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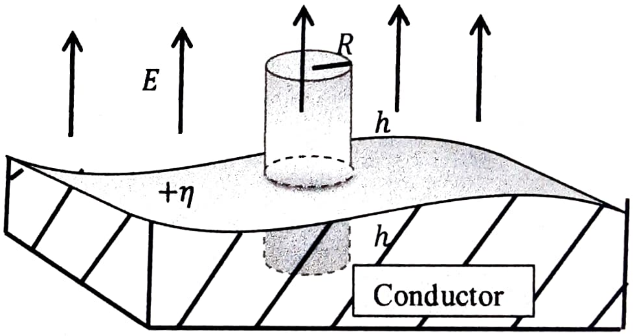
After this activity, you should know: *• The electric field inside and just outside a conductor in electrostatic equilibrium. • How to find the charge on different surfaces of a conductor.*

1. What is true of a conductor in electrostatic equilibrium? Electrostatic equilibrium means that there is no current, i.e., no moving charges. More than one choice may be true. Circle all **true** statements.
   - The electric field inside a conductor in equilibrium is zero. This is because any external electric field will cause the free charges in the conductor to redistribute to the surface until the electric field of these charges cancel out the external electric field leading to no net field inside the conductor.
   - The electric field is always zero inside a conductor even if there is a current going through the conductor.
   - The electric field just outside the surface of the conductor is always perpendicular to the surface.
   - The electric field just outside the surface of the conductor is always parallel to the surface.
   - The electric field just outside the surface of the conductor is always zero.
   - Any unbalanced charge must be on the surface of the conductor.

2. If you very close to the surface on a conductor it will look flat. Just as the Earth appears flat to us because we are on the surface. We want to find the electric field at a point P just outside the conductor. Assume the conducting surface near P has a positive charge per area η. We draw a Gaussian cylinder of radius R and height 2h cutting through the surface.



   a. What is the flux through the curved portion of the Gaussian surface? Write the answer in terms of the unknown electric field E, R and/or h.

   $\cancel{E\pi R^2}$ 0

   b. What is the flux through the bottom endcap?

   0

   c. What is the flux through the top endcap?

   $E\pi R^2$

   d. Write the charge enclosed by the Gaussian surface in terms of η, R and/or h?

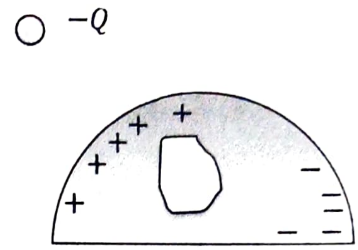
   $\eta \cdot \pi R^2 h$

   e. Use Gauss's law to find the electric field just outside the conductor.

   $E\pi R^2 = \frac{\eta}{\epsilon_0}$ $E = \frac{\eta}{\pi R^2 \epsilon_0}$

3. Assume a solid conductor is placed next to a negatively charged sphere. This causes the surface of the conductor near the sphere to become positively charged so that the net electric field inside the conductor is zero.

   Now we cut a hole so that it is entirely encased by the conductor.

   cross-section of 3D conductor

   a. Does removing part of the inside of the conductor affect the electric field?

      No

   b. What is the electric field inside the hole?

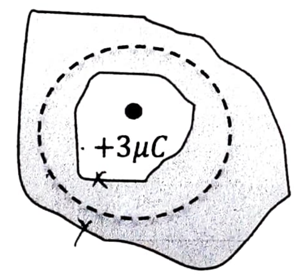
      Q

   c. Explain why sensitive equipment are often placed inside conductors. For example, circuit boards are typically shipped in foil-lined bags while cell phone signals are weaker inside warehouses with metal sides.

      The Conductor will stop charges from causing a field to be created inside it and damage the equipment.

