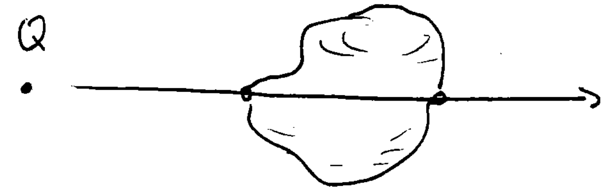
Consider Q outside



A line of force entering also leaves

Gauss's Law

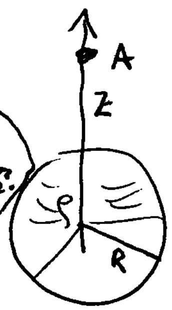
$$\int_{surf} \vec{E}\cdot d\vec{A} = \frac{1}{4\pi\epsilon_0} 4\pi Q_{inside} = \frac{1}{\epsilon_0} Q_{inside}$$

Also one of Maxwell's equations

Why do you care?

One can use Gauss's law + Symmetry to solve for $\vec{E}$ ALMOST Trivially

what is symmetry?
What Gaussian surface do I choose?
⇒ ∞ line charge
⇒ ∞ plane
⇒ sphere



recall our awful example of Field outside Sphere of uniform charge density

Consider $r > R$

$$\phi = \frac{Q_{inside}}{\epsilon_0} = \int \vec{E}\cdot d\vec{A} = |\vec{E}| \int d\vec{A} = |\vec{E}|\, 4\pi r^2$$

$$|\vec{E}| = \frac{Q_{inside}}{4\pi\epsilon_0 r^2}$$ same as pt charge w/ $q = Q_{inside}$

$$Q_{inside} = \frac{4}{3}\pi R^3 \rho$$

$$|\vec{E}|_{r>R} = \frac{\frac{4}{3}\pi R^3 \rho}{4\pi\epsilon_0 r^2} = \frac{R^3\rho}{3\epsilon_0 r^2} = \frac{1}{4\pi\epsilon_0}\frac{Q}{r^2}$$

by Symmetry E is in $\hat{r}$ direction

Transparency 8
Figure 23-23, page 704
Gaussian surface outside a spherical shell (left) and inside a spherical shell (right)

