TEACHING INSTRUCTIONAL DESIGN (BRP)

COURSE

QUANTUM PHYSICS 2

by

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UNIVERSITAS INDONESIA
FACULTY OF MATHEMATICS AND NATURAL SCIENCES
PHYSICS UNDERGRADUATE STUDY PROGRAM

TEACHING INSTRUCTIONAL DESIGN

Course Name	Quantum Physics 2	**Credit(s)**	**Prerequisite course(s)**	**Requisite for course(s)**	**Integration Between Other Courses**
Course Code	SCPH602122	3	Quantum Physics 1	Relativistic Quantum Mechanics, Quantum Field Theory	None
Relation to Curriculum	Compulsory Course				
Semester	5th				
Lecturer(s)	Prof. Dr. Drs. Terry Mart				
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.				
Online Class Link	https://emas.ui.ac.id/course/view.php?id=2923				

Program Learning Outcome (PLO)	
PLO-1	Apply concepts in physics in solving general problems in physics.
PLO-2	Formulate problems and solutions in mechanics, electrodynamics, electricity, and magnetism that involve quantum effects.
PLO-3	Derive specific equations for advanced quantum problems, obtain their solution, and analyze it.

Course Learning Outcome (CLO)	
CLO-1	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.
Sub-CLO(s)	
Sub-CLO 1	Calculate the effects of the interaction between an electron and an electromagnetic field (C3).
Sub-CLO 2	Derive operator representations in matrix form (C3).
Sub-CLO 3	Calculate the summation of angular momenta (C3).
Sub-CLO 4	Derive the formula for time-independent perturbation theory and analyze its applications (C3, C4).
Sub-CLO 5	Calculate several observables of a real Hydrogen atom (C3).
Sub-CLO 6	Analyze the characteristics of a Helium atom (C4).
Sub-CLO 7	Analyze simple molecules such as H_2 Hydrogen molecules (C3).
Sub-CLO 8	Derive the formula for time-dependent perturbation theory and apply it in several cases in physics (C3).
Sub-CLO 9	Derive the general formula for scattering theory (C3).
Study Materials	– 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 – 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 – 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

	– Summation of two spin – 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 – 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 – Molecule orbitals – 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-section – Elastic and inelastic scattering – Low energy cross-section – 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
Reading List	[1] S. Gasiorowicz, *Quantum Physics* 3rd Ed., John Wiley & Sons, Inc., 2003. [2] A. Goswami, *Quantum Mechanics* 2nd Ed., Wm. C. Brown Publishers, 1997.

I. Teaching Plan

Week	Sub-CLO	Study Materials [reference]	Teaching Method [estimated time]	Teaching Mode	Learning Experiences (*O-E-F)		Sub-CLO Achievement Indicator	Sub-CLO Weight on Course (%)
					Online	Offline	General Indicator; Specific Indicator	
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 and discussion** (50 minutes) **Structured individual learning** 1. Reading study materials and deriving formulas from the textbook. (50 minutes) 2. Doing problem sets in the book. (50 minutes)	**Synchronous** MS Teams **Asynchronous**	**O (40%)** **Synchronous:** Face-to-face lecture via MS Teams. **F (30%)** **Synchronous:** Question and answer session during the lecture	**E (30%)** **Asynchronous:** Reading study materials and deriving formulas from the textbook. **Asynchronous:** Problem set.	**General Indicator:** After the synchronous lecture, reading study materials, and doing problem sets, students can derive and analyze the effects of the interaction between an electron and an electromagnetic field. **Specific Indicator:** Students can derive and analyze the equation of motion for an electron under an electromagnetic field.	50
2	1	- Effects of a constant magnetic field and its application on the normal Zeeman effect	**Face-to-face lecture and discussion** (50 minutes)	**Synchronous** MS Teams **Asynchronous**	**O (40%)** **Synchronous:** Face-to-face lecture via MS	**E (30%)** **Asynchronous:** Students find reference	**General Indicator:** After the synchronous lecture, reading study	50

		- 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	**Structured individual learning** 1. Reading study materials and deriving formulas from the textbook. (50 minutes) 2. Doing problem sets in the book. (50 minutes)		Teams. **F (30%)** **Synchronous:** Question and answer session during the lecture	material to answer questions in the problem set. **Asynchronous:** Problem set.	materials, and doing problem sets, students can derive and analyze the effects of the interaction between an electron and an electromagnetic field. **Specific Indicator:** 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 - Orbital angular momentum operator in	**Face-to-face lecture and discussion** (50 minutes)	**Synchronous** MS Teams **Asynchronous**	**O (40%)** **Synchronous:** Face-to-face lecture via MS Teams.	**E (30%)** **Asynchronous:** Students find reference material to	**General Indicator:** After the synchronous lecture, reading study materials, and doing	100

