Teaching Portfolio

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Teaching Portfolio

Introduction

This portfolio documents my experiences in teaching while at the University of Notre Dame. My experiences fall into two general categories: being a teaching assistant for General Physics Tutorials and performing observed lectures as part of the Teaching Practicum course offered by the Physics Department. For each of the experiences (where appropriate), I provide an overview, a lesson plan, my lecture notes, feedback, and a reflection.

Overall, the General Physics Tutorials were a much shorter time-span for lecturing — on the order of 5 minutes for a brief review of concepts before students worked in groups on discussion questions. However, I had more control over the structure of the class and was responsible for almost every aspect of the class. For example, I designed the review lectures, provided my own solutions to the discussion questions, graded the discussion questions, managed the grade book on Sakai, and received evaluations from the students. The two aspects I did not have control over were the specific discussion questions and the general format of group work.

The Physics Department Teaching Practicum provides graduate students the opportunity to give a full lecture to physics students and receive feedback from an observer. I completed three lectures as part of the teaching practicum — one upper level physics course with only ~10 students and one lower level physics course with ~ 100 students. It was interesting to design and deliver lectures to such varied audiences. All lectures were observed by a professor in the Physics Department, and they expressed very complementary opinions of my teaching. The two General Physics lectures were observed by professionals from the Kaneb Center for Teaching and Learning[1] at the University of Notre Dame. The Kaneb Center was able to provide more extensive feedback that I found very beneficial.

[1]More information on the Kaneb Center can be found at their website https://kaneb.nd.edu/.

Summary of Teaching Experience

1. General Physics Tutorials (PHYS 10310, 10320, 12320)
   Fall 2013, Fall 2014, Spring 2014
   ~20 students per section
   lower level course for non-majors

2. Quantum Mechanics II (PHYS 40454)
   1/30/2017, 11:30 am - 12:20 pm
   Professor Morten Eskildsen
   Observed by Professor Jonathan Sapirstein
   ~10 students
   upper level course for physics majors
   Topic: Relativistic Correction to the Fine Structure of Hydrogen

3. General Physics II (PHYS 10320)
   9/22/2017, 8:20 am - 9:10 am
   Professor Manoel Couder
   Observed by Alex Ambrose of the Kaneb Center and Professor Adam Martin
   ~100 students
   lower level course for non-majors
   Topic: Energy in Capacitors

4. General Physics II (PHYS 10320)
   9/22/2017, 2:00 pm - 2:50 pm
   Professor Randal Ructi
   Observed by Kevin Barry of the Kaneb Center and Professor Adam Martin
   ~100 students
   lower level course for non-majors
   Topic: Energy in Capacitors

General Physics Tutorials

Overview

I was a teaching assistant for the General Physics I & II tutorials for three semesters: Fall 2013, Spring 2014, and Fall 2014. The purpose of the tutorials was to practice problem-solving techniques in a group setting. Each section consisted of 15 - 20 students. I structured the tutorials with a 5 minute lecture to review the important concepts/equations, 35-40 minutes of group work time, and 5-10 minutes at the end for groups to present their solutions. The tutorial questions were provided by the professor in charge of the course and used by all tutorial sections. I received mid-semester and end of the semester evaluations for the Fall of 2014.

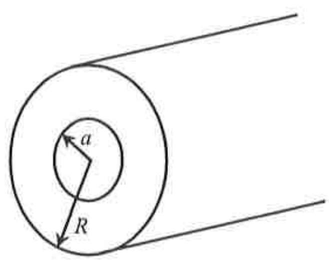
Example Discussion Questions

Physics 10320 Fall 2014
Discussion Section Questions

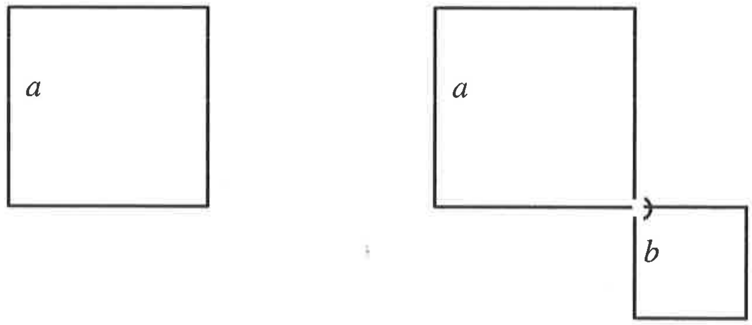
November 4, 2014

Directions: One person in your group should act as "scribe" to record your group's solution on a sheet of paper. Please make sure your answers are legible and comprehensible.

1. A very long, straight connector with a cylindrical cross section of radius R carries a current I uniformly distributed over the cross sectional area of the conductor. The conductor is hollow, with a cylindrical hole of radius a whose axis coincides with that of the outer conductor. Find the magnetic field due to the current everywhere in space.



2. A magnetic field with time variation $B(t) = B_0 \sin \omega t$ is oriented such that $\vec{B}$ is perpendicular to the page. A square loop whose side has length a lies in the plane of the paper.
(a) Find the amplitude of the current induced in the loop if the resistance per unit length is ρ.
(b) Now, as shown on the right, a twist is added in the form of another square loop. Find the induced current in this case if the new loop is made of the same wire.

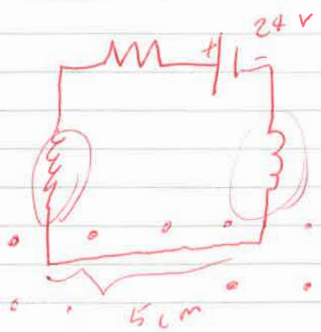


Example Review Lecture

11 / 4 / 14

Lecture

Last time



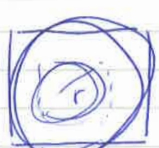
2 springs

$\therefore F_{spring} = \underline{2} K \Delta x$

I didn't take off points (in case on test they ask for k of one spring)

Ampere's law

$\int B \cdot dl = \mu_0 I_{enc}$



$\int B \cdot dl = \mu_0 I_{enc}$ fraction $V_{enc}\left(\frac{I}{V}\right)$ current density

Lenz's Law

$\mathcal{E}_{ind} = -\frac{d\Phi_B}{dt} = -\frac{d}{dt}\int B\,dA$

opposes change in flux

Biot Savart Law $dB = \frac{\mu_0}{4\pi} \frac{N I \, d\vec{l} \times \vec{r}}{r^2}$

Example Solutions

Discussion Questions

11/4/14

#1) conducting cylinder
radius R
current I
hollow (radius a)
magnetic field

$I = \vec{J} \cdot A$

Ampéres law $\int B \cdot dl = \mu_0 I_{enc}$

inside $(r<a)$

$$\int B_{in} \cdot dl = \mu_0 \cancel{I_{enc}}^{0}$$

$$\boxed{B = 0} \quad | \ (r<a)$$

middle $(R>r>a)$

$$\int B \cdot dl = \mu_0 I_{enc} = \mu_0 \vec{J} A_{enc}$$

$$B(2\pi r) = \mu_0 \left(\frac{I}{\pi(R^2-a^2)}\right)(\pi r^2 - \pi a^2)$$

$$\boxed{B = \frac{\mu_0 I}{2\pi r} \frac{(r^2-a^2)}{(R^2-a^2)}} \quad (a<r<R)$$

outside $(R<r)$

$$\int B \cdot dl = \mu_0 I_{enc}$$

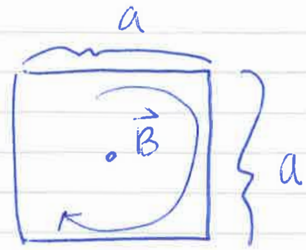
$$B(2\pi r) = \mu_0 I$$

$$\boxed{B = \frac{\mu_0 I}{2\pi r}} \quad (r>R)$$

$$\therefore B = \begin{cases} 0 & (r<a) \\ \frac{\mu_0 I}{2\pi r} \frac{r^2-a^2}{R^2-a^2} & (r>R) \\ \frac{\mu_0 I}{2\pi r} & (a<r<R) \end{cases}$$

