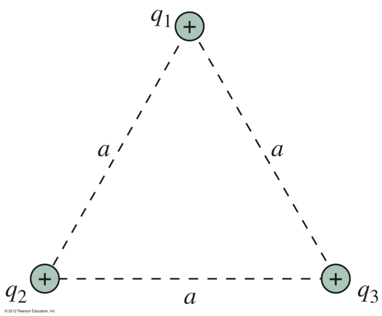

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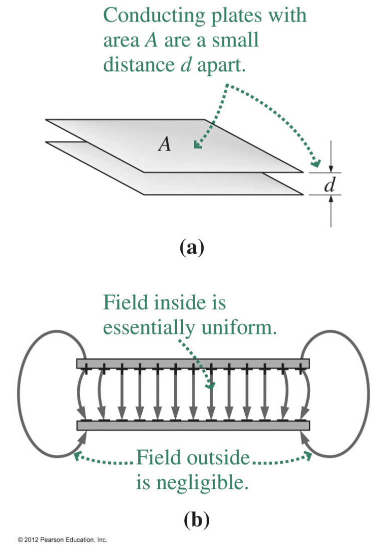

Exam Review
(Chapter 23, Capacitors, is deferred)
Exam Wed Feb 12 Lab Fri Feb 14

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Monday, February 10 2014

Happy Birthday to Chloe Grace Moretz, Emma Roberts, Elizabeth Banks, Boris Pasternak, and Walter Houser Brattain (Nobel Prize 1956)!

Summary: Chapter 22: Electric Potential

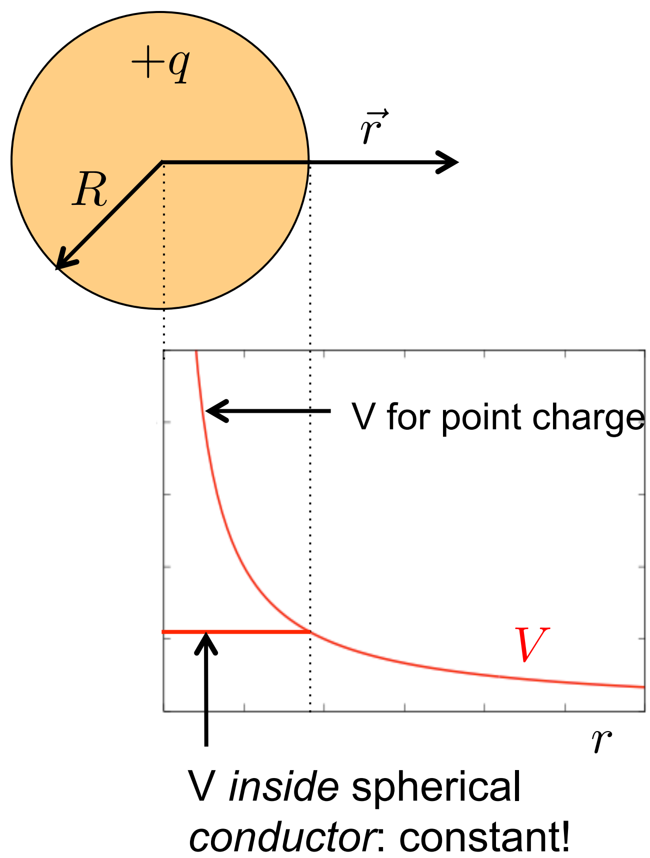
- **Electric potential difference** describes the work per unit charge involved in moving charge between two points in an electric field:

$$\Delta U_{\mathrm{AB}} = q\Delta V_{\mathrm{AB}} \qquad \Delta V_{\mathrm{AB}} = -\int_{\mathrm{A}}^{\mathrm{B}} \vec{E}\cdot d\vec{r}$$

  - The SI unit of electric potential is the volt (V), equal to 1 J/C.
  - Electric potential *always* involves two points;
    - To say "the potential at a point" is to assume a second reference point at which the potential is defined to be zero.
  - Electric potential differences of a point charge

