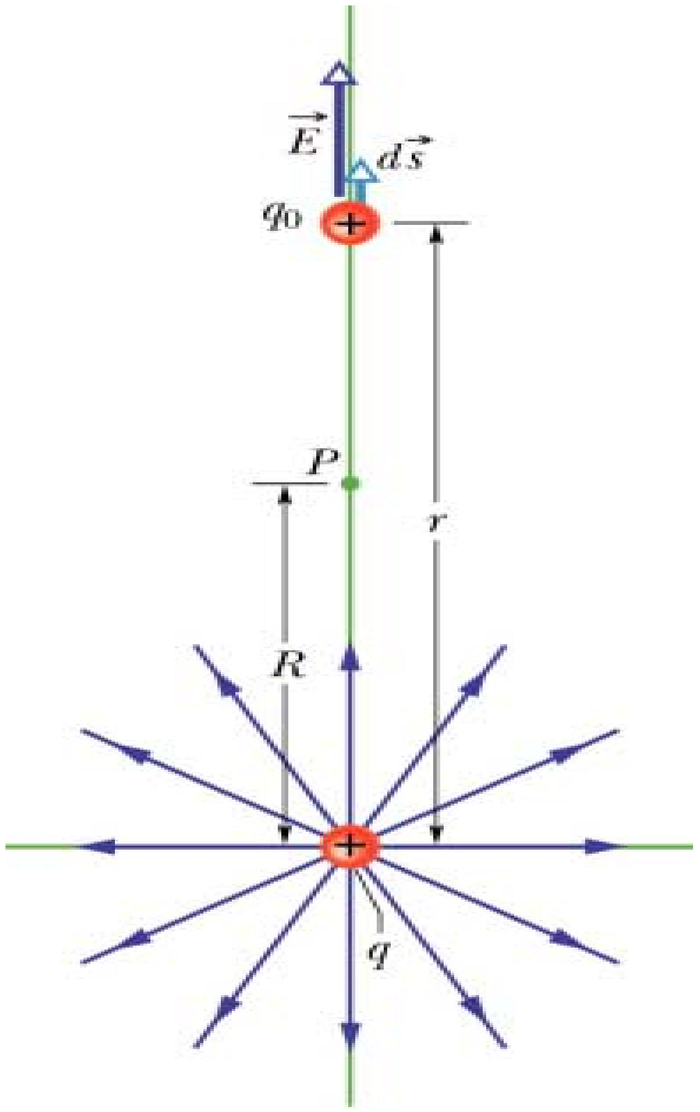
Electric Potential (23)

- What is the force F, electric field E, and potential V, at a point P a distance r away from a point charge?

$$\vec{F} = k\frac{|q||q_0|}{r^2}$$

$$\vec{E} = k\frac{q}{r^2}$$

$$V = k\frac{q}{r}$$



Electric Potential (24)

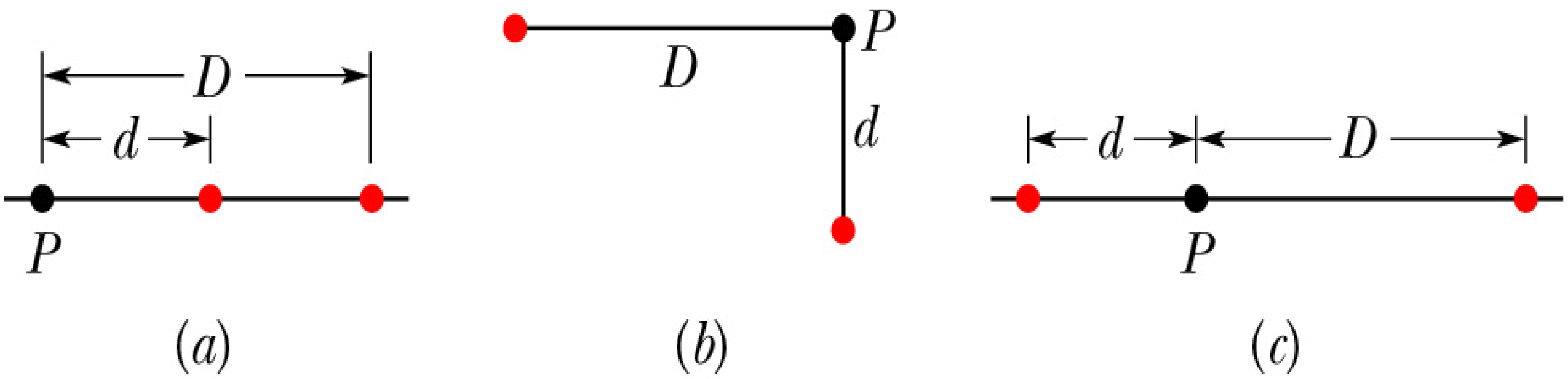
- Use superposition principle to find the potential due to *n* point charges

