Your Comments

Do we still get the 80% back on homework? It doesn't seem to be showing that.

I am extremely confused with the section on spheres and shells and when the field is zero and everything. Please please please clarify this!

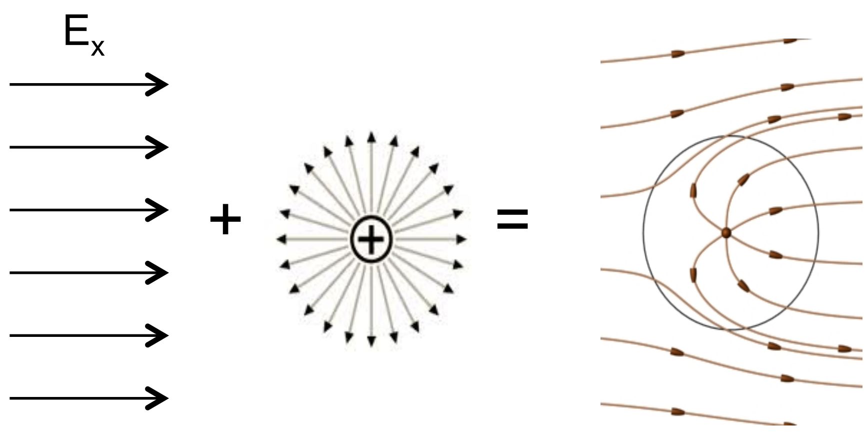
I am confused about concentric charges and also how to choose Gaussian surfaces.

Can you please go over the conducting sphere and induced charge density because that kind of blew my mind.

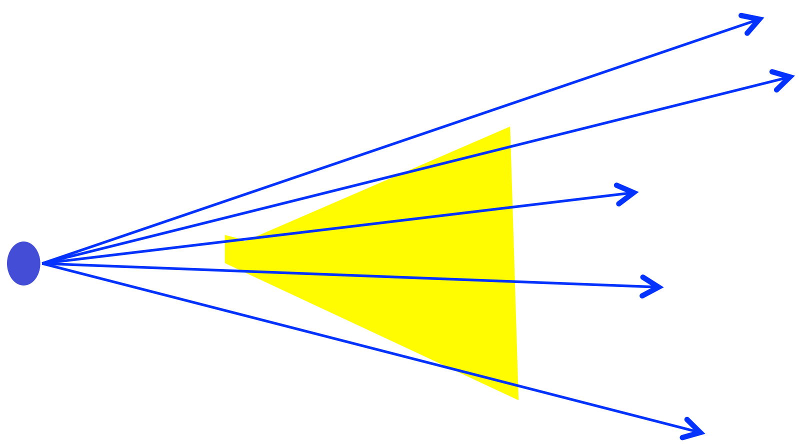
Please go over how, even after placing a point charge within a charged shell, the net field within the shell is zero. What if the point charge was massively stronger than the charge on the shell?

"Back in my day, just the mere mention of a Gaussian surface would land you in prison" - Some Weird Guy Who Sat Next To Me On The Bus on Tuesday.

Follow-up from Last Lecture



- Vector superposition of fields!
- # of flux lines increased to right of charge, decreased to left of charge



- Field lines extend straight from charged object
- For charge <u>outside</u> closed surface, same # of field lines from that charge enter and leave surface

Electricity & Magnetism
Lecture 4

Today's Concepts:

A) Conductors

B) Using Gauss' Law

Conductors and Insulators

Conductors = charges free to move

e.g. metals

Insulators = charges fixed

e.g. glass

Define: Conductors = Charges Free to Move

Claim: $E = 0$ inside any conductor at equilibrium

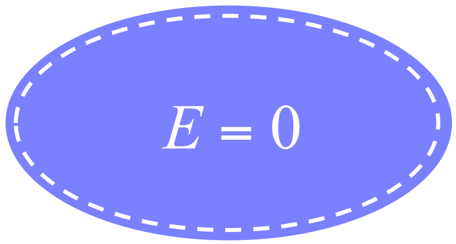
Charges in conductor move to make E field zero inside. (Induced charge distribution).

If $E \neq 0$, then charge feels force and moves!

Claim: Excess charge on conductor only on surface at equilibrium

Why?

- Apply Gauss' Law
- Take Gaussian surface to be just inside conductor surface
  - $E = 0$ everywhere inside conductor $\longrightarrow$ $\oint_{surface} \vec{E} \cdot d\vec{A} = 0$
  - Gauss' Law: $\oint_{surface} \vec{E} \cdot d\vec{A} = \dfrac{Q_{enc}}{\varepsilon_o}$ $\longrightarrow$ $\boxed{Q_{enc} = 0}$



SIMULATION 2

Gauss' Law + Conductors + Induced Charges

$$\oint_{surface} \vec{E} \cdot d\vec{A} = \frac{Q_{enc}}{\varepsilon_o}$$

ALWAYS TRUE!

