PHYS 121 Feb. 7, 2025

To do: - Complete HW5 by 23:59 today

- Complete Pre-Lab #3 before start of Lab #3

- If participating in Hands-On Bonus project, please email me your project proposal by 23:59 on Monday, February 10.

Recall Gauss's Law

$$\Phi = \oint \vec{E} \cdot d\vec{A} = \frac{q_{encl}}{\varepsilon_0}$$

For a spherical Gaussian surface surrounding a spherical charge dist'n:

$$\oint \vec{E} \cdot d\vec{A} = E \underbrace{(4\pi r^2)}_{\text{surface area of sphere of radius } r}$$

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A point charge $q = -8.0 \times 10^{-12}$ C is placed at the centre of a spherical conducting shell of inner radius 3.6 cm and outer radius 3.9 cm. The electric field just above the surface of the conductor is directed radially outward and has magnitude 9.5 N/C.

Part 1

What is the charge density on the inner surface of the shell?

$\sigma_{\text{inner}} =$ number (rtol=0.03, atol=0) $\mathrm{C/m^2}$

Part 2

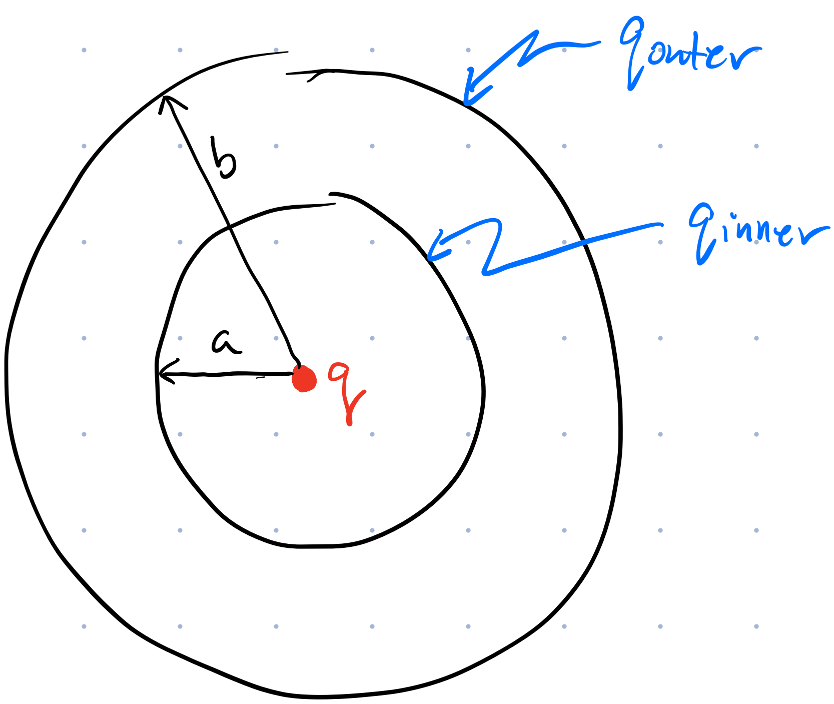
What is the charge density on the outer surface of the shell?

$\sigma_{\text{outer}} =$ number (rtol=0.03, atol=0) $\mathrm{C/m^2}$

Part 3

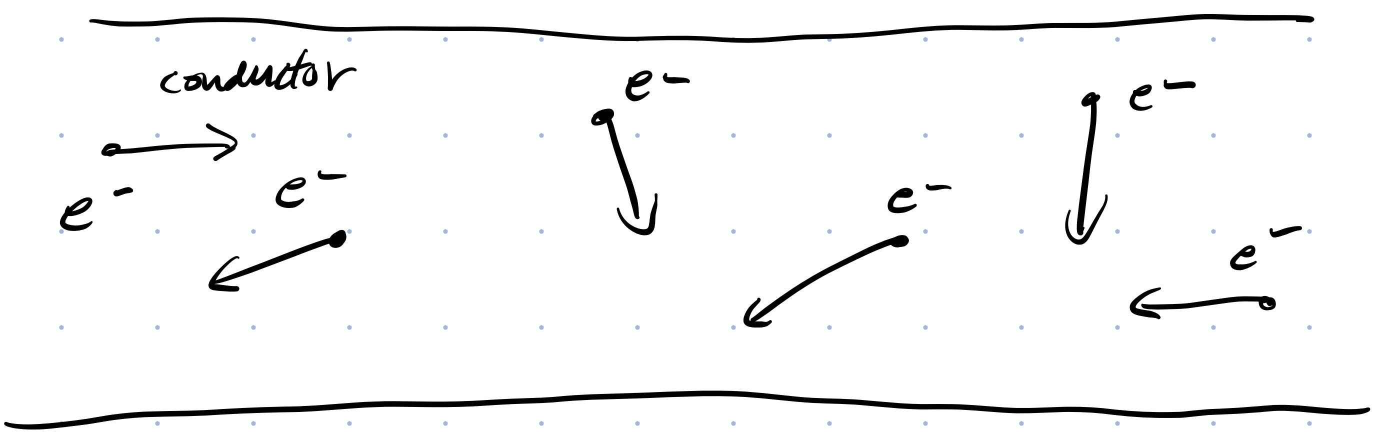
What is the net charge on the conductor?

