NPRE446: Radiation Interactions With Matter I

University of Illinois, Urbana-Champaign

Fall 2019

Instructor:	Prof. Kathryn Huff	**Time:**	MWF 9:00– 10:00
Email:	kdhuff@illinois.edu	**Place:**	305 Materials Science
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Course Pages:

1. `https://compass2g.illinois.edu`
2. `https://github.com/katyhuff/npre446`
3. `https://katyhuff.youcanbook.me`

TA Office Hours: The teaching assistant for the course, Natalie Gaughan, will hold office hours in 120 Talbot Laboratory MW 10-12am and TuTh 1-3pm.

Office Hours: Prof. Huff will hold office hours by appointment only, in her office, 118 Talbot Laboratory, 104 S. Wright St.. Please make use of the teaching assistant and your colleagues before booking an appointment with Prof. Huff. You can make an appointment at `katyhuff.youcanbook.me`.

Main References: A few essential references for this course will be assigned as readings. The required texts for this course are [1] and [2]. The more recent [3] is not required, but can be used instead of the second edition. Additional,a recommended texts include [4, 5, 6].

[1] David J. Griffiths. *Introduction to Quantum Mechanics*. Pearson Prentice Hall, Upper Saddle River, NJ, 2nd edition edition, April 2004.

[2] Sidney Yip. *Nuclear Radiation Interactions*. World Scientific Publishing Company, October 2014.

[3] David J. Griffiths and Darrell F. Schroeter. *Introduction to Quantum Mechanics*. Cambridge University Press, Cambridge ; New York, NY, 3 edition edition, August 2018.

[4] Kenneth S. Krane. *Introductory Nuclear Physics.* Wiley, New York, 3 edition edition, October 1987.

[5] Robert Eisberg and Robert Resnick. *Quantum Physics of Atoms, Molecules, Solids, Nuclei, and Particles.* John Wiley & Sons, New York, 2nd edition edition, 1985.

[6] Robley Dunglison Evans. *Atomic Nucleus.* TATA McGraw-Hill, Bombay, New Delhi, 1955.

Description: The classical and quantum theories of the interaction of radiation (neutrons, photons, and charged particles) with matter are the core components of nuclear and materials science and engineering. At UIUC, we offer a sequence of four courses (446, 447, 521, and 529) at progressively deepening levels on this subject. The sequence, in the aggregate, aims to provide the students with solid training in essential physical principles, mathematical competence, and computational skills. In this course, we provide a quantitative introduction to introductory quantum mechanics, fundamentals of atomic and nuclear physics, and interactions of radiation with matter.

Objectives:

The quantum physics elements of this course will equip students to

- Recognize the limitations of classical theory (stable atomic model, black-body radiation, the photoelectric effect, and Compton scattering).
- Apply classical theory to fundamental problems.
- Explain the implications of wave-particle duality.
- Apply operators in physical equations.
- Solve the Schrödinger equation for canonical problems.
- Understand and apply fundamental concepts (eigenstates, observables, statistical interpretation, probability conservation, bound/unbound states).
- Identify the bound and unbound states in key potentials: square potential, Harmonic oscillator, ladder operators, free particle, δ potential.
- Define, derive, and apply the uncertainty principle.

The atomic and nuclear physics elements of this course will equip students to:

- Fundamentally describe atomic structure and nuclear properties.
- Understand and use nuclear physics terminology.
- Differentiate nuclei and interactions via their size, distributions of charge and mass, abundance, and binding energy.
- Identify and calculate nuclear phenomena via Q-value, separation energy, semi-empirical mass formula, liquid drop model, mass parabola, spin, parity, electromagnetic moments), nuclear force and nuclear structure.

- Define and apply the properties of nuclear forces, deuteron structure, neutron-proton scattering, phase shift, partial wave approximation, scattering length, differential cross section, exchange force model, nuclear shell model, nuclear magic numbers.
- Model and solve equations related to radioactive decay and binary nuclear reactions.

The interaction of radiation with matter portion of this course will equip students to:

- Categorize and characterize neutron interations with matter.
- Identify and quantify neutron-proton scattering, energy dependence of cross sections, and moderation.
- Categorize and characterize gamma interactions with matter.
- Identify and quantify gamma attenuation, the photoelectric effect, Compton scattering, pair production.
- Categorize and characterize heavy and light charged particle interactions with matter.
- Identify and calculate the features of charged particle stopping power, Bragg curve, range, ionization loss, and radiation loss.