NOTE: can "check" answers by seeing if they match at boundaries! (i.e. $r=a$, $r=b$)

#2) time varying mag field
$B(t) = B_0 \sin(\omega t)$
square loop (side a)



a) amp. of induced current
(resistance per length ρ)

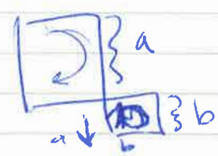
$$\mathcal{E} = -\frac{d\Phi_B}{dt} = -\frac{d}{dt}\left[\int B \cdot da\right] = -A\frac{dB}{dt}$$

constant

emf = IR

$$IR = -A\frac{dB}{dt}$$
$$I(\rho \cdot 4a) = -a^2 \frac{d}{dt}\left[B_0 \sin(\omega t)\right]$$
$$4\rho I = -a B_0 \cos(\omega t)\,\omega$$
$$\boxed{I = \frac{-a\omega B_0}{4\rho} \cos(\omega t)}$$

b.) twist added
new induced current



everything is the same exact
area & length changes

~~$I\rho(4a+4b) = (a^2+b^2) B_0 \cos(\omega t)$~~ ω

→ solve independently
subtract current from b
(flows in "opposite direction" as a)

like 2 opposing batteries.

$$\boxed{I = \frac{-\omega B_0 (a-b)}{4\rho} \cos\omega t}$$

Teaching Effectiveness — Student Evaluations

Mid-semester Quantitative Evaluations:
Below are average student responses from 21 students on a scale of 1 - 5, where 1 is “strongly agree” and 5 is “strongly disagree.”

Statement	Average Response
The problems worked in this class help me in working other problems on my own.	2.48
The problems worked in this class help me in learning the content ideas in this class.	2.38
My group works well together.	1.48
I feel that I need more guidance for our group work.	2.45
I find it helpful if the instructor summarizes results obtained as part of group work.	1.71

Mid-semester Qualitative Evaluations:
Below are comments from students in response to the question “What do you like the most about the Discussion sections?”

> “Ability of TA to explain content is outstanding.”
>
> “I like that we can work on it as a group and get help from instructor on parts that confuse us. The instructor is also very nice and helpful.”
>
> “I like working in groups and I like when the TA goes through a brief pre-worksheet recap on the board.”

Below are comments from students in response to the question “What do you like the least about the Discussion sections?”

> “Sometimes for hard tutorial sessions, it’s hard to reach the instructor because everyone asks for help.”
>
> “When everyone is stuck on a problem and the TA goes to individual groups to help them solve it rather than teach the whole class at once.”
>
> “Difficulty of problem sets seems a bit much.”

End of Semester Quantitative Evaluations:

CIF

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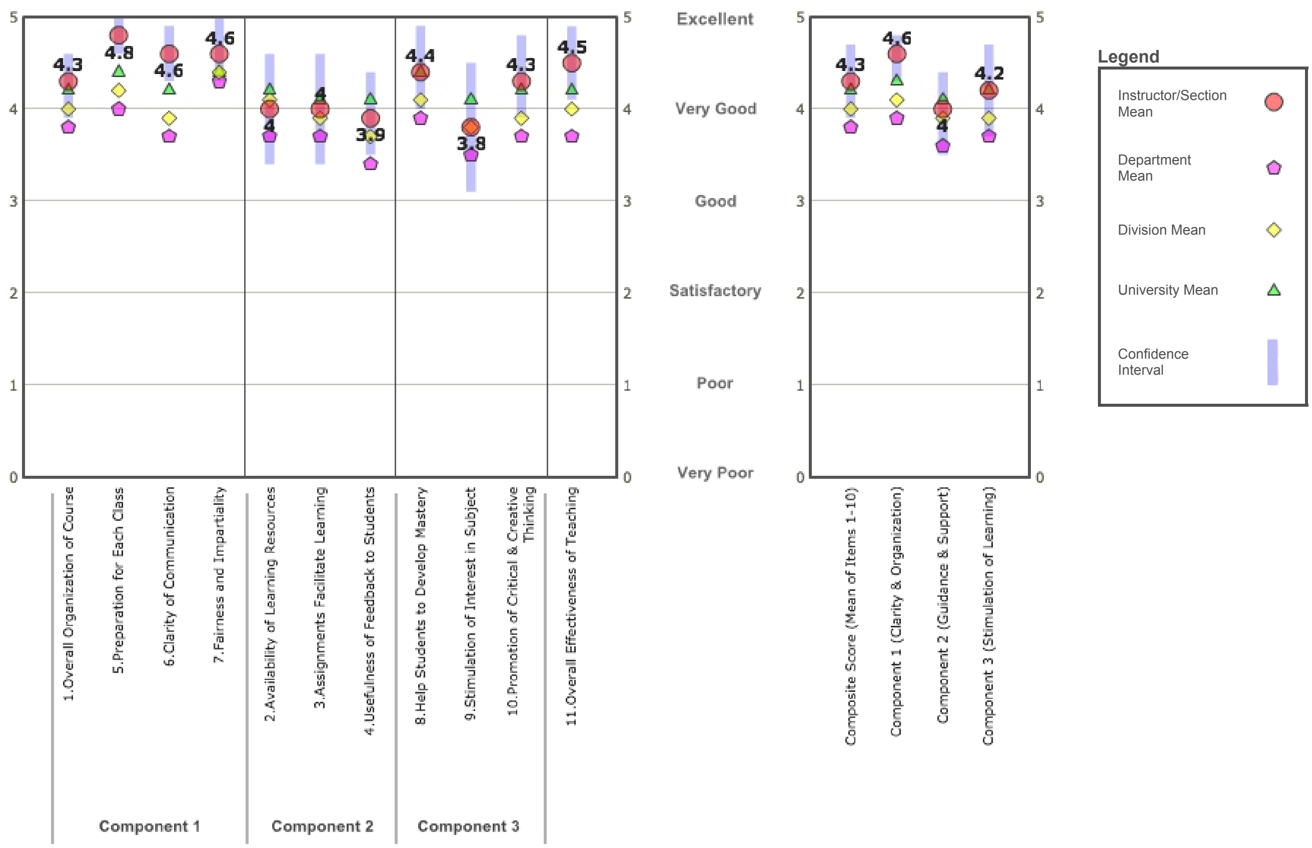
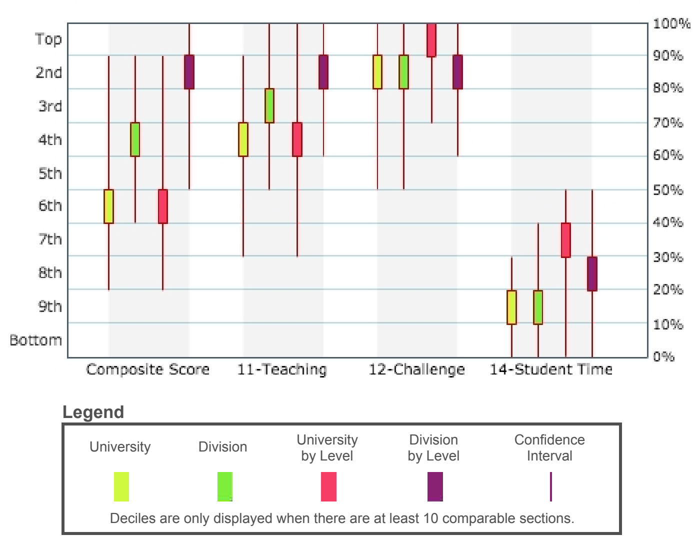
Instructor Summary Report