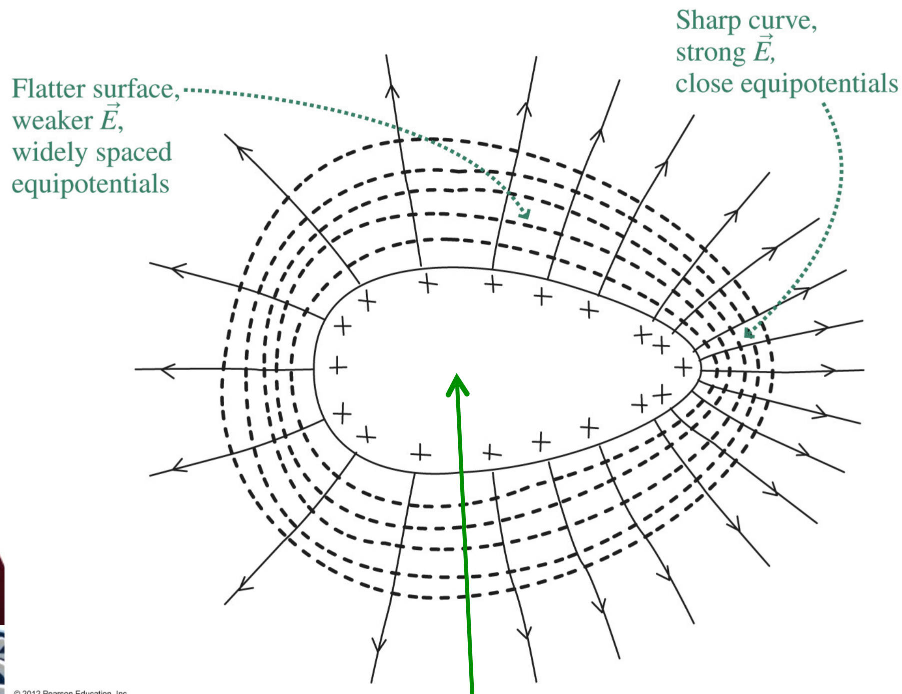
$$V_r = \frac{kq}{r}$$

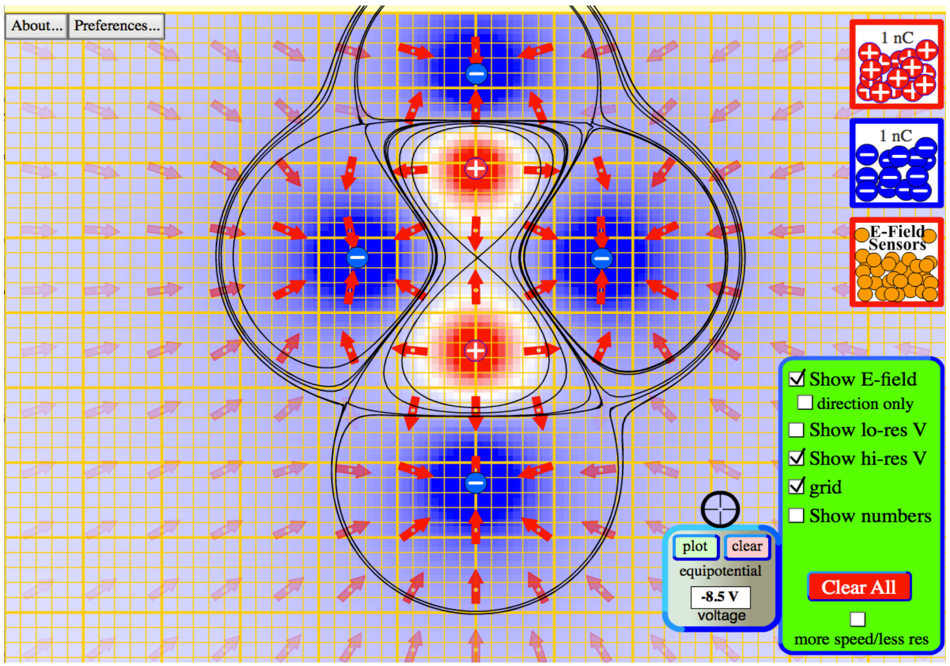
    - where the "other point" of potential is taken to be zero at infinity.



Summary: Chapter 22: Equipotentials and Conductors

- **Equipotentials** are surfaces of constant potential.
  - The electric field and the equipotential surfaces are always perpendicular.
  - Equipotentials near a charged conductor approximate the shape of the conductor.
    - A conductor in equilibrium is an equipotential throughout the conductor.



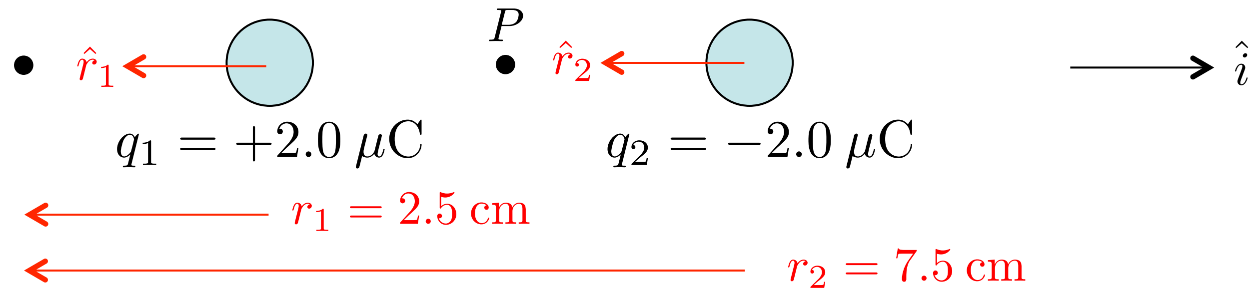


Equipotential *inside* condugtor

Review: Homework 20.27 (a)

- In the figure, point P is midway between the two charges.
  - (a) Find the electric field in the plane of the page 5.0 cm to the left of P.

$$\boxed{\vec{E} = \frac{kq}{r^2}\hat{r}}$$



Remember that $\hat{r} = \vec{r}/r$ is just a direction

Remember that r is the length of $\vec{r}$ (always positive!)

