TEACHING INSTRUCTIONAL DESIGN (BRP)

COURSE

QUANTUM MECHANICS 2

by

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Depok
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PREFACE

The Quantum Mechanics 2 course is a 5th semester course for students who have finished the Quantum Mechanics 1 course. For 12 weeks students will receive lecture materials on the classical equation of motion for an electron under an electromagnetic field, the Schrödinger equation for an electron under an electromagnetic field, gauge transformation and minimal substitution, the effects of a constant magnetic field and its application on the normal Zeeman effect, the effects of a strong magnetic field by using the Schrödinger equation, the effects of a magnetic field on simple cases: Landau levels, Hall effect, and Aharanov-Bohm effect, harmonic oscillator operators in matrix form, orbital angular momentum operators in matrix form, spin angular momentum operators in matrix form, the magnetic moment of a particle with spin-½, paramagnetic resonance, the summation of two spins, the summation of spin-½ with orbital angular momentum, the summation of angular momenta and its application on cases involving identical particles, the Clebsch-Gordan coefficient, notation, and how to read coefficient values, the application of summing angular momenta on cases involving particle parity, perturbation theory for non-degenerate cases, perturbation theory for degenerate cases, the Stark effect, the degeneration of a hydrogen atom with n = 2 due to spin-orbit coupling, the anomalous Zeeman effect, hyperfine structures, the ionization energy of a Helium atom, the effects of the repulsive force between electrons, the impact of Pauli's exclusion principle, molecule orbitals, the expected energy value of an H_2 molecule, molecule rotational and vibrational energy, time-dependent perturbation theory, constant perturbation in time-dependent perturbation theory, atom coupling with electromagnetic fields, phase space and calculation of matrix elements based on selection rules, scattering cross-sections, elastic and inelastic scattering, low energy cross-sections, the Breit-Wigner formula and S-wave scattering in cases involving a square well, formulation of the Born approximation, and scattering in general in cases involving identical particles.

It is hoped that after finishing the Quantum Mechanics 2 course students will be able to apply advanced concepts and formulations in quantum mechanics on related problems in physics, such as the interaction between charged particles and an electromagnetic field, perturbation in quantum systems, and particle scattering due to electromagnetic interaction.

Depok, September 2020

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I. General Information

1.	Name of Program / Study Level	:	Physics / Undergraduate
2.	Course Name	:	Quantum Mechanics 2
3.	Course Code	:	SCFI603116
4.	Semester	:	5
5.	Credit	:	3 credits
6.	Teaching Method(s)	:	Interactive lecture and discussion
7.	Prerequisite course(s)	:	Quantum Mechanics 1
8.	Requisite for course(s)	:	Relativistic Quantum Mechanics, Quantum Field Theory
9.	Integration Between Other Courses	:	-
10.	Lecturer(s)	:	Prof. Dr. Drs. Terry Mart
11.	Course Description	:	This course discusses the advanced concepts and formulations in quantum mechanics and trains students' capability in understanding and applying those concepts to related problems in physics, such as the interaction between charged particles and an electromagnetic field, perturbation in quantum systems, and particle scattering due to electromagnetic interaction.

II. Course Learning Outcome (CLO) and Sub-CLOs

A. CLO

After the completion of this course, students will be able to apply advanced concepts and formulations in quantum mechanics on related problems in physics, such as the interaction between charged particles and an electromagnetic field, perturbation in quantum systems, and particle scattering due to electromagnetic interaction.

B. Sub-CLO

After the completion of this course, students will be able to:

1. Calculate the effects of the interaction between an electron and an electromagnetic field (C3),
2. Derive operator representations in matrix form (C3),
3. Calculate the summation of angular momenta (C3),
4. Derive the formula for time-independent perturbation theory and analyze its applications (C3, C4),
5. Calculate several observables of a real Hydrogen atom (C3),
6. Analyze the characteristics of a Helium atom (C4),
7. Analyze simple molecules such as H2 Hydrogen molecules (C3),
8. Derive the formula for time-dependent perturbation theory and apply it in several cases in physics (C3),
9. Derive the general formula for scattering theory (C3).

