Course Outline: Phys 4602 & 5602, Winter 2025
The Physics of Elementary Particles

Course description: What is particle physics?

Particle physics addresses the challenging questions: What are the fundamental constituents of matter? How do they interact? The smallest objects observed so far - quarks, leptons, and gauge bosons - behave in a manner that we can now describe in great detail. Yet, despite tremendous progress in this field, many fundamental mysteries remain. What is the origin of mass? Why do neutrinos appear to have very tiny masses? Why is there a three-fold replication of a basic set of particles (the generation puzzle)? Are quarks truly elementary particles? Why are some conservation laws violated by a narrow class of processes? Why is there much more matter than antimatter in the universe? Is there, as theorists predict, an undiscovered supersymmetric partner for every known type of particle?

To make progress in the study of elementary particles, one needs sophisticated experimental and theoretical tools. We use accelerators of monumental size to produce particle collisions at energies that are equal to those shortly after the big bang. We routinely collide matter with antimatter, destroying the initial particles and creating new ones. The detectors that we use to study these collisions are nearly as impressive. Underground, undersea or under the ice, we develop detector arrays to trap elusive particles. Here at Carleton, the particle physics group is very active in constructing such detectors and in analyzing the results of experiments that we perform at various accelerators and underground laboratories.

The theoretical tools required to analyze elementary particle phenomena are also extremely interesting and challenging. Nearly all processes involve phenomena that must be described with relativistic quantum mechanics. Theories must also cope with the fact that, in high-energy collisions, particles are usually created or destroyed. In other words, we don't simply smash two watches together and observe the little pieces come flying out, entirely new pieces are created! We have come to understand that the "new" particles observed in such experiments are every bit as fundamental and important to piecing together the puzzle of matter as the particles that make up atoms. The theoretical framework for describing these processes is called quantum field theory.

In **Physics 4602/5602** we will make a start towards understanding the nature of elementary particles and their interactions. We will present basic introductory ideas and historical views, which will lead to experimental methods, conservation laws, and invariance principles. Consequently, we will deal with the fundamental interactions between leptons & quarks and discuss unification of the various interactions. We can go quite far without using the full apparatus of quantum field theory. We will, however, need to use **special relativity** and **quantum mechanics** routinely.

Note: *Lectures are three hours per week and laboratory or tutorial sessions are an additional three hours per week. Students are also* ***expected*** *to* ***read selected chapters*** *in the* ***textbook*** *and exercise, including by* ***solving*** *the required* ***assignments****.*

Instructors and contact information

Alain Bellerive	PHYS 4602/5602 instructor	alainbellerive@cunet.carleton.ca

Material for the lectures is available on the course Brightspace page. Office hours are posted below and on Brightspace. The Brightspace websites should be consulted carefully and frequently.

Email communications must be done using your Carleton University account. Email early about any possible issues. Please keep copies of all exchanges until the end of the term.

Some Advice on How to Succeed in this Course

This course will be different from many of your upper division physics courses. You may find it hard to keep track of all the new terminology and ideas. Here is some advice on how to deal with it

1. Keep up with the reading and do the homework on time. Take careful notes when you read the textbook and bring lots of questions to class. Come to office hours to get mysterious concepts clarified!
2. Remember information: constants, particle names and quantum numbers, masses, lifetimes, as much as you can. You may be used to solving idealized problems that are simply meant to give you insight into applying a particular physical law.
3. Here things are different: you need to learn and understand the properties of real physical systems. In order to understand why certain observations are crucial, you must be able to put the information into context. Without the background information in your head, you will have a hard time understanding this context. Creating your own mental database also helps you to develop physical intuition in a subject that is very unfamiliar.
4. How to proceed: The course will be presented in formal lectures on the blackboard and will not follow the reference manual in exact order. Hence the student will have two complementary descriptions of particle physics: 1) one by the professor in the lecture notes, and 2) one by reading the reference book of Thomson.
5. Remember the main results of homework problems. Many of the problems will address important issues; they are not simply cooked-up examples. Use the assignments as a way to summarize the formal lectures and the concepts described by Thomson.
6. Graduate level: Graduate students registered to 5602 will have extra problems for each assignment and will be asked to cover more material. There will be a take-home assignment at the end of the term for the graduate students.

Physics provides an ideal opportunity to learn the art of quantitative thinking. To solve a problem, you must critically examine the information available in a given situation; determine an effective method to obtain the solution and carry through with confidence, including a critical examination of the final answer. These skills will serve you throughout your future career. This course is a good step towards that end. The goal of physics is to understand the physical universe and be able to accurately describe and predict what is observed. Physics is based on such critical thinking, and hence helps to develop independence. Learning physics is not a spectator sport. To learn physics, you must do work outside of class thinking about, and interacting with, the course material. ***No one ever learns physics by simply reading about it or listening to someone talk about it. You learn by making the effort to understand the course material and by solving problems using the principles learned.*** *The standard at university is that you spend at least one hour outside of class for every hour in class.*

Textbook and Reference

Required: *Modern Particle Physics*, by Mark Thomson [**ISBN:** 9781107034266].