Instructor:	De Waard, Elizabeth R.	Term:	Fall 2014				
Enrollment:	23	Respondents:	18	Response Rate:	78%	Credit Hours:	0
	Title	Course / Section #	Division	Department	Campus	Level	
Primary Listing:	General Physics II Tutorial	PHYS 12320-14	SC	PHYS	Main	1	

Mean Scores for Individual Items and Composites



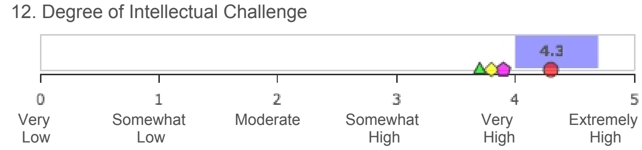
Decile Rankings



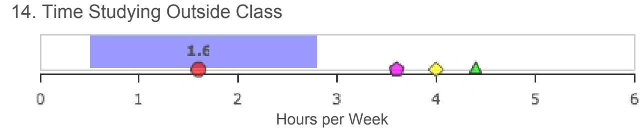
Student Engagement

13. Average Self-reported Attendance: **99%**

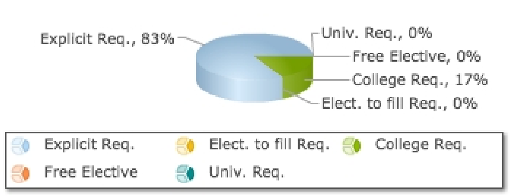
12. Degree of Intellectual Challenge



14. Time Studying Outside Class



Students Taking Class As



End of Semester Qualitative Evaluations:

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Student Comments Report

Instructor:	De Waard, Elizabeth R.	Term:	Fall 2014				
Enrollment:	23	Respondents:	18	Response Rate:	78%	Credit Hours:	0
	Title	Course / Section #	Division	Department	Campus	Level	
Primary Listing:	General Physics II Tutorial	PHYS 12320-14	SC	PHYS	Main	1	

Question List

Reference #	Question
U1	Please comment on how well the activities, readings, lectures, and assignments helped you learn in this course.
U2	Please identify what you perceive to be the greatest strengths of this instructor's teaching.
U3	Please identify areas where this instructor could improve his/her teaching.

Student Responses

Reference #	Student #	Response
U1	1	Class assignments were difficult and sometimes hard to finish in the time allotted. But helpful for the exams.
U1	2	The worksheets are very similar to test questions and this helps!
U1	3	Tutorials problems are usually more challenging than homework or test questions, which I dislike, but they became more understandable towards the end and were a good way to practice the material.
U1	4	The tutorial worksheets should relate what we do in class, which some of them do not.
U1	5	The worksheets helped to bring a better understanding of the course materials.
U1	8	the tutorial problems were too challenging I think and unlike what we were tested on also sometimes they were on things we hadn't learned yet, which made it difficult
U1	9	The problems given were a good challenge to see how well I knew the material.
U1	10	The tutorial worksheets seem way too hard in my opinion. I do not know if it is because I am bad at Physics or because I just did not like Physics, but I never saw the usefulness or relevance of these worksheets.
U1	11	Of the assignments we had in Physics in general, the tutorial assignments were the closest to the exam problems.
U1	12	Homework was relevant.
U2	1	Very helpful for explaining and helping us get to the idea of the problem. You were also very kind and didn't look down on us when we struggled with something.
U2	2	Kind and cares about the students. Good at explaining the material.
U2	3	I like how she formatted the tutorials by having us do the problems in groups but have someone explain problems to the class on the board if there were ones that were more difficult. Liz was pretty helpful and usually good at explaining concepts.
U2	4	Elizabeth is awesome and ran tutorial in the best way possible. She actually wanted to make sure that we learned the material instead of just completing the worksheets. Awesome TA.
U2	5	Very friendly and helpful. Does a good job of explaining material.
U2	6	Really approachable with questions.
U2	7	Very helpful in walking students through problems and assisting them in learning the material.
U2	8	You are very helpful in explaining the material to us when we ask questions
U2	9	She was good at guiding us in the right direction while still making us think to solve the problems.

U2	10	She would go over briefly what equations we needed to transfer from lecture to complete the worksheets. She was very able and willing to answer questions as well.
U2	11	Loved this TA. She was awesome. Extremely helpful.
U2	12	Excellent communication skills. Great job of drawing the answers out of the students, rather than being unhelpful / giving them the answer. Truly great job.
U3	2	n/a
U3	4	Nope.
U3	5	Could have more students be involved with the tutorial.
U3	6	No real improvements needed
U3	7	N/A
U3	8	N/a
U3	10	I never felt engaged in Physics tutorial. I would literally look at the questions and have no idea what to do. Luckily we were in groups otherwise I would have gotten nothing done.
U3	11	Nothing. She's great. The actual class, Physics 2, is garbage. But Elizabeth was great.
U3	12	The problems in this course really stemmed from the writers of the tutorial questions (some were next to impossible to do in the alotted time), rather than Liz. She did an awesome job this semester.

Lecture 1

Overview

In this lesson, I taught upper-level physics majors how to apply time-independent perturbation theory to the Hydrogen atom. This lecture was for Professor Morten Eskildsen's Quantum Mechanics II (PHYS 40454). The class consisted of approximately 10 students in their junior year. I opted to deliver the lecture by handwriting notes, equations, and derivations on the blackboard, as opposed to using prepared slides. The lecture was observed by Professor Jonathan Sapirstein of the University of Notre Dame Physics department.

Lesson Plan

Main Idea: Derive the relativistic correction to the fine structure of the Hydrogen atom using time-independent perturbation theory. The material covered corresponds to section 6.3.1 of *Introduction to Quantum Mechanics* by David J. Griffiths.

Outline of Lesson:

1. Review of time-independent perturbation theory
2. Hamiltonian of the Hydrogen atom - kinetic and potential energy
3. Corrections to the Hydrogen atom (in descending order of magnitude):
    1. Motion of Nucleus
    2. Fine Structure (relativistic and spin-orbit coupling)
    3. Lamb Shift
    4. Hyperfine Structure
4. For the relativistic portion of Fine Structure, we incorporate the relativistic momentum into the kinetic energy term of the Hamiltonian
5. The new relativistic term in the Hamiltonian is small and can be treated as a perturbation
6. Reminder - the Virial Theorem used to derive a $1/r$ term in the energy last lecture
7. If time allows, cover the Feynman-Hellmann Theorem that can be used to derive the $1/r^2$ term in the energy
8. Combine all of the terms for a final energy expression

Demonstration: The Fine Structure of Hydrogen can be observed in the energy spectra, have the students use diffraction gratings to look at a tube of hydrogen gas.

QM II

1. Review
2. Basic H
3. Order of Mag
4. Relativistic T
5. perturbation
6. $\langle 1/r \rangle$ H spin
7. $\langle 1/r^2 \rangle$
8. put it all together

Fine Structure: Relativistic Correction

1. REVIEW: T-Ind. Perturbation Theory

In QM, there are very few problems that are exactly solveable

Pertubation theory systematically finds approximate solutions from the unperturbed case

non-degenerate

$\boxed{Q}$ 1st order correction to the energies

$$[\#1) \quad E_n^{(1)} = \langle \psi_n^\circ | \underbrace{\mathcal{H}'}_{\text{pert.}} | \psi_n^\circ \rangle]$$

unpert. G.S.