If choose a Gaussian surface that is entirely in metal, then $E = 0$ so $Q_{enclosed}$ must also be zero!

$$E = \frac{Q_{enc}}{A\varepsilon_o}$$

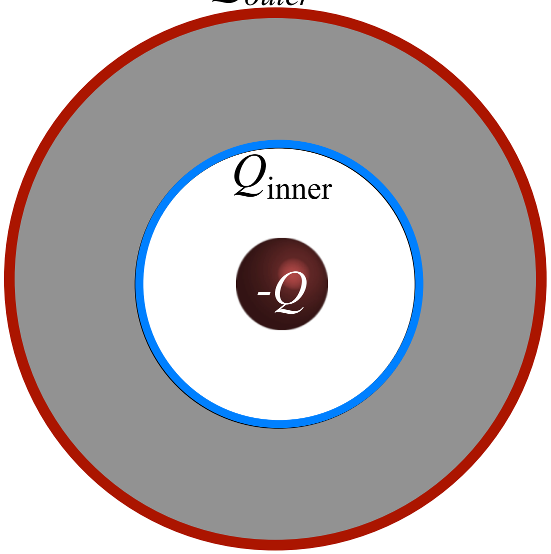
How Does This Work?

Charges in conductor move to surfaces to make $Q_{enclosed} = 0$.

We say charge is induced on the surfaces of conductors

Charge in Cavity of Conductor

A particle with charge $-Q$ is placed in the center of an uncharged conducting hollow sphere. How much charge will be induced on the inner and outer surfaces of the sphere?



A) inner = $-Q$, outer = $+Q$

B) inner = $-Q/2$, outer = $+Q/2$

C) inner = 0, outer = 0

D) inner = $+Q/2$, outer = $-Q/2$

E) inner = $+Q$, outer = $-Q$

- Gauss' Law: $\oint_{surface} \vec{E} \cdot d\vec{A} = \dfrac{Q_{enc}}{\varepsilon_o}$

Since $E = 0$ in conductor

$$0 = \frac{Q_{enc}}{\varepsilon_o}$$

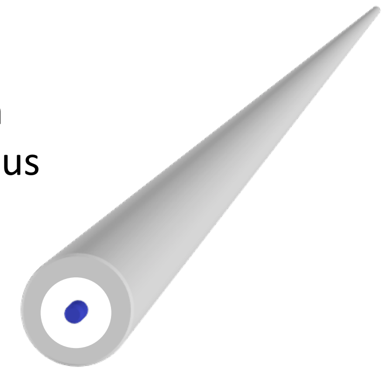
$$0 = -Q + Q_{inner}$$

Since conductor is uncharged

$$Q_{inner} + Q_{outer} = 0$$

$$Q_{outer} = -Q_{inner}$$

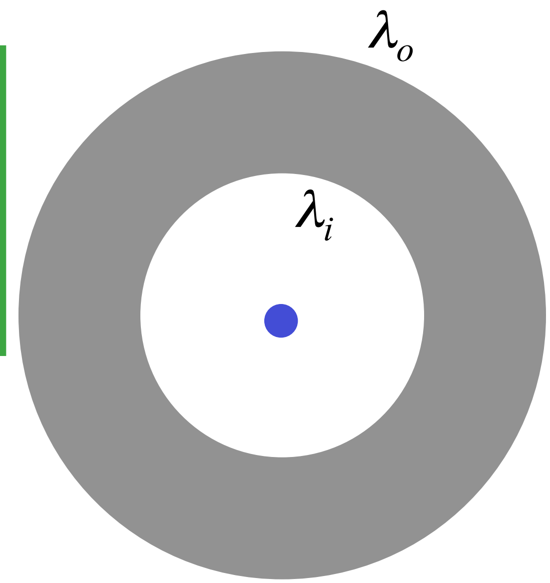
Infinite Cylinders



A long thin wire has a uniform positive charge density of 2.5 C/m. Concentric with the wire is a long thick conducting cylinder, with inner radius 3 cm, and outer radius 5 cm. The conducting cylinder has a net linear charge density of -4C/m.

What is the linear charge density of the induced charge on the inner surface of the conducting cylinder (λ_i) and on the outer surface (λ_o)?

λ_i:	+2.5 C/m	−4 C/m	0	−2.5 C/m	−2.5 C/m
λ_o:	−6.5 C/m	0	-4 C/m	+2.5 C/m	−1.5 C/m
	A	B	C	D	E



Gauss' Law

I'm confused with how to determine which gaussian surface is best suited to calculate an electric field

$$\int \vec{E} \cdot d\vec{A} = \frac{Q_{enc}}{\varepsilon_0}$$

ALWAYS TRUE!

In cases with symmetry can pull E outside and get $E = \frac{Q_{enc}}{A\varepsilon_0}$

In General, integral to calculate flux is difficult…. and not useful!

To use Gauss' Law to calculate E, need to choose surface carefully!

