Lecture Notes

Physics 2

Fall 2020

Jasper Runco

Instructed by:
Emily Marshman

Contents

Chapter 1

Electric Charge and Electric Field

DATE: 2020-08-17

ANNOUNCEMENTS:

Instructor - Dr. Emily Marshman
Office Hours - M 12:00pm - 1:00pm, T 10:00am - 1:00pm, W 12:00pm - 1:00am
Email - emarshman@ccac.edu
Book - University Physics with Modern Physics by Young and Freedman, 15th edition

Assignment (Sept 20 11:59): Chapter 21 Homework

Assignment (Aug 31): Lab 1

1.1 Introduction

1.1.1 Learning outcomes

- How objects become charged, and how we know it's conserved.
- How to use Coulombs law.
- Distinction between electric force and field.
- How to use idea of electric field lines.
- Calculate properties of electric charge distributions.

1.2 Electric Charge and Electric Fields

1.2.1 Electric charge

When we rub glass rods with silk, the rods become charged and repel each other.

A charged plastic rod **attracts** a charged glass rod, and both attract the cloth.

This shows there are two kinds of charge.

Electric charge and the structure of matter

The particles of the atoms are:

- the negative electrons
- the positive protons
- the uncharged neutrons

Atoms and Ions

A neutral atom has the same number of protons as electrons
A **positive ion** has one or more electrons removed.
A **negative ion** has an excess of electrons.

1.2.2 Conservation of Charge

- The proton and electron have the same magnitude of charge.
- This magnitude is **quantized** unit of charge.
- **principle of charge conservation** states the sum of all charges in a closed system is constant.

$$\boxed{\text{1 Coulomb} \ = \ \text{charge on } 6.241 \times 10^{18} \mathit{protons}} \tag{1.1}$$

Coulomb

$$\boxed{\text{Charge on 1 proton, +e } = 1.6 \times 10^{-19} C} \tag{1.2}$$

Proton charge

$$\boxed{\text{Charge on 1 electron, -e } = -1.6 \times 10^{-19} C} \tag{1.3}$$

Electron charge

Example 1. *Common static electricity involves charges ranging from nanocoulombs to mircrocoulombs.*
(a) How many electrons are needed to form a charge of $-2.00nC$*?*
(b) How many electrons must be removed from a neutral object to leave a net charge of $0.500\mu C$

Solution 1 (a).

$$\begin{aligned}
\textit{Charge of } e &= -1.6 \times 10^{-19} C \\
-2.00\mu C &= -2.00 \times 10^{-9} C \implies \\
\frac{-2.00 \times 10^{-9} C}{-1.6 \times 10^{-19} C} &= 1.25 \times 10^{10} \textit{ electrons}
\end{aligned}$$

Solution 2 (b).

$$\begin{aligned}
0.500\mu C &= 0.500 \times 10^{-19} C \implies \\
\frac{0.500 \times 10^{-9} C}{-1.6 \times 10^{-19} C} &= 3.13 \times 10^{11} \textit{ electrons removed}
\end{aligned}$$

Definition 1 (Conductor)**.** *A material that allows charge to flow through it easily (most metals).*

Definition 2 (Insulator)**.** *a material that does not allow charge to flow through it easily (e.g. plastic, paper, nylon, wood).*

1.3 Conductors, Insulators, and Induced Charges

1.3.1 Charge by contact

Electrons are transfered by rubbing the negatively charged rod on the metal sphere.

When the rod is removed, the electron distribute themselves over the surface.

1.3.2 Without contact (Induction)

1. An uncharged metal ball stands on an insulator
2. free electrons in the metal ball are repelled by the excess in the rod, and shift away from the rod.
3. While the rod is near, connect the ball to the ground with a conducting wire.
4. Free electrons in the metal ball are repelled by the excess in the rod, and shift away from the rod.
5. disconnect the wire and a net positive charge is left on the ball. The earth acquires an equal negative charge.

1.3.3 Electric Forces on Uncharged Objects

- negative plastic come causes shifting of charges within the neutral insulator, called **polarization**
- a charged object of **either** sign exerts an **attractive** force on an uncharged insulator.