$\boxed{Q}$ 1st order correction to the wavefunctions

$$[\#2) \quad \psi_n^{(1)} = \sum_{m \neq n} \underbrace{C_m^{(n)}}_{\text{coefficient}} \psi_m^\circ]$$

$$\left[\frac{\langle \psi_m^\circ | \mathcal{H}' | \psi_n^\circ \rangle}{E_n^\circ - E_m^\circ} \right]$$

again using unpert. G.S.

$\boxed{Q}$ potential problem?

If $E_n^\circ = E_m^\circ$, this blows up

(i.e. degenerate)

\#2) still use non-degenerate IF we find the good linear combos of wavefunctions

2

good ones are such that no matrix element cross term

#3.) [$W_{ij} \equiv \langle \psi_i^\circ | \mathcal{H}' | \psi_j^\circ \rangle = 0$]

to find good ones.

[a) $[A, \mathcal{H}^\circ] = 0$ } Hermitian op that commutes

b) $[A, \mathcal{H}'] = 0$

c.) ψ°'s $\rightarrow$ simultaneous eigenfunctions of $\mathcal{H}^\circ$ & A

#4) If you can't do that ↑
there is an expression for E
using the matrix elements of $\mathcal{H}'$

(don't write) $\rightarrow E_{\pm}^{(1)} = \frac{1}{2}\left[W_{aa} + W_{bb} \pm \sqrt{(W_{aa} - W_{bb})^2 + 4|W_{ab}|^2}\right]$

II. Hydrogen

Apply to the Hydrogen Atom

First, need the Hamiltonian

Q: [$\mathcal{H} = T + V$
$= \underbrace{-\frac{\hbar^2}{2m}\nabla^2} - \frac{e^2}{4\pi\epsilon_0}\frac{1}{r}$]

could express in radial coordinates

[$-\frac{\hbar^2}{2m}\frac{d^2}{dr^2} + \frac{\hbar^2}{2m}\frac{\ell(\ell+1)}{r^2}$]

(write & box for later

9.109×10^{-31} $m_{e} \approx 10^{-31}$ $[mc^2] \Rightarrow \frac{kg\, m^2}{s^2} = J$ 3

$c \approx 10^8$

$1 J = 6.24 \times 10^{18}$ eV

$(10^{-31})(10^8)^2 \sim 10^{-15} J \cdot 10^{18} \frac{eV}{J} \approx 10^3$

when solved before, found n: principle Q #

$\psi_{nlm} \leftarrow$ 3 Quantum # l: azimuthal m: magnetic

Bohr Energy

$$E_n = \left[-\frac{m}{2\hbar^2} \left(\frac{e^2}{4\pi\epsilon_0} \right)^2 \right] \frac{1}{n^2} = \frac{E_1}{n^2} = \frac{-13.6\text{ eV}}{n^2}$$

III Corrections

How can we improve our treatment of Hydrogen?

$\boxed{\text{Table 6.1}}$

- Motion of nucleus
- Fine structure → relativistic, spin-orbit coupling
- Lamb shift
- Hyperfine

smaller

How ~~important~~ large is this correction?

Order of Mag Analysis For e^-

$$\frac{\langle T \rangle}{mc^2} = \frac{-E_n}{mc^2} \leftarrow \text{from Virial theorem}$$

$$\approx \frac{10\text{ eV}}{511\text{ keV}}$$

$$\approx 2 \times 10^{-5} \approx 0.4\,\alpha^2$$

fine structure $\alpha = \frac{1}{137}$

4

small correction
$\therefore$ perturbation theory is ok
only have to worry about 1st order

Bohr E $\propto$ α^2
Fine struct. $\propto$ α^4
$\therefore \left(\frac{1}{137}\right)^2 \sim 10^{5}$
10^5 smaller

IV. Relativistic Correction

(refer back to Hamiltonian)
Here, we have a classical expression

Relativity:
$$T = \underbrace{\frac{mc^2}{\sqrt{1-(v/c)^2}}}_{\text{total E}} - \underbrace{mc^2}_{\text{rest E}}$$

express in terms of relativistic momentum
$$p = \frac{mv}{\sqrt{1-(v/c)^2}}$$

5

sub in p &
express w/common denom

$$p^2c^2 + m^2c^4 = \frac{(mv)^2c^2 + m^2c^4\left[1-(v/c)^2\right]}{1-(v/c)^2}$$

expanding 2nd term

$$= \frac{\cancel{(mvc)^2} + m^2c^4 - \cancel{(mvc)^2}}{1-(v/c)^2}$$

which leaves

$$= \frac{m^2c^4}{1-(v/c)^2}$$

or, comparing w/ T expression

$$= (T + mc^2)^2$$

Rearrange to solve for T in terms of p gives

$$T = \sqrt{p^2c^2 + m^2c^4} - mc^2$$

why did we go through all this work?
B/C if we think about nonrelativistic limit
[$p \ll mc$]
we can expand in powers of small numbers
(factor out mc^2)

$$T = mc^2\left[\underbrace{\sqrt{1+\left(\tfrac{p}{mc}\right)^2}}_{(1+\epsilon)^n \approx 1 + n\epsilon + \frac{n(n-1)}{2}\epsilon^2 + \dots} - 1\right]$$

giving: $T = mc^2\left\{\cancel{1} + \frac{1}{2}\left(\frac{p}{mc}\right)^2 - \frac{1}{8}\left(\frac{p}{mc}\right)^4 + \dots - \cancel{1}\right\}$

HALF-WAY?

11:55

[$T = \underbrace{\frac{p^2}{2m}}_{\text{original term}} - \underbrace{\frac{p^4}{8m^3c^2}}_{\text{1st order correction}} + \cdots$]

$$\boxed{\mathcal{H}_R' = -\frac{p^4}{8m^3c^2}}$$

note $p = -i\hbar\vec{\nabla}$

general result!

* QUESTIONS?

V. Perturbation

now we just need to perform the perturbation (still working generally)

[$E_R' = \langle \psi_n^0 | \mathcal{H}_R' | \psi_n^0 \rangle$

$= -\frac{1}{8m^3c^2} \langle \psi_n^0 | p^4 | \psi_n^0 \rangle$]

p^2: Hermitian ($p^* = p$)

beware! $p^4 \neq$ always Hermitian

example problem #6.15 (not on HW)

[$= -\frac{1}{8m^3c^2} \langle p^2 \psi_n^0 | p^2 \psi_n^0 \rangle$]

7

VI. To proceed, we will need the T-ind. Schrödinger Eq:

$\boxed{Q:}$ (question students)

$$\left(\frac{p^2}{2m} + V\right)\psi = E\psi$$

$$p^2\psi = 2m(E-V)\psi$$

$$E_R' = \frac{-(2m)^2}{8m^3c^2}\langle (E_n^0 - V)\psi_n^0 \mid (E_n^0 - V)\psi_n^0 \rangle$$

$$= -\frac{1}{2mc^2}\langle (E_n^0 - V)^2 \rangle$$

expanding

$$= \frac{-1}{2mc^2}\left[(E_n^0)^2 - 2E_n^0 \langle V \rangle + \langle V \rangle^2 \right]$$

still general.

to proceed we need to apply specifics

$\boxed{Q:}$ For H, What are these energies?

Bohr Energies

What are the potentials?

$$V = -\frac{e^2}{4\pi\epsilon_0 r}$$

$\boxed{Q:}$ Any reservations before we proceed?

8

Except for ψ_{100} → all H eigenstates highly degenerate

$\boxed{Q:}$ So what do we do?

