Physics 248 Lecture 1

Topics:

• Course information and policies

• Begin electrostatics →
  
  Electric charge, electrostatic force, electric field

(Purcell Ch. 1)

Welcome to Physics 248!

www.physics.wisc.edu/undergrads/courses/spring2012/248/

Professor Daniel Chung } lectures and
discussion sections

Professor Lisa Everett

Leon Maurer } labs and HW grading

See website for course information + contact information
Topic: classical electromagnetism — with connections to special relativity
transition to need for QM

Text: E. M. Purcell

Electricity and Magnetism

recommended but not required — general physics texts such as Bauer + Westfall
or Tipler, Serway, Halliday-Resnick-Walker, etc.

We'll aim to get through most of Purcell's text this term
esp. Ch 1 - 9 in detail
10, 11 → brief overview

Course Structure —

Same as Physics 247

weekly HW, 3 midterm exams, 1 final exam

grading breakdown: 30% HW, 20% lab, 20% final, 30% midterms

⅓ best + 2nd best, ⅓ 3rd best
midterm dates are 2/22, 3/21, 4/25 in class
Final exam: 5/16 2:45-4:45 PM, room TBA
Labs: 11 labs → no labs during midterm exam week
Labs are mandatory. Policies/grading as in Physics 247.

Prerequisite: Physics 247

ie assume familiarity with vectors + vector algebra

important mathematical concepts: vector functions
vector calculus
differential eqns → \{ ordinary differential eqns, partial differential eqns \}

we'll introduce such concepts as needed throughout the course
Electrostatics (Purcell Ch. 1)

classical electromagnetism → tremendously important branch of physics

- governs basic physical & chemical properties of matter
- theory of light (electromagnetic radiation)
- technological applications

- beautiful theory → summarized by Maxwell's equations
  \[ \text{gauge invariance} \rightarrow U(1)_{\text{EM}} \]
  basis for the construction of the Standard Model of particle physics

- consistent with special relativity
  (unlike Newtonian mechanics)
  indeed, special relativity grew out of classical E&M

- quantum modifications to the theory only required at subatomic distances \( \sim O(10^{-10} \text{ cm}) \)
Electric Charge

empirically: • occurs in positive \(\oplus\) and negative \(\ominus\)

like charges repel
opposite charges attract

electron: \(\ominus\) charge
proton: \(\oplus\) charge

(convention)

• Charge is conserved.

total electric charge in an isolated system is invariant
(relativistically invariant)

• Charge is quantized

electron: one unit of charge \((-1e\)\)
proton: \(\text{“”””}\) \((+1e\)\)
\[ e = 1.6 \times 10^{-19} \text{ C} \]

\[ \epsilon_0 \text{ Coulomb's unit of charge} \]

(I'll write \( |e| \) and \( -|e| \) because many books take \( e < 0 \) i.e. charge of electron)

electrons not known to have any internal structure

but protons do \( \rightarrow \) quarks + gluons \( \rightarrow \) charge neutral

\( \frac{1}{3} \) charge \( \epsilon/3 \) multiples

idea of point charges \( \rightarrow \) electron is prototype

"Continuous distributions" of charge \( \rightarrow \) idealization (averaged quantity)

well consider these later

Electrostatics

study of forces/fields of stationary charges

electrical interaction between charges \( \rightarrow \) Coulomb's Law
**Coulomb's Law**

\[ \overrightarrow{F_{12}} = \overrightarrow{F_2} - \overrightarrow{F_1} \]

\[ k = \text{constant} \]

**SI units** → \( k = 8.99 \times 10^9 \text{ N} \cdot \text{m}^2/\text{C}^2 \)

\[ k = \frac{1}{4\pi \epsilon_0} \quad \rightarrow \epsilon_0 = 8.85 \times 10^{-12} \text{ C}^2/\text{N} \cdot \text{m}^2 \quad \text{"permittivity of free space"} \]

**CGS electrostatic units** → \( k = 1 \), measure charges in esu, force in dynes

\[ e = 4.8023 \times 10^{-10} \text{ esu} = 1.6 \times 10^{-19} \text{ C} \]

Here we'll use SI units. This will be annoying at times because Purcell uses CGS-ESU, & W & others use SI units.
Coulomb force → depends on the product of the electrical charges
inverse-square law \( \sim \frac{1}{r^2} \)

long range force → like gravity

Cavendish experiment → test for deviations from inverse square law
none found over broad range of distances

(very large + very small distances – still unknown)

\[ 10^{-2} \text{cm} < 10^{-17} \text{cm} \]

Obey linear superposition → forces due to different sources add (via vector addition)

\[ \vec{F}_{on_i} = \vec{F}_{on_i} \text{by } q_2 + \vec{F}_{on_i} \text{by } q_3 \]
Energy of assembling charges:

\[ W = - \int F \cdot d\mathbf{s} \] (work done by external agent)

bring in \( q_1 \) from \( \infty \), \( q_2 \) fixed (or vice versa)

\[ W_{12} = - \int_\infty^{12} k \frac{q_1 q_2}{r^2} \, dr = k \frac{q_1 q_2}{r_{12}} \]

bring in a third charge

\[ W_3 = - \int_{R_{23}} k \frac{q_2 q_3}{r^2} \, dr - \int_\infty^{R_{13}} k \frac{q_1 q_3}{r^2} \, dr \]

\[ = \frac{kq_2 q_3}{r_{23}} + \frac{kq_1 q_3}{r_{13}} \]

total work to assemble \( q_1, q_2, q_3 \) →

\[ W = W_{12} + W_3 = k \frac{q_1 q_2}{r_{12}} + k \frac{q_2 q_3}{r_{23}} + k \frac{q_1 q_3}{r_{13}} \]

(sum over all distinct pairs)
Work done by external agent to assemble charges →

\[ U = \frac{1}{2} \sum_i \sum_j \frac{q_i q_j}{r_{ij}} \]

Potential energy of system

---

**The Electric Field**

Return to our configuration of charges \( q_1, q_2, q_3 \) fixed in space. Consider the effect of these charges on another charge \( q_0 \).

\[ \vec{F} = \sum_{i=1}^{3} k \frac{q_0 q_i}{|\vec{r}_{q_0} - \vec{r}_{q_i}|^3} (\vec{r}_{q_0} - \vec{r}_{q_i}) \]

Force proportional to \( q_0 \) → can divide it out to define the electric field \( \vec{E} \)
\[ \vec{E}(\vec{r}) = \sum_i \frac{k q_i}{|\vec{r} - \vec{r}_i|^3} (\vec{r} - \vec{r}_i) \]

units: SI \quad N/C
\quad cgs \quad \text{dynes/esu}

The electric field is a vector field \rightarrow a vector function in space.

(cater well consider fields that are functions of time as well as space)
field description will prove very useful \rightarrow
field is a local property at every point in the system.

Visualize it \rightarrow \vec{E} field lives

\[ \vec{E}_q = \frac{k q}{r^2} \]

Rules: Start on \( \oplus \), end on \( \ominus \)
don't terminate in free space can't cross