مـركـز الاعـتماد
وضمان الجودة
ACCREDITATION & QUALITY ASSURANCE CENTER

Course Syllabus

1	**Course title**	Advanced Quantum Mechanics I	
2	**Course number**	0302754	
3	**Credit hours**	3	
	Contact hours (theory, practical)	(3,0)	
4	**Prerequisites/corequisites**		
5	**Program title**	M.Sc. in Physics	
6	**Program code**		
7	**Awarding institution**	The University of Jordan	
8	**School**	Science	
9	**Department**	Physics	
10	**Course level**	Master degree	
11	**Year of study and semester(s)**	2023, Fall	
12	**Other department(s) involved in teaching the course**		
13	**Main teaching language**	English	
14	**Delivery method**	☒Face to face learning ☐Blended ☐Fully online	
15	**Online platforms(s)**	☐Moodle ☒Microsoft Teams ☐Skype ☐Zoom ☐Others…………	
16	**Issuing/Revision Date**	25/12/2023	

17 Course Coordinator:

Name: **Mohd Hussein** Contact hours: Sunday, Tuesday 13.30-14.30

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18 Other instructors:

Name:

Office number:

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Contact hours:

Name:

Office number:

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19 Course Description:

This course is intended for the first year graduate students who have studied Quantum Mechanics (QM) at the undergraduate senior level. It provides a modern introduction to nonrelativistic QM. The focus is on the formalism and little emphasis is left on applications. The latter is addressed in detail in the second part of the course; namely Advanced QM II (954).

20 Course aims and outcomes:

1) Use Stern-Gerlach (SG) Experiment to rationalize some peculiarities of QM.

2) Define Hermitian operators and urge the students to browse some literature regarding Non-Hermitian Quantum Mechanics.

3) Study the outer product, projection operator, and the matrix representation of an operator.

4) Analyze sequential SG experiments using the projection operator.

5) Learn about the compatible and incompatible observables, and the commutation relations.

6) Prove the general uncertainty relation.

7) Master the similarity and unitary transformation.

8) Define the infinitesimal translation operator and its generator.

9) Define the time evolution operator and derive Schrodinger equation.

10) Derive Heisenberg equation of motion.

11) Study the density operator and time evolution of ensembles.

12) Study Harmonic oscillator using Dirac's approach: Schwinger oscillators, Quantization of the electromagnetic fields, and Coherent states.

13) Define the infinitesimal rotation operator and its generator.

14) Analyze the precession of a spin-1/2 particle in a magnetic field using the time evolution operator and the rotation operator.

A- Aims:

B- Students Learning Outcomes (SLOs):

For purposes of mapping the course SLOs to the physics program SLOs, at the successful completion of the physics program, graduates are expected to be able to:

SLO (1) Master professionally a broad set of knowledge concerning the fundamentals in the basic areas of physics: Quantum Mechanics, Classical Mechanics, Electrostatics and Magnetism, Thermal Physics, Optics, Theory of Special Relativity, Mathematical Physics, Electronics.

SLO (2) Apply knowledge of mathematics and fundamental concepts in the basic areas of physics to identify and solve physics related problems.

SLO (3) Utilize computers and available software in both data collections and data analysis.

SLO (4) Utilize standard laboratory equipment, modern instrumentation, and classical techniques to design and conduct experiments as well as to analyze and interpret data.

SLO (5) Develop a recognition of the need and ability to engage in life-long learning.

SLO (6) Demonstrate ability to use techniques, skills, and modern scientific tools necessary for professional practice.

SLO (7) Communicate clearly and effectively in both written and oral forms.

SLO (8) Apply proficiently team-work skills and employ team-based learning strategies.

SLO (9) Apply professional and ethical responsibility to society.

Upon successful completion of this course, students will be able to:

Program SLOs / Course SLOs	SLO (1)	SLO (2)	SLO (3)	SLO (4)	SLO (5)	SLO (6)	SLO (7)	SLO (8)	SLO (9)
1. Use Stern-Gerlach (SG) Experiment to rationalize some peculiarities of QM.	✓	✓							
2. Define Hermitian operators and urge the students to browse some literature regarding Non-Hermitian Quantum Mechanics.	✓	✓							
3. Study the outer product, projection operator, and the matrix representation of an operator.	✓	✓							

4. Analyze sequential SG experiments using the projection operator.	✓	✓							
5. Learn about the compatible and incompatible observables.	✓	✓							
6. Prove the general uncertainty relation.	✓	✓							
7. Master the similarity and unitary transformation.	✓	✓							
8. Define the infinitesimal translation operator and its generator.	✓	✓							
9. Define the time evolution operator and derive Schrodinger equation.	✓	✓							
10. Derive Heisenberg equation of motion.	✓	✓							
11. Study the density operator and time evolution of ensembles.	✓	✓							
12. Study Harmonic oscillator using Dirac's approach: Schwinger oscillators, Quantization of the electromagnetic fields, and Coherent states.	✓	✓							
13. Define the infinitesimal rotation operator and its generator.	✓	✓							
14. Analyze the precession of a spin-1/2 particle in a magnetic field using the time evolution operator and the rotation operator.	✓	✓							

