UNIVERSITY OF THE PHILIPPINES
College of Science
National Institute of Physics

Physics 180 – Nuclei and Particles
1st Semester, AY 2021-2022

COURSE GUIDE

COURSE DESCRIPTION: Basic nuclear properties and classification of fundamental particles; symmetries and invariance principles; strong, weak, and electromagnetic interactions; SU (3) quarks, and other selected topics

COURSE PREREQUISITE: Physics 142 (Quantum Physics II)

COURSE LEARNING OUTCOMES:
After completing this course, you should be able to …
1. Derive basic nuclear properties from semi-empirical models
2. Analyze the consequences of the Dirac equation
3. Calculate the cross-section of electron-positron annihilation with the help of Feynman diagrams
4. Discuss how we know the structure of the proton using deep inelastic scattering

COURSE OUTLINE

0. Orientation
0.1. Class introduction and briefing on course outline & policies
0.2. Historical introduction to nuclear and particle physics

1. Nuclear Phenomenology
1.1 Mass spectroscopy
1.2 Nuclear shapes and sizes
1.3 Semi-empirical mass formula – the liquid drop model

4.4 Feynman rules for QED

5. Electron-positron annihilation
5.1 Calculations in perturbation theory
5.2 Electron-positron annihilation
5.3 Spin in electron-positron annihilation
5.4 Chirality
5.5 Trace techniques

6. Electron-proton elastic scattering
6.1 Probing the structure of the proton
6.2 Rutherford and Mott scattering
6.3 Form factors
6.4 Relativistic electron-proton elastic scattering
6.5 The Rosenbluth formula

7. Deep elastic scattering
7.1 Electron-proton inelastic scattering
7.2 Deep inelastic scattering
7.3 Electron-quark scattering
7.4 The quark-parton model
7.5 Electron-proton scattering at the HERA collider
7.6 Parton distribution function measurements

MODE OF DELIVERY

The mode of delivery will be asynchronous learning which means for the most part, as a student enrolled in this course, you will be studying on your own. The course guide can be obtained from the University Virtual Learning Environment (UVLE) at the course: Physics 180 (Flores) 1st Sem AY 2021-22. The enrolment key is: **physicsconquersall**

COURSE MATERIALS

A. Main References

A1. B. Martin & G. Shaw, "*Nuclear and Particle Physics – An Introduction, 3rd Edition*"
A copy of the entire FIRST edition (note that we'll be using THIRD) of the book has been uploaded by the University of Porto here:
https://qa.ff.up.pt/rq2020/Bibliografia/Books/Martin%20-%20Nuclear%20and%20Particle%20Physics%20-%20An%20Introduction.pdf

A2. M. Thomson, "*Modern Particle Physics*"
A copy of the entire book has been uploaded by the Shahrood University of Technology here:
https://shahroodut.ac.ir/fa/download.php?id=1111130873

B. Online References

MIT Open Courseware on "Introduction to Nuclear and Particle Physics" https://ocw.mit.edu/courses/physics/8-701-introduction-to-nuclear-and-particle-physics-fall-2020/
MIT Video Playlist on the course (very short videos on YouTube labeled L0.1 up to L10.4):
https://youtube.com/playlist?list=PLUl4u3cNGP60Do91PdN978llIsvjKW0au

C. Other Resources

Portia P. Padilla, Keri 'Yan! (Going the Distance to Learn) https://www.youtube.com/watch?v=Ys-toUK61-0 (13 mins or so)
Portia P. Padilla, Walang Forever (Making the Most of Remote Learning) https://www.youtube.com/watch?v=IRhx3InOqqo (13 mins or so)

D. Miscellaneous (Not Required)

You may read/watch these at your own leisure for further understanding but they are not required for this course:

Textbooks

- D. Griffiths, "*Introduction to Elementary Particles, 2nd Ed.*"
  This is the usual undergrad textbook when covering particle physics. Very extensive discussions on Feynman rules.

- A. Das & T. Ferbel, "*Introduction to Nuclear and Particle Physics*"
  Undergrad textbook that covers both nuclear and particle physics.

Films/Documentaries

- CERN People, www.youtube.com/user/CERNPeople/featured
  A collection of short documentary films by filmmaker Liz Mermin. She has interviewed numerous scientists and provides a rather intimate and very human perspective of the people that work at CERN.

- Particle Fever, https://youtu.be/-fXAsrZ-ePM
  A documentary on the discovery of the Higgs boson that includes interviews with scientists at the forefront.

- Beyond Higgs: The Wild Frontier of Particle Physics, https://youtu.be/no3qLqUYBLo
  World Science Festival program with experts that talk about what comes next after the Standard Model. Moderated by Brian Greene.