$$\vec{E}_1 = \frac{kq}{r_1^2}\hat{r}_1 = \frac{(9\times 10^9\ \mathrm{N\,m^2/C^2})(2.0\times 10^{-6}\ \mathrm{C})}{(0.025\ \mathrm{m})^2}(-\hat{i}) = (-2.9\times 10^7\ \mathrm{N/C})\hat{i}$$

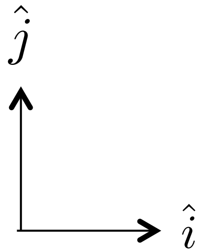
$$\vec{E}_2 = \frac{kq}{r_2^2}\hat{r}_2 = \frac{(9\times 10^9\ \mathrm{N\,m^2/C^2})(-2.0\times 10^{-6}\ \mathrm{C})}{(0.075\ \mathrm{m})^2}(-\hat{i}) = (+3.2\times 10^6\ \mathrm{N/C})\hat{i}$$

$$\vec{E} = \vec{E}_1 + \vec{E}_2 = \boxed{(-2.6\times 10^7\ \mathrm{N/C})(\hat{i}) = \vec{E}}$$

Review: Homework 20.27 (b)

- In the figure, point P is midway between the two charges.
  - (a) Find the electric field in the plane of the page 5.0 cm above P.

$$\vec{E} = \frac{kq}{r^2}\hat{r}$$



$$\vec{r}_1 = (2.5\ \mathrm{cm}, 5.0\ \mathrm{cm})$$

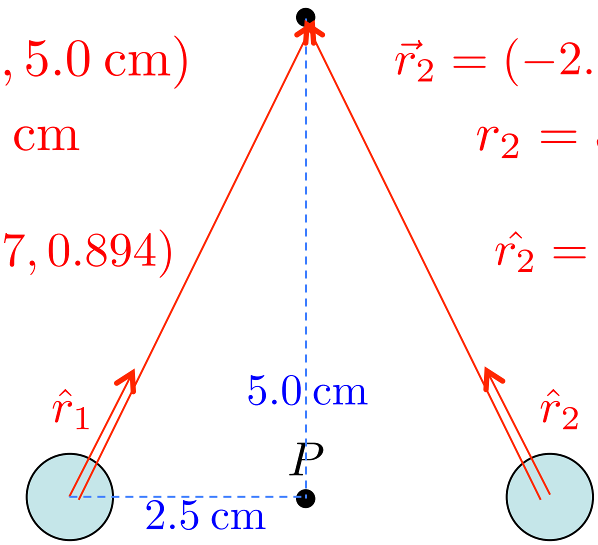
$$r_1 = 5.59\ \mathrm{cm}$$

$$\hat{r}_1 = \frac{\vec{r}_1}{r_1} = (0.447, 0.894)$$

$$\vec{r}_2 = (-2.5\ \mathrm{cm}, 5.0\ \mathrm{cm})$$

$$r_2 = 5.59\ \mathrm{cm}$$

$$\hat{r}_2 = \frac{\vec{r}_2}{r_2} = (-0.447, 0.894)$$



$q_1 = +2.0\ \mu\mathrm{C}$ $\quad$ $q_2 = -2.0\ \mu\mathrm{C}$

This is NOT a 30-60-90 triangle!

$$\vec{E}_1 = \frac{kq_1}{r_1^2}\hat{r}_1 = \frac{(9\times 10^9\ \mathrm{N\,m^2/C^2})(2.0\times 10^{-6}\ \mathrm{C})}{(0.0559\ \mathrm{m})^2}(0.447, 0.894) = (2.57, 5.15)\times 10^6\ \mathrm{N/C}$$

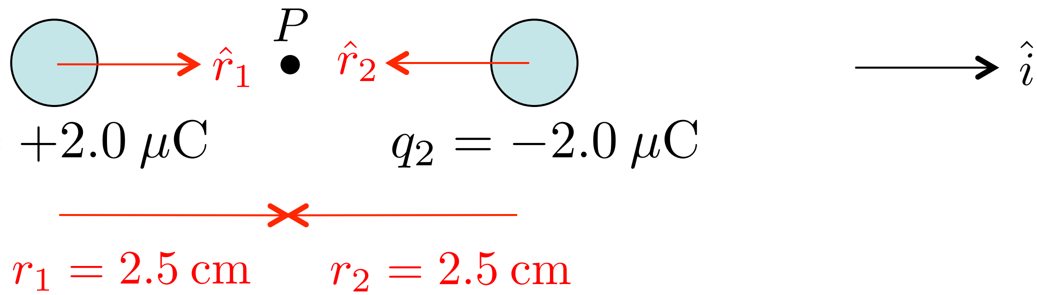
$$\vec{E}_2 = \frac{kq_2}{r_2^2}\hat{r}_2 = \frac{(9\times 10^9\ \mathrm{N\,m^2/C^2})(-2.0\times 10^{-6}\ \mathrm{C})}{(0.0559\ \mathrm{m})^2}(-0.447, 0.894) = (2.57, -5.15)\times 10^6\ \mathrm{N/C}$$

$$\vec{E} = \vec{E}_1 + \vec{E}_2 = \boxed{(+5.15, 0.0)\times 10^6\ \mathrm{N/C} = \vec{E}}$$