$Q =$ number (rtol=0.03, atol=0) C



Conductors in Electric Fields

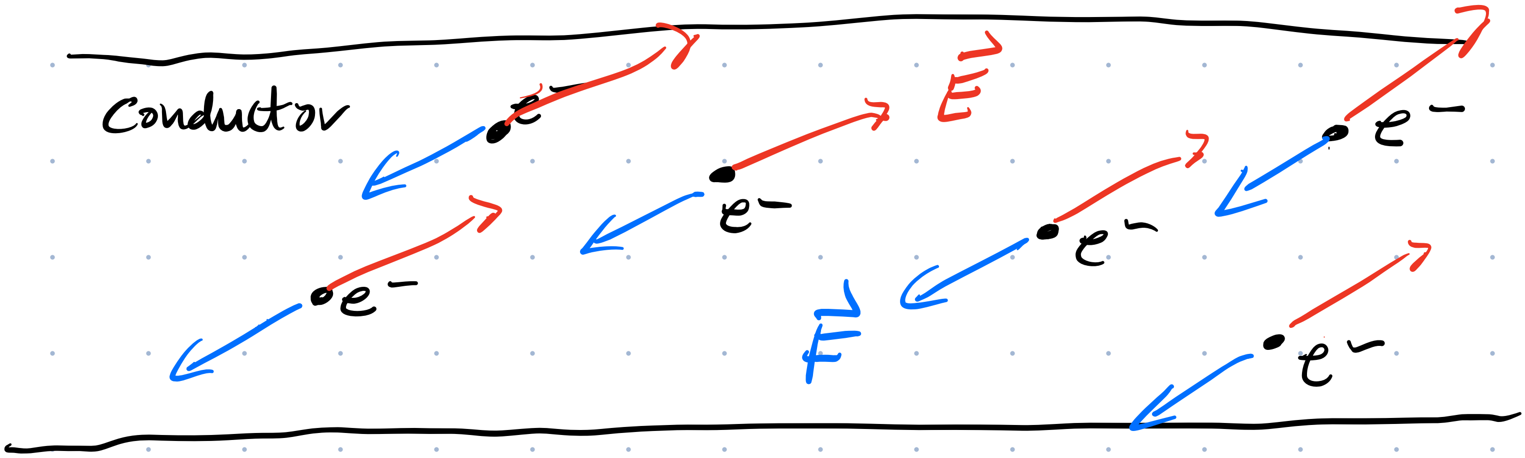
Some electrons in a conductor are free move around. → called conduction electrons.



A conductor is said to be in equil. when there is no net flow of charge in any particular dir'n.