$$V = \sum_{i=1}^{n} V_i = k \sum_{i=1}^{n} \frac{q_i}{r_i}$$

- This is an algebraic sum, not a vector sum
- Include the sign of the charge

Electric Potential (25)

- Checkpoint #4 – Rank a), b) and c) according to net electric potential V produced at point P by two protons. (Greatest first.)

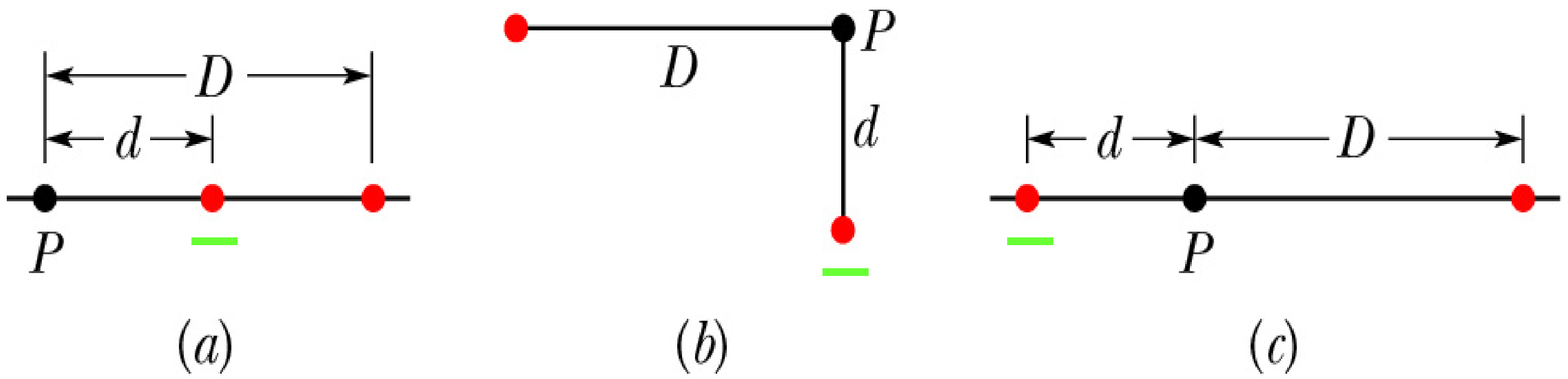


$$V = k\left(\frac{q}{d} + \frac{q}{D}\right)$$

ALL EQUAL

Electric Potential (26)

- Replace one of the protons by an electron. Rank the arrangements now.



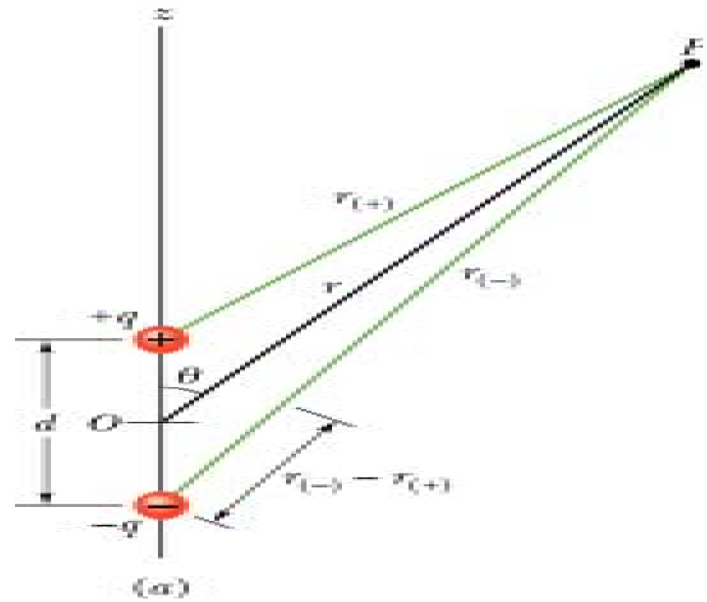
$$V = k\left(-\frac{q}{d} + \frac{q}{D}\right)$$

