PHYS 509: Standard Model Phenomenology

January 2022 – April 2022

Territory Acknowledgement: *We acknowledge and respect the lək̓ʷəŋən peoples on whose traditional territory the university stands, and the Songhees, Esquimalt and WSÁNEĆ peoples whose historical relationships with the land continue to this day.*

Instructor: Dr. Heather Russell
Email: hrussell@uvic.ca
Office: Elliot 206
Course webpage: We will use brightspace
Office Hours: [to be mutually agreed upon during our first class]

Lectures:

Lectures will be held online from 10 – 24 January following university policy. I will let you know if this changes

Tuesdays, Wednesdays, and Fridays at 12:30 – 13:20 on zoom (the link is in brightspace)
Future in-person lectures will be held in Elliot 161 unless otherwise specified

First lecture: Tuesday, 11 January 2022 @ 12:30

Since this will likely be a very small class, attendance is strongly encouraged. If you do have to miss a class, please do your best to email me in advance. If a majority of you will miss a class, we will discuss rescheduling the lecture or holding it over zoom. There will be multiple in-class discussions during lectures, so prioritizing attendance over e.g. completing the assignments for this course is important.

Lectures will be recorded and posted on Brightspace following each class, so if absences are unavoidable you may watch the lectures at a later time.

Communication:

We will try using Microsoft Teams (https://teams.microsoft.com/) for discussions, since it has a very nice chat functionality where you'll be able to ask questions. I'll monitor this, but I also expect you to try to answer each other's questions.

If you send me an email, please start the subject with "PHYS 509".

Please feel free to stop by my office at any time: I am often in even if my office door is closed. I am also happy to arrange a chat over zoom.

Prerequisites:

There are no formal pre- or co-requisites for this course, though a previous course in introductory particle physics would be helpful.

Textbook / reading materials:

There is no assigned text for this course, though you may find the following books helpful. Where possible, I will point out specific sections of texts to supplement material we cover in class.

The group theory text provide a "physicists" introduction to group theory, with a specific focus on applications to symmetries in particle physics and other fields. They contain far more material than we will utilize in this course, but should provide useful points of reference.

The gauge theory texts focus on quantum field theory, and go well beyond the content of this course. They do contain the relevant material on symmetries of the Standard Model, its gauge sector, and spontaneous symmetry breaking, but you may need to pick out the appropriate chapters and sections (and sometimes appendices) that overlap with the course syllabus. Of course, this is just a short list, and there are many other good texts on the Standard Model, a number of which are also available in the library.

The following texts are available in the library:

Group Theory in Physics:

- *Lie Algebras in Particle Physics*, H. Georgi
- *Group Theory in Physics: An Introduction*, J. Cornwell

Gauge Theory and the Standard Model:

- *Gauge Theories in Particle Physics (Vol 2)*, I. Aitchison and A. Hey
- *Gauge Theory of Elementary Particle Physics*, T.-P. Cheng and L.-F. Li

Additionally, these texts are a useful reference:

- *Groups, Representations and Physics*, H. Jones
- *The Standard Model: A Primer*, C. Burgess and G. Moore

Course-level Intended Learning Outcomes:

1. By the end of this course, when asked you will be able to describe the underlying symmetries of the Standard Model and how they inform the mathematical formalism.
2. When presented with appropriate scenarios, you will derive and explain the consequences of the corresponding symmetry-breaking mechanisms.
3. Following a discussion of the Standard Model Lagrangian, you will identify limitations on extensions to the theory as they relate to symmetry constraints.
4. Through developing your project, you will be apply your knowledge of group theory and symmetries to an aspect of particle physics not discussed in-class.

We will work our way through the following topics:

- Introduction
  - Symmetries, kinematics, and constraints
- Group Theory and Lie Algebras
  - Basic group theory
  - Lie algebras and representations
  - Applications - global symmetries in field theory
- Spacetime Symmetries, Representations and Particles
  - Poincaré group
  - Scalar, vector and spinor representations
  - Particles and fields, Coleman-Mandula theorem
- Local Symmetry and Gauge Theory
  - Abelian gauge theory
  - Nonabelian gauge theory
- Spontaneous Symmetry Breaking
  - Global symmetry breaking - Goldstone mechanism
  - Local gauge symmetry breaking - Higgs mechanism
- Standard Model Structure
  - Chirality and the electroweak gauge group
  - Higgs sector and symmetry breaking
  - Flavour symmetry and interactions
  - Standard Model Lagrangian
- Beyond the Standard Model (*subject to time)
  - Symmetry constraints on new physics
  - Running couplings,
  - Grand unification

Additionally, a few lectures will be set aside to discuss current issues in particle physics.

Assessment:

Assignments	**40%**
Take-home final	**15%**
Project	**45%**

Assignment of final grades will follow the official grading system used by the Faculty of Graduate Studies.