ψ_{nlm} → eigenstates of L^2 & L_z

BUT! these commute w/ H_R' (due to spherical symmetry).

they also have different eigenvalues for a given n

∴ ok! use non-degenerate theory

p. 168-169 on angular momentum

now we have:

$$E_R' = -\frac{1}{2mc^2}\left[(E_n^0)^2 + 2E_n \frac{e^2}{4\pi\epsilon_0}\left\langle \frac{1}{r} \right\rangle + \left(\frac{e^2}{4\pi\epsilon_0}\right)\left\langle \frac{1}{r^2} \right\rangle\right]$$

just need to find 2 expectation values

Prof. Eskildsen told me last time you guys worked through the virial theorem and derived this ($\langle \frac{1}{r} \rangle$) result.

$\boxed{Q:}$ any one remember what it was?

$$\boxed{\left\langle \frac{1}{r} \right\rangle = \frac{1}{n^2 a}}$$

nice derivation on wiki

take derivative $\frac{d}{d\lambda}\left[E_\lambda = \langle\psi_\lambda|H_\lambda|\psi_\lambda\rangle\right]$

$H_\lambda|\psi_\lambda\rangle = E_\lambda|\psi_\lambda\rangle$ 9

$\langle\psi_\lambda|\psi_\lambda\rangle = 1$

$\therefore \frac{d}{d\lambda}\langle\psi_\lambda|\psi_\lambda\rangle = 0$

VII Feynmann-Hellman $\langle 1/r^2\rangle$

IF TIME (i.e. >10 min left) 12:10

this term is a little more involved.

use ~~Feynmanx~~ Feynman-Hellmann theorem (6.33)

$$\left[\frac{\partial E_n}{\partial\lambda} = \langle\psi_n|\frac{\partial H}{\partial\lambda}|\psi_n\rangle\right]$$

using radial version of Ham: hopefully still on board

$$H = \frac{-\hbar^2}{2m}\frac{d^2}{dr^2} + \frac{\hbar^2}{2m}\frac{l(l+1)}{r^2} - \frac{e^2}{4\pi\epsilon_0}\frac{1}{r}$$

$$\left[E_n = -\frac{me^4}{32\pi^2\epsilon_0^2\hbar^2(j_{max}+l+1)^2}\right]$$

can derive $\langle\frac{1}{r^2}\rangle$ using $[\lambda = l]$

give 5 minutes then discuss

If you use

$$\left[\begin{array}{l} a = \frac{4\pi\epsilon_0\hbar^2}{m_e e^2} \\ n = j_{max} + l + 1 \end{array}\right] \quad (4.67)$$

result

$$\boxed{\langle\frac{1}{r^2}\rangle = \frac{1}{(l+1/2)n^3a^2}}$$

10

The rest is easy, we simply have to gather all the terms.

$$E_R' = \frac{1}{2mc^2}\left[E_n^2 + 2E_n\left(\frac{e^2}{4\pi\epsilon_0}\right)\frac{1}{n^2 a} + \left(\frac{e^2}{4\pi\epsilon_0}\right)^2 \frac{1}{(l+1/2)n^3 a}\right]$$

± rearranging using

$$a = \frac{4\pi\epsilon_0\hbar^2}{m_e e^2}\,; \qquad E_n = -\left[\frac{m}{2\hbar^2}\left(\frac{e^2}{4\pi\epsilon_0}\right)^2\right]\frac{1}{n^2}$$

Bohr Energy

$$\boxed{E_R' = \frac{-(E_n)^2}{2mc^2}\left[\frac{4n}{l+1/2} - 3\right]}$$

right order of mag

$$E_R' \propto \frac{E_n}{mc^2}(E_n) \qquad (\alpha^2)^2$$

found at the beginning to be $\sim 10^{-5}$

$\boxed{\text{Questions?}}$ $\longrightarrow$ H spectra.

Observer Comments

Professor Sapirstein thought the lecture went very well and did not offer any constructive criticism.

Reflection

Overall, I also thought the lecture went very well. My main goal of this lecture was to ask leading questions in such a way as to have the students themselves direct the derivation. In my lecture notes, I included notes of where it would be reasonable to request information from the students (indicated by a boxed "Q:" in red) as well as when I should check for comprehension from the students (indicated by a boxed "Questions?" in red). In my opinion, asking students to progress the lecture in this manner keeps them more engaged, especially when covering heavy or lengthy derivations. I also thought the review of time-independent perturbation theory at the beginning of the lecture was particularly helpful. It put the students in a "physics" frame of mind, and I kept the equations that were useful for the current lecture on the board for easy reference during the lecture. Finally, I think the demonstration using the tube of Hydrogen gas helped the students connect all of the math we had just covered to the "real-world."

From this lecture, I noticed several areas where my teaching can improve, specifically with the pacing of the lecture, summarizing material, and promoting entire class engagement. I have a tendency to speak quickly, which is not conducive for students attempting to write notes and process information. Even with the demonstration, I covered the full lecture material with a little over 5 minutes to spare. In the future, I will attempt to speak slower and incorporate pauses after writing equations on the board. Overall, I could have done a better job summarizing the important concepts from the lecture. In particular, providing the students with an outline for what I intended to cover that lecture would have given context for all of the intermediary steps. Asking the students to summarize what they learned at the end of the lecture would reinforce the main ideas and provide a check for holes in comprehension. Finally, while the student-directed derivation did help with student engagement, most answers were provided by the same two students. In the future, I need to find a tactful way of encouraging other students to respond. While difficult for this type of derivation lecture, providing students the opportunity to work through some section of the material could help engage students who are too shy to speak up in front of the entire class.

Lectures 2 & 3

Overview

In these lessons, I taught non-physics majors about the energy stored in capacitors and electric fields. Both lectures were for two different sections of General Physics II (PHYS 10320), the first was for Professor Manoel Couder and the second, for Professor Randal Ructi. These classes consisted of approximately 100 students. I opted to use the same power point slides used for every section of General Physics II at the University of Notre Dame. These power point slides provided a general outline of the material; the specifics were filled in using a tablet as the lecture was given. Professor Adam Martin of the University of Notre Dame Physics Department observed both lectures; from the Kaneb Center, Alex Ambrose observed the first lecture and Kevin Barry, the second.

Lesson Plan

Main Idea: Derive the amount of energy stored in a capacitor and relate it to the energy of an electric field.

Outline of Lesson:

1. Review of capacitance (C):
   1. Defining equation.
   2. Parallel-plate capacitor.
   3. Combinations (series or parallel) in circuits.
2. Example - how to find capacitance for a general geometry using the electric field (E), emphasize the end result is a function of *geometry only.*
3. Energy Derivation
   1. Review - work to move a charge through a potential V.
   2. The energy can be derived by adding up the work to build up a series of charges on the plates.
   3. Energy stored can be expressed in terms of Q, C, or V.
   4. Energy (density) stored can also be expressed in terms of E.
4. Examples:
   1. Energy change with change in plate separation.
   2. Energy to build up charge on a sphere.
   3. Two capacitor circuit problems.