1) Want E to be constant and equal to value at location of interest

OR

2) Want E dot $A = 0$ so doesn't add to integral

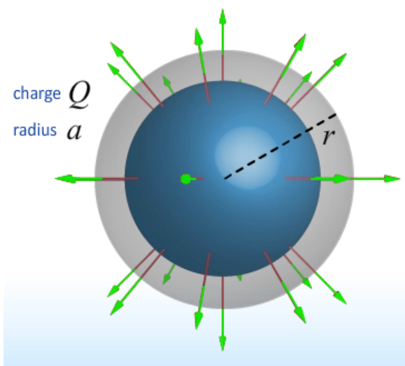
Gauss' Law Symmetries

$$\int \vec{E} \cdot d\vec{A} = \frac{Q_{enc}}{\varepsilon_0}$$

ALWAYS TRUE!

In cases with symmetry can pull E outside and get $E = \dfrac{Q_{enc}}{A\varepsilon_0}$

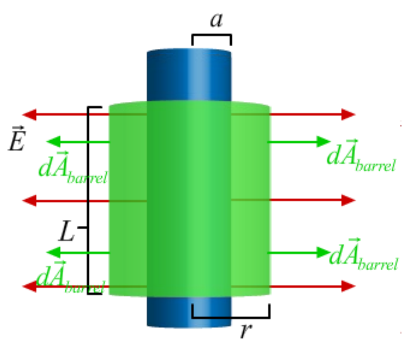
Spherical



$$A = 4\pi r^2$$

$$E = \frac{Q_{enc}}{4\pi r^2 \varepsilon_0}$$

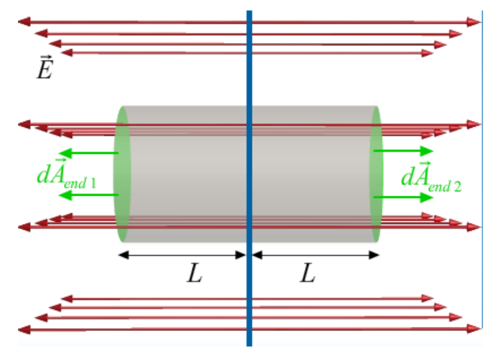
Cylindrical



$$A = 2\pi rL$$

$$E = \frac{\lambda}{2\pi r \varepsilon_0}$$

Planar

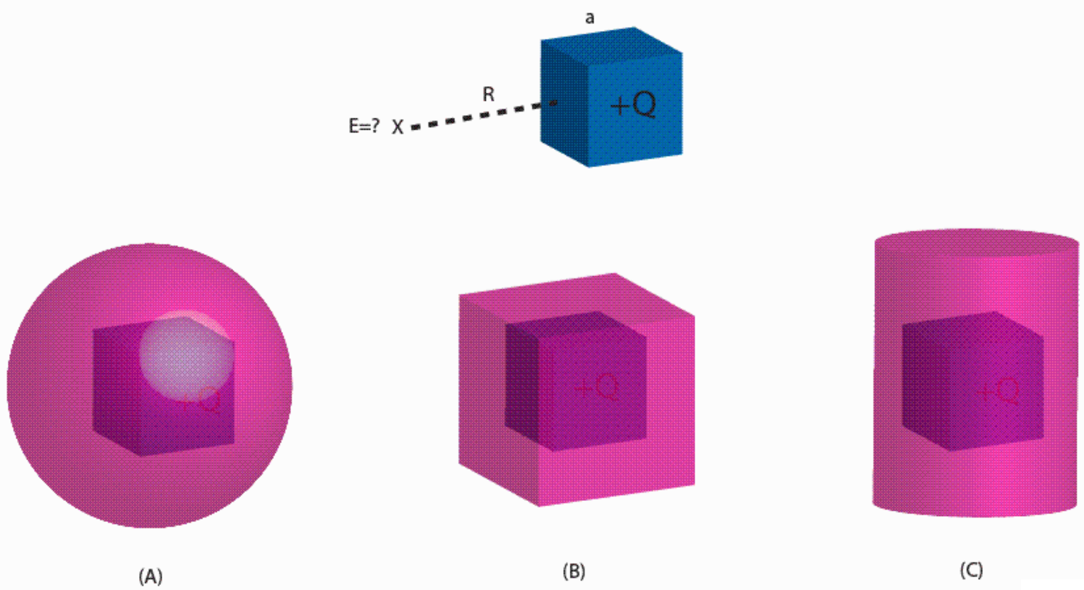


$$A = 2\pi r^2$$

$$E = \frac{\sigma}{2\varepsilon_0}$$

CheckPoint 1

2) You are told to use Gauss' Law to calculate the electric field at a distance R away from a charged cube of dimension a. Which of the following Gaussian surfaces is best suited for this purpose?



D) The field cannot be calculated using Gauss' Law

E) None of the above

THE CUBE HAS NO GLOBAL SYMMETRY!