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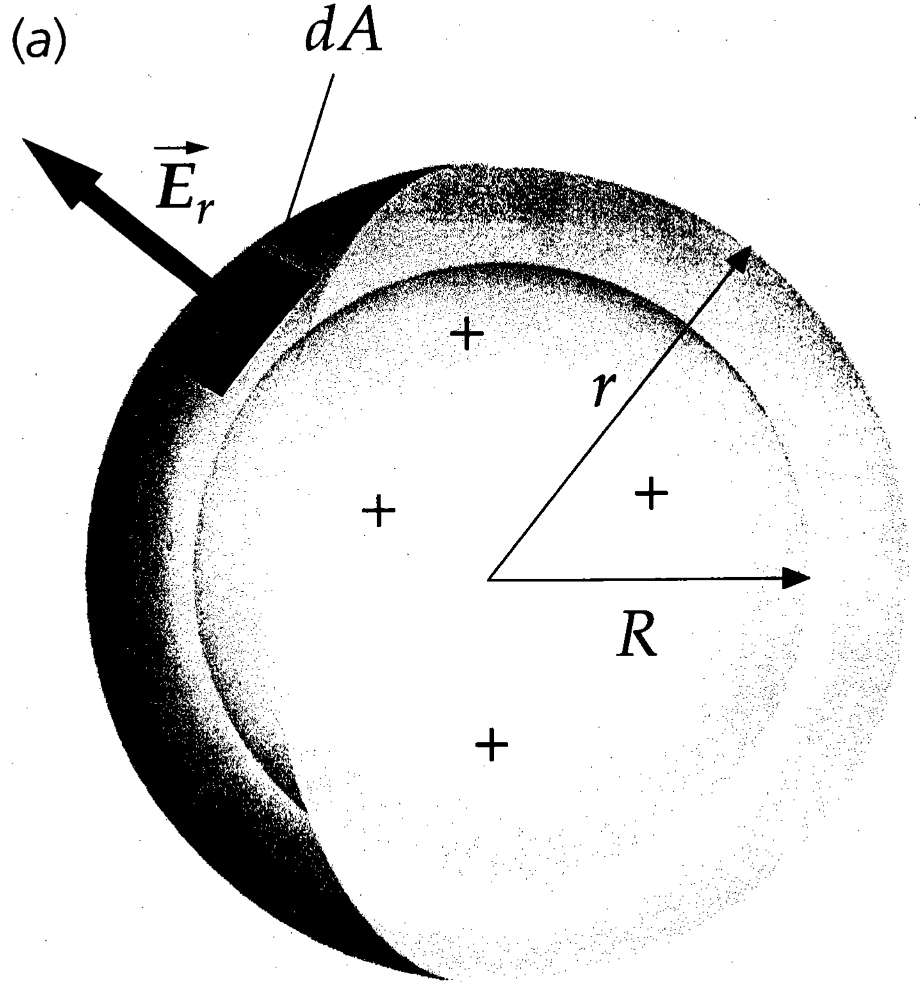
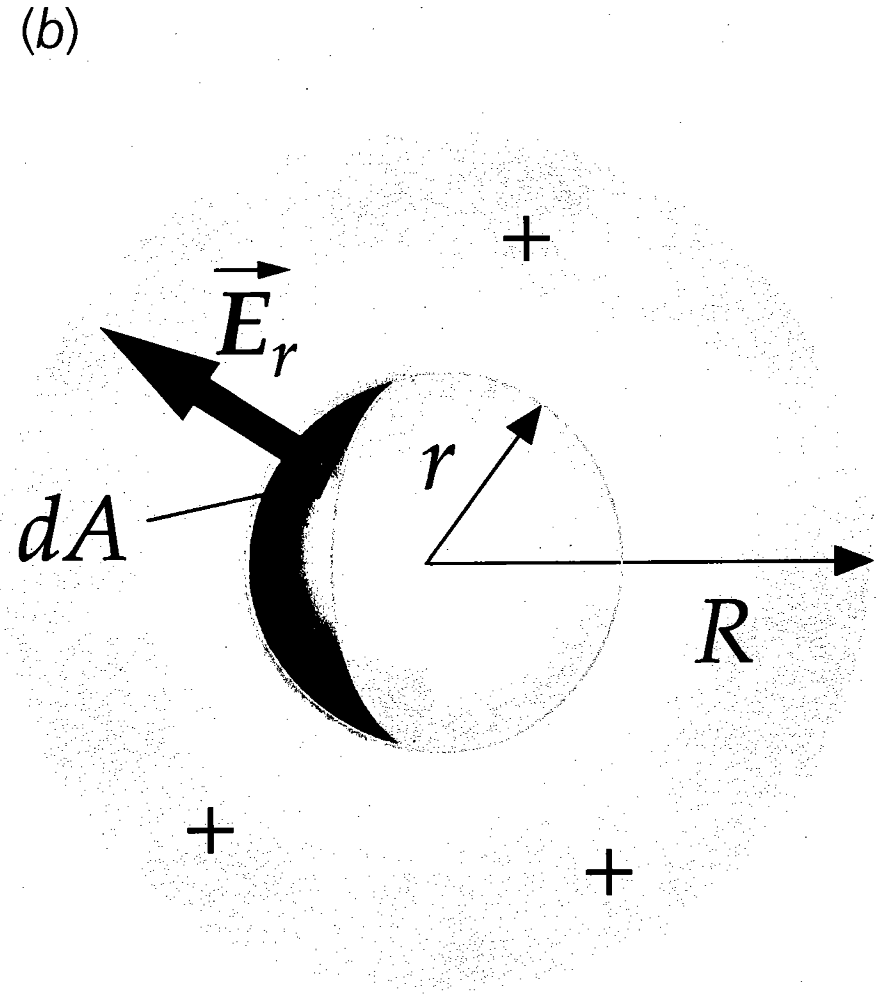
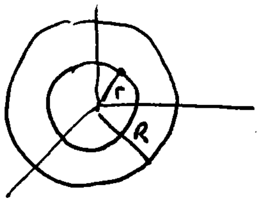




$$\underline{\underline{50}} \qquad \vec{E}_{r>R} = \frac{\rho R^3}{3\epsilon_0 r^2} = \frac{1}{4\pi\epsilon_0}\frac{Q}{r^2}\hat{r} \qquad r \geq R$$