4. Now we want find the charge on the inner and outer surfaces of conductors.

   A solid conductor has a hole inside. Inside the hole there is a point charge of $+3\mu C$. The net charge of the conductor is $-2\ \mu C$. That is, the sum of the charge on the inner and outer surfaces of the conductor is $-2\ \mu C$.

   a. What kind of charge (positive or negative) will be attracted to the inner surface of the conductor?

      negative

      $-x+y=-2$

      $-3+1$

   b. The dashed line represents a three-dimensional Gaussian surface which entirely inside the conductor but outside the hole. What is the electric flux through this surface?

      0

   c. Based on your result for (b), what is the total charge enclosed by the Gaussian surface?

      $0\mu C$

   d. Based on your result for (c), what must be the charge on the inner surface?

      $-3\mu C$

   e. Based on your result for (d) and the fact the total charge of the conductor is $-2\ \mu C$, what is the charge on the outer surface of the conductor?

      $1\mu C$

5. A neutral spherical conducting shell of radius $2R$ has a concentric spherical hole of radius R inside it. There is a point charge $+2Q$ at the center of the hole.

   a. What is the charge on the inner surface of the shell?

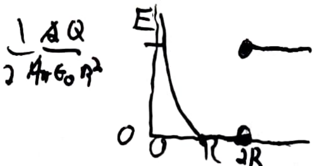
   $-2Q$

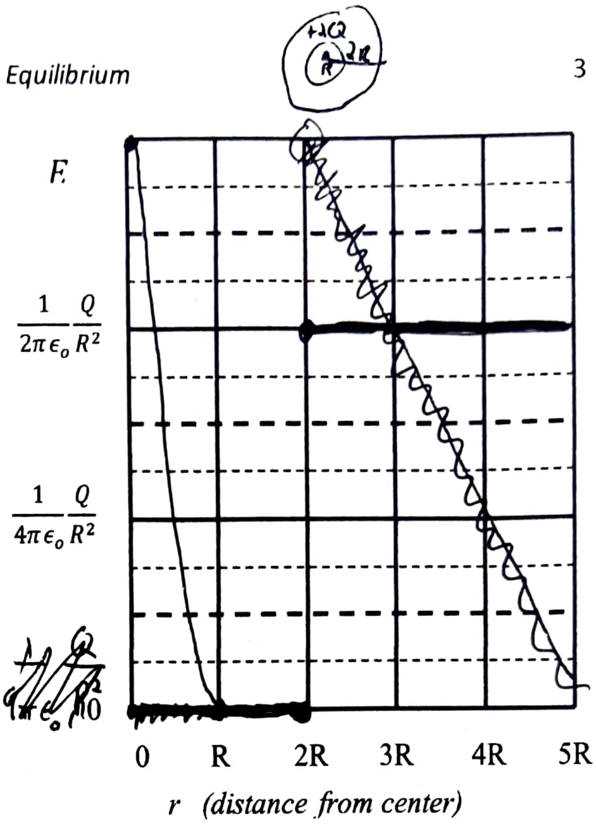
   b. What is the charge on the outer surface of the shell?

   $+2Q$

   c. Make a graph of the electric field as a function of r, the distance from the center of the shell.

   $K2Q$

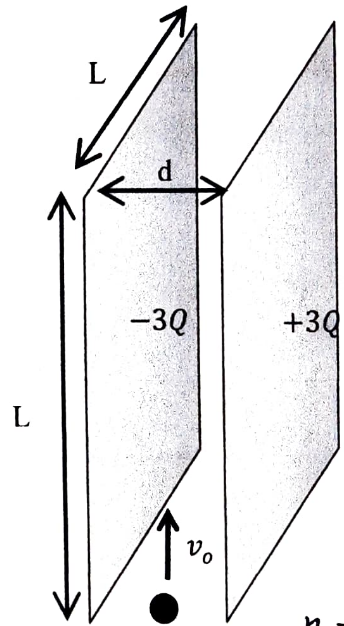




6. A capacitor is a device to store charge. The parallel plate capacitor consists of two large flat square conducting plates of sides L. One plate has charge $+3Q$ and the other plate has opposite charge $3-Q$. Assume that the gap between the plates d is small compared to L. Ignore edge effects.