COURSE REQUIREMENTS

Problem sets (weekly) – 60%
Written Notes – 20%
Long Exams (Midterm and Final) – 20%

GRADE EQUIVALENTS

Score (X)	Grade
$90 \leq X \leq 100$	1.0
$85 \leq X < 90$	1.25
$80 \leq X < 85$	1.5
$75 \leq X < 80$	1.75
$70 \leq X < 75$	2.0
$65 \leq X < 70$	2.25
$60 \leq X < 65$	2.5
$55 \leq X < 60$	2.75
$50 \leq X < 55$	3.0
$45 \leq X < 50$	4.0
$0 \leq X < 45$	5.0

ABOUT THE INSTRUCTOR

Marvin M. Flores obtained his B.S. Physics degree from Silliman University graduating Summa Cum Laude. He finished his M.S. degree and obtained his Ph.D. in Physics from the National Institute of Physics (NIP), University of the Philippines Diliman where he was awarded the Most Outstanding Ph.D. Graduate of the College of Science. He is currently an Assistant Professor at NIP having just returned from his postdoctoral research on high energy physics at the University of the Witwatersrand, Johannesburg, South Africa. He is also a member of the ATLAS Collaboration at CERN and heads the ATLAS Group that will be based in the Philippines, with NIP recently becoming an ATLAS Associate Member at CERN. His research is focused on physics searches beyond the Standard Model.

HOUSE RULES

1. Problem sets are due weekly every Monday no later than 5:00 pm. Upload your assignments in the Physics 180 UVLE page.
2. Should there be any issues with UVLE, you may submit your assignment through email at mflores@nip.upd.edu.ph. However, please ensure that you registered to our Physics 180 UVLE page no later than September 30, 2021.
3. Optional online consultations, feedback, and discussions will be done every Friday at 10:00 AM if our internet connection allows. The recorded video will then be uploaded to our UVLE page for your later/repeated viewing.
4. For any concerns on the course delivery, please send an email to mflores@nip.upd.edu.ph.

Week	Topics *(specify sub-topics)*	Target Learning Outcomes	Learning Resource/s	Learning Activity/ies
0 **Sept. 17**	Orientation / Remote Learning Historical Introduction	After studying this topic, you should be able to … • *Know what to expect of remote learning and how to make the most of it* • *Know what to expect from this course* • *Know the interesting history of nuclear and particle physics*	Course Guide/Syllabus Reference C Reference A1 – Section 1.1 Reference B – L0.5	Watch Videos from Reference C Week 0 Reading Assignment: Course Guide Week 0 Reading Assignment: Reference A1 Section 1.1 Watch Video L0.5 from Reference B: https://youtu.be/B53W30-GJ10
1 **Sept. 22/24**	Mass spectroscopy Nuclear Shapes and Sizes Semi-empirical mass formula: the liquid drop model	After studying this topic, you should be able to … • *Examine the different ways of measuring masses of stable and unstable nuclei* • *Discuss the methods to find the charge distribution and matter density of the nucleus* • *Examine the different terms parametrizing the binding energy*	Reference A1 – Sections 2.1, 2.2, 2.3 Reference B – L9.1, L9.2, L9.5	Week 1 Reading Assignment: Reference A1 Sections 2.1, 2.2, 2.3 Watch Videos L9.1, L9.2, L9.5 from Reference B **Probset** 1: Problems 2.3 and 2.10 (due 9/27/2021)

Week	Topics *(specify sub-topics)*	Target Learning Outcomes	Learning Resource/s	Learning Activity/ies
2 **Sept. 29 / Oct. 1**	Nuclear Instability Nuclear Reactions	After studying this topic, you should be able to … • *Explain nuclear instability* • *Classify the various ways that a heavy nucleus can disintegrate*	Reference A1 – Sections 2.4, 2.5, 2.6, 2.7, 2.8, 2.9 Reference B – L9.6, L9.7	Week 2 Reading Assignment: Reference A1 Sections 2.4, 2.5, 2.6, 2.7, 2.8, 2.9 Watch Videos L9.6, L9.7 from Reference B **Probset 2**: Problems 2.13 and 2.15 (due 10/4/2021)
3 **Oct. 6/8**	Nucleon-nucleon Potential Other nuclear models Nonspherical nuclei	After studying this topic, you should be able to … • *Explain the force that holds nucleons together* • *Examine nuclear models other than the liquid drop* • *Compute the consequences of treating nuclei as nonspehrical*	Reference A1 – Sections 8.1, 8.2, 8.3, 8.4, 8.5	Week 3 Reading Assignment: Reference A1 Sections 8.1, 8.2, 8.3, 8.4, 8.5 **Probset 3**: Problems 8.1 and 8.5 (due 10/11/2021)
4 **Oct. 13/15**	α, β, γ decays	After studying this topic, you should be able to … • *Compare and differentiate α, β, γ decays*	Reference A1 – Sections 8.6, 8.7, 8.8	Week 4 Reading Assignment: Reference A1 Sections 8.6, 8.7, 8.8 **Probset 4:** Problems 8.9 and 8.15 (due 10/18/2021)