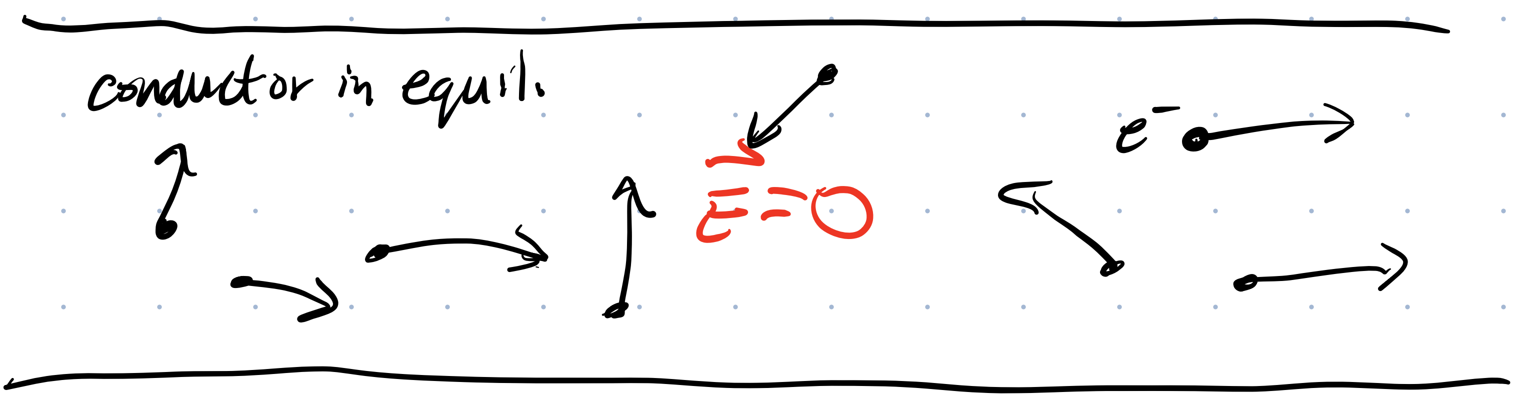
Charge still moves around randomly, but in equil there cannot be any net motion in any single dir'n.

① For a conductor in equil., the electric field inside the body is zero.