Review: Homework 20.27 (c)

- In the figure, point P is midway between the two charges.
  - (c) Find the electric field in the plane of the page at P.

$$\vec{E} = \frac{kq}{r^2}\hat{r}$$



Remember that $\hat{r} = \vec{r}/r$ is just a direction

Remember that r is the length of $\vec{r}$ (always positive!)

$$\vec{E}_1 = \frac{kq}{r_1^2}\hat{r}_1 = \frac{(9\times 10^9\ \text{N m}^2/\text{C}^2)(+2.0\times 10^{-6}\ \text{C})}{(0.025\ \text{m})^2}(+\hat{i}) = (+2.9\times 10^7\ \text{N/C})\hat{i}$$

$$\vec{E}_2 = \frac{kq}{r_2^2}\hat{r}_2 = \frac{(9\times 10^9\ \text{N m}^2/\text{C}^2)(-2.0\times 10^{-6}\ \text{C})}{(0.025\ \text{m})^2}(-\hat{i}) = (+2.9\times 10^7\ \text{N/C})\hat{i}$$

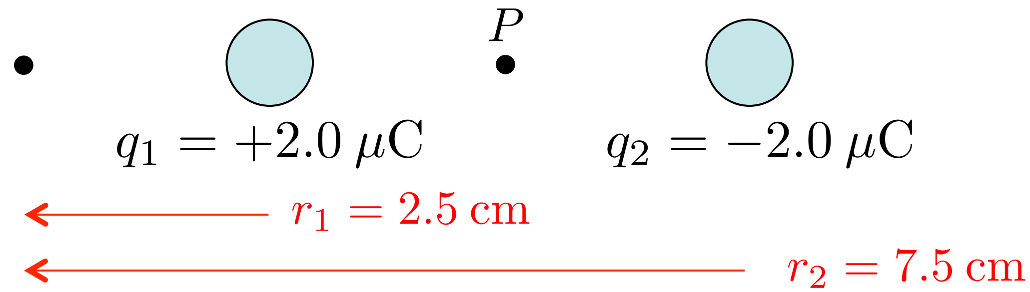
$$\vec{E} = \vec{E}_1 + \vec{E}_2 = \boxed{(5.8\times 10^7\ \text{N/C})\hat{i} = \vec{E}}$$

Review: Homework 20.27 (a) Variant

- In the figure, point P is midway between the two charges.
  - (a) Find the electric **potential** in the plane of the page 5.0 cm to the left of P.

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

(from V=0 very far away)



$$\text{Remember that } r \text{ is the length of } \vec{r} \text{ (always positive!)}$$

$$V_1 = \frac{kq_1}{r_1} = \frac{(9 \times 10^9\ \text{N m}^2/\text{C}^2)(2.0 \times 10^{-6}\ \text{C})}{(0.025\ \text{m})} = +720\ \text{kV}$$

$$V_2 = \frac{kq_2}{r_2} = \frac{(9 \times 10^9\ \text{N m}^2/\text{C}^2)(-2.0 \times 10^{-6}\ \text{C})}{(0.075\ \text{m})} = -240\ \text{kV}$$

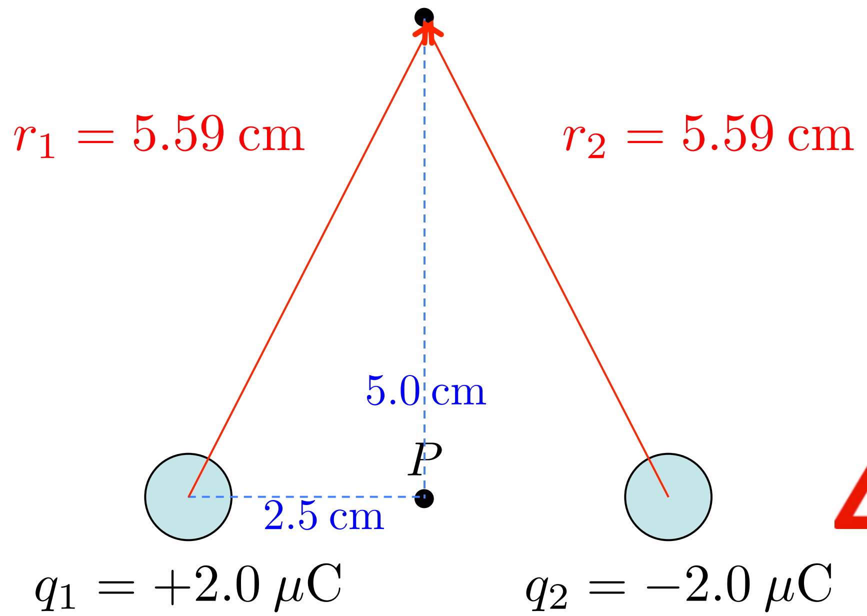
$$V = V_1 + V_2 = \boxed{+480\ \text{kV} = V}$$

Review: Homework 20.27 (b) Variant

- In the figure, point P is midway between the two charges.
  - (a) Find the electric **potential** in the plane of the page 5.0 cm above P.

