

Nuclear and Elementary Particle Physics

Prof. Anders Knospe

Course Information:

Course Number: PHY 364

Semester: Spring 2024

Meeting Day and Time: Monday, Wednesday, and Friday, 9:20–10:10 a.m. Eastern Time

Physical Meeting Location: Lewis Lab 511

Virtual Lecture Location: Zoom link on CourseSite (not the same as for Office Hours)

Instructor's Contact Information:

Office: Lewis Lab 412

Office Phone: 610-758-6431 (86431 on campus)

Main Physics Office Phone: 610-758-3931 (83931 on campus)

Email: ank220@lehigh.edu

Virtual Office Hour Location: Zoom link on CourseSite (not the same as for lectures)

Pronouns: I use the “he” suite of pronouns. Please feel free to tell me yours.

Office Hours:

Tuesday 1:00–2:00 p.m. Eastern Time

Friday 4:00–5:00 p.m. Eastern Time

Or by appointment: I am happy to meet with you outside my scheduled office hours. Just ask.

If you are sick, please meet with me on Zoom.

I will be physically present in my office and also available for virtual meetings at these times. You are welcome to visit me in person or we can talk online. There will also be occasions during the semester when I will be unable to be present for in-person office hours; I will inform you of these. For virtual meetings, I will be logged into the Zoom room throughout the designated time. Please say hello when you log in so I know that you are there. If I have stepped away from the computer for a minute, please be patient and stick around: I will come back. Note that virtual office hours use a **different Zoom room** than lectures.

Scheduling Appointments:

To reduce the amount of emailing I have to do, I ask that my students first try to schedule an appointment in my calendar. The link is near the top of our CourseSite page, or you can click [here](#). You just need to choose a time that works for you and enter some information. Each appointment slot is 15 minutes long. If you need a longer appointment, please book multiple consecutive 15-minute slots. I am happy to meet in-person, but you must tell me that is how you want to meet. Otherwise, I will assume a Zoom meeting. Meetings held before 9 a.m. or after 6 p.m. will only be on Zoom. If none of the available times work for you, then you can send me an email directly. The calendar does not allow appointments to be made on the same day, so you will need to email me in that case. When you email me, please include a variety of **specific times** when you would be available to meet.

Virtual Class Meetings:

In-person attendance is strongly encouraged—and part of your grade. However, I do not want to encourage you to come to the classroom if you are sick, and I recognize that you may need to be away from the classroom from time to time. Therefore, I will broadcast the lectures synchronously on Zoom. The connection information is available on CourseSite. If connecting remotely, please keep your microphone muted unless you need to speak. But please do participate in class! I may record Zoom sessions for the benefit of students who are unable to attend the meetings. When this happens, I will post the videos in the Panopto section of our CourseSite (on the lower-right side of the page).

Course Description:

The course will cover the following topics: Special Relativity, Quantum Mechanics, the Standard Model, symmetries and conservation laws, Quantum Electrodynamics, Quantum Chromodynamics, Electroweak Theory, the Higgs mechanism, neutrino mixing, Fermi's Golden Rule, Feynman diagrams, the interaction of particles and matter, nuclear models and decays.

Prerequisites:

1. PHY 031 and MATH 205 and PHY 362
2. complex numbers, trigonometry, calculus, matrices, vector spaces, eigenvalues
3. special relativity
4. basic quantum mechanics

Course Learning Objectives:

By the end of this course, successful students will

1. be able to explain the main ways nuclei decay and the circumstances during which different types of decays occur.
2. be able to determine whether a given nuclear or particle reaction is possible; if not, why; and if so, which interaction is responsible.
3. be able to accurately draw Feynman diagrams showing any possible reaction.
4. be able to perform tree-level QED calculations.
5. understand the connection between symmetries and conservation laws, and specifically how this corresponds to *CPT* symmetries.
6. be able to demonstrate a basic understanding of the Standard Model of particle physics.
7. be able to demonstrate a basic understanding of the liquid-drop and shell models of nuclear structure.