   A proton (mass M, charge $+e$) enters the region between the plates from the bottom as shown. Its initial velocity is v_o straight upwards.

   Determine how far the proton moves horizontally as it goes through gap between the plates. Assume the deflection is small enough it does not hit the plates. Gravitational forces are negligible.



$V_0 t = L$ $\quad t = \frac{L}{V_0}$

$Ma_x = +e \cdot \frac{6Q}{\epsilon_0 L^2}$ $\quad \iint a_x dt = \iint \frac{6Q}{\epsilon_0 L^2 M} dt$

$2E = \frac{\eta}{\epsilon_0}$ $\quad \eta = \frac{3Q}{L^2}$

$\frac{6Q}{\epsilon_0 L^2} = E$

$\frac{3Q}{\epsilon_0 L^2 M} t^2 \Big|_0^{L/V_0}$

$\boxed{\frac{3Qe}{2\epsilon_0 M V_0^2}}$

$\cancel{\frac{3QV_0^2}{\epsilon_0 L^4 M}} = \Delta Y$

7. Summarize the Gauss's law results. Give answers in terms of relevant parameters such as λ_{enc}.:

   a. What is the electric field at a distance r from the center of a spherical charge distribution?

   $\cancel{\frac{1}{4\pi\epsilon_0}\frac{Q}{R^2}}$ $\frac{Q}{\epsilon_0}$

   b. What is the electric field at a distance r from the center of a cylindrical charge distribution?

   $\frac{\lambda}{\epsilon_0}$

   c. What is the electric field at a distance x from a large thin sheet with charge spreaded uniformly over its surface?

   $\frac{\eta}{\epsilon_0}$

   d. What is the electric field inside a conductor in electrostatic equilibrium?

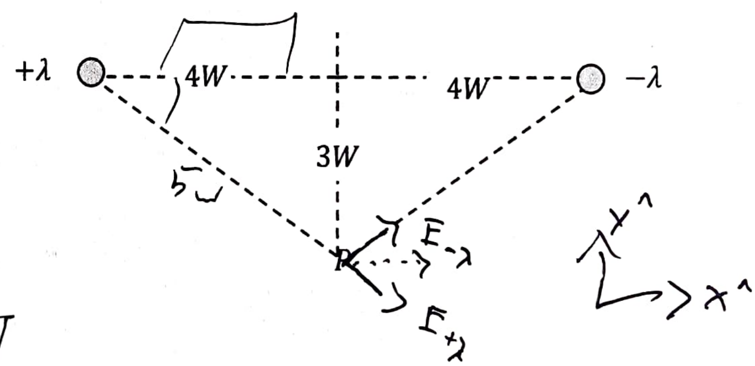
   0

   e. What is the electric field just outside a conductor in electrostatic equilibrium?

   $\frac{Kq}{R^2}$

8. **Bonus (3 – you must complete the rest of the worksheet first to receive credit).** Two very thin long rods carry uniform charge per length $+\lambda$ and $-\lambda$ respectively. The rods go in and out of the page.

   a. What is the magnitude and direction (left/right/top/bottom/in/out) of the electric field at point P? Answer in terms of λ and W. Follow the steps you used to find the electric field of multiple objects.



$$2 \cdot \frac{K\lambda}{(4w)^2+(3w)^2} \cdot \frac{4w}{\sqrt{(4w)^2+(3w)^2}} = 5w$$

$$\frac{2K\lambda}{25w^2} \cdot \frac{4w}{5w} \quad \cancel{\boxed{\frac{8k\lambda}{125w^2}}}$$

$$E = \frac{2\lambda}{125\pi\epsilon_0 W^2}$$

direction = $+x$

   b. What is the magnitude and direction of the electric force on an electron placed at point P? Answer in terms of λ, W and/or e.

Direction = $-x$

Force $= \frac{+e \cdot 2\lambda}{125\pi\epsilon_0 W^2} = QE$

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