Week	Topics *(specify sub-topics)*	Target Learning Outcomes	Learning Resource/s	Learning Activity/ies
5 **Oct. 20/22**	Klein-Gordon Equation Dirac Equation Covariant forms	After studying this topic, you should be able to … • *Examine the Klein-Gordon equation and learn why it is problematic as a relativistic equation* • *Examine the Dirac equation and learn how it solves the problems plaguing the Klein-Gordon* • *Express the Dirac equation in its covariant form*	Reference A2 – Sections 4.1, 4.2, 4.3, 4.4, 4.5 Reference B – L4.1	Week 5 Reading Assignment: Sections 4.1, 4.2, 4.3, 4.4, 4.5 If you are not confident of your QM/SR background, Review Chapter 2 of Reference A2. Watch Video L4.1 from Reference B **<u>Probset 5</u>**: Problems 4.7 and 4.8 (due 10/25/2021)
6 **Oct. 27/29**	Solutions to Dirac equation Antiparticles Spin and helicity states Intrinsic parity of Dirac fermions	After studying this topic, you should be able to … • *Derive solutions to the Dirac equation* • *Interpret the negative energy solutions to Dirac equation as antiparticles* • *Calculate the helicity spinors*	Reference A2 – Sections 4.6, 4.7, 4.8, 4.9 Reference B – L4.2, L4.3	Week 6 Reading Assignment: Reference A2 Sections 4.6, 4.7, 4.8, 4.9 Watch Videos L4.2, L4.3 from Reference B **<u>Probset 6</u>**: Problems 4.3, and 4.9 (due 11/8/2021)
7 **Nov. 3/5**	MIDTERM EXAM			November 5, 2021 (Tentative Midterm Exam)

Week	Topics *(specify sub-topics)*	Target Learning Outcomes	Learning Resource/s	Learning Activity/ies
8 **Nov. 10/12**	Interaction by particle exchange	After studying this topic, you should be able to … • *Apply the Feynman rules to tree-level diagrams*	Reference A2 – Sections 1.1.4, 1.1.5, 1.1.6, Chapter 5	Week 8 Reading Assignment: Reference A2 Sections 1.1.4, 1.1.5, 1.1.6, Chapter 5 **<u>Probset 7</u>**: Problems 5.1 and 5.3 (due 11/15/2021)
9 **Nov. 17/19**	Electron-positron annihilation (Helicity formalism)	After studying this topic, you should be able to … • *Calculate the cross-section of e^+e^- to $\mu^+\mu^-$ using the helicity formalism*	Reference A2 – Sections 6.1, 6.2, 6.3, 6.4	Week 6 Reading Assignment: Reference A2 Sections 6.1, 6.2, 6.3, 6.4 **<u>Probset 8</u>**: Problem 6.7 (due 11/22/2021)
10 **Nov. 24/26**	Electron-positron annihilation (Trace formalism)	After studying this topic, you should be able to … • *Calculate the cross-section of e^+e^- to $\mu^+\mu^-$ using the trace formalism*	Reference A2 – Section 6.5 Reference B – L4.5, L4.6, L4.7, L4.8	Week 8 Reading Assignment: Reference A2 Section 6.5 Watch Videos L4.5, L4.6, L4.7, L4.8 from Reference B **<u>Probset 9</u>**: Problem 6.10 (due 11/29/2021)

Week	Topics *(specify sub-topics)*	Target Learning Outcomes	Learning Resource/s	Learning Activity/ies
11 **Dec. 1/3**	Electron-proton elastic scattering	After studying this topic, you should be able to … • *Examine form factors and how they are used to study the charge and magnetic moment distributions of the proton*	Reference A2 – Chapter 7	Week 9 Reading Assignment: Reference A2 Chapter 7 **Probset 10**: Problems 7.4 and 7.8 (due 12/6/2021)
12 **Dec. 10**	Electron-proton inelastic scattering Deep inelastic scattering Electron-quark scattering	After studying this topic, you should be able to … • *Differentiate e-p inelastic scattering from elastic* • *Examine inelastic scattering at low energies*	Reference A2 – Sections 8.1, 8.2, 8.3 Reference B – L5.4	Week 10 Reading Assignment: Reference A2 Sections 8.1, 8.2, 8.3 Watch Video L5.4 from Reference B **Probset 11**: Problems 8.2 and 8.3 (due 12/13/2021)
13 **Dec. 15/17**	The quark-parton model e-p scattering at the HERA collider Parton distribution function measurements	After studying this topic, you should be able to … • *Describe deep inelastic scattering in terms of the quark-parton model* • *Examine parton distribution functions*	Reference A2 – Sections 8.4, 8.5, 8.6	Week 11 Reading Assignment: Reference A2 Sections 8.4, 8.5, 8.6 **Probset 12**: Problem 8.7 (due 12/20/2021)
14 **Jan. 5/7**	INTEGRATION PERIOD			