Prerequisites:

- Junior standing is recommended.
- MATH 285
- PHYS 211 - 214, or equivalent.
- Linear Algebra (MATH 125) is not required, but highly recommended.

Grading Policy: Grades will be assigned as a weighted sum of the following work.

Work	Weight
Homework	(35%)
Quizzes	(5%)
Midterm 1	(15%)
Midterm 2	(15%)
Final	(30%)
Total	(100%)

Important Dates: The following dates are subject to change.

Midterm #1 .... September 27, 2019, 9:00am-9:50am
Midterm #2 .... November 6, 2019, 9:00am-9:50am
Final Exam .... December 18, 2019, 1:30pm-4:00pm

Class Policies:

Integrity: This is an institution of higher learning. You will be swiftly ejected from the course if you are caught undermining its integrity. Note the Student's Quick Reference Guide to Academic Integrity and the Academic Integrity Policy and Procedure.

Attendance: Regular attendance is mandatory. Request approval for absence for extenuating circumstances prior to absence.

Electronics: Active participation is essential and expected. Accordingly, students must turn off all electronic devices (laptop, tablets, cellphones, etc.) during class. Exceptions may be granted for laptops if engaging in computational exercises or taking notes.

Collaboration: Collaboratively reviewing course materials and studying for exams with fellow students can be enriching. This is recommended. However, unless otherwise instructed, homework assignments are to be completed independently and materials submitted as homework should be the result of one's own independent work.

Late Work: Late work has a halflife of 1 hour. That is, adjusted for lateness, your grade $G(t)$ is a decaying percentage of the raw grade G_0. An assignment turned in t hours late will receive a grade according to the following relation:

$$G(t) = G_0 e^{-\lambda t}$$

where

$$\begin{aligned} G(t) &= \text{grade adjusted for lateness} \\ G_0 &= \text{raw grade} \\ \lambda &= \frac{ln(2)}{t_{\frac{1}{2}}} = \text{decay constant} \\ t &= \text{time elapsed since due [hours]} \\ t_{1/2} &= 1 = \text{half-life [hours]} \end{aligned}$$

Make-up Work: There will be no negotiation about late work except in the case of absence documented by an absence letter from the Dean of Students. The university policy for requesting such a letter is in the Student Code. Please note that such a letter is appropriate for many types of conflicts, but that religious conflicts require special early handling. In accordance with university policy, students seeking an excused absence for religious reasons should complete the Request for Accommodation for Religious Observances Form, which can be found on the Office of the Dean of Students website. The student should submit this form to the instructor and the Office of the Dean of Students by the end of the second week of the course to which it applies.

Grade Disputes: It is important that you understand and agree with the grade you receive on assignments and exams. If you would like to dispute your score, you must send an explanation by email to Prof. Huff within one week of recieving the grade. **Do not expect me to regrade anything while in conversation with you** as that would not be fair to the other students in the class, whose homeworks were graded without them present. If you request a regrade, be aware that the entire assignment will be regraded and is subject to double-jeopardy: it is possible that your score will go down. Regrade requests should be based on an error on my part (e.g., adding up the points incorrectly) or what you suspect is a misunderstanding of your work (e.g., arriving at the correct answer using an unexpected technique). Regrade requests that argue with the rubric (e.g., "this is wrong, but you took too many points off") will be returned without consideration. **Your work should stand alone.** If an assignment is disorganized or ambiguous, and requires an extensive explanation to the grader, you will likely still lose points. The homeworks not only evaluate your understanding of the material - they also evaluate your ability to communicate that understanding clearly and concisely.

Accessibility: I hope that this course will be inclusive and accommodating for all learners. As such, I am committed upholding the vision and values of Inclusive Illinois in my classroom. With regard to accommodating all learners, please note that many resources are provided through the Division of Disability Resources and Educational Services. To request particular accommodations, please contact me as soon as possible so that we can work out any necessary arrangements.

Other Resources: University students typically experience a wide range of stressors during their time on campus. Accordingly, campus resources exist to help students manage stress levels, mental health, physical health, and emergencies while navigating this environment. I hope you will take advantage of these campus resources as soon as they can be of help.