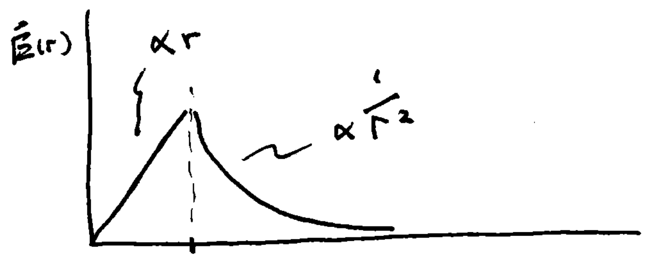
Suppose $r \leq R$

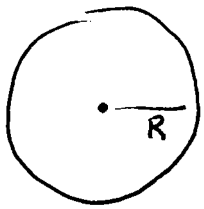


$$|\vec{E}| = \frac{Q_{inside}}{4\pi\epsilon_0 r^2}$$

$$Q_{inside} = \rho \tfrac{4}{3}\pi r^3$$

$$\vec{E} = \frac{\rho \frac{4}{3}\pi r^3}{4\pi\epsilon_0 r^2} = \frac{\rho r}{3\epsilon_0} = \frac{1}{4\pi\epsilon_0}\frac{Q}{R^3}\hat{r} \qquad r \leq R$$





do Telegrams

Transparency 10
Figure 23-21, page 702; Figure 23-24, page 705
E due to a spherical shell of charge (left) and due to a solid sphere of charge (right)

