PHY-112 | Principles of Physics-2

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Department of Mathematics & Natural Sciences

Recap of the previous class!

What we studied in Class #3

Refer to Class #3 slides for details!

- What Electric Dipoles are and what each term mean
- How to measure the strength of a dipole and its polarity direction using the Electric Dipole Moment vector
- How to measure net force, the torque of a dipole when released in a uniform field
- Why there can be no translational work done but rotational work done on the dipole when released in a uniform field
- How this rotational work done can store potential energy in the dipole and how this leads to a stable and an unstable equilibrium for the dipole
- Why does a non uniform field always attract the dipole (apart from rotation) to the positive end of the field

Going Continuous

One Problem Solving Strategy to Rule them All
One strategy to bind them!

Recipe for Discrete calculation

- Start with $\vec{E} = \left(\frac{Cq}{r^2}\right)\hat{r}$
- Superpose them: $\vec{E} = \sum_{i}^{N}\left(\frac{Cq_i}{r_i^2}\right)\hat{r}_i$ (Discrete)

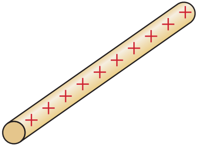
Recipe for Continuous calculation

- Start with $d\vec{E} = \left(\frac{Cdq}{r_{dq}^2}\right)\hat{r}_{dq}$
- Integrate them: $\vec{E} = \int\left(\frac{Cdq}{r_{dq}^2}\right)\hat{r}_{dq}$ (Continuous)

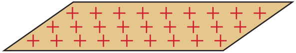
3 Key $\vec{E}$ Field Sources that we may study

Keep the intensity the same all over

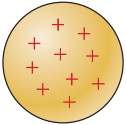
Line Charge



Surface Charge



Volume Charge



Enter Electric Flux

What is Flux? Why do we need it?
Fighting fire with water!

Flux $\Longrightarrow$ Way to measure the **intensity** of a source flow

What is Flux? What does $\vec{E}$ have to do with it?

Electric Flux
How much field through an area?

Q: What does electric flux measure?

- **Visually**: the number of electric field lines passing through a given surface.
- **Numerically**: the surface integral of $\vec{E}$-fields
  - $\Phi_E = \vec{E} \cdot \vec{A}$ (Uniform)
  - $\Phi_E = \displaystyle\int \vec{E} \cdot d\vec{A}$ (Non-Uniform)
  - Unit: [N m^2 C^{-1}] or [V m]
  - It is a scalar

Measure Electric Flux

Electric Flux

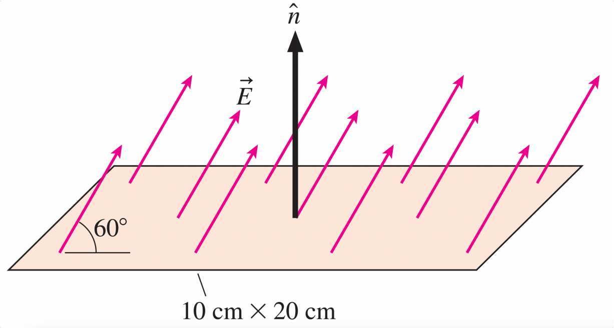
Measure field lines through an open surface

$$\Phi_E = \vec{E} \cdot \vec{A} = \vec{E} \cdot \hat{n}\,(A) = EA\cos\phi \quad \text{(Uniform field)}$$

Incepting Ideas (1)

Hint: The key is to find the angle

Q: Calculate electric flux through the surface shown.



Electric Flux

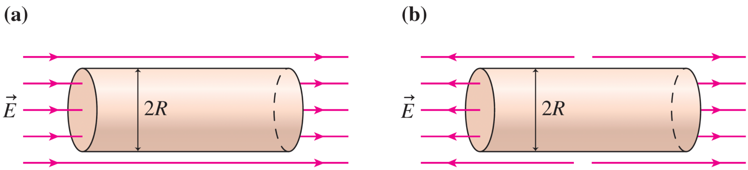
Measure field lines through a closed surface

$$\Phi_E = \int \vec{E} \cdot \hat{n}\,(dA) = EdA\cos\phi \quad \text{(Non-Uniform field)}$$

Incepting Ideas (2)

Hint: The key is to find the angle

Q: What is the net electric flux through the two cylinders shown. Give your answer in terms of R and E.



Enter Gauss's Law

Quantitative Statement of Gauss's Law

We use what we know so far

Measure the net flux of a point charge source. A spherical surface of radius R that has a point charge Q at its center. The electric field everywhere on this surface is normal to the surface and has the magnitude $E_n = \dfrac{Q}{4\pi\epsilon_0 R^2}$.

The net flux through this spherical surface is

$$\begin{aligned}\Phi_{\text{net}} &= \oint E_n dA \\ &= E_n \oint dA \\ &= \frac{Q}{4\pi\epsilon_0 R^2} \cdot 4\pi R^2 \\ &= \frac{Q}{\epsilon_0}.\end{aligned}$$

Gauss's Law and Electric fields

How much field through an area?