Media: Video of the energy discharged from a capacitor to demonstrate how much energy capacitors can store. Walk through an order of magnitude calculation for the energy stored in a typical capacitor. URL: https://www.youtube.com/watch?v=-3IbAerYj8I

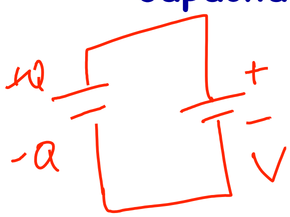
Lecture Notes

News/Reminders

Prof. Martin
NSH 316
1-6466
amarti41@nd.edu

Office Hours: Ruchti (NSH 408): M 3-5pm;
Martin: Th 2-4pm; Couder (NSH 222): Th 4-6pm
HW #4 due Fri 9/23, 11:59pm
No RQ/tutorials next week. Labs will meet as usual.
See Sakai Announcements for exam #1 details!
Help Sessions: Wed, Thurs evenings 5-7pm, NSH 123

Capacitance and Dielectrics

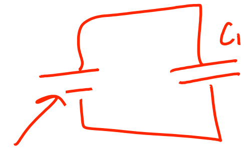


$$C = \frac{Q}{V}$$

$$C_{\text{parallel plate}} = \frac{\epsilon_0 A}{d}$$

1

2 Setups:

① 

$V_{bat} = V_c \equiv V$

constant!

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

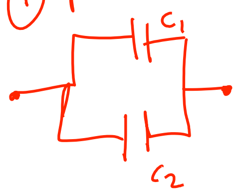
② 

Q constant

$Q = C\uparrow\downarrow V\downarrow\uparrow$

Combining capacitors

① parallel



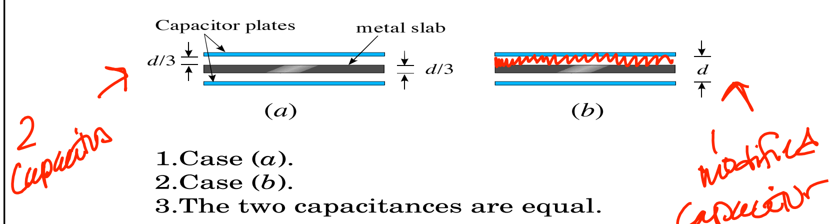
same V

$C_{eq} = C_1 + C_2$

② series

$\frac{1}{C_{eq}} = \frac{1}{C_1} + \frac{1}{C_2}$

Consider two capacitors, each having plate separation d. In each case, a slab of metal of thickness $d/3$ is inserted between the plates. In case (a), the slab is not connected to either plate. In case (b), it is connected to the upper plate. The capacitance is higher for



1. Case (a).
2. Case (b).
3. The two capacitances are equal.

2

SERIES

A) C_1

C_2

2 identical // plate

$C_1 = C_2 = C_{\text{par plate}} = \frac{\epsilon_0 A}{d}$, $d = \frac{d}{3}$

$$\frac{1}{C_{eq}} = \frac{1}{C} + \frac{1}{C} = \frac{2}{C}$$

$$\boxed{C_A = \frac{3}{2}\frac{\epsilon_0 A}{d}}$$

B) MOD

$3d/3$

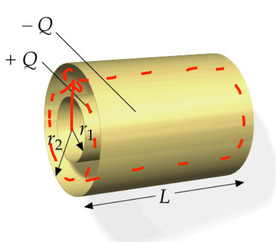
$$\boxed{C_B = \frac{3\epsilon_0 A}{d}}$$ ← bigger!

A cylindrical capacitor consists of two concentric conductors of length L. The smaller cylinder has radius r_1, and the larger one is a coaxial shell of radius r_2. Assume both radii are much smaller than the length L. Our goal here is to find the capacitance of this capacitor.

A) How can we get V?

$C = \frac{Q}{\Delta V}$ ✓

a) $V(r_2) - V(r_1) = -\int_{r_1}^{r_2} \vec{E}\cdot d\vec{l}$



b.) $\phi = \oint \vec{E}\cdot d\vec{A} = \frac{Q_{enc}}{\epsilon_0}$

$|E|\oint dA =$

$E(2\pi r \cancel{L}) = \frac{\lambda \cancel{L}}{\epsilon_0}$

$$\boxed{\vec{E}(r) = \frac{1}{2\pi\epsilon_0}\frac{\lambda}{r} = \frac{2k\lambda}{r}\hat{r}}$$

B) How can we get E?

C) Now, find the capacitance.

3

$$V(r_2) - V(r_1) = -\int_{r_1}^{r_2} \underbrace{\vec{E}}_{E(r)\,\hat{r}} \cdot \underbrace{d\vec{\ell}}_{dr\,\hat{r}}$$

$$= -\int_{r_1}^{r_2} \left(\frac{2k\lambda}{r}\right) dr = -2k\lambda \ln(r)\Big|_{r_1}^{r_2}$$

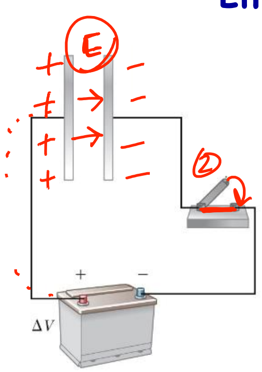
$$\boxed{|\Delta V| = +2k\lambda \ln\left(\frac{r_2}{r_1}\right)} \qquad \lambda = \frac{Q}{L}$$

depends on shape

c) $\therefore\; C = \dfrac{Q}{\Delta V} = \dfrac{\cancel{Q}}{2k\frac{\cancel{Q}}{L}\ln\left(\frac{r_2}{r_1}\right)} = \boxed{\dfrac{L}{2k\ln\left(\frac{r_2}{r_1}\right)}}$

Energy in Capacitors

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



(1) switch open

$\Delta V_{bat} = \Delta V \equiv V_i$

$\Delta V_C = 0$

(2) switch closed

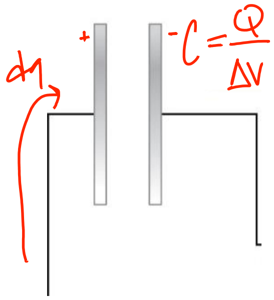
"electrostatic equilibrium"

$\Delta V_{bat} = \Delta V_C \equiv \Delta V_f$

$V_f - V_i = -\int \vec{E} \cdot d\vec{\ell} \leftarrow$ work? energy?

4

Energy in Capacitors



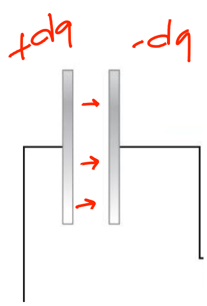
$C = \frac{Q}{\Delta V}$

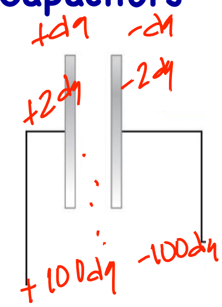
dq: from battery → plate

$\Delta V_{Bat} = \Delta V$

$dV_c = \frac{dq}{C}$

Energy in Capacitors





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

$dV = \frac{2dq}{C}$

$dV = \frac{100dq}{C}$

eq.