The textbook can be bought new (print for $75.00 or digital for $102.00), or rent (digital for $81.50) at the Carleton bookstore.

Textbook webpage: https://www.hep.phy.cam.ac.uk/~thomson/MPP/ModernParticlePhysics.html

List of errata: https://www.hep.phy.cam.ac.uk/~thomson/MPP/ModernParticlePhysics_Errata.pdf

Reference: *Introduction to Elementary Particles [2nd, Revised Edition]*, by David Griffiths.

For graduate students (complement): *Quarks and Leptons: An Introductory Course in Modern Particle Physics*, by F. Halzen and A.D. Martin.

Course delivery

This course for Winter 2025 is an IN-PERSON WITH ON-CAMPUS ATTENDANCE. The course is delivered synchronously in person lectures. The specific dates and activities are described below. The asynchronous activities are intended to provide flexibility to students. Students are expected to remain up to date with the deadlines and due dates as provided by the instructors.

Please note that course materials are protected by copyright. These are for your own educational use, but you are not permitted to publish to third party sites, e.g. social media sites or any course material websites. ***All solutions and answers to any assignment or exam in this course must be your own work.***

Lectures

This course is divided into 25 lectures. Each lecture is an in-person 90-minute traditional lecture. The lecture note of each class will be posted on Brightspace. Below is the list of the topics that will be covered within each week, as well as the corresponding textbook sections recommended for reading.

The table below also details the concepts of the lectures and identifies the subject matters of the assignment, as well as the due date of each assignment.

**** Subject to change / weekly lecture will provide the real roadmap ****

Week	Subject	Textbook chapter (Thomson)	Assign due
1	(*week of Jan 6*) Overview, Units & Feynman diagrams	**Chap 1:** Introduction **Chap 2:** Underlying concepts	Jan 16
2	(*week of Jan 13*) Special Relativity	**Chap 2:** Underlying concepts	Jan 23
3	(*week of Jan 20*) Dirac and Klein-Gordon equations	**Chap 4:** The Dirac equation	Jan 30
4	(*week of Jan 27*) Symmetries & Conservation laws	**Griffiths:** chapter 4	Feb 6
5	(*week of Feb 3*) Quark Model Quantum numbers and Isospin	**Chap 2:** Underlying concepts **Chap 9:** Symmetries and the quark model	Feb 13
6	(*week of Feb 10*) Bound states	**Griffiths:** chapter 5	
Reading week			
7	**Midterm** = Tuesday Feb 25 (*week of Feb 24*) Baryon mass and Wavefunction	Suggested problems in the textbook **Chap 10:** QCD (survey 10.1 to 10.6)	
8	(*week of Mar 3*) Cross section and lifetime	**Chap 3:** Decay rates and cross section	Mar 6
9	(*week of Mar 10*) Feynman rules	**Chap 5:** Interaction by particle exchange	Mar 13
10	(*week of Mar 17*) QED and QCD	**Chap 6:** Electron-positron annihilation	Mar 20
11	(*week of Mar 24*) Weak interaction and CKM matrix	**Chap 11:** The weak interaction **Chap 14:** CKM matrix (14.2 & 14.3)	Mar 27
12	(*week of Mar 31*) Neutrinos Osc. *or* CP violation *or* Higgs	**Chap 13 *or* 14 *or* 17** Students to decide on the topics!	Apr 8
13	(*week Apr 7*) Review	Suggested problems in the textbook	

Prerequisites and Calendar description

Standard Model. Properties of leptons, quarks, hadrons. Fundamental interactions: photon, gluons, W/Z bosons. Higgs boson. Conservation laws, invariance principles, quantum numbers. Decay rates and scattering cross-sections. Quantum electrodynamics and chromodynamics. Resonances. Weak interactions, CKM matrix, parity and CP violation. Neutrino masses and oscillations. Future directions. Prerequisite(s): PHYS 4707 or permission of the Department.

Office Hours and Lecture Time

Office hours: Tuesday and Thursday 11:30am to 13:30. Outside of office hours, contact me via e-mail to arrange a time to meet.

Lecture time: Tuesday and Thursday 10:30am to 11:30am

Grade distribution

Assignments	35%
Midterm examination	25%
Final examination	40%
TOTAL	**100%**

Assignments:

There will be assignments on a weekly basis throughout the term, and they will generally be *due one week after their distribution*. **Assignments will be posted on Brightspace. Students will be asked to upload their solutions (PDF format preferred) onto Brightspace.** Late assignments will not be accepted without an acceptable and documented reason such as illness. The work you turn in must be your own. The assignments are a critical part of the course and working through the problems yourself is essential to learn the material. Your homework solutions should be thorough, self-contained, and logical, with all steps explained. Assignments must be deemed legible by the marker. Late assignments will lose 10% per day. An assignment can no longer be submitted 10 days following its initial deadline. **Graduate students registered to 5602 will have extra problems for each assignment and will be asked to cover more advanced material in the textbook for a final take-home.**

Mental Health

If you are struggling, please do not hesitate to reach out to your instructors. We are happy to listen, and/or direct you to resources that might help. We will work with you. Remember that Carleton also offers an array of mental health and well-being resources, which can be found here.