		matrix form - Spin angular momentum operator in matrix form - Magnetic moment of a particle with spin-½ - Paramagnetic resonance	**Structured individual learning** 1. Reading study materials and deriving formulas from the textbook. (50 minutes) 2. Doing problem sets in the book. (50 minutes)		**F (30%)** **Synchronous:** Question and answer session during the lecture	answer questions in the problem set. **Asynchronous:** Problem set.	problem sets, students can derive operator representations in matrix form. **Specific Indicator:** Students can derive harmonic oscillator, orbital angular 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 spin - Summation of spin-½ with orbital angular momentum - Summation of angular momenta and its application on cases involving identical particles	**Face-to-face lecture and discussion** (50 minutes) **Structured individual learning** 1. Reading study materials and deriving formulas from	**Synchronous** MS Teams **Asynchronous**	**O (40%)** **Synchronous:** Face-to-face lecture via MS Teams. **F (30%)** **Synchronous:** Question and answer session during the lecture	**E (30%)** **Asynchronous:** Students find reference material to answer questions in the problem set. **Asynchronous:** Problem set.	**General Indicator:** After the synchronous lecture, reading study materials, and doing problem sets, students can calculate the summation of angular momenta. **Specific Indicator:**	50

			the textbook. (50 minutes) 2. Doing problem sets in the book. (50 minutes)				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 and discussion** (50 minutes) **Structured individual learning** 1. Reading study materials and deriving formulas from the textbook. (50 minutes) 2. Doing problem sets in the book. (50 minutes)	**Synchronous** MS Teams **Asynchronous**	**O (40%)** **Synchronous:** Face-to-face lecture via MS Teams. **F (30%)** **Synchronous:** Question and answer session during the lecture	**E (30%)** **Asynchronous:** Students find reference material to answer questions in the problem set. **Asynchronous:** Problem set.	**General Indicator:** After the synchronous lecture, reading study materials, and doing problem sets, students can calculate the summation of angular momenta. **Specific Indicator:** Students can calculate the Clebsch-Gordan coefficient use its notation, and apply it	50
6	4	- Perturbation theory for non-degenerate cases	**Face-to-face lecture and discussion** (50 minutes)	**Synchronous** MS Teams **Asynchronous**	**O (40%)** **Synchronous:** Face-to-face lecture via MS	**E (30%)** **Asynchronous:** Students find reference	**General Indicator:** After the synchronous lecture, reading study	50

			Structured individual learning 1. Reading study materials and deriving formulas from the textbook. (50 minutes) 2. Doing problem sets in the book. (50 minutes)		Teams. **F (30%)** **Synchronous:** Question and answer session during the lecture	material to answer questions in the problem set. **Asynchronous:** Problem set.	materials, and doing problem sets, students can calculate the summation of angular momenta. **Specific Indicator:** 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 and discussion** (50 minutes) **Structured individual learning** 1. Reading study materials and deriving formulas from the textbook. (50 minutes) 2. Doing problem sets in the book. (50 minutes)	**Synchronous** MS Teams **Asynchronous**	**O (40%)** **Synchronous:** Face-to-face lecture via MS Teams. **F (30%)** **Synchronous:** Question and answer session during the lecture	**E (30%)** **Asynchronous:** Students find reference material to answer questions in the problem set. **Asynchronous:** Problem set.	**General Indicator:** After the synchronous lecture, reading study materials, and doing problem sets, students can derive the formula for time-independent perturbation theory and analyze its applications. **Specific Indicator:** Students can apply time-independent perturbation theory for degenerate cases	50

							and analyze the Stark effect	
8	**Mid-Term Exam**							
9	5	- Degeneration of a hydrogen atom with n = 2 due to spin-orbit coupling - Anomalous Zeeman effect - Hyperfine structure	**Face-to-face lecture and discussion** (50 minutes) **Structured individual learning** 1. Reading study materials and deriving formulas from the textbook. (50 minutes) 2. Doing problem sets in the book. (50 minutes)	**Synchronous** MS Teams **Asynchronous**	**O (40%)** **Synchronous:** Face-to-face lecture via MS Teams. **F (30%)** **Synchronous:** Question and answer session during the lecture	**E (30%)** **Asynchronous:** Students find reference material to answer questions in the problem set. **Asynchronous:** Problem set.	**General Indicator:** After the synchronous lecture, reading study materials, and doing problem sets, students can calculate several observables of a real Hydrogen atom. **Specific Indicator:** 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.	100
10	6	- Ionization energy of a Helium atom - Effects of the repulsive force between electrons - Impact of Pauli's	**Face-to-face lecture and discussion** (50 minutes)	**Synchronous** MS Teams **Asynchronous**	**O (40%)** **Synchronous:** Face-to-face lecture via MS Teams.	**E (30%)** **Asynchronous:** Students find reference material to answer	**General Indicator:** After the synchronous lecture, reading study materials, and doing problem sets,	100