$V_c = V_{Bat} = \frac{Q_{max}}{C}$

$\boxed{Q_{max} = C V_{battery}}$

5

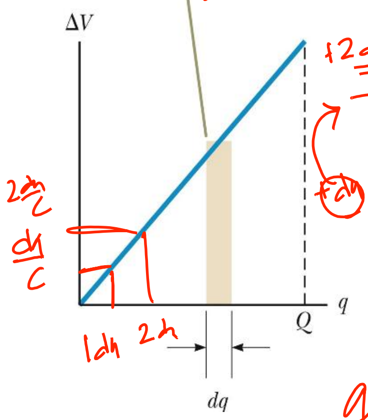
Energy in Capacitors

work

$dU = q\,dV$

$V_c = \frac{q}{C}$

slope $= 1/C$



+2dq -2dq

+dq

① 1dq → 2dq

$dU = (dq)\left(\frac{dq}{C}\right)$

② 2dq → 3dq

$dU = (dq)\left(\frac{2dq}{C}\right)$

generally... $dU = dq\left(\frac{q}{C}\right)$

$dU = dq\left(\frac{q}{C}\right)$

$$U_{tot} = \int dU = \int_0^{Q_{max}} dq\left(\frac{q}{C}\right) = \frac{1}{2C} q^2 \Big|_0^{Q_{max}}$$

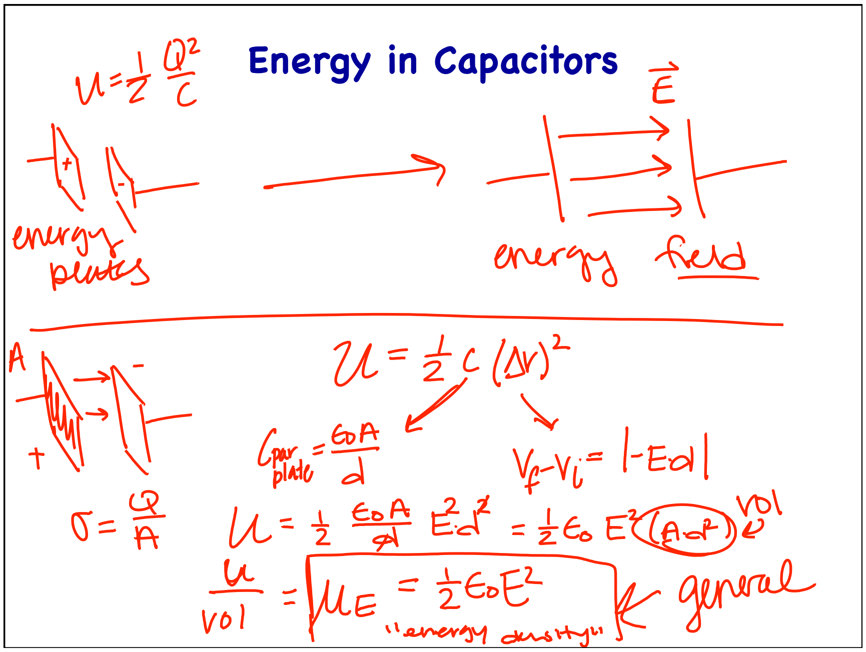
$U_{tot} = \frac{Q_{max}^2}{2C}$ ← cap. completely charged!

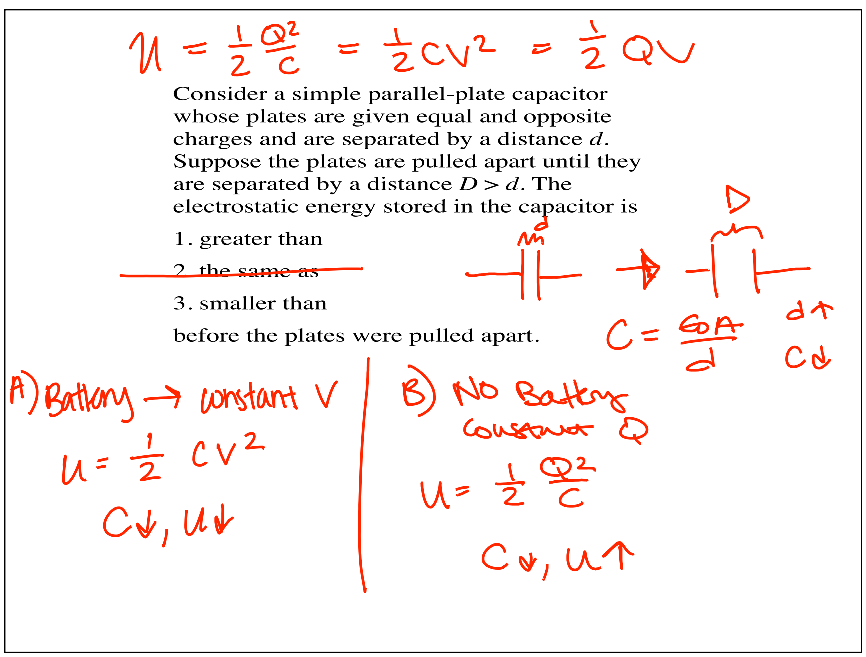
$C = \frac{Q}{\Delta V}$

$$\boxed{U = \frac{Q^2}{2C} = \frac{1}{2}CV^2 = \frac{1}{2}QV}$$

$\frac{1}{2}(0.5\,\mu F)(3000\,V)^2 = 0.25\times10^{-6} \times 9\times10^{6} = 2.25\,J$

6


Energy in Capacitors
$U = \frac{1}{2}\frac{Q^2}{C}$
$\vec{E}$
energy plates
energy field
A
+
-
$U = \frac{1}{2} C (\Delta V)^2$
$C_{\text{par plate}} = \frac{\epsilon_0 A}{d}$
$V_f - V_i = |-Ed|$
$\sigma = \frac{Q}{A}$
$U = \frac{1}{2}\frac{\epsilon_0 A}{d} E^2 d^2 = \frac{1}{2}\epsilon_0 E^2 (A d)$
vol
$\frac{U}{\text{vol}} = \boxed{u_E = \frac{1}{2}\epsilon_0 E^2}$
"energy density"
general


$U = \frac{1}{2}\frac{Q^2}{C} = \frac{1}{2}CV^2 = \frac{1}{2}QV$
Consider a simple parallel-plate capacitor whose plates are given equal and opposite charges and are separated by a distance d. Suppose the plates are pulled apart until they are separated by a distance $D > d$. The electrostatic energy stored in the capacitor is
1. greater than
~~2. the same as~~
3. smaller than
before the plates were pulled apart.
d
D
$C = \frac{\epsilon_0 A}{d}$
$d\uparrow$
$C\downarrow$
A) Battery → constant V
$U = \frac{1}{2} C V^2$
$C\downarrow, U\downarrow$
B) No Battery
constant Q
$U = \frac{1}{2}\frac{Q^2}{C}$
$C\downarrow, U\uparrow$

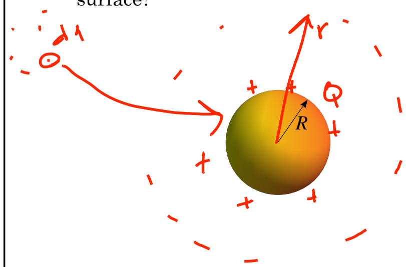
7

A an isolated spherical shell is initially uncharged. We will charge it by moving small amounts of charge dq from to the surface of the sphere at radius R. What is the total change in potential energy ΔU when we have deposited a total charge Q on the surface?

point charge

$\vec{E} = \frac{1}{4\pi\epsilon_0}\frac{q}{r^2}\hat{r}$ $(r>R)$

$\vec{E} = 0$ $(r<R)$



energy density

$u_E = \frac{1}{2}\epsilon_0 E^2$

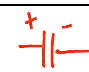
$u_E = \frac{1}{2}\epsilon_0\left(\frac{1}{4\pi\epsilon_0}\frac{q}{r^2}\right)^2$

$$U = \int u_E\, dV = \int_0^\infty u\, 4\pi r^2 dr = \frac{\epsilon_0}{2}\left(\frac{Q}{4\pi\epsilon_0}\right)^2 \int_0^\infty 4\pi r^2 \left(\frac{1}{r^2}\right)^2 dr$$

$$= \frac{1}{2}\left(\frac{Q^2}{4\pi\epsilon_0}\right)\left(-\frac{1}{r}\right)\Big|_0^\infty \Rightarrow \boxed{U = \frac{1}{8\pi\epsilon_0}\frac{Q^2}{R}}$$

53. A 100 pF capacitor and a 400 pF capacitor are both charged to 2.0 kV. They are then disconnected from the voltage source and are connected together, positive plate to positive plate and negative plate to negative plate. (a) Find the resulting potential difference across each capacitor. (b) Find the energy lost when the connections are made.