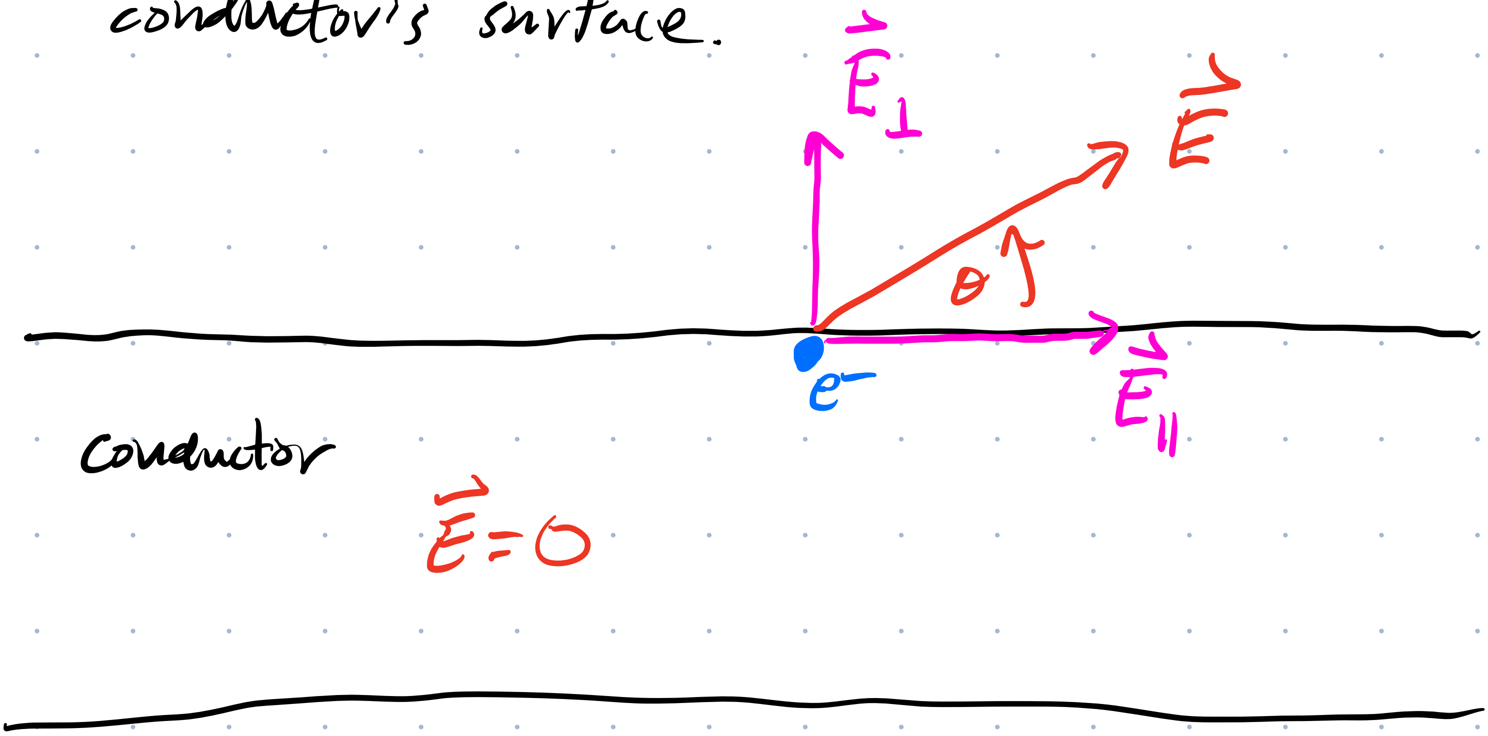


If $\vec{E} \neq 0$ inside conductor (as shown above), it exerts a force $\vec{F} = -e\vec{E}$ on each of the mobile electrons. This force would cause a net flow of charge to the btm-left of the conductor.

$\Rightarrow$ conductor is <u>not</u> in equil.



② For a conductor in equil., the electric field just outside the conductor is $\perp$ to conductor's surface.

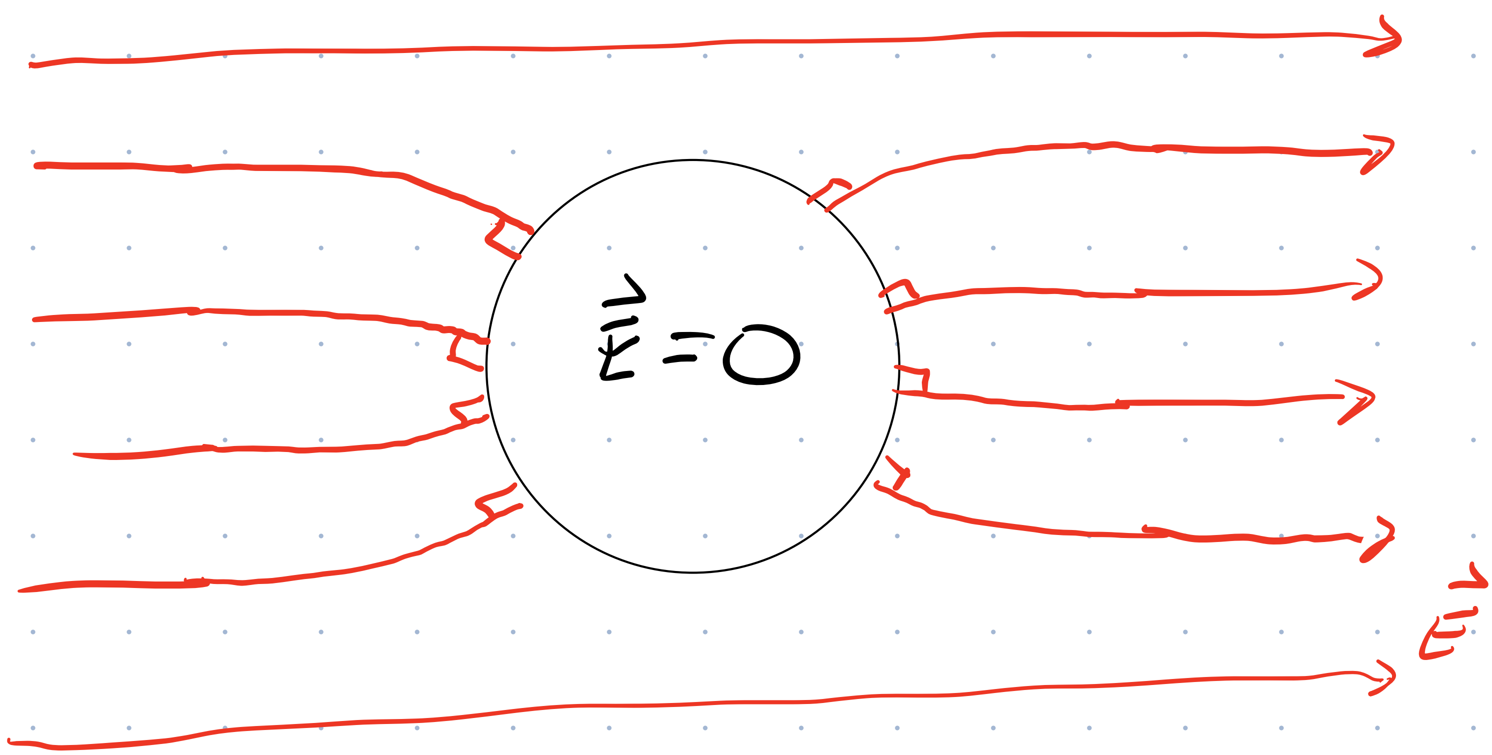


If there is an $\vec{E}$ outside conductor that is <u>not</u> $\perp$ to surface, it causes e^- near surface to flow in the opp. dir'n to $\vec{E}_\parallel$.