ALL EQUAL

Electric Potential (27)

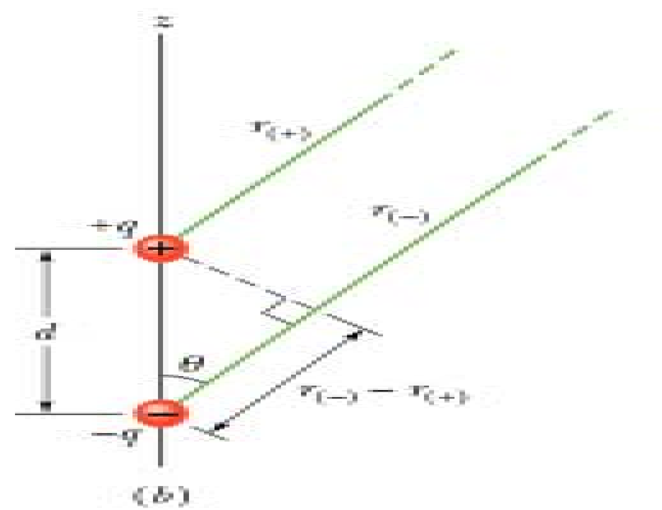
- Potential due to a dipole
- Sum *V* for 2 charges

$$V=\sum_{i=1}^{2}V_i=k\left(\frac{-q}{r_-}+\frac{q}{r_+}\right)=kq\left(\frac{-r_+ + r_-}{r_- r_+}\right)$$



- Usually far away from dipole so $r >> d$

$$r_- - r_+ \approx d\cos\theta \qquad r_- r_+ \approx r^2$$



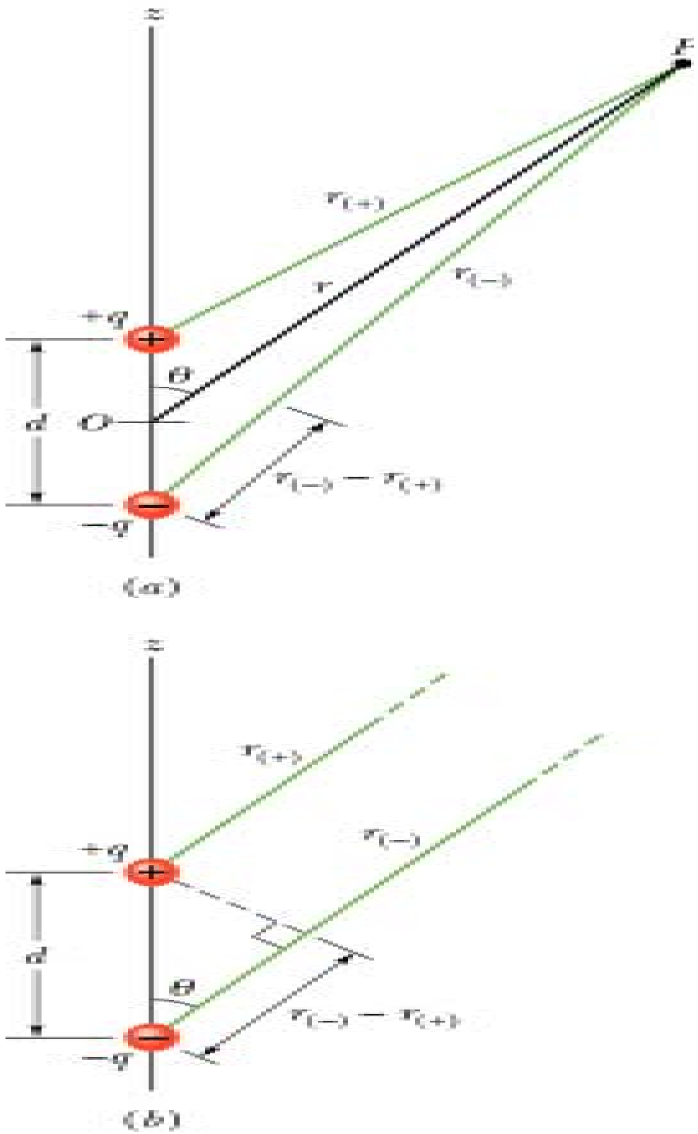
Electric Potential (28)

$$V = kq\left(\frac{-r_+ + r_-}{r_- r_+}\right) = k\left(\frac{qd\cos\theta}{r^2}\right)$$