III. Teaching Plan

Week	Sub-CLO	Study Materials	Teaching Method	Time Required	Learning Experiences (*O-E-F)	Sub-CLO Weight on Course (%)	Sub-CLO Achievement Indicator	References
1	1	• Introduction • Classical equation of motion for an electron under an electromagnetic field • Schrödinger equation for an electron under an electromagnetic field • Gauge transformation • and minimal substitution	Face-to-face lecture, discussion, and structured individual learning	3x50 minutes	40% O, 30% E, 30% F	50%	Students can derive and analyze the equation of motion for an electron under an electromagnetic field.	
2	1	• Effects of a constant magnetic field and its application on the normal Zeeman effect • Effects of a strong magnetic field by using the Schrödinger equation • Effects of a magnetic field on simple cases: Landau levels, Hall effect, and Aharanov-Bohm effect	Face-to-face lecture, discussion, and structured individual learning	3x50 minutes	40% O, 30% E, 30% F	50%	Students can derive and analyze the effects of a constant magnetic field on the normal Zeeman effect, the effects of a strong magnetic field by using the Schrödinger equation, and the effects of a magnetic field on simple cases, such as Landau levels, Hall effect, and Aharanov-Bohm effect.	
3	2	• Harmonic oscillator operator in matrix form	Face-to-face lecture, discussion, and	3x50 minutes	40% O, 30% E, 30% F	100%	Students can derive harmonic oscillator, orbital angular	

		• Orbital angular momentum operator in matrix form • Spin angular momentum operator in matrix form • Magnetic moment of a particle with spin-½ • Paramagnetic resonance	structured individual learning				momentum, and spin angular momentum operators in matrix form, the magnetic moment of a particle with spin-½, and apply them to cases involving paramagnetic resonance.	
4	3	• Summation of two spins • Summation of spin-½ with orbital angular momentum • Summation of angular momenta and its application on cases involving identical particles	Face-to-face lecture, discussion, and structured individual learning	3x50 minutes	40% O, 30% E, 30% F	50%	Students can calculate the summation of two spins, spin-½ with orbital angular momentum, and angular momenta along with its application on cases involving identical particles.	
5	3	• Clebsch-Gordan coefficient, notation, and how to read coefficient values • Application of summing angular momenta on cases involving particle parity	Face-to-face lecture, discussion, and structured individual learning	3x50 minutes	40% O, 30% E, 30% F	50%	Students can calculate the Clebsch-Gordan coefficient use its notation and apply it.	
6	4	• Perturbation theory for non-degenerate cases	Face-to-face lecture, discussion, and structured individual learning	3x50 minutes	40% O, 30% E, 30% F	50%	Students can calculate the Clebsch-Gordan coefficient use its notation and apply it.	
7	4	• Perturbation theory for degenerate cases • Stark effect	Face-to-face lecture, discussion, and	3x50 minutes	40% O, 30% E, 30% F	50%	Students can apply time-independent perturbation theory for	

			structured individual learning				degenerate cases and analyze the Stark effect	
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9	5	• Degeneration of a hydrogen atom with n = 2 due to spin-orbit coupling • Anomalous Zeeman effect • Hyperfine structure	Face-to-face lecture, discussion, and structured individual learning	3x50 minutes	40% O, 30% E, 30% F	100%	Students can calculate the degeneration of a Hydrogen atom with n = 2 due to spin-orbit coupling, analyze the anomalous Zeeman effect, and hyperfine structures.	
10	6	• Ionization energy of a Helium atom • Effects of the repulsive force between electrons • Impact of Pauli's exclusion principle	Face-to-face lecture, discussion, and structured individual learning	3x50 minutes	40% O, 30% E, 30% F	100%	Students can calculate the ionization energy of a Helium atom, analyze the effects of the repulsive force between electrons, and the impact of Pauli's exclusion principle.	
11	7	• Molecule orbitals • Expected energy value of an H2 molecule • Molecule rotational and vibrational energy	Face-to-face lecture, discussion, and structured individual learning	3x50 minutes	40% O, 30% E, 30% F	100%	Students can calculate molecule orbitals, the expected energy value of an H2 molecule, and the rotational and vibrational energy of a molecule.	
12	8	• Time-dependent perturbation theory • Constant perturbation in time-dependent perturbation theory	Face-to-face lecture, discussion, and structured individual learning	3x50 minutes	40% O, 30% E, 30% F	50%	Students can use time-dependent perturbation theory and apply it for constant perturbations.	
13	8	• Atom coupling with electromagnetic fields	Face-to-face lecture,	3x50 minutes	40% O, 30% E, 30% F	50%	Students can apply time-dependent	

		• Phase space and calculation of matrix elements based on selection rules	discussion, and structured individual learning				perturbation theory for cases with atom coupling with electromagnetic fields, analyze phase space, and calculate matrix elements based on selection rules.	
14	9	• Scattering cross-section • Elastic and inelastic scattering • Low energy cross-section	Face-to-face lecture, discussion, and structured individual learning	3x50 minutes	40% O, 30% E, 30% F	50%	Students can calculate scattering cross-sections in general, in cases with elastic scattering and inelastic scattering, and the cross-section for low energy.	
15	9	• Breit-Wigner formula and S-wave scattering in cases involving a square well • Formulation of the Born approximation • Scattering in general in cases involving identical particles	Face-to-face lecture, discussion, and structured individual learning	3x50 minutes	40% O, 30% E, 30% F	50%	Students can analyze the Breit-Wigner formula and S-wave scattering for cases involving a square well, derive the formulation for the Born approximation and apply scattering formulas in general for cases involving identical particles.	
16	**Final Exam**							

*) O : Orientation
E : Exercise
F : Feedback

References:

1. S. Gasiorowicz, Quantum Physics, John Wiley & Sons, Inc., 1996.
2. A. Goswami, Quantum Mechanics 2nd Ed., Wm. C. Brown Publishers, 1997.