$\therefore$ Conductor is <u>not</u> in equil.

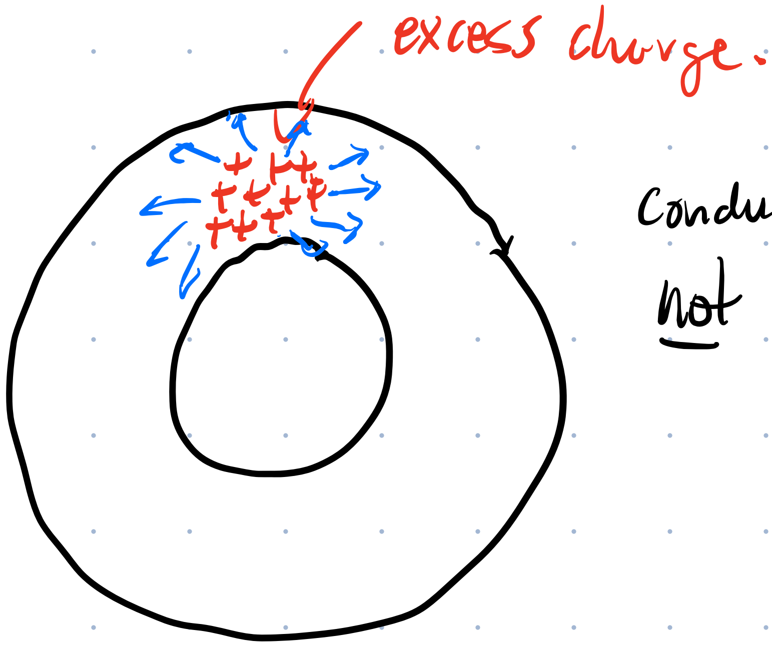
Require $\vec{E}_\parallel = 0$ for conductors in equil.

Eg. Consider a conductor in equil. placed in a uniform $\vec{E}$-field.

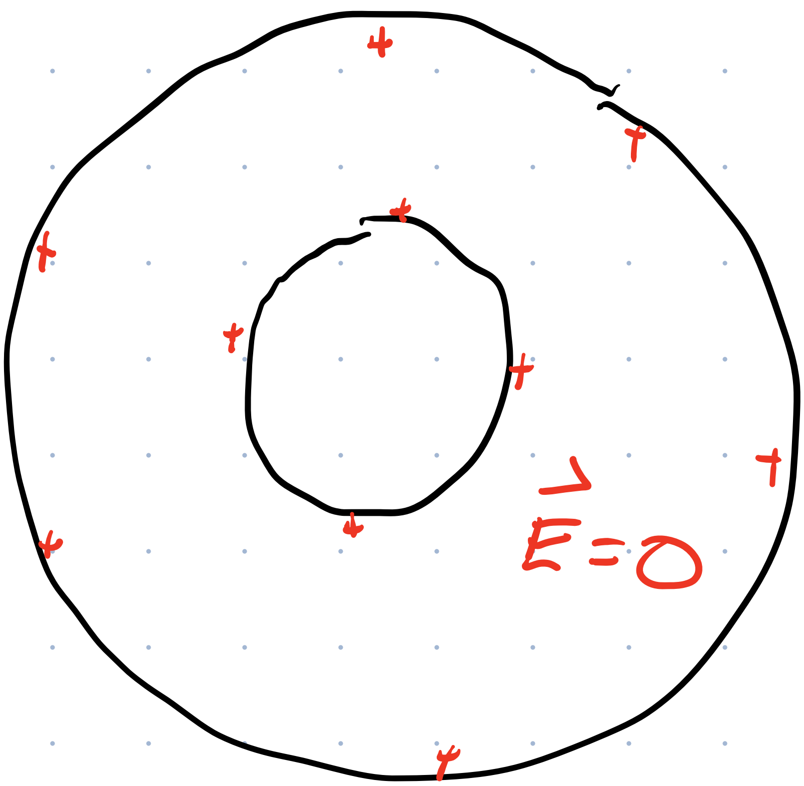


③ All excess charge on a conductor in equil. resides at the conductor surfaces.