Assignments:

There will be four assignments spaced throughout the semester. Each of these assignments will be worth 10% of your final grade, and you will have approximately one week to complete them after all material has been covered in class. If we fall behind schedule, the assignments will be delayed accordingly.

Working together and discussing assignments is strongly encouraged. However, all work must still be individual. Do not be tempted to copy solutions: if you are pressed for time, please request an extension instead.

On your assignments, all answers must be presented with full explanations. We will discuss what this looks like in class, and I will remind you on each assignment.

You must attempt all assignments, the take home exam, and the project to pass the course. Each assignment will have a due date, though because this is a small class we can afford some flexibility here. You will receive one no-questions-asked 48-hour extension. Once you have used this, please contact me by email if you require more than 48 hours or extensions on additional assignments.

One week after the assignment deadlines the solutions will be posted. After this time you can receive at most 50% credit for an assignment.

Take-home final exam:

There will be an open-book, take-home exam we will mutually agree upon a date for during class. It will focus mostly on material from the end of the course. We will agree upon a date and expectations for the exam during class.

Participation:

Participation in-class is strongly encouraged. Some classes will include a short in-class or post-class task, though no participation grade will be tied to the completion of these tasks due to the COVID-related uncertainty surrounding this semester.

Project:

The project will consist of peer-teaching an aspect of group theory as it applies to particle physics. A possible list of topics, a rubric you will be assessed on, and the possible modes of delivery will be provided in-class.

Project proposals will be due by 5 pm on **15 February 2022**, and must include the topic you will be discussing, an outline of the material you will cover, and your proposed method of delivery. If you are choosing a topic from outside the list provided, please discuss this with me before preparing your proposal. The proposal will be worth 10% of the project grade (4.5% of your final grade).

Each project will have up to one full class to present their material (45 minutes) and should be presented in a manner that teaches the material, not as a list of facts you have learned. You will be assessed primarily on the demonstration of your knowledge and understanding of the topic, not the delivery itself, should you choose to give an in-class presentation.

Course Policies and Information for Students

1. **Student Code of Conduct:** You are expected to behave in a manner compatible with the student code of conduct: https://www.uvic.ca/services/advising/assets/docs/tri-fac-student-code-of-conduct.pdf
2. **Inclusive Learning Environment:** The best learning environment is one in which all members feel respected while being productively challenged. At UVic, we are dedicated to fostering an inclusive atmosphere, in which all participants can contribute, explore, and challenge their own ideas as well as those of others. Every participant has an active responsibility to foster a climate of intellectual stimulation, openness, and respect for diverse perspectives, questions, personal backgrounds, abilities, and experiences, and instructors bear the primary responsibility for its maintenance. A range of resources is available if you perceive an issue related to our learning environment. If possible, I encourage you to come to me with any suggestions or concerns you have regarding a particular situation or instructional space. Alternatively, you may take concerns to another trusted advisor or administrator (such as an academic advisor, mentor, department chair, or dean).
3. **Academic Integrity:** Ethical behavior is an essential component of learning and scholarship. You are expected to understand, and adhere to UVic's academic integrity policy. If you have any doubts about what constitutes a violation of the Academic Integrity policy, or any other issue related to academic integrity, please ask your instructor. Some examples of appropriate ethical scholarship include:
    a. Always citing your sources when you present ideas and/or language that you have not developed yourself, including material from class lectures and discussions.
    b. Not using online or unapproved resources for assignment answers
    c. Being civil, respectful, and supportive of an inclusive learning environment for all students.
    d. Bringing issues of ethical or inclusivity concerns, for yourself or another student, to me, the department chair, or a trusted advisor.
4. **Masks**: Please follow university policy on mask wearing, and maintain physical distance where possible.
5. **Accessible Learning**: The University of Victoria is committed to creating a learning experience that is as accessible as possible. If you anticipate or experience any barriers to learning in this course, please feel welcome to discuss your concerns with me. If you have a disability or chronic health condition, or think you may have a disability, you may also want to meet with an advisor at the Centre for Accessible Learning (CAL).
6. **Mental Health:** A note to remind you to take care of yourself. Do your best to maintain a healthy lifestyle this semester by eating well, exercising, getting enough sleep and taking some time to relax. This will help you achieve your goals and cope with stress. All of us benefit from support during times of struggle. You are not alone. The following resources are available to you:
    a. The UVic Student Wellness Centre provides cost-free and confidential mental health serivces to help you manage personal challenges that impact your emotional or academic well-being: https://www.uvic.ca/student-wellness/
    b. Counselling Services can help you make the most of your university experience. They offer free professional, confidential, inclusive support to currently registered UVic students: https://www.uvic.ca/services/counselling/
    c. University Health Services provides a full service primary health clinic for students, and coordinates healthy student and campus initiatives: http://www.uvic.ca/services/health/