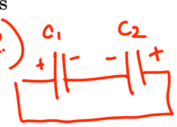
1)



$C_1 = 100\text{pF}, V_1 = 2\text{kV}$

$C_2 = 400\text{pF}, V_2 = 2\text{kV}$

2)



a) Charge conserved
Initial charge:

$Q = CV$

$\left.\begin{array}{l} Q_{1i} = C_1 V_{1i} \\ Q_{2i} = C_2 V_{2i} \end{array}\right\}$ initial

charges re-equilibrate

$Q_f = \frac{Q_{1i} + Q_{2i}}{2} = \frac{1}{2}(C_1 + C_2)V_i$

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

$V_{1f} = \frac{(C_1 + C_2)V_i}{2C_1}$

$V_{2f} = \frac{(C_1 + C_2)V_i}{2C_2}$

8

b.) Energy Lost

C, V_i

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

$$U_i = \frac{1}{2}\left(\frac{Q_{1i}^2}{C_1} + \frac{Q_{2i}^2}{C_2}\right)$$

$$U_f = \frac{1}{2}Q_f^2\left(\frac{1}{C_1} + \frac{1}{C_2}\right)$$

$$= \frac{1}{2}\left(\frac{Q_{1i}+Q_{2i}}{2}\right)^2 \cdot \left(\frac{1}{C_1} + \frac{1}{C_2}\right)$$

$$= \frac{1}{8}\left(Q_{1i} + Q_{2i}\right)^2\left(\frac{1}{C_1} + \frac{1}{C_2}\right)$$

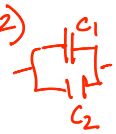
$C = \frac{Q}{V}$

55. A 1.2 μF capacitor is charged to 30 V. After charging, the capacitor is disconnected from the voltage source and is connected to another uncharged capacitor. The final voltage is 10 V. (a) What is the capacitance of the other capacitor? (b) How much energy was lost when the connection was made?

1)

$C_1 = 1.2\mu F$, $V_A = 30V$

2)



V_B 10V

something is holding it at 10V

Disconnect, Q cons.

$Q_{1i} = C_1 V_A = 1.2\mu F \cdot 30V = 36\mu C$

$Q_{1f} = C_1 V_B = 1.2\mu F \cdot 10V = 12\mu C$

$\therefore Q_{2f} = 36 - 12 = 24\mu C$

$C_2 = \frac{Q_{2f}}{V_B} = \frac{24\mu C}{10V} = \boxed{2.4\mu F}$

b) $U = \frac{1}{2}QV$

$U_i = \frac{1}{2}Q_{1i}V_A = \frac{1}{2}(36\mu C)(30V)$

$= 540\mu J$

$U_f = \frac{1}{2}(Q_{1f} + Q_{2f})V_B$

$= \frac{1}{2}(36\mu C)(10V)$

$= 180\mu J$

9

Observer Comments

Notes from the Kaneb Center:

Strengths

- Preparation — in class and ready to go on time
- Clear organization
  - Day's topic identified
  - Orderly progression through examples
- Clear mastery of the material
- Engaged students with short problems / questions
- Use of tablet to create drawings, illustrate examples, write out problems
- Incorporation of media — capacitor discharge
- Connecting with humor

Opportunities for Improvement

- Pace seemed fast
  - Steps combined when completing examples
  - Opportunities for explanation missed in favor of moving through equations quickly
  - Some students are probably left behind
- Deepen student engagement
  - Give defined problem-solving time before asking for responses
  - Increase wait time — several wait times under 2 seconds, especially when checking for understanding
  - Take time to look around the room for questions — one student raised hand 3 times between 2:25 and 2:27 but was not acknowledged
- Class ending. With 4 minutes left a final example was attempted but required a rushed finish with time expiring. Using that 4 minutes to review important ideas (or better, have students identify them) would have a greater impact.
- Careful with humor
  - Avoid self-deprecating or anti-intellectual humor, e.g.:
    - Shouldn't be doing physics on a Friday ad-lib response to first problem
    - That was boring … let's watch a video

Other Notes

We recommend using amplification whenever available. Typically, in rooms over 50. Avoids fatigue, lost communication effectiveness when turned to board or screen, and forcing someone with hearing loss to have a need to self-identify.

Reflection

Overall, I thought both lectures went well. This style of teaching — filling in details on prepared powerpoint slides — was new to me and it was a great learning experience. For a lower level class like General Physics I or II, using a tablet in this manner seemed to retain the best aspects of powerpoint presentations and handwritten "blackboard" lectures. Not only did it help the actual lecture go smoothly, but it provides a great resource to make available to the students. I would like to try making the unfilled-in powerpoint slides available to the class prior to the lecture, as this would enable students to prepare for lecture or even print the slides to use as an aide when taking notes. Similar to my Quantum Mechanics lecture, I liked the review of prior material at the beginning of class and the incorporation of media (here the video of a capacitor discharging). In this case, the video provided a break after covering especially difficult material.

Unfortunately, I still struggled with pacing in these two lectures, despite my identification of that issue after the Quantum Mechanics lecture. I showed some improvement in that I attempted to incorporate pauses, but I did not follow through by providing adequate time for those pauses. More specifically, I did a good job of *asking* about comprehension/questions, but I did not do a good job of providing the students enough time to process/formulate questions. I did a good job of *asking* students questions, but I did not do a good job of providing them enough time to engage and respond. For this level of material, I could have provided students with a question to work through. However, with a class of this size, I thought it would be too difficult to ensure all of the students were engaging with the material. In the future, I would like to try to incorporate more "poll" style, multiple-choice questions for large classes. Ideally, the students would have "clickers" so they can respond anonymously, but having students raise their hands is also feasible if clickers are unavailable. Finally, I agree with the Kaneb Center that asking the students to summarize what they learned at the end of the lecture would have been a better use of time than rushing through an example.

One interesting aspect of giving the same lecture twice is the opportunity to improve the second lecture based on the first. For example, I received an excellent question at the end of the first lecture that I had not considered. In between the two lectures, I worked out the alternate derivation and incorporated it into the second lecture. One negative aspect of giving the same lecture twice was my familiarity with the lecture resulted in a faster delivery. I was not even aware that I was going through the material faster until I finished the lecture early.

Overall Reflections

Through this process I have determined that I prefer an interactive lecture style with opportunities for students to engage with the material on their own. I value critical thinking and self-directed learning, and where possible I strive to have the students answer leading questions in order to progress the lecture. I also think it is important to provide students with the opportunity to work through portions of the material individually or in small groups, as this forces them to engage with the material. These experiences have also shown me that my greatest weakness in teaching is my pacing. I intend to work on slowing down my delivery and pausing more often to allow students time to process information or formulate questions. Overall, I prefer teaching smaller classes. It is easier to ask for input from and connect with the students.

Things I intend to work on in my teaching:

- Taking longer breaks more often throughout the lecture, allowing students to process the information and formulate questions.
- Remembering to scan the room frequently for questions, and pausing to ask for questions.
- Keeping handwriting legible.
- Avoiding ad-libbed jokes - I tend to have a self-deprecating style of humor (as mentioned by the Kaneb center) and this is not the best type of joke to make in front of students. However, I do like incorporating humor overall, I believe it helps the students connect more with me and feel more comfortable asking questions.
- Summarizing important concepts at the beginning and end of lecture.
- Repeating questions/comments from students to ensure the entire class was able to hear.
- Stating the time frame (i.e. 2 - 3 minutes) to work and actually giving the students the full amount of time.