1.4 Coulomb's Law

The magnitude of the electric force between two point charges is directly proportional to the product of their charges and inversely proportional to the square of the distance between them.

$$\boxed{F_e = k\frac{|q_1 q_2|}{r^2}} \tag{1.4}$$

Coulomb's Law

The direction of the force depends on the relative sign of the charge.

$$\boxed{k = \frac{1}{4\pi\epsilon_0} = 9.0 \times 10^9 \frac{Nm^2}{C^2}} \tag{1.5}$$

Proportionality Constant

$$\boxed{\epsilon_0 = 8.85 \times 10^{-12} \frac{C^2}{Nm^2}} \tag{1.6}$$

Electric constant

Example 2 (Applying Coulomb's law).

1.5 Electric Fields

A charged object modifies the properties of the space around it. E.g. in the vicinity of a positive charge, other positives repell and negatives attract

Gravitational field:

$$
\begin{aligned}
F_g &= \frac{GMm}{r^2} \\
\frac{F_g}{m} &= \frac{GM}{r^2} \\
&\text{near earths surface} \\
\frac{\overline{F}_g}{m} &= \overline{g} = 9.8\frac{m}{s^2} \\
\overline{F}_g &= m\overline{g}
\end{aligned}
$$

Electric field:

$$
\begin{aligned}
F_e &= \frac{k\,|Qq_0|}{r^2} \\
\frac{F_e}{q_0} &= \frac{kQ}{r^2} = \overline{E}
\end{aligned}
$$

force / charge : electric field of point charge

$$
\boxed{\overline{E} = \frac{1}{4\pi\epsilon_0}\frac{q}{r^2}\hat{r}} \tag{1.7}
$$

Electric field of a point charge

ϵ_0 Electric constant

q - Value of point charge

r - Distance from point charge to where field is measured

$\hat{r}$ **-** unit vector from point charge towards where the field is measured

Direction: electric field points **radially inward** towards negative charge and **radially outward** for positive charge.

Chapter 2

Electric Fields Cont'd

DATE: 2020-08-24
ANNOUNCEMENTS:

2.1 Electric field lines

Definition 3 (Electric field line)**.** *An imaginary line or curve whose tangent at any point is the direction of the electric field vector at that point.*

- Field lines always start at a positive charge and end at a negative charge and can never cross.
- Show the direction of the electric field at each point.
- Spacing gives idea of magnitude of field at each point.

2.1.1 Electric field lines of a dipole

Definition 4 (Electric dipole)**.** *A pair of equal and opposite electric charges.*

- The field radiates outward from the positive and towards the negative.

Example 3 (1)**.** *A positive point charge $+Q$ is released from rest in an electric field. At any later time, the velocity of the point charge*

A. in the direction of the electric field? B. opposite the direction of the electric field? C. not enough information.

Solution 3 (1)**.** *The question does not state a uniform electric field, and remember field lines are not trajectories. C.*

Example 4 (2)**.** *What happens when I place an electric dipole in a uniform electric field pointing to the right.*

Net Force? Net Torque?