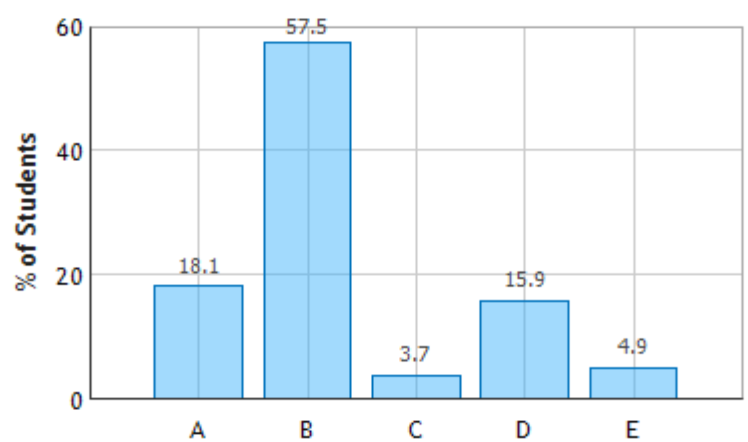
THE FIELD AT THE FACE OF THE CUBE

IS NOT

PERPENDICULAR OR PARALLEL

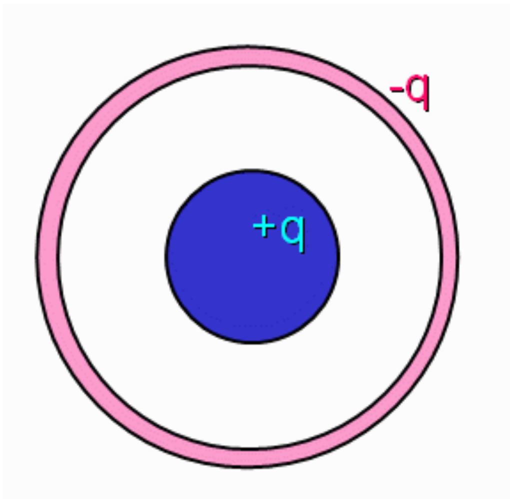
3D	POINT	SPHERICAL
2D	LINE	CYLINDRICAL
1D	PLANE	PLANAR

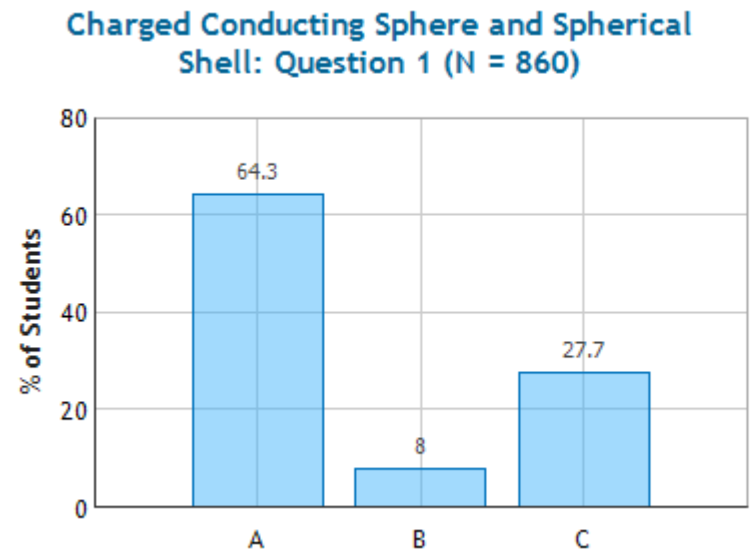
Gaussian Surface Choice: Question 1 (N = 863)



CheckPoint 3.1

4) A positively charged solid conducting sphere is contained within a negatively charged conducting spherical shell as shown. The magnitude of the total charge on each sphere is the same.





What is direction of field between blue and red spheres?

○ The field point radially outward ○ The field point radially inward ○ The field is zero

A) Outward B) Inward C) Zero

Careful: what does inside mean?
This is always true for a solid conductor (within the material of the conductor)
Here we have a charge "inside"

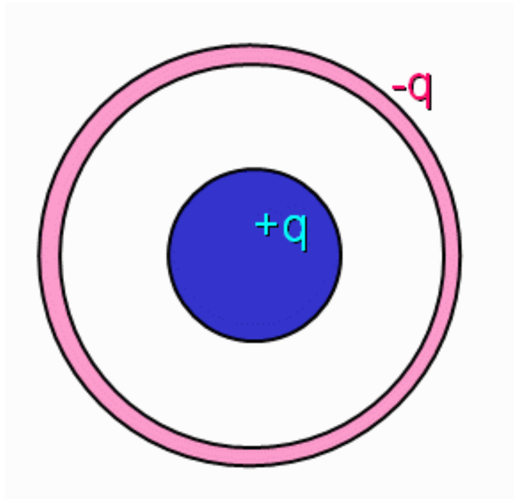
"The field points from the positive charge to the negative charge."

"It must point inward to cancel out the field outward due to the charge inside the shell to completely cancel out the e-field inside the shell"

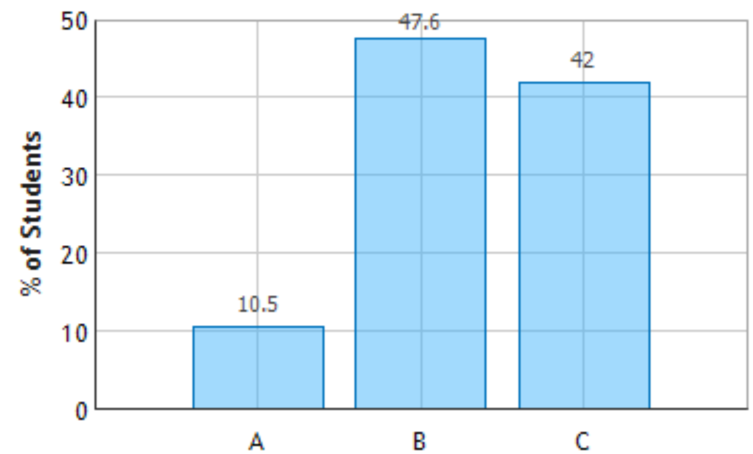
"The fields cancel out."