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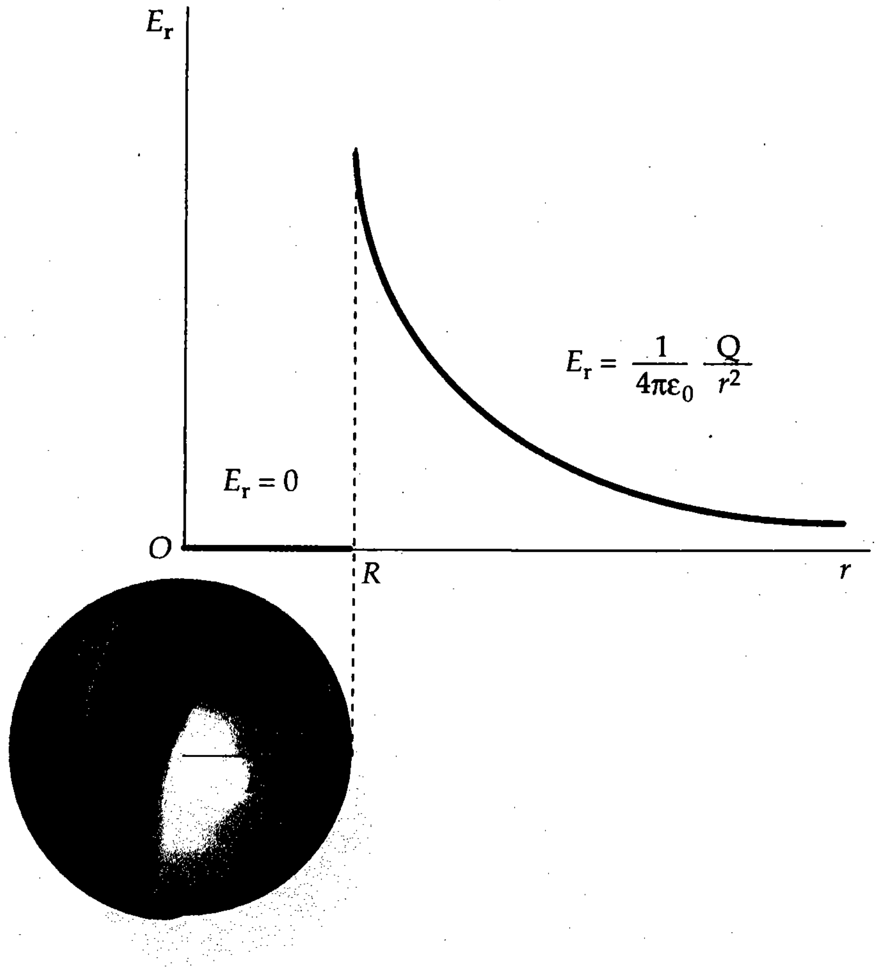
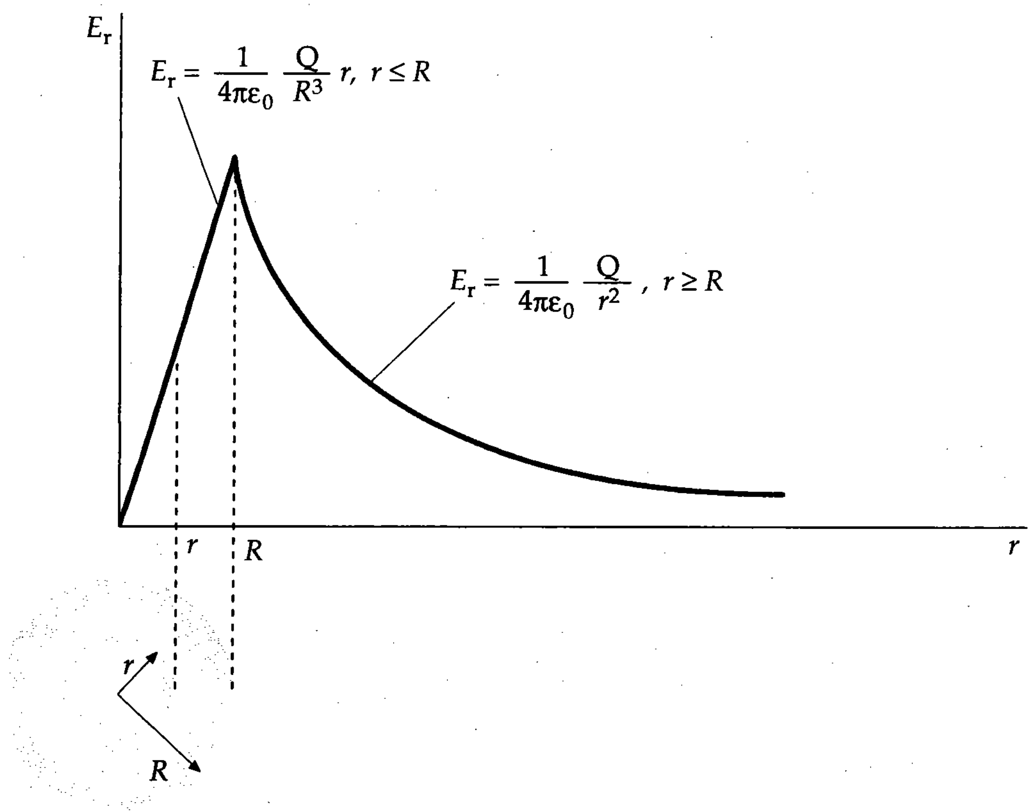




P114 Telegram:

$\bar{E}$ can be calculated directly from ρ (or λ, or Q.)

$$\vec{E} = \int \frac{k\rho}{r^2}\hat{r}$$

often This is hard

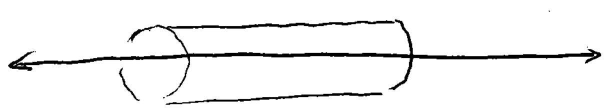
Use Gauss's Law when symmetry allows $|\bar{E}|$ to be moved out of integral

$$\int \bar{E}\cdot d\bar{a} = Q/\epsilon_0 \rightarrow |\bar{E}|\int dA = Q/\epsilon_0$$