- For dipole $p = qd$

$$V = k\frac{p\cos\theta}{r^2}$$

- Measure θ from dipole axis to r



Electric Potential (29)

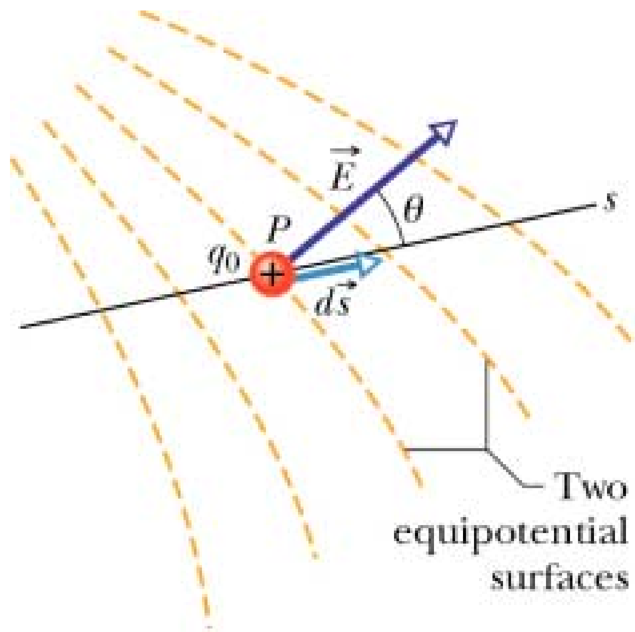
- How do we calculate *E* from *V* ?

$$W = -q_0 \Delta V$$

$$W = \vec{F} \bullet \vec{d} = q\vec{E} \bullet \vec{d}$$

$$-q_0 dV = q_0 E \cos\theta ds$$

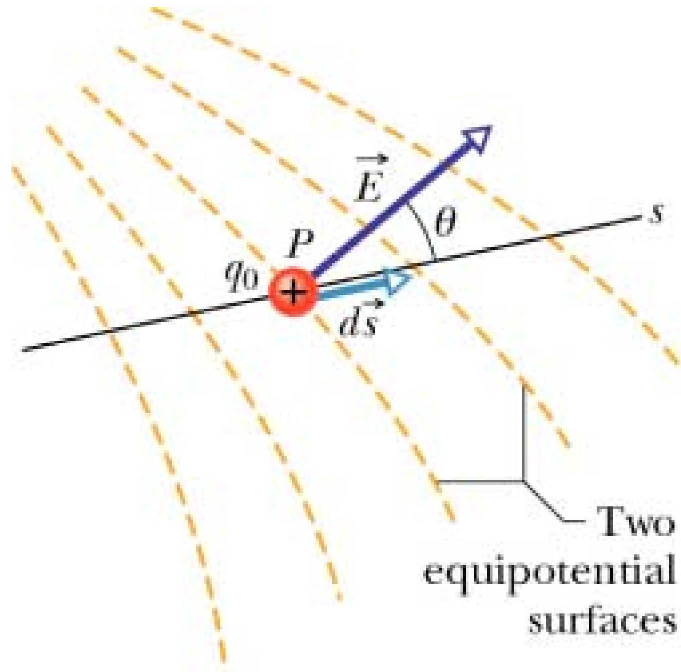
$$E\cos\theta = -\frac{dV}{ds}$$



Electric Potential (30)

- How do we calculate *E* from *V* ?

$$E\cos\theta = -\frac{dV}{ds}$$



- Component of *E* in direction of ds

$$E_s = -\frac{\partial V}{\partial s}$$

- Component of *E* in any direction is neg. rate of change of *V* with distance in that direction

Electric Potential (31)