CheckPoint 3.3

4) A positively charged solid conducting sphere is contained within a negatively charged conducting spherical shell as shown. The magnitude of the total charge on each sphere is the same.



Charged Conducting Sphere and Spherical Shell: Question 3 (N = 860)



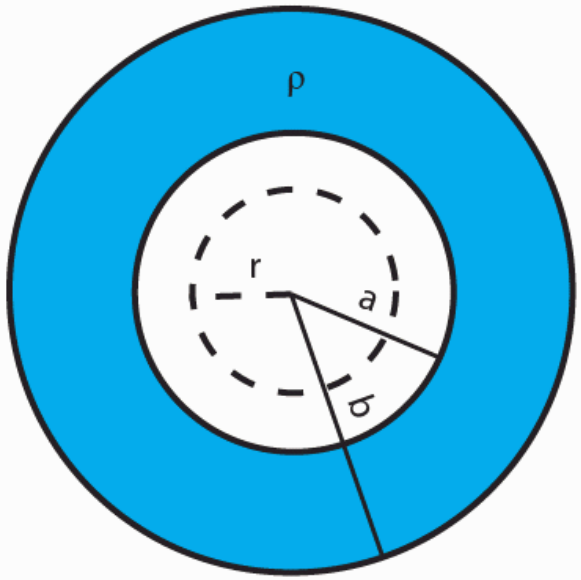
What is direction of field OUTSIDE the red sphere?

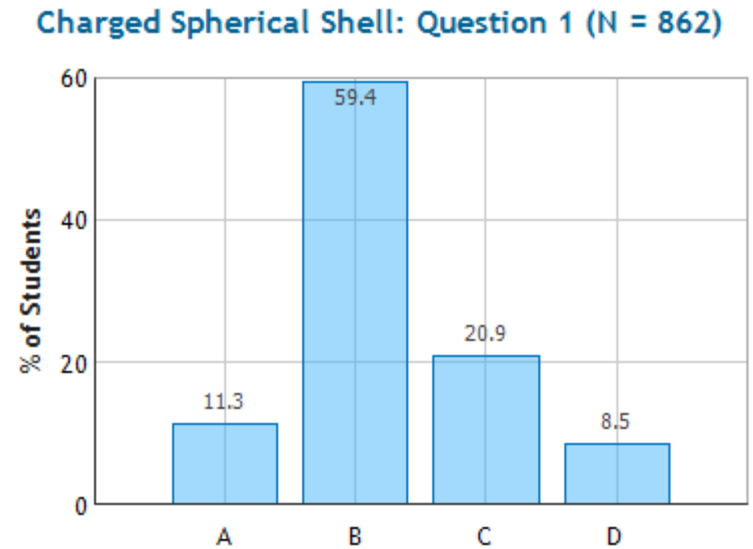
- The field point radially outward
- The field point radially inward
- The field is zero

A) Outward B) Inward C) Zero

CheckPoint 2

4) A charged sphererical insulator shell has inner radius a and outer radius b. The charge density on the shell is ρ.





What is magnitude of E at dashed line (r)?

A) $\dfrac{\rho}{\varepsilon_0}$ "It is p/e0 because that is the e-field due to the outside of the sphere and the inside must be equal to that in magnitude."

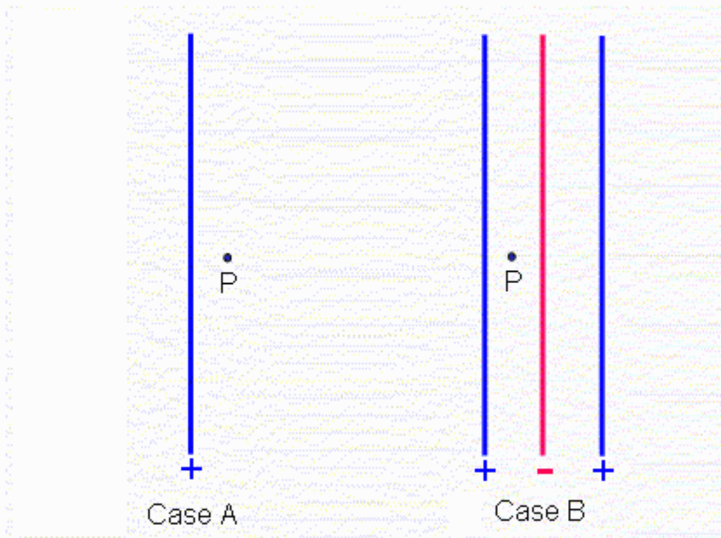
B) $\boxed{\text{Zero}}$ "Within r<a there is no charge enclosed."