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

(from V=0 very far away)



This is NOT a 30-60-90 triangle!

$$V_1 = \frac{kq_1}{r_1} = \frac{(9\times10^9\ \mathrm{N\,m^2/C^2})(2.0\times10^{-6}\ \mathrm{C})}{(0.0559\ \mathrm{m})} = 322\ \mathrm{kV}$$

$$V_2 = \frac{kq_2}{r_2} = \frac{(9\times10^9\ \mathrm{N\,m^2/C^2})(-2.0\times10^{-6}\ \mathrm{C})}{(0.0559\ \mathrm{m})} = -322\ \mathrm{kV}$$

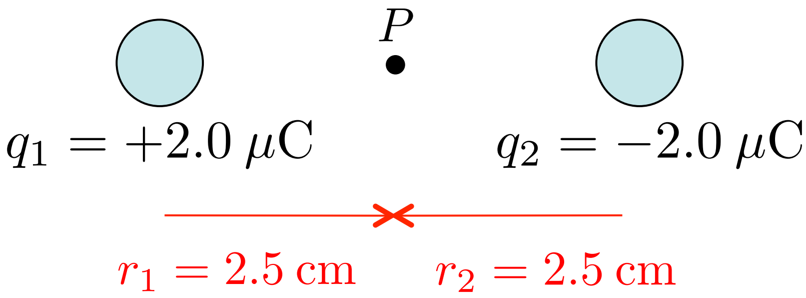
$$V = V_1 + V_2 = \boxed{0\ \mathrm{kV} = V}$$

Review: Homework 20.27 (c) Variant

- In the figure, point P is midway between the two charges.
  - (c) Find the electric field in the plane of the page at P.

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

(from V=0 very far away)



$$V_1 = \frac{kq_1}{r_1} = \frac{(9 \times 10^9\ \mathrm{N\,m^2/C^2})(2.0 \times 10^{-6}\ \mathrm{C})}{(0.025\ \mathrm{m})} = +72\ \mathrm{kV}$$

$$V_2 = \frac{kq_2}{r_2} = \frac{(9 \times 10^9\ \mathrm{N\,m^2/C^2})(-2.0 \times 10^{-6}\ \mathrm{C})}{(0.025\ \mathrm{m})} = -72\ \mathrm{kV}$$

$$V = V_1 + V_2 = \boxed{0\ \mathrm{kV} = V}$$

Same as part (b) Variant!

Review: Homework 20.27 (b-c) Insight

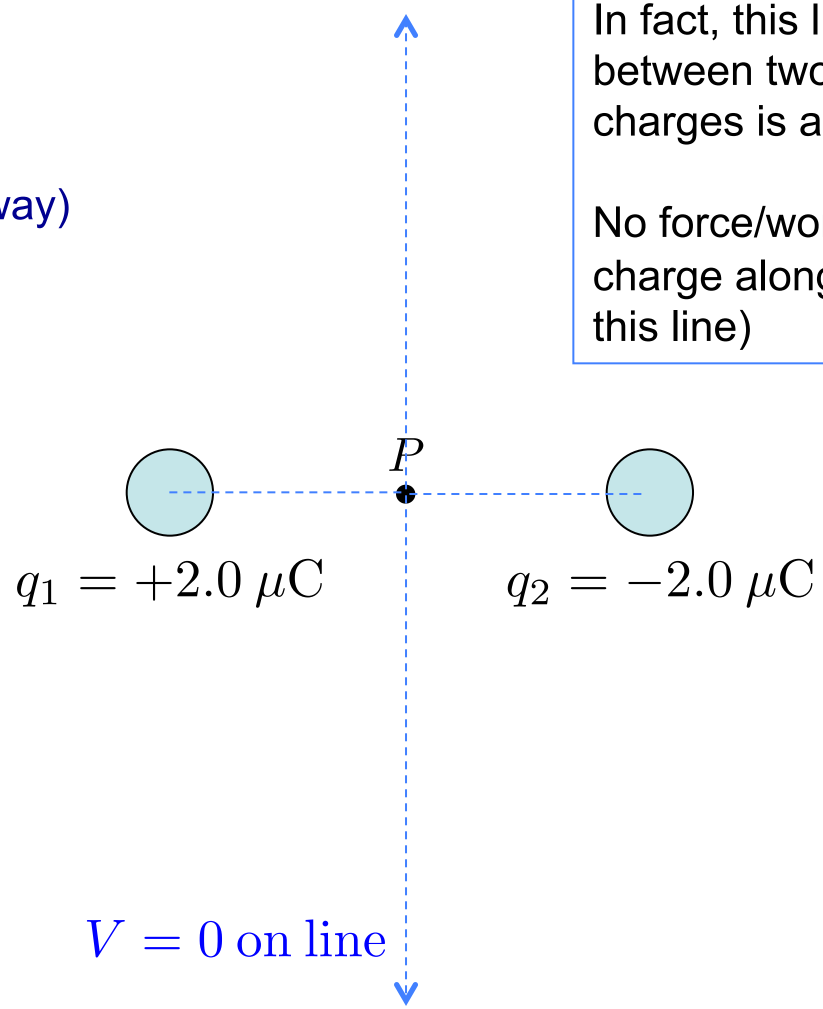
- In the figure, point P is midway between the two charges.
  - Observed that (b,c) answers were the same with V=0