Required Texts:

1. D. Griffiths, *Introduction to Elementary Particles, Second, Revised Edition*, John Wiley & Sons, Hoboken, NJ, 2008 ISBN-13: 978-3527406012, ISBN-10: 9783527406012
[NOTE: you need the **Second, Revised Edition**]
2. W. N. Cottingham and D. A. Greenwood, *An Introduction to Nuclear Physics*, Cambridge University Press, Cambridge, 2001; The electronic version is available **for free** through the Lehigh University Library: <https://doi-org.ezproxy.lib.lehigh.edu/10.1017/CBO9781139164405>
3. R. L. Workman *et al.* (Particle Data Group), “The Review of Particle Physics”, *Prog. Theor. Exp. Phys.* **2022**, 083C01 (2022), <https://pdg.lbl.gov> . Commonly known as “the PDG,” this is a standard resource for professional particle physicists. Please bookmark it. You are expected become familiar with it, particularly the Particle Listings, where you can look up the masses, lifetimes, and decay modes of many different particles. The “Reviews, Tables & Plots” section is also quite useful and includes a listing of the most up-to-date values for many physical constants at <https://pdg.lbl.gov/2023/reviews/rpp2023-rev-phys-constants.pdf> .
4. I may provide supplemental material free of charge through CourseSite.

Time Commitment:

The general expectation at Lehigh is that you should spend 3–4 hours per credit per week on each course. This includes time spent in lecture, reading, studying, and doing homework. This course is 3 credits, so you should spend **9–12 hours per week** on this course.

Problem Sets:

A significant portion of your grade will be problem sets, which will be done mostly as homework, with a few in-class quizzes. Generally, each homework assignment will cover three lectures and will be due in the evening on the Tuesday of the week after it was assigned. There will be occasional exceptions to this structure, so please keep track of the due dates as each assignment is announced. In-class quizzes will occur occasionally and will be announced in advance.

Each homework assignment will usually be worth between 100 and 200 points. The exact number of points will vary between assignments. Your total grade for problem sets (homework and in-class quizzes combined) will be determined using the following formula:

$$\text{grade} = \frac{\text{sum of all points earned on all assignments}}{\text{sum of all points possible for all assignments}}. \quad (1)$$

The numerator and denominator of the ratio are calculated by summing up all of your assignments: that is, all points from all assignments are thrown together to calculate the ratio. Extra credit points may occasionally be offered; in this case, those points will be included in the numerator but not the denominator in Equation 1. Your problem-set grade can exceed 100%. Note that since no points or assignments are dropped, it is always to your advantage to try to get as many points as you can. If you don't have time to complete an assignment, you should do as much as you can and turn it in.

Collaboration is acceptable on homework (but not on in-class quizzes). However, you cannot just copy from somebody else or from AI. I expect you to **understand everything you write** on your homework papers. I may question you on things you write on your homework and deduct points if you cannot explain your work.

Reading Quizzes:

I will assign short automated online quizzes to verify that you have done the assigned reading. In general, reading quizzes will be due a few minutes before the start of class of Fridays. Late reading quizzes are not allowed and will receive no credit. You will have only one attempt to complete each reading quiz. Each reading quiz will be time-limited; the limit will be somewhere around 10–20 minutes and will be announced in the quiz description.

Your combined reading quiz grade will also be determined using Equation 1. (To be clear: the reading-quiz grade is a separate calculation using the same formula. Reading-quiz points will not be added to problem-set points.) Each question is worth 1 point, and fractional points are possible. CourseSite reports your grade out of 100%, but note that your combined reading-quiz score is not the simple average of those scores (different quizzes will have different weights).

Exams:

There will be three exams: two during the semester and one final exam.

Exams 1 & 2: Each of these two exams will take place over two consecutive 50-minute class meetings. Different problems will be given each day, and you are expected to complete both parts of both exams. Here are the tentative exam dates (subject to change):

Exam 1: February 28 & March 1

Exam 2: April 15 & 17

For those four days, we will essentially operate a flipped classroom: your problem sets (exams) will be done in class, and I will assign pre-recorded lecture videos for you to watch on your own. The content of those lectures will be fairly easy, but you will still be expected to watch them. You may be quizzed on their content and you may need to do problems related to them on later homework or exams. There will be no homework due during the weeks of February 19 and April 15.

Final Exam: The Final Exam will take place during the regular exam period after the end of classes. The date will be announced later. The exam will include both an in-class and a take-home part.

Exam Help: For in-class exams, you will have access to a printed copy of the Griffiths textbook, a few pages of your own notes, and other printed reference materials to be announced. **No electronic references are permitted for any in-class exam in this course.** If you arrive with electronic notes, you will not be allowed to use them. Phones and computers are not allowed. Whether or not calculators are allowed for a particular day will be announced in advance.

Collaboration with other students or seeking outside help, from humans or robots, is strictly forbidden on all quizzes and exams, including problems done in class or at home.

Extra Time:

I will be happy to grant extra time for students who have received this accommodation from the University. I request that you notify me as soon as possible of your intention to use this accommodation, since this will help with scheduling the course.