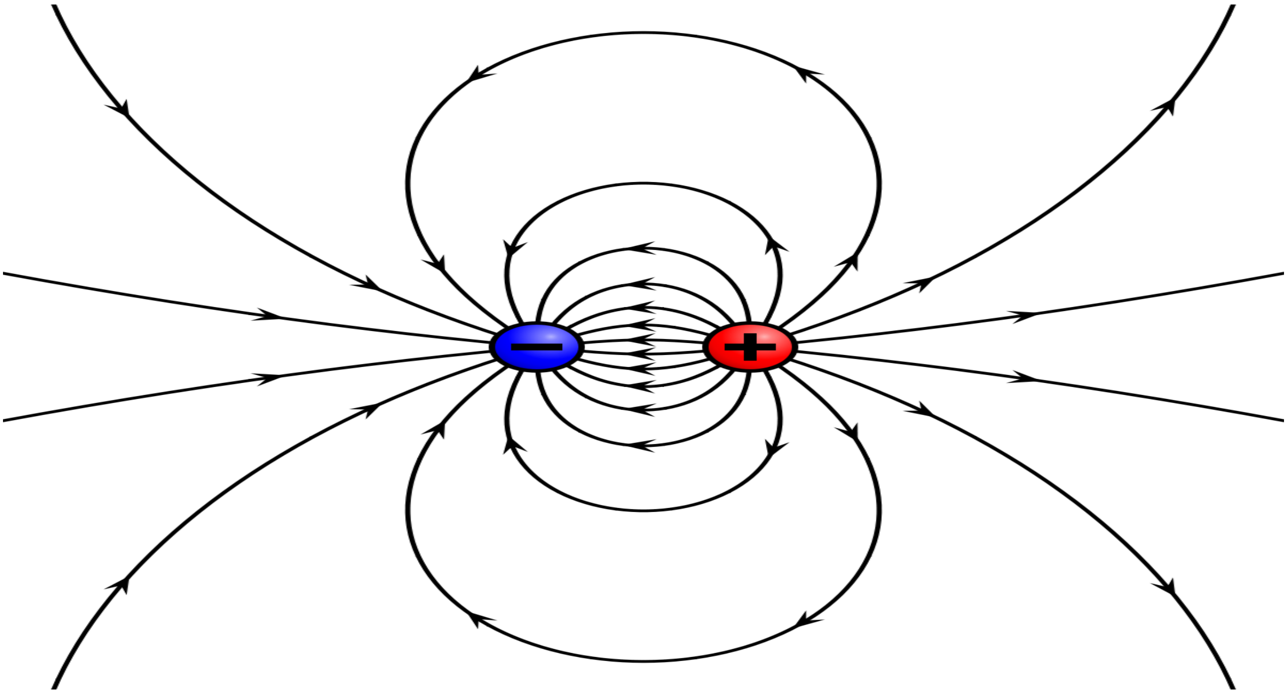

Figure 2.1: Dipole

Solution 4 (2)**.** *A. The force on the positive point charge is* $F_+ = qE$ *right.*
The force on the negative point charge pole is $F_- = qE$ *left.*
$\implies F_{net} = 0$
B. $\tau = \overline{r} \times \overline{F} = rF\sin\theta$
$\tau_+ = \left(\frac{d}{2}\right)(qE)\sin\theta$ *into page*
$\tau_- = \overline{r} \times \overline{F} = \left(\frac{d}{2}\right)(qE)\sin\theta$ *into page*
$\tau_{net} = qdE\sin\theta$ *into page*

Definition 5 (Electric dipole moment)**.**

$$\boxed{p = qd}$$

$\overline{p}$ *points from* $\boxed{-}$ *to* $\boxed{+}$
$\overline{p} \perp \overline{E}$ *, max torque*
$\overline{p} \parallel \overline{E}$ *, minimum torque*

$\tau_{net} = \overline{p} \times \overline{E}$

2.1.2 Electric field due to a charge distribution

- line of charge
- ring of charge
- disk of charge

Line of charge

Example 5 (3)**.** *What is the e-field? at point P?*

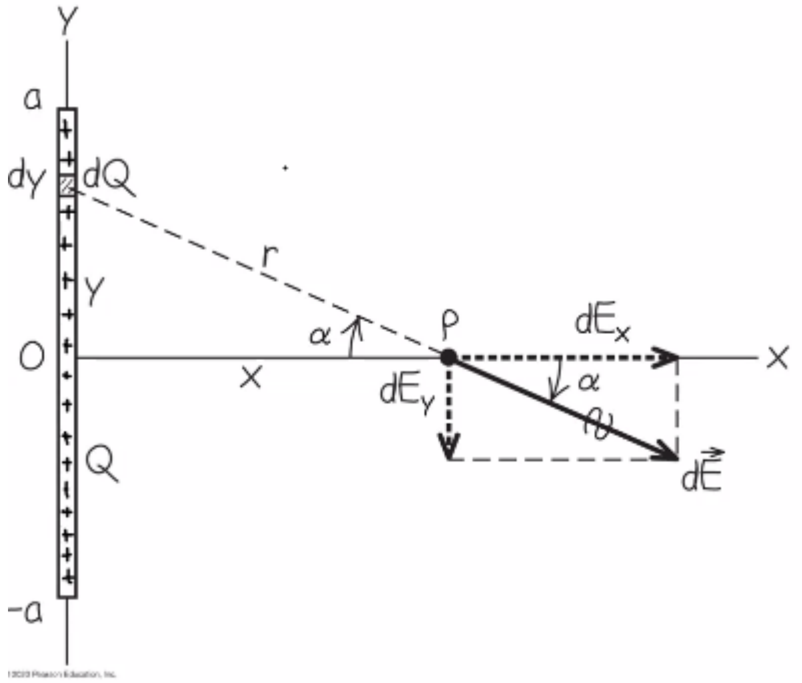

Figure 2.2: line of charge

Solution 5 (3).