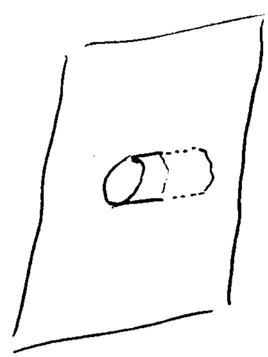
Symmetries often seen

Spherical

Spherical surface



line → cylindrical surface



Plane - pillbox

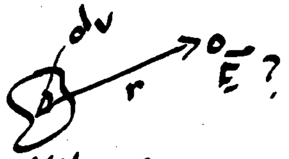
Cylindrical Surface

$\bar{E}$ calculated directly from charge distribution

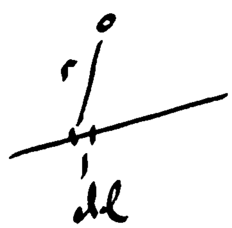
$$\vec{E} = \int \frac{k\,dQ}{r^2}\,\hat{r}$$

volume

$$\vec{E} = \int_{\text{volume}} \frac{k\,\rho\,dv}{r^2}\,\hat{r}$$



line



$$\vec{E} = \int_{\text{line}} \frac{k\,\lambda\,dl}{r^2}\,\hat{r}$$

Surface . . . etc

This is hard !!

Gauss's law allows one to calculate $\bar{E}$ in a much easier way if symmetry allows and you choose the right Gaussian surface

$$\int_{\text{Gaussian Surf}} \vec{E}\cdot d\vec{A} = \frac{Q_{enclosed}}{\epsilon_0}$$

Look at symmetry of charge distribution and choose Gaussian surface so that

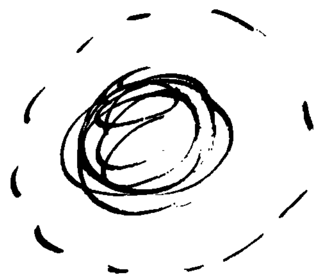
$\vec{E} \cdot d\vec{A}$ is easy to evaluate

Examples

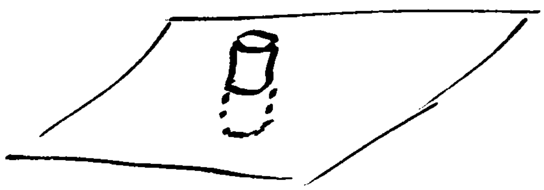
Point

Line

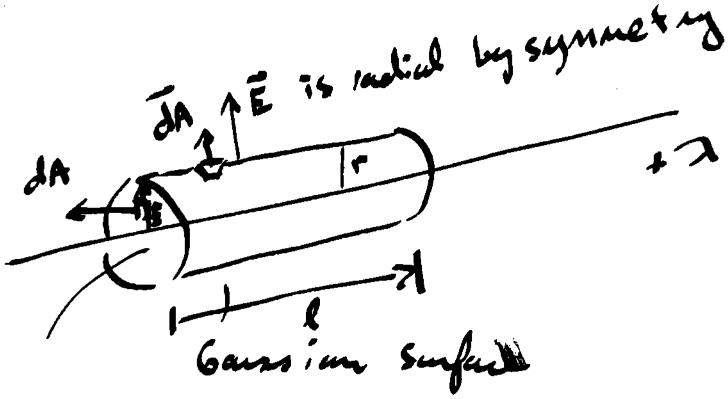
sphere



Plane



what is $\vec{E}$ for ∞ line charge



$$\oint \vec{E}\cdot d\vec{A} = \int_{\text{endcap 1}} \vec{E}\cdot d\vec{A} + \int_{\text{endcap 2}} \vec{E}\cdot d\vec{A} + \int_{\text{cylinder}} \vec{E}\cdot d\vec{A}$$