21. Topic Outline and Schedule:

The content of the lectures below describes in chronological order what is planned for the lectures and where you can read more about the material:

Lecture	Section	Theme	Digression	Problem-solving application
8/10/2023	-	Introductory lecture	The Copenhagen interpretation: Chapter 6, Norsen's text	Sections 4 & 5 of chapter 2: brush up all the elementary wave mechanics examples (check out lecture 17/12/2023)
10/10/2023	1.1	The meaning of quantization	-The peculiarities of QM -Why is (α/2π) engraved above Schwinger's name on his tombstone? -Muon g-2 experiment.	Griffiths: EM text - 4th edition: Problem 5.58.
15/10/2023	1.1	Stern-Gerlach (SG) Experiment	-Samuel A. Goudsmit: FIFTY YEARS OF SPIN: It might as well be spin. Physics Today 29, 6, 40 (1976) -George Uhlenbeck: FIFTY YEARS OF SPIN: Personal reminiscences. Phys. Today 29(6), 43 (1976)	
17/10/2023	1.2	Hilbert space	Tensor product	
22/10/2023	1.2	Hermitian operators	Non-Hermitian Quantum Mechanics, by Nimrod Moiseyev, Cambridge University Press, 2011.	Problem 1.4(b)
24/10/2023	1.3	Outer product & Matrix representation of an operator	-Projection operator. -Matrix Algebra: brush up	-Problems 1.5, 1.7 -Griffiths: QM text - 3rd edition: Compare [footnote 19 on page 36 and footnote 42 on page 169] with footnote 18 on page 103!
29/10/2023	1.3	Spin-1/2 system	Sequential SG experiments using the projection operator	
31/10/2023	1.4	Measurement in QM: Physics Vs. Philosophy Vs. Metaphysics -Expectation value: a misleading term in QM.	Chapters 3 & 5, Norsen's text. Chapter 7, Lederman's text	-Problem 1.8 -Verify the set of equations of chapter 3 (from Eq 2.26 to Eq 2.41)
5/11/2023	1.4	-Compatible and incompatible observables -The proof of the	-Degeneracy and Schmidt orthogonalization -Understanding QM, by Omnes, part 2	-Problems 1.6, 1.15, 1.16, 1.17 -Problems 1.18(a,b), 1.19, 1.20

		general uncertainty relation		
7/11/2023	1.5	Similarity transformation	-Problems 1.4 (a), 1.10, 1.23 -Problem 11 of chapter 1 Vs Problem 2 of chapter 2	
12/11/2023	1.5	Unitary transformation	Examine Eq 2.5 of chapter 2 for the active and passive transformation. Examine Eq 3.7 of chapter 3 for the unitary unimodular matrix	-Problems 1.2, 1.3 -Problem 1 of chapter 3
14/11/2023	-	Recitation session: Discussing problem 1.9 in detail and solving other problems relevant to section 1.5	Problem 1.13 (using the results of problem 1.9)	-Problems 1.12, 1.14, 1.24, 1.25, 1.26
19/11/2023	1.6	The infinitesimal translation operator	Compare Eq 6.32 of chapter 1 with Eq 1.21 of chapter 2 and Eq 1.15 of chapter 3	
21/11/2023	1.6	The commutation relations	-Abelian Vs non-Abelian groups: QED Vs QCD -Verify Eq 1.20 of chapter 3 -Why is ($pq - qp = h/2\pi i$) engraved on the tombstone of Max Born?	-Problems 1.1, 1.28, 1.29, 1.30 -Verify Eq 2.7 & Eq 2.8 of chapter 2 and solve Problem 1.31
26/11/2023	1.7	Wave function in position and momentum space	-The certainty in Heisenberg uncertainty relation! -Planck scale physics: Fermilab Today Nov. 1, 2013, and Phy.Rev.**135**, B849	Problem 1.33
28/11/2023	1.7	Gaussian wave packet	-Different representations of Dirac delta function: brush up -Gaussian integrals: brush up	Problems 1.18(c), 1.21, 1.22, 1.32
3/12/2023	**First Exam (16:00 – 18:00). This is a closed-book exam covers all the materials of chapter 1. The answer key will be provided right after the end of the exam.**			
5/12/2023	2.1	The time evolution operator and Schrodinger equation	Time in non-relativistic QM and in relativistic QM	-Verify Eq 7.25 of chapter 5 -Problem 2.2 -Problem 3 of chapter 3
10/12/2023	2.1	Precession of a spin-1/2 particle in a magnetic field	Neutrino oscillations and LBNF/DUNE project	-Problem 2 of chapter 3 -Problem 2.3 -Compare Eq 2.18 of chapter 3 with Eq 1.54 of chapter 2
12/12/2023	2.2	Heisenberg equation of motion	-Ehrenfest's theorem -Problem 2.1	Problems 2.5, 2.6, 2.7, 2.8