$$\begin{aligned}
dE &= \frac{kdQ}{r^2} \\
\int dE_y &= 0 \text{ (symetry)} \\
dE_x &= \frac{kdQ}{r^2}\cos\alpha \\
E_x &= \int \frac{kdQ}{r^2}\cos\alpha \\
r^2 &= x^2 + y^2 \\
\cos\alpha &= \frac{x}{r} = \frac{x}{\sqrt{x^2+y^2}} \\
\textit{define linear charge density}\ \lambda &= \textit{ charge/length} \\
\lambda &= \frac{Q}{2a} \\
dQ &= \lambda dy \\
E_x &= \int \frac{k\lambda dyx}{(x^2+y^2)\sqrt{x^2+y^2}} \\
&= \int_{-a}^{a} \frac{k\lambda xdy}{(x^2+y^2)^{\frac{3}{2}}} \\
E_x &= \boxed{\frac{KQ}{x\sqrt{a^2+x^2}}}
\end{aligned}$$

Example 6 (4). *Ring of charge*

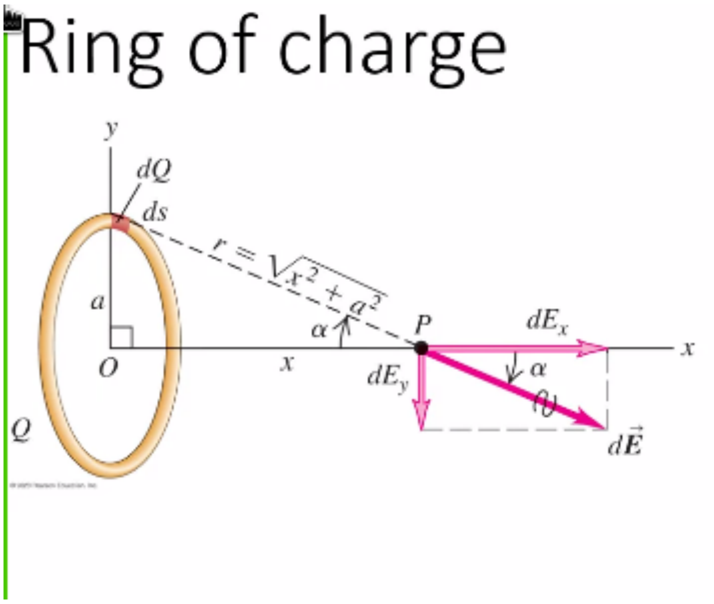

Figure 2.3: ring of charge

Solution 6 (4)**.** *Practice problem.*

Example 7 (Disk of charge)**.** *Find the electric field at point P.*

Solution 7 (Disk of charge)**.**

$$dE_x = \frac{kdQ}{r^2}\cos\theta$$
$$r'^2 = r^2 + x^2$$
$$\cos\theta = \frac{x}{r'} = \frac{x}{\sqrt{r^2+x^2}}$$
$$surface\ charge\ density\,\sigma = \frac{charge}{area}$$
$$dQ = \sigma dA = \sigma 2\pi r dr$$
$$dA = 2\pi r dr$$
$$\int dE_x = \int_0^R \frac{k\sigma 2\pi r dr}{r^2+x^2}\frac{x}{\sqrt{r^2+x^2}}$$
$$E_x = \frac{\sigma}{2\epsilon_0}\left[1 - \frac{1}{\sqrt{\frac{R^2}{x^2}+1}}\right]$$