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

$\vec{E} \perp$ to $d\vec{A}$

E is constant at a fixed radius

$$\int \vec{E}\cdot d\vec{A} = |E| \int_{\text{cylinder}} dA = E\, 2\pi r l = \frac{Q_{encl}}{\epsilon_0}$$

by Gauss's law

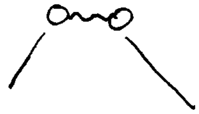
$$Q_{enc} = \lambda l$$

$\therefore$

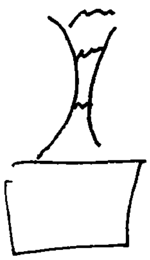
$$E = \frac{\lambda l}{2\pi r l \epsilon_0} = \frac{\lambda}{2\pi r \epsilon_0}$$ radially outward

Conductor - charges can move freely (in response to $\vec{E}$)

insulator - charges cannot move freely
under normal circumstances

Remember ·  Demo

⇒ Do

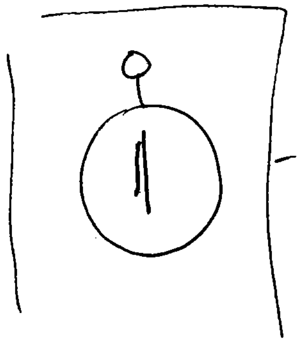


Demo

insulators *can* break down

Semiconductor - "conductivity" depends on environment
(size of electric field)

Do

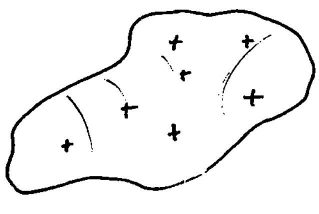


- cage

Shielded Electroscope

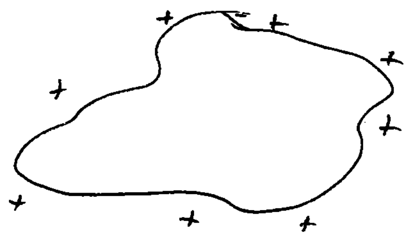
Demo

⇒ Why does this happen?



Solid conductor

⇒



Place charge instantaneously
in arbitrary spots
inside

⇒ What happens

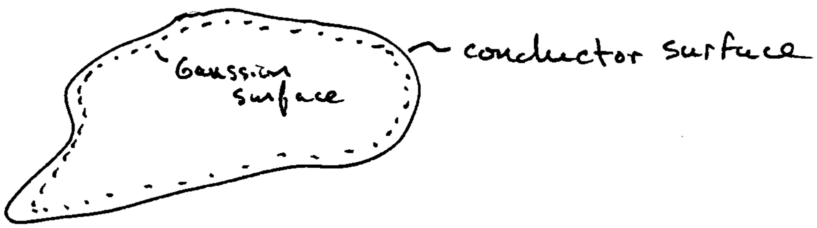
Charges rearrange until
No $\vec{E}$ inside

if $\vec{E}$ - charges flow
until No $\vec{E}$

$\therefore \quad \vec{E} = 0$ inside a conductor

Gauss's Law

$$\int \vec{E} \cdot d\vec{a} = \frac{Q_{inside}}{\epsilon_0} \quad \Rightarrow \quad \vec{E} = 0 \text{ gives } Q_{inside} = 0$$



$\therefore$ ~~all charge is~~ No charge inside

Excess charge on an isolated conductor rests entirely on the outside surface of that conductor

$\Rightarrow$ Now why does electroscope in demo NOT respond to charged rod?

Electro STATIC Shielding $\Rightarrow$ Electro Magnetic Shielding

Microwave doors
Metal cabinets on computers } etc.

Little in life is STATIC ... But we will learn concept of light as induced fields

You are conducting an important expt. for Medical research
Discover Patients brainwaves go Nuts in anticipation of coffee from coffee Man

Actually electromag. "Noise" from Coffee Man's truck

Expt Noise problems in Morning and at ~~Night~~ evening