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

(from V=0 very far away)

In fact, this line where $r_1 = r_2$ between two equal and opposite charges is an **equipotential** with V=0

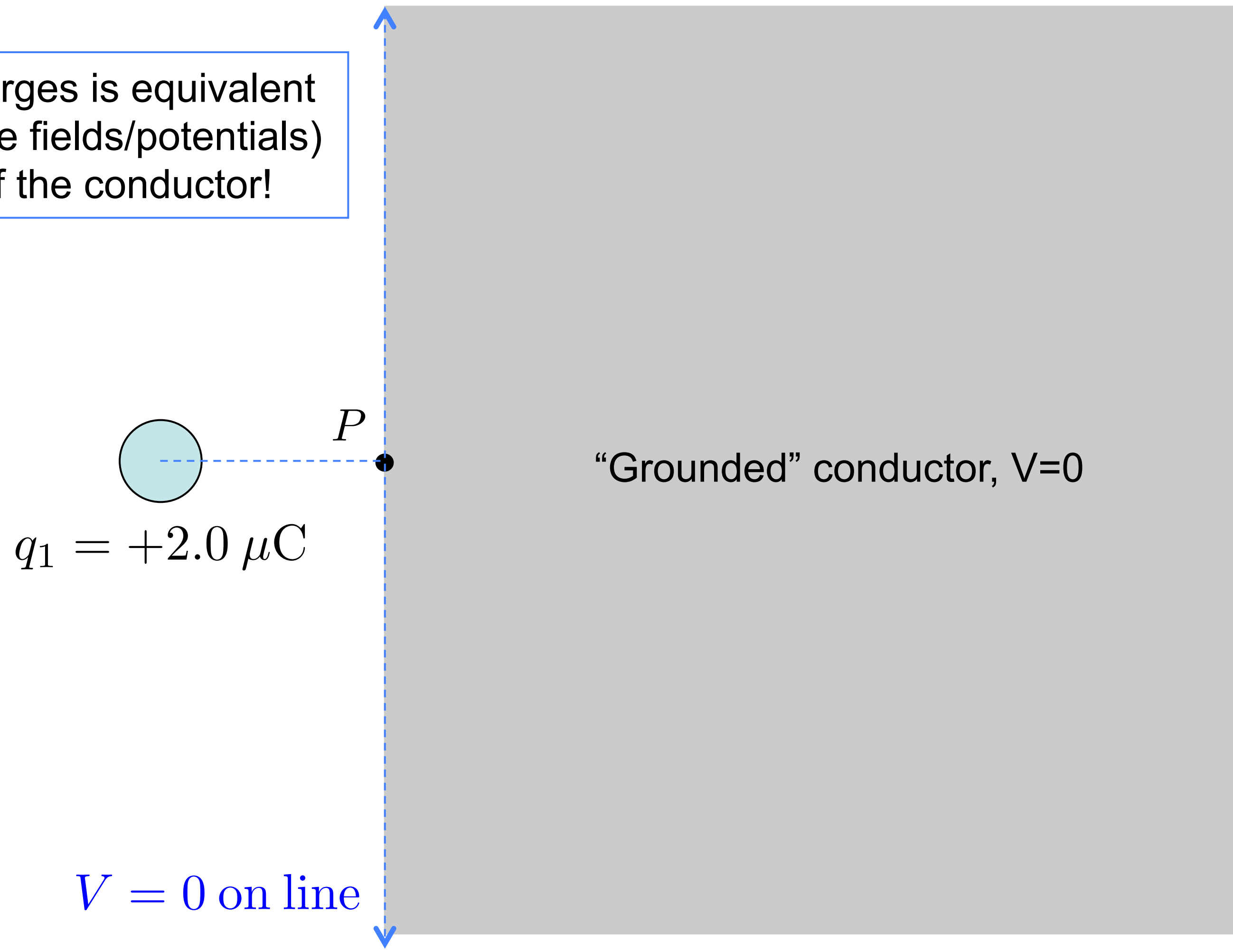
No force/work is needed to move charge along an equipotential (e.g. this line)



(Review: Homework 20.27 (b-c) Insight)

- In the figure, point P is midway between the two charges.
  - Observed V=0 equipotential, and recall that conductor is an equipotential

The picture with two charges is equivalent to this one (has the same fields/potentials) for all points to the left of the conductor!