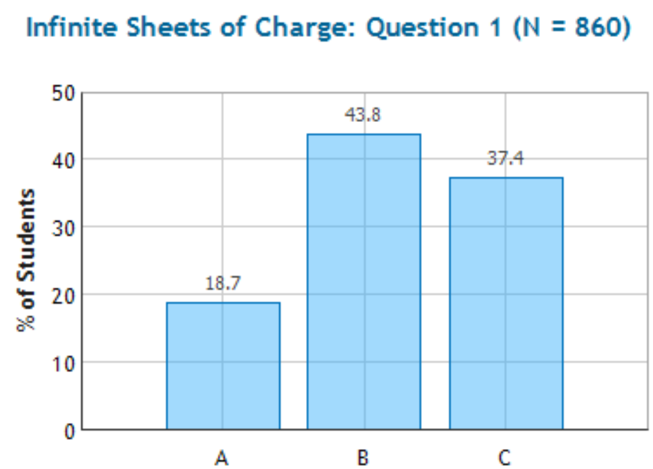
C) $\dfrac{\rho(b^3 - a^3)}{3\varepsilon_0 r^2}$ "units work out."

D) None of above "its something that is 1/r."

CheckPoint 4

10) In both cases shown below, the colored lines represent positive (blue) and negative (red) charged planes. The magnitudes of the charge per unit area on each plane is the same.





In which case is E at point P the biggest?

A) A B) B C) the same

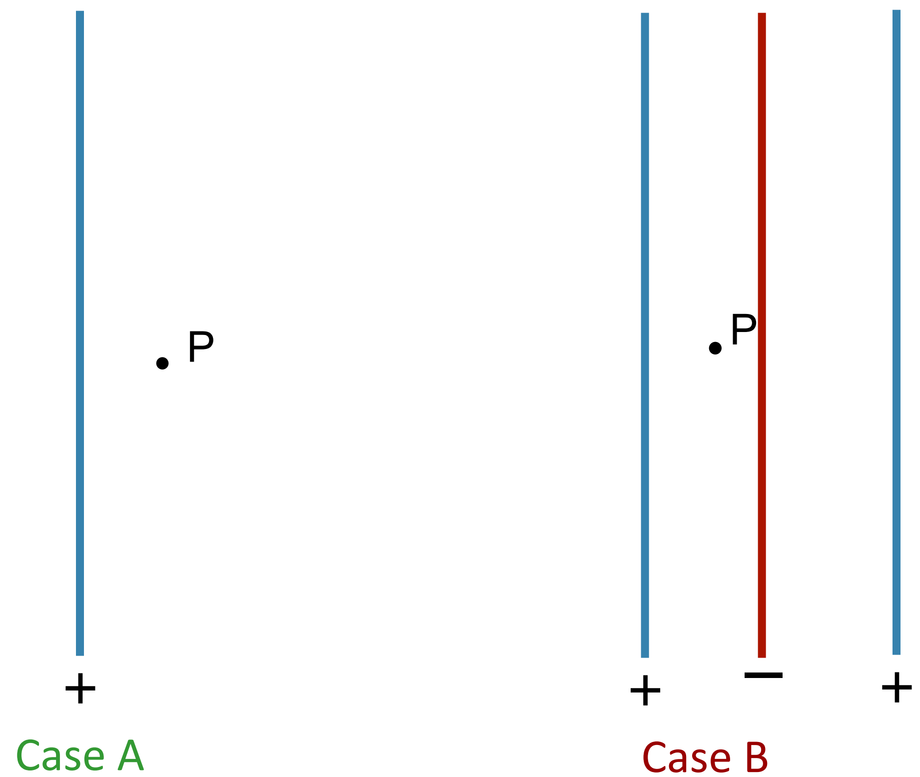
“The electric field in case B is zero, and the electric field in case A is nonzero.”

“The first positive and negatively charged planes in case B both have fields pointing to the right. These are the strongest fields because they're closest to the point P. The rightmost positive field will point to the left, but this will be weaker than either of the two fields pointing to the right, giving an overall greater field magnitude in case B.”

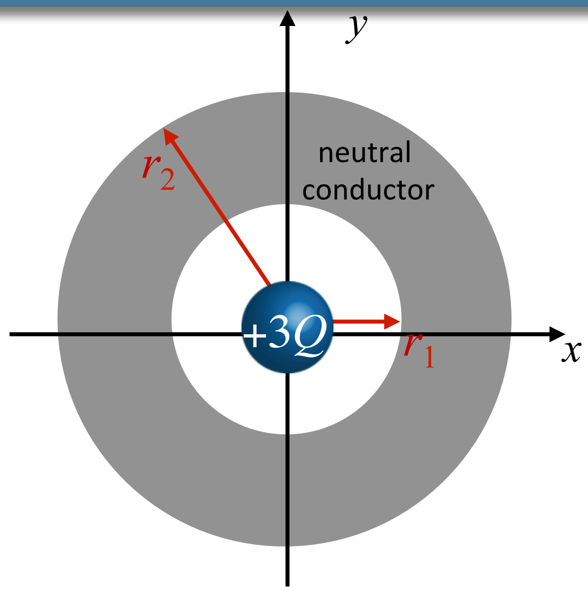
“If you superposition the electric fields, they cancel out in case B so the electric field is the same in both cases.”