further: think about R»x

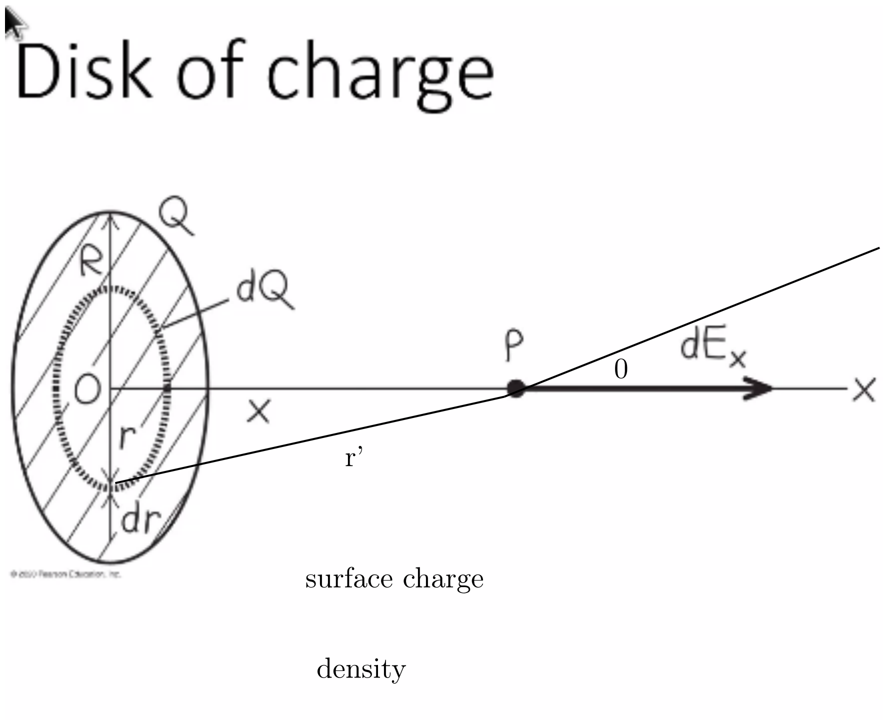

Figure 2.4: disk of charge

2.2 Chapter 22: Gauss's Law

2.2.1 Objectives

- Define electric flux and calculate through surfaces
- Define gauss's law
  - used to determine charge distribution given known e-field
  - to determine field given charge distribution
- know when Gauss's law can be used
- Do calculations with Gauss's law

Electric field due to a charged conducting sphere

We could use the electric field equations, but things get messy. Gauss's Law gives simplicity through symetry.

2.2.2 Intro to Gauss's law

- Given any general charge distribution, we surround it with an imaginary surface
- We look at the field at various points on imaginary surface
- GL is a relationship between the field at all points and total charge enclosed. it helps find the field for symmetric charge distributions.

2.2.3 Charge and electric flux

In boxes, there are positive charges within producing outward electric flux.

When boxes have negative charge inside, there is an inward electric flux.

When $\overline{E} = 0$ there is no electric flux in or out of the box.

What happens if there is no net charge inside the box?

- There is an electric field, but it flows in and out on either half
- Thus no net electric flux into or out of box.

What happens if there is charge near the box, but not inside?

- The net electric flux through the box is zero.

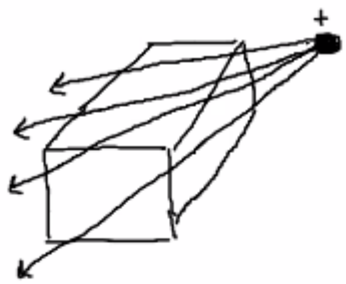

Figure 2.5: zero net flux

Quantifying electric flux

Net electric flux is **directly proportional** to net amount of charge within surface.

Net electric flux is **independent** of the size of the closed surface.

Example 8. *Suppose a Gaussian surface with rectangular sides and positive point charge $+q$ at it's center, and the surface doubles, but charge remains $+q$, what happens to the flux?*

Solution 8. *Remains the same*

Example 9. *Spherical Gaussian surface 1 has $+q$ at it's center. Spherical Gaussian surface 2, same size encloses the charge but is not centered on it. Compare flux through surface 1 and 2.*

Solution 9. *The same*

Calculating electric flux

- Consider a surface
- What affects amount of flux passing through surface?
- "net" analogy

Definition 6 (Electric flux)**.**

$$
\begin{aligned}
\Phi_E &= \Sigma \overline{E}_i \cdot d\overline{A}_i \\
&= \int E \cos\phi dA \\
&= \int E_\perp dA \\
&= \int \overline{E} \cdot d\overline{A} \\
&\rightarrow \int \overline{E} \cdot d\overline{A} \left(\frac{Nm^2}{C}\right)
\end{aligned}
$$

Φ_E **-** *Electric flux through a surface*

E **-** *Magnitude of Electric Field*

ϕ **-** *Angle between $\overline{E}$ and normal to surface*

dA **-** *Element of surface area*

$E_\perp$ **-** *Component of $\overline{E}$ perpendicular to surface*

$d\overline{A}$ **-** *Vector element of surface area*