Exams

• There will be one midterm exam (in-person). The midterm will consist of problems. The midterm exam will be in class on **Tuesday February 25, 2025 at 10:00am**. The students will have 80 minutes to answer and provide a full detailed solution of the problems in an exam booklet. The midterm exam will be in-person and closed book.

• The final exam (in-person) will be held during the final examination period in April 2025. It will consist of problems. The student will have 180 minutes to answer and provide full solution of the problems in an exam booklet. The final exam will be in-person and closed book.

• The midterm and finals exam will be with a detailed formula sheet provided by the instructor.

• No deferred exam will be set for the midterm exam. A deferred exam will be scheduled only for the final exam. If a deferred final exam is necessary for a student, that exam will replace only the final exam component of the course mark and will only be granted if adequate term work has been completed. In this context, adequate term work means completing and submitting 50% of the assignments; the term mark before the final exam must exceed 20 out of 60.

University Policies

In accordance with the Carleton University Undergraduate Calendar Regulations, the letter grades assigned in this course will have the following percentage equivalents:

A+ = 90-100	B+ = 77-79	C+ = 67-69	D+ = 57-59
A = 85-89	B = 73-76	C = 63-66	D = 53-56
A- = 80-84	B- = 70-72	C- = 60-62	D- = 50-52
F = <50			
WDN = Withdrawn from the course		DEF = Deferred	

Academic Accommodations, Regulations, Plagiarism, Etc.

Carleton is committed to providing academic accessibility for all individuals. You may need special arrangements to meet your academic obligations during the term. Email your instructor.

Deferred/missed term work for accommodation: The accommodation request processes are outlined on the Academic Accommodations website: https://students.carleton.ca/course-outline/

Paul Menton Centre for Students: The Paul Menton Centre (PMC) is the designated department at Carleton University coordinating disability services on campus. https://carleton.ca/pmc/

Statement on Chat GPT/Generative AI usage

AI Use in this course: Students may use AI tools for basic word processing and formatting functions, including:

- Grammar and spell checking (e.g., Grammarly, Microsoft Word Editor)
- Basic formatting and design suggestions (e.g., Microsoft Word's formatting tools, PowerPoint Design editor)

Documenting AI Use: It is not necessary to document the use of AI for the permitted purposes listed above. If you have questions about a specific use of AI that isn't listed above, please consult your instructor.

Why have we adopted this policy? This policy ensures that student voices and ideas are prioritized and authentically represented, maintaining the integrity of the work produced by students while allowing basic support to enhance clarity, correctness, layout, and flow of ideas. The goal of adopting a limited use of AI is to help students develop foundational skills in writing and critical thinking by practicing substantive content creation without the support of AI.

Academic Integrity

Academic Integrity is upholding the values of honesty, trust, respect, fairness, responsibility, and courage that are fundamental to the educational experience. Carleton University provides supports such as academic integrity workshops to ensure, as far as possible, that all students understand the norms and standards of academic integrity that we expect you to uphold. Your teaching team has a responsibility to ensure that their application of the Academic Integrity Policy upholds the university's collective commitments to fairness, equity, and integrity.

Examples of actions that do not adhere to Carleton's Academic Integrity Policy include:

- Plagiarism
- Accessing unauthorized sites for assignments or tests
- Unauthorized collaboration on assignment and exams
- Using artificial intelligence tools such as ChatGPT when your assessment instructions say that it is not permitted

Please review the checklist linked here to ensure you understand your responsibilities as a student with respect to academic integrity and this course.

Sanctions for Not Abiding by Carleton's Academic Integrity Policy

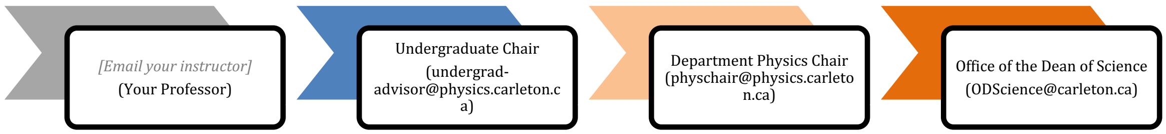
A student who has not upheld their responsibilities under Carleton's Academic Integrity Policy may be subject to one of several sanctions. A list of standard sanctions in science can be found here. Additional details about this process can be found on the Faculty of Science Academic Integrity website. Students are expected to familiarize themselves with and follow the Carleton University Student Academic Integrity Policy. The Policy is strictly enforced and is binding on all students.

Student Rights & Responsibilities

Students are expected to act responsibly and engage respectfully with other students and members of the Carleton and the broader community. See the 7 Rights and Responsibilities Policy for details regarding the expectations of non-academic behaviour of students. Those who participate with another student in the commission of an infraction of this Policy will also be held liable for their actions.

Student Concerns

If a concern arises regarding this course, **your first point of contact is your instructor**: Email or drop in during student hours and I will do my best to address your concern. If I am unable to address your concern, the next points of contact are (in this order):



Note: You can also bring your concerns to Ombuds services.