- The Campus Recreational Centers
- The Counselling Center
- The McKinley Health Clinic
- The McKinley Mental Health Clinic
- The Emergency Dean

Run. Hide. Fight. It is important that we take time to prepare for a situation in which our safety could depend on our ability to react quickly. Please review the university guidance on responding to emergency situations `https://police.illinois.edu/emergency-preparedness/run-hide-fight/`. Take a moment to learn the different ways to leave this building. If there's ever a fire alarm or something like that, you'll know how to get out and you'll be able to help others get out. Next, figure out the best place to go in case of severe weather - we'll need to go to a low-level in the middle of the building, away from windows. And finally, if there's ever someone trying to hurt us, our best option is to run out of the building. If we cannot do that safely, we'll want to hide somewhere we can't be seen, and we'll have to lock or barricade the door if possible and be as quiet as we can. We will not leave that safe area until we get an Illini-Alert confirming that it's safe to do so. If we can't run or hide, we'll fight back with whatever we can get our hands on. If you want to better prepare yourself for any of these situations, visit `police.illinois.edu/safe`. Remember you can sign up for emergency text messages at `emergency.illinois.edu`.

Course Schedule: *This schedule is subject to change*

Date	Week	Day	Unit	Chap.	Quiz Due	HW Given	HW Due
08-26	1	M	Intro	G1			
08-28	1	W	Wave Function	G1			
08-30	1	F	Wave Function	G1		HW1	
09-02	2	M	**• No Class •**		Q1		
09-04	2	W	Wave Function	G1			
09-06	2	F	Wave Function	G1			
09-09	3	M	Wave Function	G1	Q2		
09-11	3	W	Time-Independent Schrödinger	G2			
09-13	3	F	Time-Independent Schrödinger	G2		HW2	HW1
09-16	4	M	Time-Independent Schrödinger	G2	Q3		
09-18	4	W	Time-Independent Schrödinger	G2			
09-20	4	F	Time-Independent Schrödinger	G2		HW3	HW2
09-23	5	M	Time-Independent Schrödinger	G2	Q4		
09-25	5	W	Review				
09-27	5	F	**• Midterm•**	G1, G2			HW3
09-30	6	M	Formalism	G3			
10-02	6	W	Nuclear Properties	Y3			
10-04	6	F	Nuclear Properties	Y4		HW4	
10-07	7	M	Nuclear Properties	Y4	Q5		
10-09	7	W	Stability of Nuclei	Y4			
10-11	7	F	Stability of Nuclei	Y5		HW5	HW4
10-14	8	M	Energy Level Models	Y5	Q6		
10-16	8	W	Energy Level Models	Y5			
10-18	8	F	Nuclear Decay	Y6			
10-21	9	M	Collision Cross Sections	Y7	Q7		
10-23	9	W	Collision Cross Sections	Y7			
10-25	9	F	Collision Cross Sections	Y7		HW6	HW5
10-28	10	M	Collision Cross Sections	Y7	Q8		
10-30	10	W	Collision Cross Sections	Y7			
11-01	10	F	Neutron Scattering	Y9		HW7	HW6
11-04	11	M	Neutron Scattering	Y9	Q9		
11-06	11	W	Review				
11-08	11	F	**• Midterm •**	G3, Y4-Y7			
11-11	12	M	Neutron Scattering	Y9	Q11		
11-13	12	W	Neutron Scattering	Y9			
11-15	12	F	γ Scattering & Absorption	Y10		HW8	HW7
11-18	13	M	γ Scattering & Absorption	Y10	Q12		
11-20	13	W	γ Scattering & Absorption	Y10			
11-22	13	F	γ Scattering & Absorption	Y10			
11-25	14	M	**• No Class •**		Q13		
11-27	14	W	**• No Class •**				
11-29	14	F	**• No Class •**			HW9	HW8
12-02	15	M	Charged Particle Stopping	Y11	Q14		
12-04	15	W	Charged Particle Stopping	Y11			
12-06	15	F	Charged Particle Stopping	Y11			HW9
12-09	16	M	Charged Particle Stopping	Y11			
12-11	16	W	Review				
12-18	17	W	**• Final Exam •**				