Electric Field and Surface Charge on Conductor

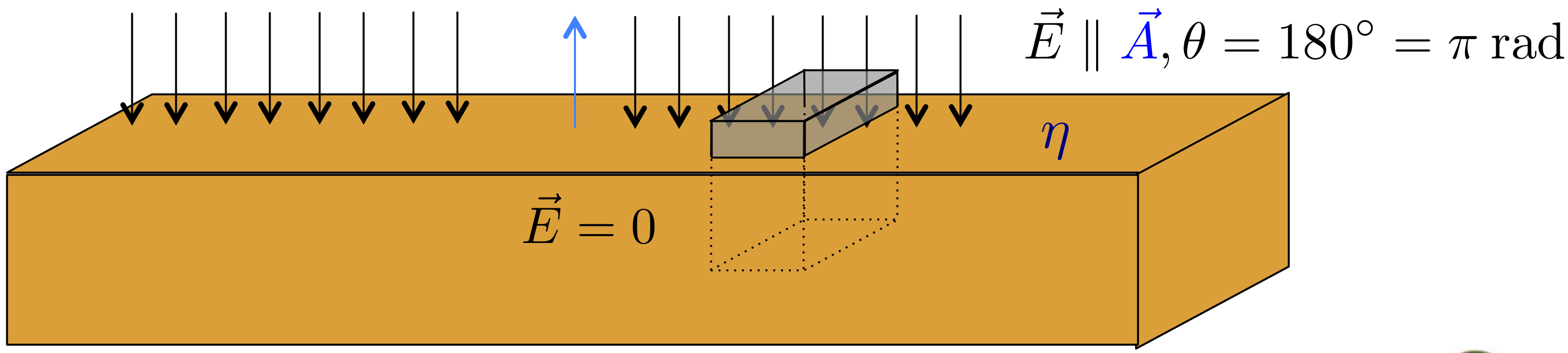
- A conductor is placed in an external electrostatic field. The external field is uniform before the conductor is placed within it. The conductor is completely isolated from any source of current or charge.
  - A) Which of the following describes the electric field inside this conductor?
    - It is in the same direction as the original external field.
    - It is in the opposite direction from that of the original external field.
    - It has a direction determined entirely by the charge on its surface.
    - **It is always zero.**

Electric Field and Surface Charge on Conductor

- A conductor is placed in an external electrostatic field. The external field is uniform before the conductor is placed within it. The conductor is completely isolated from any source of current or charge.
  - B) The charge density *inside* the conductor is:
    - **0**
    - non-zero; but uniform
    - non-zero; non-uniform
    - infinite

Electric Field and Surface Charge on Conductor

- A conductor is placed in an external electrostatic field. The external field is uniform before the conductor is placed within it. The conductor is completely isolated from any source of current or charge.
  - C) Assume that at some point just outside the surface of the conductor, the electric field has magnitude *E* and is directed **toward the surface of the conductor**. What is the charge density η on the surface of the conductor at that point? Express your answer in terms of *E* and ϵ_0.
  - *E* points in the opposite direction as derivation in class
  - So $E = -4\pi k\eta = -\eta/\epsilon_0 \quad \Rightarrow \quad \eta = -E\epsilon_0$



Electric Field of a Ball of Uniform Charge Density

- A solid **insulating** ball of radius r_b has a **uniform charge density** ρ.
  - A) What is the magnitude of the electric field E(r) at a distance $r>r_b$ from the center of the ball? Express your answer in terms of ρ, r_b, r, and ϵ_0.

  - Gauss's Law applies, with the full charge of the sphere enclosed

$$q_{\text{enclosed}} = q_{\text{sphere}} = \rho V_{\text{sphere}} = \frac{4\pi r_b^3 \rho}{3}$$

$$E A_{\text{sphere}} = 4\pi r^2 E = 4\pi k q_{\text{enclosed}} = q_{\text{enclosed}}/\epsilon_0$$

$$E(r > r_b) = \frac{4\pi r_b^3 \rho/3}{4\pi r^2 \epsilon_0} = \frac{r_b^3 \rho}{3\epsilon_0 r^2}$$

Electric Field of a Ball of Uniform Charge Density

- A solid insulating ball of radius r_b has a uniform charge density ρ.
  - B) What is the magnitude of the electric field E(r) at a distance $r<r_b$ from the center of the ball?
  - Gauss's Law applies, with only a portion of the charge of the sphere enclosed

$$q_{\text{enclosed}} = V_{\text{Gaussian surface}} \rho = \frac{4\pi r^3}{3} \rho$$

$$E A_{\text{Gaussian surface}} = 4\pi r^2 E = 4\pi k q_{\text{enclosed}} = q_{\text{enclosed}}/\epsilon_0$$

$$E(r < r_b) = \frac{4\pi r^3 \rho/3}{4\pi r^2 \epsilon_0} = \frac{r\rho}{3\epsilon_0}$$