Superposition:

Lets do calculation!



Calculation



Point charge $+3Q$ at center of neutral conducting shell of inner radius r_1 and outer radius r_2.

a) What is E everywhere?

First question: Do we have enough symmetry to use Gauss' Law to determine E?

Yes, Spherical Symmetry (what does this mean???)

A) Direction of E is along $\hat{x}$

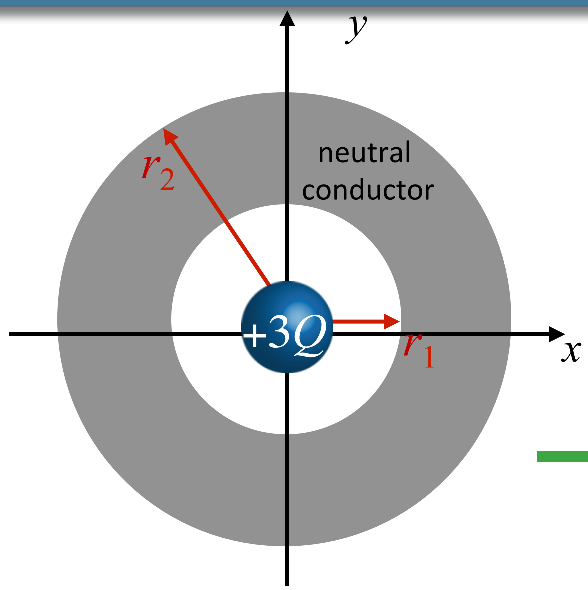
B) Direction of E is along $\hat{y}$

C) Direction of E is along $\hat{r}$

D) None of the above

Magnitude of E depends only on R

Calculation



Point charge $+3Q$ at center of neutral conducting shell of inner radius r_1 and outer radius r_2.

A) What is E everywhere?

We know:

magnitude of E is *fcn* of r

direction of E is along $\hat{r}$

We can use Gauss' Law to determine E

Use Gaussian surface = sphere centered on origin

$$\int \vec{E} \cdot d\vec{A} = \frac{Q_{enc}}{\varepsilon_0}$$

$r < r_1$

$$\int E dA = \frac{Q_{enc}}{\varepsilon_0}$$

$$E 4\pi r^2 = \frac{+3Q}{\varepsilon_0}$$

$$E = \frac{1}{4\pi\varepsilon_0}\frac{3Q}{r^2}$$

$r_1 < r < r_2$

A) $E = \frac{1}{4\pi\varepsilon_0}\frac{3Q}{r^2}$

B) $E = \frac{1}{4\pi\varepsilon_0}\frac{3Q}{r_1^2}$

C) $\boxed{E = 0}$

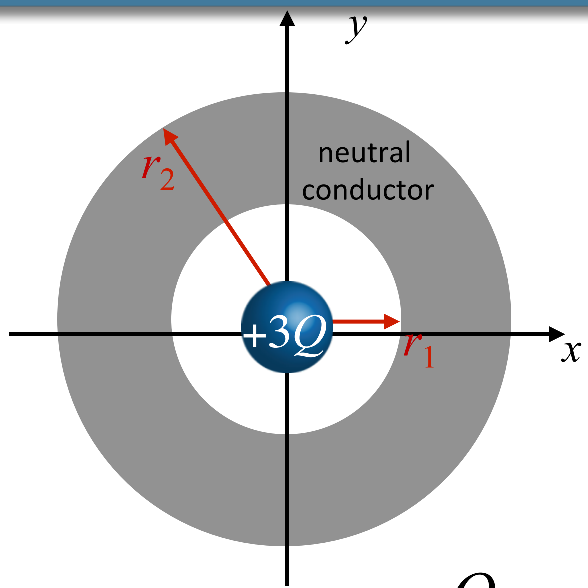
$r > r_2$

A) $\boxed{E = \frac{1}{4\pi\varepsilon_0}\frac{3Q}{r^2}}$

B) $E = \frac{1}{4\pi\varepsilon_0}\frac{3Q}{(r - r_2)^2}$

C) $E = 0$

Calculation



$$\int \vec{E} \cdot d\vec{A} = \frac{Q_{enc}}{\varepsilon_0}$$

Point charge $+3Q$ at center of neutral conducting shell of inner radius r_1 and outer radius r_2.

A) What is E everywhere?

