PHYS 507
Lecture 5: Electrostatics
Conductors

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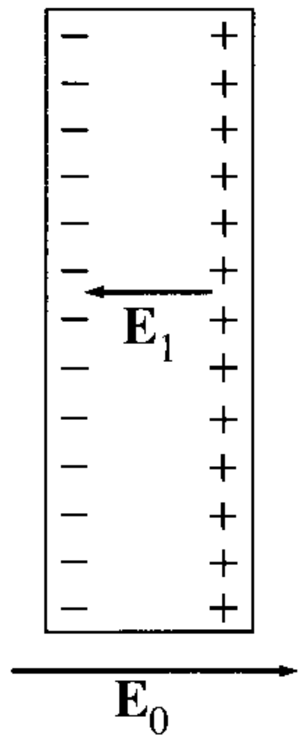
Introduction

- In an **insulator** such as glass or rubber, each electron is attached to particular atom.
- In a metallic **conductor**, by contrast , one or more electrons per atom are free to roam about at will through the material.
- A **perfect** conductor would be a material containing an **unlimited** supply of completely free charges. This is an ideal case.
- From this definition we can have the following properties for ideal conductors.

Properties of ideal conductors-a

- **(i) E=0 inside a conductor.** If you expose a conductor in an external electric field $\mathbf{E}_0$ then this will force the free electrons to move at opposite sides. This process generates an internal field $\mathbf{E}_1$ opposite to $\mathbf{E}_0$. The motion of free electrons goes on until the internal field to compensate the external one. In this case there is **no net electric field** inside the conductor.



Properties of ideal conductors-b

- **(ii) ρ=0 inside a conductor.** This follows from Gauss' Law.

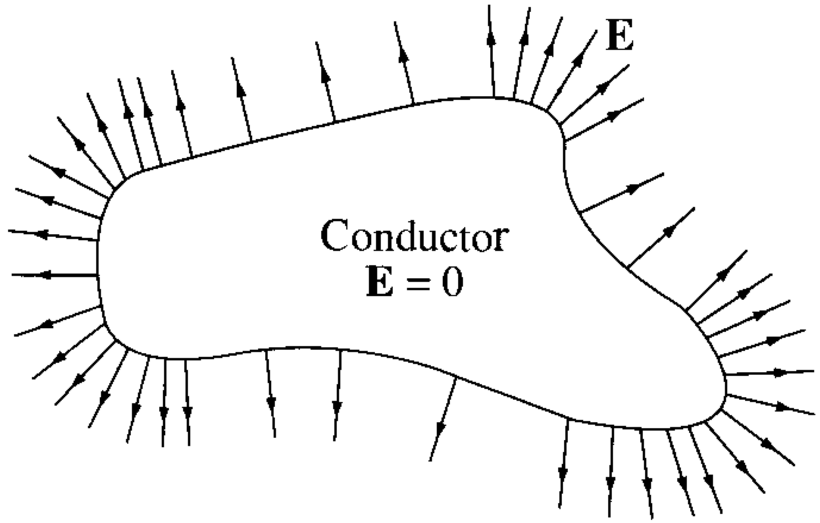
$$\nabla \cdot \mathbf{E} = \rho / \varepsilon_0 \underset{\mathbf{E}=0}{\Rightarrow} \rho = 0$$

- **(iii) Any net charge resides on the surface.** Because this is the only place it can be.
- **(iv) A conductor is an equipotential surface.** For any two points **a** and **b** on the conductor:

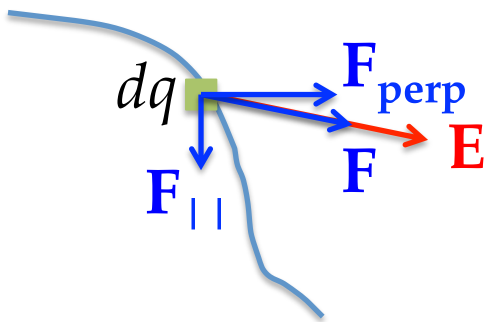
$$V(\mathbf{b}) - V(\mathbf{a}) = -\int_{\mathbf{a}}^{\mathbf{b}} \mathbf{E} \cdot d\mathbf{l} \underset{\mathbf{E}=0}{=} 0 \Rightarrow V(\mathbf{b}) = V(\mathbf{a})$$

Properties of ideal conductors-c

- **(v) E is perpendicular to the surface, just outside the conductor.**

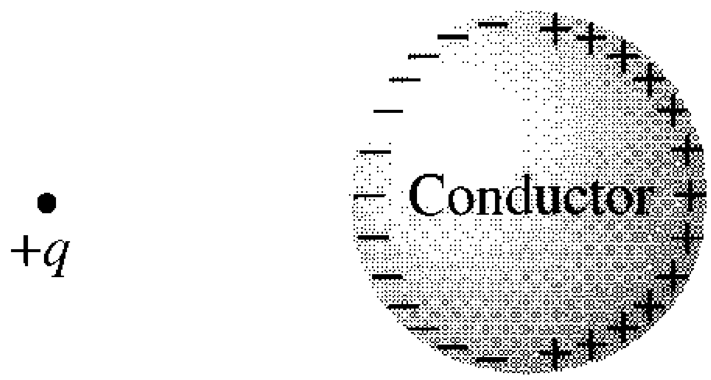


- Otherwise the charge would flow tangential to the surface.