If place excess charge on a conductor those charges repel one another & migrate the the surfaces (inner & outer surfaces in the case of a conductor w/ a cavity).



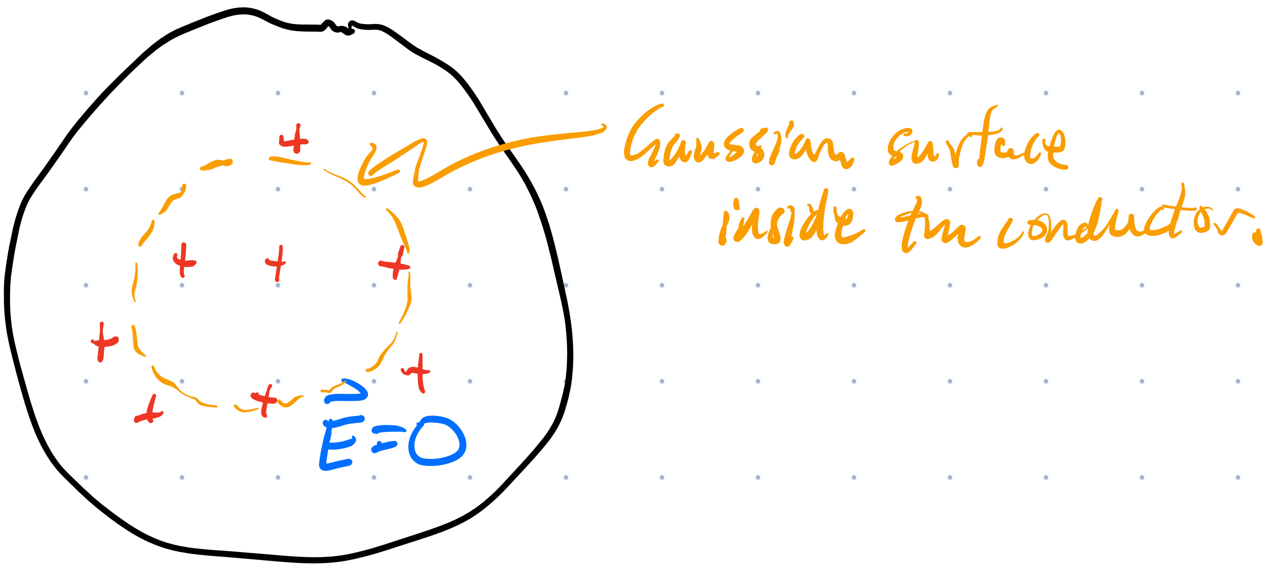
Conducting shell <u>not</u> in equil.



Conducting cavity with excess charge in equil.

Aother argument for excess charge residing at surfaces using Gauss's Law.

Solid conductor w/ excess charge.