$$E(r > r_b) = \frac{r_b^3 \rho}{3\epsilon_0 r^2}$$

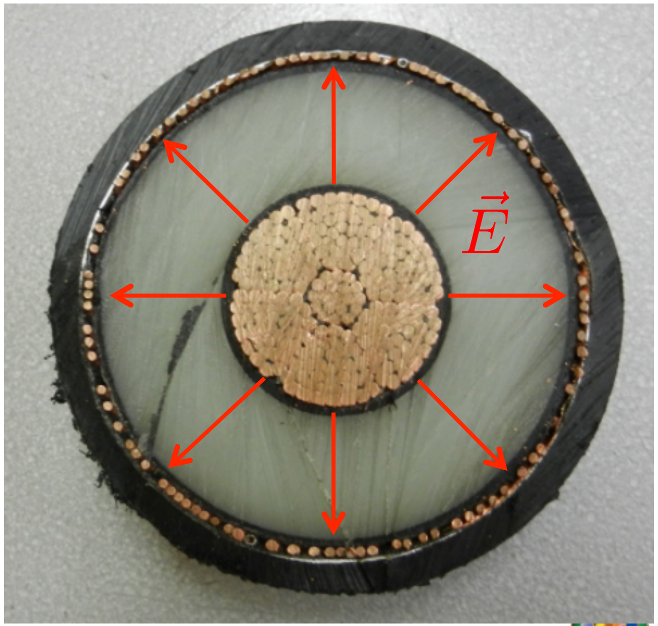
$$E(r = r_b) = \frac{r_b \rho}{3\epsilon_0}$$

Same for both solutions
(which is good: E should be continuous)

21.71-3 (From Feb 3 class notes)

- Coaxial cables are used in **many** electrical signal applications
  - Inner and outer conductors carry equal and opposite charges
- Like parallel plane capacitor
  - Electric field restricted to region between conductor surfaces
- In the region of the electric field, Gauss's Law (with a cylindrical Gaussian surface) gives

$$E = \frac{2k\lambda}{r}\hat{r}$$



22.20

- A charge of 3.0 C moves from the positive to the negative terminal of a 9.4 V battery.
  - How much energy does the battery impart to the charge?
  - Express your answer using two significant figures.

$$\Delta U_{\mathrm{AB}} = q\Delta V_{\mathrm{AB}}$$

$$\Delta U_{\mathrm{AB}} = (3.0\ \mathrm{C})(9.4\ \mathrm{V}) = \boxed{28\ \mathrm{J} = \Delta U_{\mathrm{AB}}}$$

22.21

- A proton, an alpha particle (a bare helium nucleus), and a singly ionized helium atom are accelerated through a potential difference of 100 V.
  - Find the energies that each particle gains

$$q_{\rm proton} = +e = 1.6 \times 10^{-19}\ {\rm C}$$

$$\Delta U_{\rm AB} = q_{\rm proton} \Delta V_{\rm AB} = (1.6 \times 10^{-19}\ {\rm C})(100\ {\rm V}) = 1.6 \times 10^{-17}\ {\rm J}$$

$$q_{\rm He+2} = +2e = 3.2 \times 10^{-19}\ {\rm C}$$

$$\Delta U_{\rm AB} = q_{\rm He+2} \Delta V_{\rm AB} = (3.2 \times 10^{-19}\ {\rm C})(100\ {\rm V}) = 3.2 \times 10^{-17}\ {\rm J}$$

$$q_{\rm He+1} = +e = 1.6 \times 10^{-19}\ {\rm C}$$

$$\Delta U_{\rm AB} = q_{\rm He+1} \Delta V_{\rm AB} = (1.6 \times 10^{-19}\ {\rm C})(100\ {\rm V}) = 1.6 \times 10^{-17}\ {\rm J}$$

22.24

- The classical picture of the hydrogen atom has a single electron in orbit a distance 0.0529 nm from the proton.
  - Calculate the electric potential associated with the proton's electric field at this distance.

$$V_{\mathrm{AB}} = kq\left(\frac{1}{r_{\mathrm{A}}} - \frac{1}{r_{\mathrm{B}}}\right)$$

Take reference location B to be infinity (we move the electron towards the proton from very far away).

$$V_{\mathrm{AB}} = kq\left(\frac{1}{r}\right) = (9\times 10^{9}\ \mathrm{N\,m^2/C^2})(1.6\times 10^{-19}\ \mathrm{C})\left(\frac{1}{5.29\times 10^{-11}\ \mathrm{m}}\right)$$

$$\boxed{V_{\mathrm{AB}} = 27.2\ \mathrm{V}}$$

22.26

- You're developing a switch for high-voltage power lines. The smallest part in your design is a 6.0-cm-diameter metal sphere.
  - What do you specify for the maximum potential on your switch if the electric field at the sphere's surface isn't to exceed the 3-MV/m breakdown field of air?

$$\text{diameter} = 6\text{ cm} = 0.06\text{ m} \qquad r = 0.03\text{ m}$$

$$E_{\text{surface}} = \frac{kq_{\text{sphere}}}{r^2} = 3\text{ MV/m}$$

$$V_{\text{sphere}} = \frac{kq_{\text{sphere}}}{r} = Er$$

$$V_{\text{sphere}} = (3\text{ MV/m})(0.03\text{ m}) = 9 \times 10^4\text{ V} = \boxed{90\text{ kV} = V_{\text{sphere}}}$$