- Take s axis to be x, y, or z axes

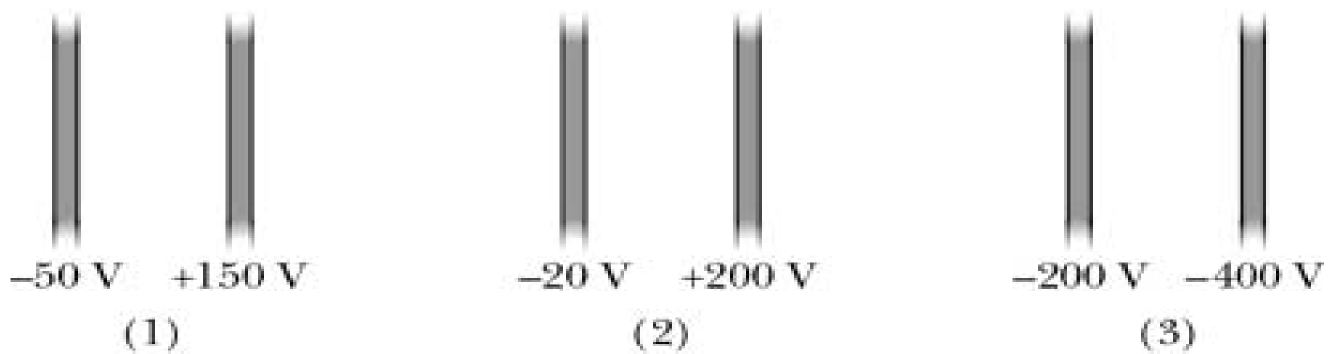
$$E_x = -\frac{\partial V}{\partial x}, E_y = -\frac{\partial V}{\partial y}, E_z = -\frac{\partial V}{\partial z}$$

- If E is uniform and s is $\perp$ to equipotential surface

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

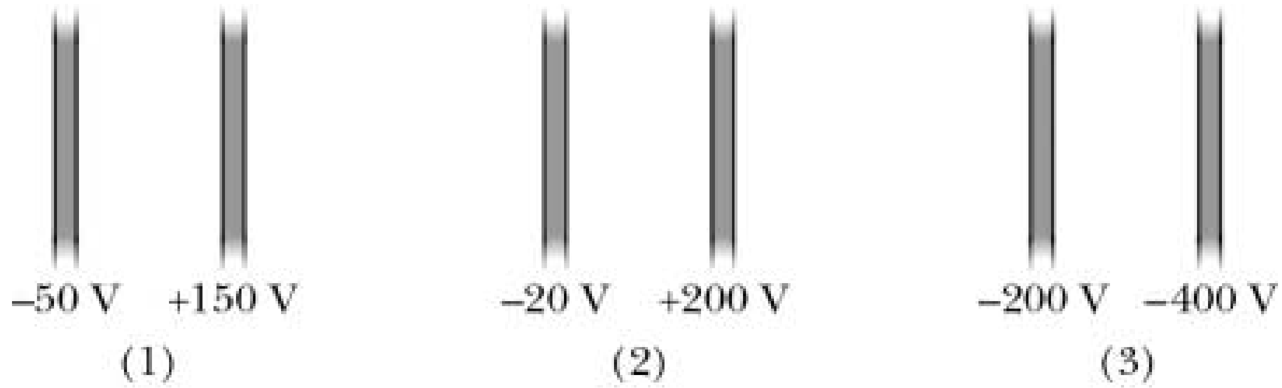
Electric Potential (32)

- Checkpoint #6 – 3 pairs of parallel plates with same separation and V of each plate. *E* field is uniform between plates and ⊥ to the plates.



- A) Rank (greatest first) magnitude of *E* between the plates

Electric Potential (33)