Late Penalties:

A late penalty will be assessed on homework and exams according to the following formula:

$$E = E_0 \left(1 - \frac{L}{T}\right) \quad (2)$$

Where E_0 is the points you earned before the penalty. For problem sets, E contributes to the total number of points earned, the numerator of Equation 1. For each exam, E is the numerator of your grade. L is the exact amount of time the work is late and T is 3 days. E will be rounded up to the nearest integer. Negative E will be set to 0. As an example, let's take an exam: if your original

grade is 134 out of 150 possible points and you turn in your work 1 day, 4 hours, and 12 minutes late, your grade will be

$$E = 134 \times \left(1 - \frac{28.2\text{h}}{72\text{h}}\right) = 81.51\bar{6} \quad \rightarrow \text{rounded to } 82.$$

Therefore, your final percent score is $\frac{82}{150} = 54.\bar{6}\%$. This penalty applies for homework and exams only. Late reading quizzes are not allowed and will receive no credit.

Attendance:

I will monitor attendance, which will be worth 15% of your grade. Each class meeting is worth 1 point. You will receive 1 point for attending the entire meeting in-person. You will receive 0 points if you are late, leave early, are absent, or attend remotely. You will need to put your name on the sign-in sheet at the front of the room before the start of each lecture. It is your job to remember to do this. No sign-in means no credit!

I understand that people are sometimes late, need to attend remotely, or need to miss a meeting. In such cases, I *may* be willing to give full credit if you have a good excuse. Examples of good excuses are being infected with COVID or having a family emergency. An example of a bad excuse is “I overslept”. I will be more likely to accept your excuse if you contact me **before** the lecture in question. Requests must be sent via email. You need to plan your travel so that you can fulfill your course obligations. “I have a plane to catch” is not a good excuse for missing a class meeting. Similarly, please do not leave for the summer before you have finished the in-class portion of the final exam for this course. Also, if you want me to write a letter of recommendation for you, you should really try to attend all meetings in-person.

Colloquia:

Physics Department colloquia will take place most Thursdays from 4:25–5:30 p.m. in LL 316. The Department administrative staff sends out weekly emails with information about speakers and topics. I will give you **10 points extra credit** on your problem sets if you attend an entire Physics Department colloquium and ask a relevant question of the speaker. If necessary, your question can be asked via email; in that case, send your questions to me and I will forward them to the speaker. You can get these extra credit points for no more than 4 colloquia during the semester. In order to receive credit, you must (1) check in with me or my designated representative before the start of the colloquium, (2) stay for the entire colloquium, and (3) ask a relevant question. Note that all three things are required to get the extra credit: no check-in means no credit, leaving early means no credit, and no question means no credit!

Computing Grades:

You can trust the grades that CourseSite records for each **individual** assignment. However, CourseSite does not know about the formulas discussed above, so do not trust CourseSite for combined scores (for problem sets or reading quizzes) or for your overall grade. CourseSite also does not allow me to enter grades greater than 100%. Therefore, when extra credit is possible, the denominator shown in CourseSite may be larger than it should be. (For example, consider an

assignment that has 140 regular points possible, plus 10 points possible extra credit. The denominator listed on CourseSite would be 150, even though the percent grade for that assignment should really be calculated out of 140 points.)

I will calculate your combined scores and average grades in my own spreadsheet. There is a link on CourseSite to a Grade Calculator (a Google Sheet) that will apply the formulas discussed above and let you get an accurate calculation of your grade. Trust that instead of CourseSite's calculation. Note that the Grade Calculator will be populated with random grades to demonstrate how to use the sheet. Those are not your grades! You will need to download or copy the sheet and insert your own grades.

Grades Breakdown:

Your **midterm** grade will be determined as follows:

44%: Problem Sets

14%: Reading Quizzes

21%: Exam 1

21%: Attendance

Your **final** grade will be determined as follows:

30%: Problem Sets

10%: Reading Quizzes

15%: Exam 1

15%: Exam 2

15%: Final Exam

15%: Attendance

Grading Scale:

94–100 = A

90–93 = A–

87–89 = B+

84–86 = B

80–83 = B–

77–79 = C+

74–76 = C

70–73 = C–

67–69 = D+

64–66 = D

60–63 = D–

< 60 = F

I reserve the right to curve grades upward if the class average is too low.

Lecture Slides:

I will make the slides for each lecture available on CourseSite. I will post “preview” slides shortly before each lecture; you can take notes on these preview slides if you like. If I forget to post the preview slides, please remind me!