The total Φ_E passing through a closed surface is proportional to the total electric charge Q_{enc} enclosed within that surface.

$$\oint_S \Phi_E = \oint_S \vec{E} \cdot d\vec{a} = \frac{Q_{\text{enclosed}}}{\epsilon_0}. \qquad \text{(Integral Form)}$$

$$\text{where} \quad \epsilon_0 = 8.854 \times 10^{-12}\,\mathrm{F\,m^{-1}}$$

$\rightarrow$ Permittivity of free space

It relates the behavior of the electric field to the distribution of electric charge. **One demands the presence of the other**.

Note: Q_{enc} is the net charge calculated by taking the algebraic sum of all charges enclosed by the Gaussian surface.

Incepting Ideas (3)

Hint: Find the enclosed charge

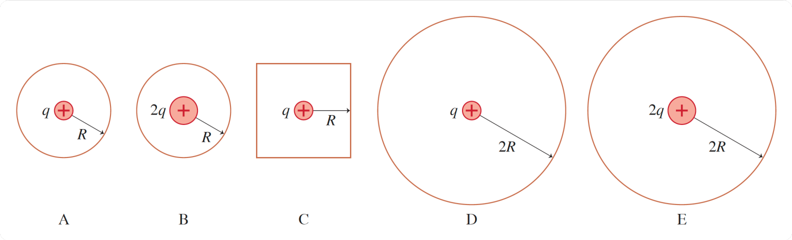
Q1: A point charge 10 nC is at the center of an imaginary sphere that has a radius equal to 0.500 m. (a) Find the surface area of the sphere. (b) Find the magnitude of the electric field at all points on the surface of the sphere. (c) What is the flux of the electric field through the surface of the sphere? (d) Would your answer to Part (c) change if the point charge were moved so that it was inside the sphere but not at its center? (e) What is the flux of the electric field through the surface of an imaginary cube that has 1.00 m-long edges and encloses the sphere?

Q2: A single point charge is placed at the center of an imaginary cube that has 20 cm-long edges. The electric flux out of one of the cube's sides is $-1.50\ \mathrm{kN\ m^2\ C^{-1}}$ How much charge is at the center?

Incepting Ideas (4)

Hint: Count the Field Lines through each face

Q: These are two-dimensional cross-sections through three-dimensional closed spheres and a cube. Rank in order, from largest to smallest, the electric fluxes Φ_A to Φ_E through surfaces *A* to *E*.



How to use Gauss's Law to calculate Field intensities?

How to apply Gauss's Law to measure $\vec{E}$ fields

One size fits all recipe for easier calculation

1. Check the source and figure out the symmetry of its $\vec{E}$ fields
2. Choose a Gaussian surface matching the field symmetry
3. Calculate the Q_{enc} enclosed by the chosen surface
4. Collect only the area portion of the chosen surface that can record flux; discard the rest
5. Confine everything to one side, keeping E on the left after You have applied Gauss's law. Et voilà!!

The template we shall follow

To simplify our field calculation. For now!!

$$\oint_S \Phi_E = \oint_S \vec{E} \cdot d\vec{a} = \frac{Q_{\text{enc}}}{\epsilon_0}$$

$$\oint E da \cos\phi = \frac{Q_{\text{enc}}}{\epsilon_0}$$

$$\pm E \oint da = \frac{Q_{\text{enc}}}{\epsilon_0}; \;\; \text{provided} \;\; \cos\phi = \pm 1$$

$$EA = \frac{Q_{\text{enc}}}{\epsilon_0}$$

$$E = \frac{1}{A} \times \frac{Q_{\text{enc}}}{\epsilon_0};$$

$$\text{where} \;\; Q_{\text{enc}} = \int dq_{\text{enc}} = \text{charge density} \times \text{distribution element}$$

The template we shall follow

To simplify our field calculation. For now!!

TLDR: We want to choose the **Gaussian Surfaces** to be symmetric with the source field. These are the suitable surfaces across where $\vec{E}$ of the source and are parallel, and the intensity is uniform.

Note: These *symmetric* surfaces are called Equipotential surfaces. We will see what they mean in the potential chapter of the story.

Incepting Ideas (5)

Hint: Practice! Practice! Practice!

Some Problems to Practice at Home on Electric Dipole

Example Problem 22.1, 22.2, p-752 | Young-Freedman
Exercise Problem 22.1, 22.2, 22.3, 22.6, p-769 | YF
Sample Problem 23.01, p-662 | Resnick-Halliday
Exercise Problem 1, 2, 4, 9, 10, p-679 | RH

YouTube:

- https://youtu.be/27u2of2ZE3Q?si=GdmHJtM4aRr2LY3I

That is it for today!