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

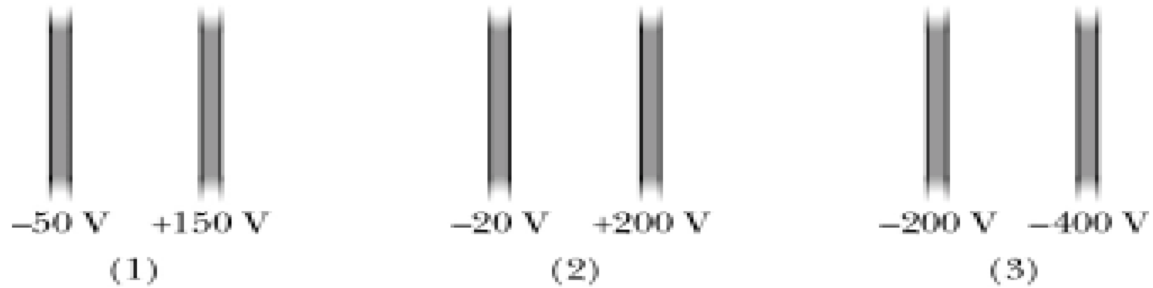
but asked for magnitude of *E*

$$E_1 = \frac{200}{d} \qquad E_2 = \frac{220}{d} \qquad E_3 = \frac{200}{d}$$

2, then 1 & 3

Electric Potential (34)

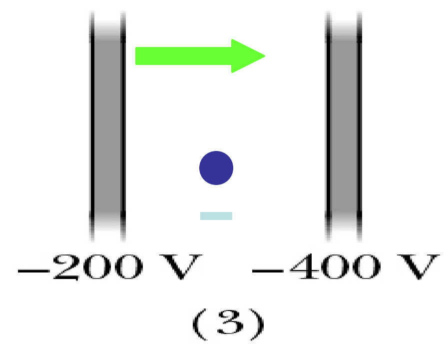
- Checkpoint #6 – b) For which pair does E point to the right?



#3

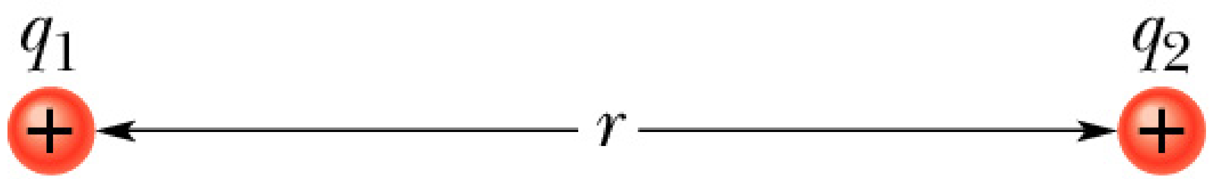
- C) If an electron is released midway between plates in (3) what does it do?

Accelerate to the left



Electric Potential (35)

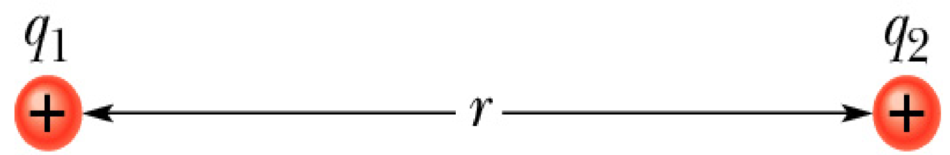
- Define electric potential energy, *U*, of a system of charges as = to the *W* done by an external *F* to assemble the system, bringing each charge from ∞



- Bring q_1 from ∞, $W = 0$ since no electric *F* yet
- Bring q_2 from ∞, $W_{app} = q_2 V$ because q_1 exerts electrostatic *F* on q_2 during the move

Electric Potential (36)

- Potential due to q_1 is



$$V = k\frac{q_1}{r}$$

- From definition of potential energy

$$U = W = q_2 V = k\frac{q_1 q_2}{r}$$

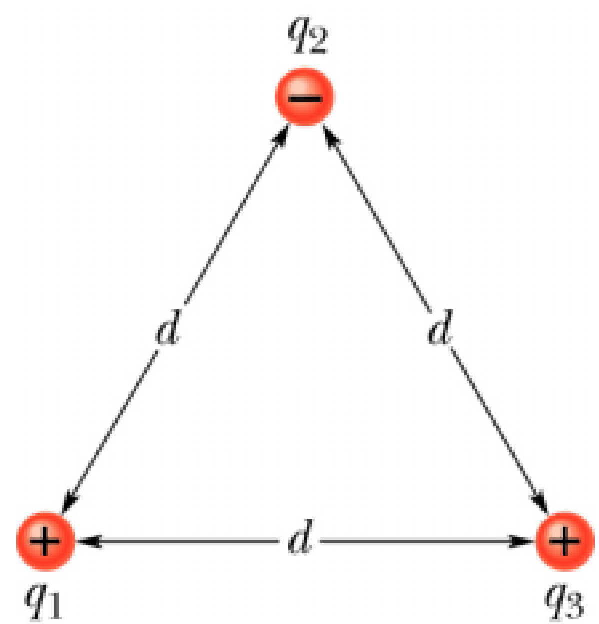
- Charges of like sign, *W* and *U* are +
- Charges of opposite sign, *W* and *U* are -

Electric Potential (37)

- What is the potential energy when add an additional charge to system?