Gauss's Law

$$\Phi = \oint \vec{E} \cdot d\vec{A} = \frac{q_{encl}}{\varepsilon_0}$$

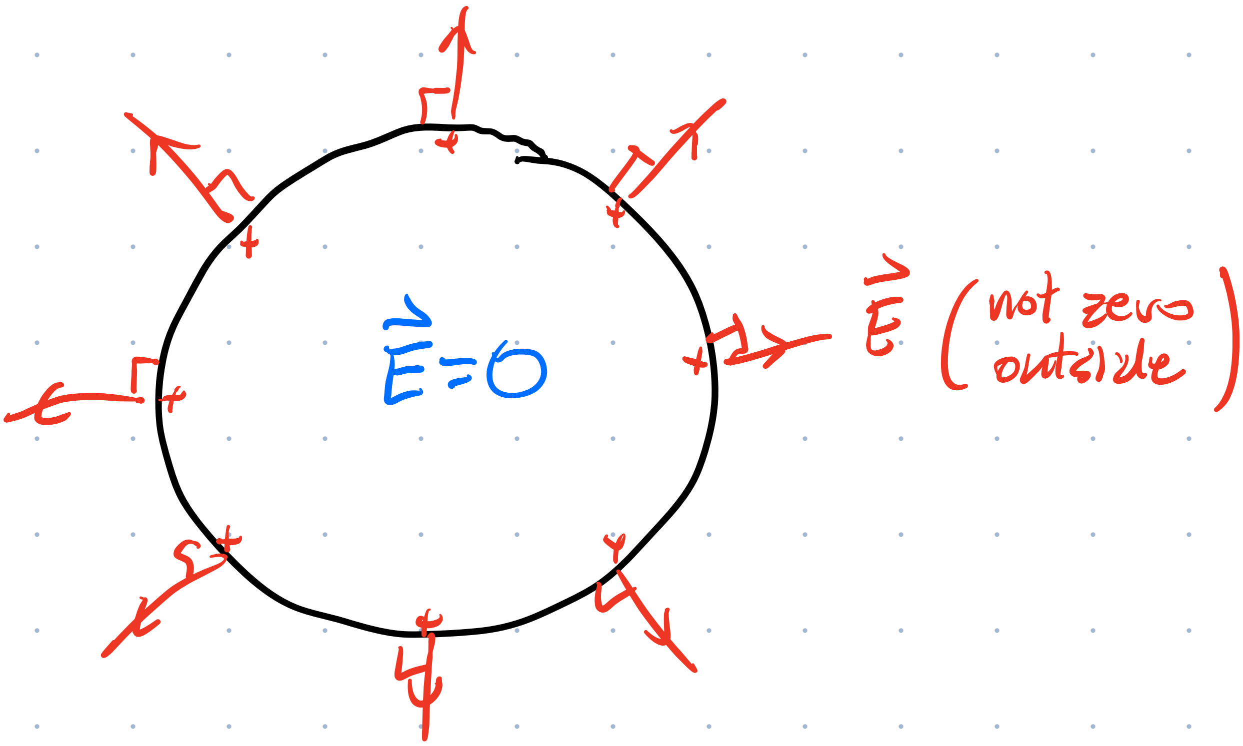
$\vec{E} = 0$ for conductor : $\oint \vec{E} \cdot d\vec{A} = 0$

$$\Phi = 0 = \frac{q_{encl}}{\varepsilon_0} \Rightarrow \text{must have } q_{encl} = 0$$

$\therefore$ no charge inside Gaussian surface $\rightarrow$ no charge in centre of conductor.

All charge is at conductor surface.

Conductor w/ excess charge in Equil.



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A point charge $q = -8.0 \times 10^{-12}$ C is placed at the centre of a spherical conducting shell of inner radius 3.6 cm and outer radius 3.9 cm. The electric field just above the surface of the conductor is directed radially outward and has magnitude 9.5 N/C.

Part 1

charge per unit area σ

What is the charge density on the inner surface of the shell?