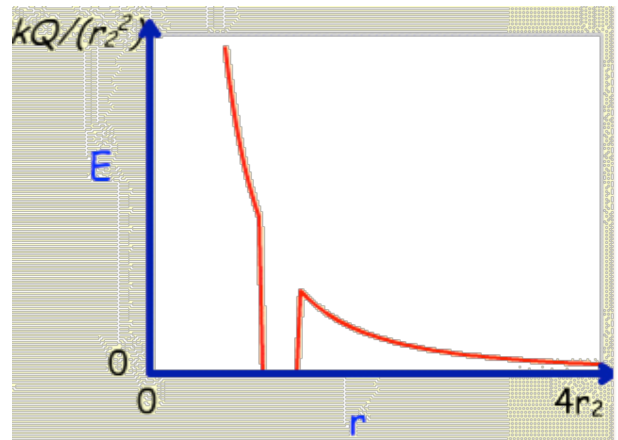
We know:

$r < r_1$

$r > r_2$

$$E = \frac{1}{4\pi\varepsilon_0}\frac{3Q}{r^2}$$

$r_1 < r < r_2$ $\quad E = 0$

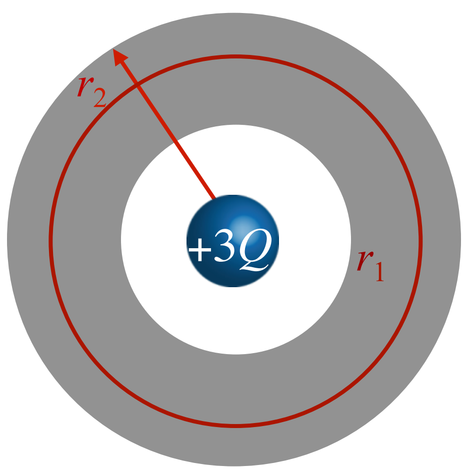


B) What is charge distribution at r_1?

A) $\boxed{\sigma < 0}$

B) $\sigma = 0$

C) $\sigma > 0$



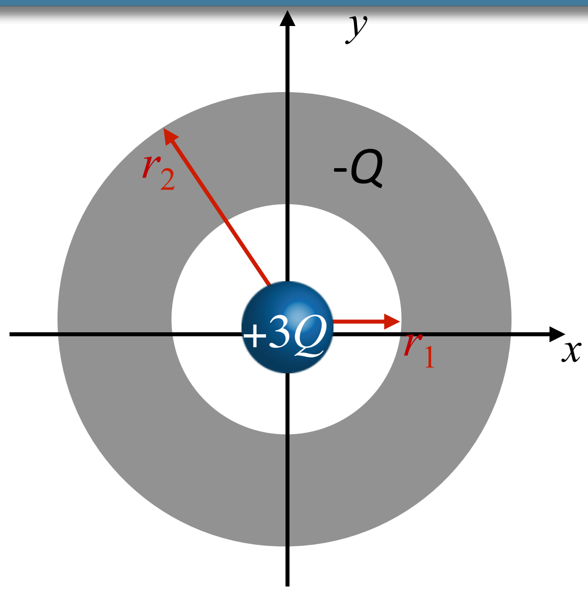
Gauss' Law:

$$E = 0 \rightarrow Q_{enc} = 0 \rightarrow \sigma_1 = \frac{-3Q}{4\pi r_1^2}$$

Similarly:

$$\sigma_2 = \frac{+3Q}{4\pi r_2^2}$$

Calculation

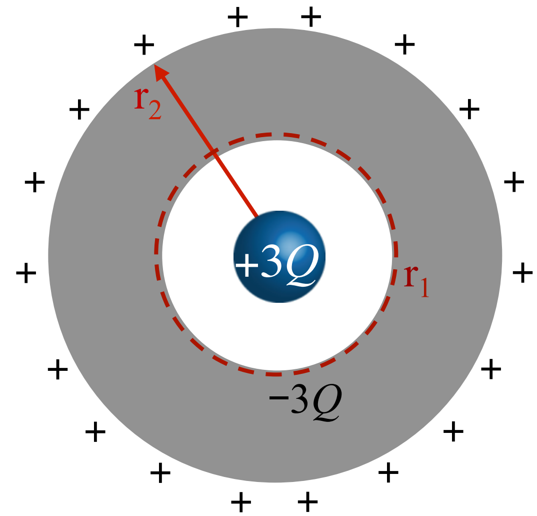


Suppose give conductor a charge of $-Q$

A) What is E everywhere?

B) What are charge distributions at r_1 and r_2?

$$\int \vec{E} \cdot d\vec{A} = \frac{Q_{enc}}{\varepsilon_0}$$



$r < r_1$

A) $E = \dfrac{1}{4\pi\varepsilon_0}\dfrac{3Q}{r^2}$

B) $E = \dfrac{1}{4\pi\varepsilon_0}\dfrac{2Q}{r^2}$

C) $E = \dfrac{1}{4\pi\varepsilon_0}\dfrac{Q}{r^2}$

$r > r_2$

A) $E = \dfrac{1}{4\pi\varepsilon_0}\dfrac{3Q}{r^2}$

B) $E = \dfrac{1}{4\pi\varepsilon_0}\dfrac{2Q}{r^2}$

C) $E = \dfrac{1}{4\pi\varepsilon_0}\dfrac{Q}{r^2}$

$r_1 < r < r_2$

$$E = 0$$

REMEMBER:

$$\sigma = \frac{Q_{net}}{\text{surface area}}$$