Note that I may leave out some information from the preview slides (*e.g.* answers to questions or the results of calculations). If you take notes on the preview slides, you should fill in that information. While I encourage participation in class, if I ask you a question, please don’t just read the answer off of the preview slides!

Although I make every effort to avoid typos or other mistakes on my slides, the preview slides are more likely to have those problems. After each lecture, I will post updated slides, with any necessary corrections, to CourseSite. You should use the **final** versions of the slides as references for your homework.

Communication:

I will try to respond to your messages promptly. But I make no promise that I will respond outside of normal working hours, on weekends or holidays, or less than 24 hours after I get your message. A faster response is a bonus, not a guarantee.

Please use the forum on CourseSite to ask any questions that may be of interest to the other students. A private email to the professor would ideally only be used for questions that are specific to you. If you send me a general question via private email, I will encourage you to post it to the

forum instead. Of course, if you are a bit timid about asking questions publicly, I would be happy to post your question to the forum without your name attached.

There Is No Such Thing As a Stupid Question:

This is the most important rule of PHY 364. There is also no such thing as a stupid answer. I want all of you to feel comfortable asking and answering questions in this course. Please don't hesitate. Remember: sometimes "stupid" questions are actually the smartest questions.

Health:

The COVID-19 emergency is over, but that disease and others are still with us. I expect you all to be good citizens and protect the health of your classmates and me. Wearing a mask is perfectly acceptable in class. I may choose to do so from time to time. But unless you are ill, masking is optional and I expect you all to **respect each other's personal masking choices**. However, I emphatically request that you wear a mask if you are actively coughing or sneezing (even if it is not COVID). Keep your mask on when you cough or sneeze. Any cough or sneeze not captured by a mask should be into your hands, elbow, etc. In short: please do not spray your classmates with your respiratory droplets! If you have COVID or some other nasty bug, I will be happy to allow remote attendance of class meetings.

Student Senate Statement on Academic Integrity:

We, the Lehigh University Student Senate, as the standing representative body of all undergraduates, reaffirm the duty and obligation of students to meet and uphold the highest principles and values of personal, moral and ethical conduct. As partners in our educational community, both students and faculty share the responsibility for promoting and helping to ensure an environment of academic integrity. As such, each student is expected to complete all academic course work in accordance to the standards set forth by the faculty and in compliance with the University's Code of Conduct.

The Principles of Our Equitable Community:

Lehigh University endorses The Principles of Our Equitable Community. We expect each member of this class to acknowledge and practice these Principles. Respect for each other and for differing viewpoints is a vital component of the learning environment inside and outside the classroom.

http://www.lehigh.edu/~inprv/initiatives/PrinciplesEquity_Sheet_v2_032212.pdf

Accommodations for Students with Disabilities:

Lehigh University is committed to maintaining an equitable and inclusive community and welcomes students with disabilities into all of the University's educational programs. In order to receive consideration for reasonable accommodations, a student with a disability must contact Disability Support Services (DSS), provide documentation, and participate in an interactive re-

view process. If the documentation supports a request for reasonable accommodations, DSS will provide students with a Letter of Accommodations. Students who are approved for accommodations at Lehigh should share this letter and discuss their accommodations and learning needs with instructors as early in the semester as possible. For more information or to request services, please contact Disability Support Services in person in Williams Hall, Suite 301, via phone at 610-758-4152, via email at indss@lehigh.edu, or online at

<https://studentaffairs.lehigh.edu/disabilities> .

My office and the classroom are on the 4th and 5th floors of Lewis Lab, respectively. Both rooms are accessible by elevator.

Lehigh University Policy on Harassment and Non-Discrimination:

Lehigh University upholds The Principles of Our Equitable Community and is committed to providing an educational, working, co-curricular, social, and living environment for all students, staff, faculty, trustees, contract workers, and visitors that is free from harassment and discrimination on the basis of age, color, disability, gender identity or expression, genetic information, marital or familial status, national or ethnic origin, race, religion, sex, sexual orientation, or veteran status. Such harassment or discrimination is unacceptable behavior and will not be tolerated. The University strongly encourages (and, depending upon the circumstances, may require) students, faculty, staff or visitors who experience or witness harassment or discrimination, or have information about harassment or discrimination in University programs or activities, to immediately report such conduct.

If you have questions about Lehigh's Policy on Harassment and Non-Discrimination or need to report harassment or discrimination, contact the Equal Opportunity Compliance Coordinator (Alumni Memorial Building / 610.758.3535 / eocc@lehigh.edu).