- Move q_1 from ∞, $W = U = 0$
- Move q_2 from ∞

$$W_{12} = U_{12} = k\frac{q_1 q_2}{d}$$



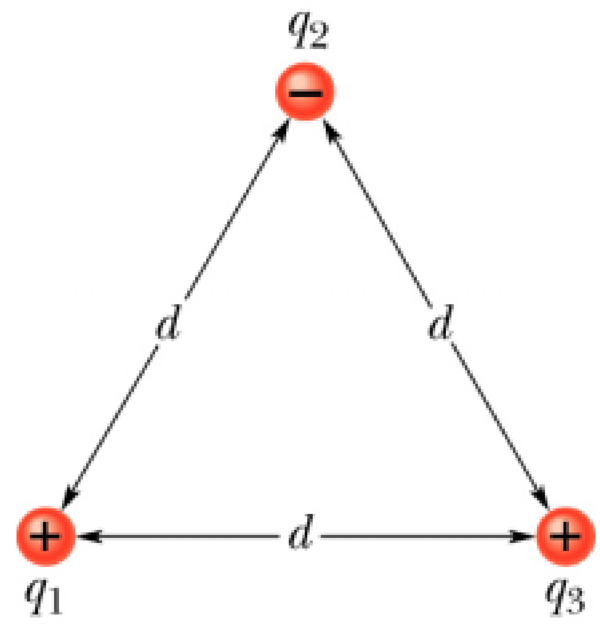
Electric Potential (38)

- Now bring in q_3

$$W_{13} = U_{13} = k\frac{q_1 q_3}{d}$$

- Must also remember q_2

$$W_{23} = U_{23} = k\frac{q_2 q_3}{d}$$

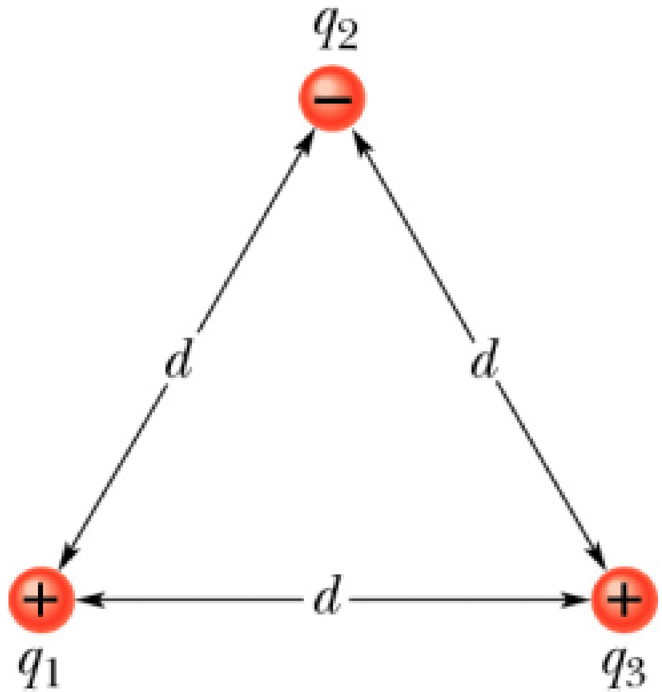


Electric Potential (39)

- Total potential energy is the scalar sum

$$U = U_{12} + U_{13} + U_{23}$$

$$q_1 = +q, q_2 = -4q, q_3 = +2q$$



$$U = k\left(\frac{(+q)(-4q)}{d} + \frac{(+q)(+2q)}{d} + \frac{(-4q)(+2q)}{d}\right) = -k\frac{10q^2}{d}$$

Electric Potential (40)

- Using what we know about conductors
  - $E = 0$ inside
  - All excess charge is on surface
- All points of a conductor – whether inside or on the surface – are at the same potential
  - A conductor is an equipotential surface