IV. Assignment Design

Week	Assignment Name	Sub-CLO	Assignment	Scope	Working Procedure	Deadline	Outcome
1	Exercise 1	1	Problem set	• Introduction • Classical equation of motion for an electron under an electromagnetic field • Schrödinger equation for an electron under an electromagnetic field	Individual homework	1 Week	Answer sheet
2	Exercise 2	1	Problem set	• Gauge transformation and minimal substitution • Effects of a constant magnetic field and its application on the normal Zeeman effect • Effects of a strong magnetic field by using the Schrödinger equation • Effects of a magnetic field on simple cases: Landau levels, Hall effect, and Aharanov-Bohm effect	Individual homework	1 Week	Answer sheet
3	Exercise 3	2	Problem set	• Harmonic oscillator operator in matrix form • Orbital angular momentum operator in matrix form • Spin angular momentum operator in matrix form • Magnetic moment of a particle with spin-½ • Paramagnetic resonance	Individual homework	1 Week	Answer sheet
4	Exercise 4	2	Problem set	• Summation of two spins • Summation of spin-½ with orbital angular momentum • Summation of angular momenta and its application on cases involving identical particles • Clebsch-Gordan coefficient, notation, and how to read coefficient values • Application of summing angular momenta on cases involving particle parity	Individual homework	1 Week	Answer sheet

5	Exercise 5	3	Problem set	• Perturbation theory for non-degenerate cases • Perturbation theory for degenerate cases • Stark effect • Degeneration of a hydrogen atom with n = 2 due to spin-orbit coupling • Anomalous Zeeman effect • Hyperfine structure • Ionization energy of a Helium atom • Effects of the repulsive force between electrons • Impact of Pauli's exclusion principle	Individual homework	1 Week	Answer sheet
6	Exercise 6	3	Problem set	• Molecule orbitals • Expected energy value of an H2 molecule • Molecule rotational and vibrational energy	Individual homework	1 Week	Answer sheet
7	Exercise 7	4	Problem set	• Time-dependent perturbation theory • Constant perturbation in time-dependent perturbation theory • Atom coupling with electromagnetic fields	Individual homework	1 Week	Answer sheet
8	Exercise 8	4	Problem set	• Phase space and calculation of matrix elements based on selection rules • Scattering cross-section	Individual homework	1 Week	Answer sheet
9	Exercise 9	5	Problem set	• Elastic and inelastic scattering • Low energy cross-section • Breit-Wigner formula and S-wave scattering in cases involving a square well	Individual homework	1 Week	Answer sheet
10	Exercise 10	5	Problem set	• Formulation of the Born approximation • Scattering in general in cases involving identical particles	Individual homework	1 Week	Answer sheet

V. Assessment Criteria (Learning Outcome Evaluation)

Evaluation Type	Sub-CLO	Assessment Type	Frequency	Evaluation Weight (%)
Weekly Assignment	1, 2, 3, 4, 5, 6, 7, 8, 9	Homework	10	30
Midterm Exam	1, 2, 3, 4	Written exam	1	30
Final Exam	5, 6, 7, 8, 9	Written exam	1	40
Total				**100**

VI. Rubric

A. Criteria of Presentation Score

Score	Presentation Delivery
85-90	Group is able to deliver the explanation logically, fluently, and punctual and be able to answer the questions from other students and lecturer
75-84	Group is able to deliver the explanation logically and fluently and be able to answer the questions from other students and lecturer, but be less punctual on delivering the explanation
65-74	Group is able to deliver the explanation fluently, but be less able to deliver the reasoning logic of the explanation
55-64	Group is less able to deliver the explanation fluently and punctual and be less able to deliver the reasoning logic of the explanation
<55	

B. Criteria of Assignment and Exam Scores

Score	Answer Quality
100	Answer is very precise and all the concept and main component are explained completely
76-99	Answer is fairly precise and the concept and main component are explained fairly complete
51-75	Answer is less precise and the concept and main component are explained less complete
26-50	Answer is poorly precise and the concept and main component are explained poorly complete
<25	Answer is wrong