$\sigma_{inner} =$ number (rtol=0.03, atol=0) $\mathrm{C/m^2}$

Part 2

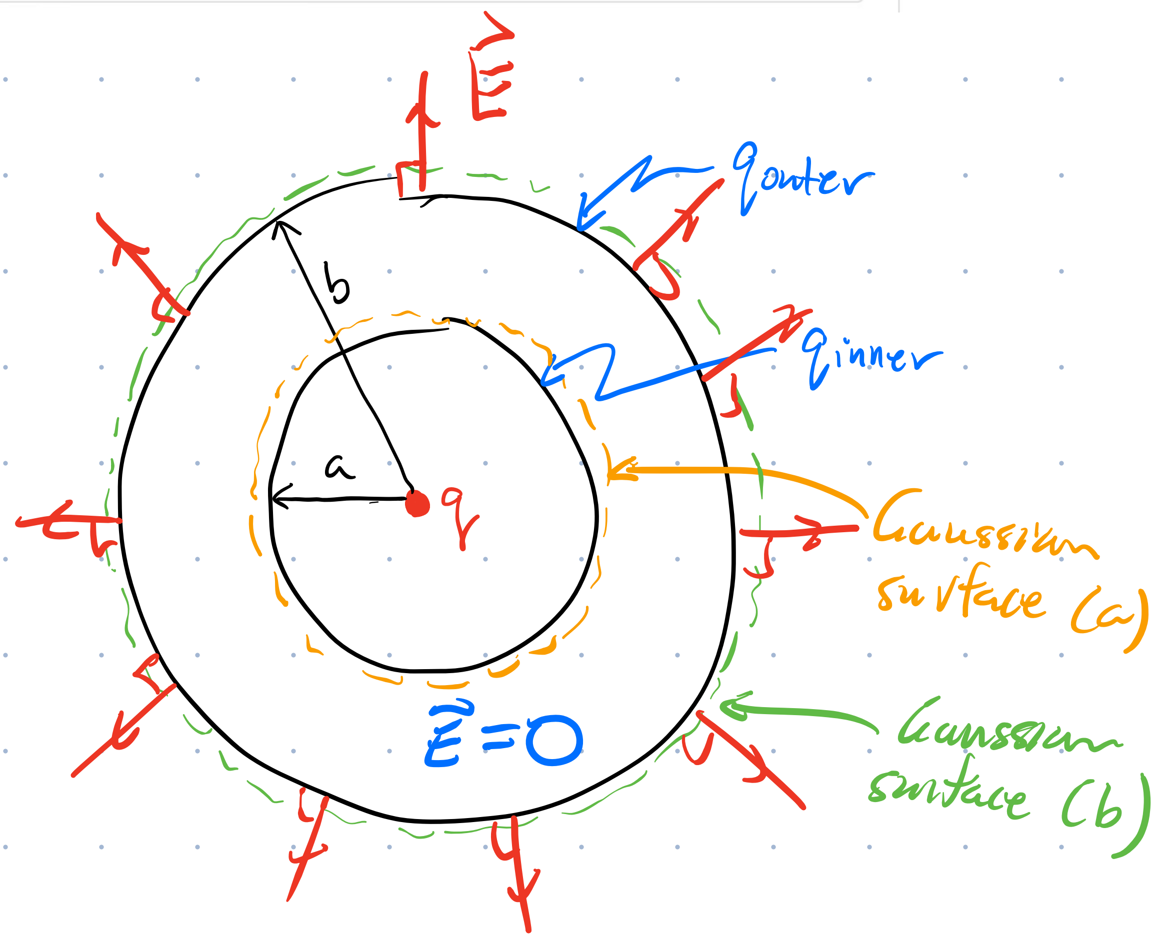
What is the charge density on the outer surface of the shell?

$\sigma_{outer} =$ number (rtol=0.03, atol=0) $\mathrm{C/m^2}$

Part 3

What is the net charge on the conductor?

$Q =$ number (rtol=0.03, atol=0) C



(a) Find σ at inner surface.

Place a Gaussian surface around the inner surface of conducting shell.

Since $\vec{E}=0$ inside conductor & our Gaussian surface is inside the conductor;

$$\Phi = \oint \vec{E}\cdot d\vec{A} = 0$$

$$\Phi = \frac{q_{encl}}{\varepsilon_0} = 0 \Rightarrow q_{encl} = 0$$

Pt charge q & q_{inner} are inside Gaussian surface

$$\therefore \quad q_{encl} = q + q_{inner} = 0$$

$$\therefore \quad q_{inner} = -q$$

$$\therefore \quad \sigma_{inner} = \frac{q_{inner}}{A_{inner}} = \frac{-q}{4\pi a^2}$$

(b) Find the charge density $\sigma_{outer} = \frac{q_{outer}}{A_{outer}}$

Select a Gaussian surface that just encloses the outer surface of the shell.

Since $\vec{E}$ is $\perp$ to conductor surface & has a const. value @ conductor surface:

$$\Phi = \oint \vec{E} \cdot d\vec{A} = \oint E\,dA = E \oint dA$$

$A_{outer} = 4\pi b^2$

$$\Phi = E(4\pi b^2)$$

equal

$$\Phi = \frac{q_{encl}}{\varepsilon_0} = \frac{\cancel{q} + \cancel{q_{inner}} + q_{outer}}{\varepsilon_0} = \frac{q_{outer}}{\varepsilon_0}$$

$$\therefore E(4\pi b^2) = \frac{q_{outer}}{\varepsilon_0}$$

$$\boxed{\sigma_{outer} = \frac{q_{outer}}{A_{outer}} = \frac{q_{outer}}{4\pi b^2} = \varepsilon_0 E}$$

(c) what is net charge on conductor?

$$q_{net} = q_{inner} + q_{outer}$$

$$= -q + \varepsilon_0 E (4\pi b^2)$$