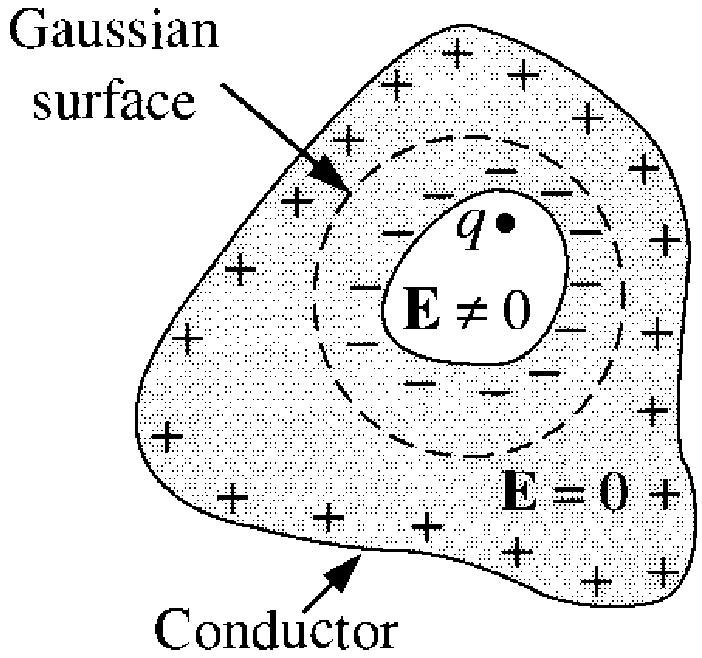
Induced charges in a conductor-a

- If you hold a charge $+q$ near an uncharged conductor, the two will attract each other. The reason for this is that q will pull minus charges over to the near side and repel plus charges to the far side.



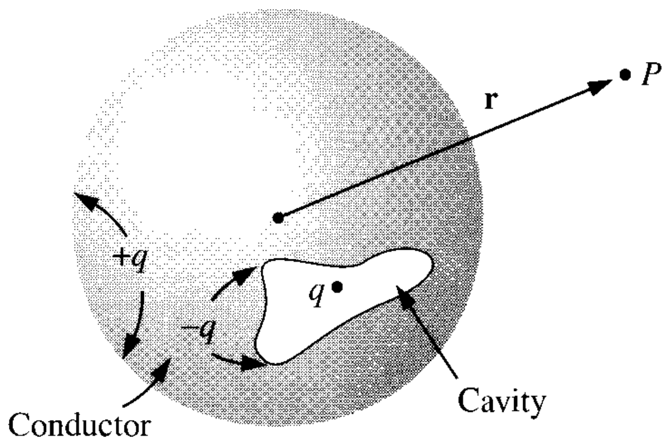
Induced charges in a conductor-b

- If there is some cavity in the conductor, and within the cavity there is some charge, then the field in the cavity will not be zero.
- But in a remarkable way the cavity and its contents are electrically isolated from the outside world.
- **No external fields penetrate the conductor**!



Induced charges in a conductor-c

- If we have an asymmetric cavity with a charge *q* placed inside, what is the electric field at a point P outside the sphere?
- The electric field is not affected by the geometry of the asymmetrical cavity. The positive induced charge on the outer surface is distributed uniformly so the electric field is given by:



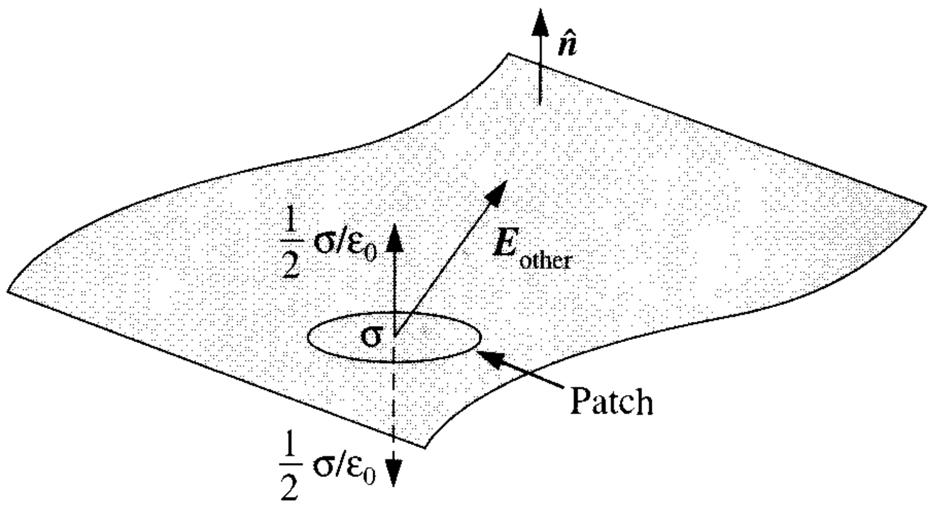
$$\mathbf{E} = \frac{1}{4\pi\varepsilon_0}\frac{q}{r^2}\hat{\mathbf{r}}$$

Surface Charge & Force on a Conductor

- We can show that in the presence of electric field the surface of a conductor experiences a force per unit area:

$$\mathbf{f} = \frac{1}{2\varepsilon_0}\sigma^2\hat{\mathbf{n}}$$

- This force tends to draw the conductor into the field, regardless the sign of σ.



Capacitors

- A system of two conductors with charges +Q and –Q respectively maintained at a potential difference V is called a capacitor.
- A capacitor is characterized by the **capacitance *C***.
- Capacitance is a purely geometrical quantity determines by sizes, shapes and separation of two conductors

$$C = \frac{Q}{V}$$

The capacitance is measured in Farad (1F=1V/C). Since this is a large value we normally use 1 μF, 1nF and 1pF.

Energy of a Capacitor

- Capacitors are used to store electric energy. The energy stored in a capacitor is given by:

$$W = \frac{1}{2}QV \qquad W = \frac{1}{2}CV^2 \qquad W = \frac{1}{2}\frac{Q^2}{C}$$