17/12/2023	2.6	Propagators in wave equation: Rule of thumb	Self-reading: sections 2.4 and 2.5 (Recall lecture 8/10/2023)	
19/12/2023	3.4	Density operator and time evolution of ensembles	Problems 3.10, 3.11, 3.12	
24/12/2023	2.3	Harmonic oscillator	-Schwinger oscillators -Quantization of the electromagnetic fields	-Verify the set of equations of chapter 3 (from Eq 9.1 to Eq 9.12) -Verify Eq 6.18 of chapter 7 -Problem 7 of chapter 7
26/12/2023	2.3	Harmonic oscillator	Coherent state	Problems 2.11, 2.12, 2.13, 2.14, 2.15, 2.17, 2.18, 2.19
31/12/2023	3.1	The infinitesimal rotation operator	-Verify the set of equations of section 6 (from Eq 6.1 to Eq 6.21) -Problem 3.16	
2/1/2024	3.2	Precession of a spin-1/2 particle: Revisited	Compare the results of this section with that of section 2.1	Tackle Problem 3.2 of lecture 10/12/2023 again using today's approach
7/1/2024	**Second Exam (16:00 – 18:00). This is a closed-book exam covers all the materials of chapters 2 & 3. The answer key will be provided right after the end of the exam.**			
9/1/2024	Epilogue			
21/1/2024	**Final Exam (16:00 – 19:00). This is a closed-book comprehensive exam covers all the materials of the course.**			

22 Evaluation Methods:

Opportunities to demonstrate achievement of the SLOs are provided through the following assessment methods and requirements:

Evaluation Activity	Mark	Topic(s)	SLOs	Period (Week)	Platform
First Exam	30%	The materials of Chapter 1	SLO 1 - SLO 8	3/12/2023	In class
Second Exam	30%	The materials of Chapter 2 & 3	SLO 9 - SLO 14	7/1/2024	In class
Final Exam	40%	All the materials of the course.	SLO 1 - SLO 14	21/1/2024	In class

23 Course Requirements

N/A

24 Course Policies:

A- Attendance policies: According to JU by-laws.

B- Absences from exams and submitting assignments on time: According to JU by-laws.

C- Health and safety procedures: N/A

D- Honesty policy regarding cheating, plagiarism, misbehavior: According to JU by-laws.

E- Grading policy: According to JU by-laws.

F- Available university services that support achievement in the course: N/A

25 References:

A- Required book(s), assigned reading and audio-visuals:

Text: Modern QM, by J. Sakurai and J. Napolitano, 3rd edition, Cambridge University Press 2021, ISBN 978-1-108-47322-4.

B- Recommended books, materials, and media:

- References: any advanced book on a level comparable to Sakurai's book. Recommended titles (among others): QM by Merzbacher, Principles of QM by Shankar, QM by Schiff, QM by Messiah, and QM by Rae. It is extremely beneficial to glance -at least- at superb books written by some of the major creators of QM: The Principles of QM by Dirac, Lectures on QM by Weinberg, and Advanced QM by Dyson. For linear algebra I highly recommend the text of Gilbert Strang: Introduction to Linear Algebra, 5th edition, Cambridge University Press 2016.
- Self-reading titles: Foundations of Quantum Mechanics, by Travis Norsen, 2017, Springer. Quantum Physics for Poets, by Leon Lederman and Christopher Hill, 2011, Prometheus Books. How to Understand Quantum Mechanics, by John Ralston, 2017, IOP. Understanding Quantum Mechanics, by Roland Omnes, 1999, Princeton University Press. The Interpretation of Quantum Mechanics, by Roland Omnes, 1994, Princeton Series in Physics. Quantum: Einstein, Bohr and the Great Debate about the Nature of Reality, by Manjit Kumar, 2009, Icon Books Ltd. Quantum Physics: Illusion or Reality? By Alastair Rae, 2004, Cambridge University Press.

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26 Additional information:

N/A

Name of Course Coordinator: **Mohd Hussein** Signature: ***Moh'd A, Hussein*** Date: **25/12/2023**
Head of Curriculum Committee/Department: --------------------------- Signature: ------------------------------------
Head of Department: -- Signature: ------------------------------
Head of Curriculum Committee/Faculty: --------------------------------------- Signature: ---------------------------
Dean: -- Signature: --