		exclusion principle	**Structured individual learning** 1. Reading study materials and deriving formulas from the textbook. (50 minutes) 2. Doing problem sets in the book. (50 minutes)		**F (30%)** **Synchronous:** Question and answer session during the lecture	questions in the problem set. **Asynchronous:** Problem set.	students can analyze the characteristics of a Helium atom. . **Specific Indicator:** 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 H_2 molecule - Molecule rotational and vibrational energy	**Face-to-face lecture and discussion** (50 minutes) **Structured individual learning** 1. Reading study materials and deriving formulas from the textbook. (50 minutes) 2. Doing problem sets in the book. (50 minutes)	**Synchronous** MS Teams **Asynchronous**	**O (40%)** **Synchronous:** Face-to-face lecture via MS Teams. **F (30%)** **Synchronous:** Question and answer session during the lecture	**E (30%)** **Asynchronous:** Students find reference material to answer questions in the problem set. **Asynchronous:** Problem set.	**General Indicator:** After the synchronous lecture, reading study materials, and doing problem sets, students can analyze simple molecules such as H_2 Hydrogen molecules. **Specific Indicator:** Students can calculate molecule orbitals, the expected energy value of an H_2 molecule, and the	100

							rotational and vibrational energy of a molecule.	
12	8	- Time-dependent perturbation theory - Constant perturbation in time-dependent perturbation theory	**Face-to-face lecture and discussion** (50 minutes) **Structured individual learning** 1. Reading study materials and deriving formulas from the textbook. (50 minutes) 2. Doing problem sets in the book. (50 minutes)	**Synchronous** MS Teams **Asynchronous**	**O (40%)** **Synchronous:** Face-to-face lecture via MS Teams. **F (30%)** **Synchronous:** Question and answer session during the lecture	**E (30%)** **Asynchronous:** Students find reference material to answer questions in the problem set. **Asynchronous:** Problem set.	**General Indicator:** After the synchronous lecture, reading study materials, and doing problem sets, students can derive the formula for time-dependent perturbation theory and apply it in several cases in physics. **Specific Indicator:** Students can use time-dependent perturbation theory and apply it for constant perturbations.	50
13	8	- Atom coupling with electromagnetic fields - Phase space and calculation of matrix elements based on selection rules	**Face-to-face lecture and discussion** (50 minutes) **Structured individual learning**	**Synchronous** MS Teams **Asynchronous**	**O (40%)** **Synchronous:** Face-to-face lecture via MS Teams. **F (30%)** **Synchronous:**	**E (30%)** **Asynchronous:** Students find reference material to answer questions in the problem set.	**General Indicator:** After the synchronous lecture, reading study materials, and doing problem sets, students can derive the formula for time-	50

			1. Reading study materials and deriving formulas from the textbook. (50 minutes) 2. Doing problem sets in the book. (50 minutes)		Question and answer session during the lecture	**Asynchronous:** Problem set.	dependent perturbation theory and apply it in several cases in physics. **Specific Indicator:** Students can apply time-dependent 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 and discussion** (50 minutes) **Structured individual learning** 1. Reading study materials and deriving formulas from the textbook. (50 minutes)	**Synchronous** MS Teams **Asynchronous**	**O (40%) Synchronous:** Face-to-face lecture via MS Teams. **F (30%) Synchronous:** Question and answer session during the lecture	**E (30%) Asynchronous:** Students find reference material to answer questions in the problem set. **Asynchronous:** Problem set.	**General Indicator:** After the synchronous lecture, reading study materials, and doing problem sets, students can derive the general formula for scattering theory. **Specific Indicator:** Students can calculate scattering cross-sections in	50

			2. Doing problem sets in the book. (50 minutes)				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 and discussion** (50 minutes) **Structured individual learning** 1. Reading study materials and deriving formulas from the textbook. (50 minutes) 2. Doing problem sets in the book. (50 minutes)	**Synchronous** MS Teams **Asynchronous**	**O (40%)** **Synchronous:** Face-to-face lecture via MS Teams. **F (30%)** **Synchronous:** Question and answer session during the lecture	**E (30%)** **Asynchronous:** Students find reference material to answer questions in the problem set. **Asynchronous:** Problem set.	**General Indicator:** After the synchronous lecture, reading study materials, and doing problem sets, students can derive the general formula for scattering theory. **Specific Indicator:** 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.	50
16	**Final Exam**							

II. Assignment Design

Week	Assignment Name	Sub-CLOs	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 electromagnetic field	Individual homework	1 week	Uploaded answer in EMAS
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	Uploaded answer in EMAS
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	Uploaded answer in EMAS
4	Exercise 4	2	Problem set	- Summation of two spin - Summation of spin-½ with orbital angular momentum - Summation of angular	Individual homework	1 week	Uploaded answer in EMAS

				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			
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	Uploaded answer in EMAS
6	Exercise 6	3	Problem set	- Molecule orbitals - Expected energy value of an H_2 molecule - Molecule rotational and vibrational energy	Individual homework	1 week	Uploaded answer in EMAS
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	Uploaded answer in EMAS

8	Exercise 8	4	Problem set	- Phase space and calculation of matrix elements based on selection rules - Scattering cross-section	Individual homework	1 week	Uploaded answer in EMAS
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	Uploaded answer in EMAS
10	Exercise 10	5	Problem set	- Formulation of the Born approximation - Scattering in general in cases involving identical particles	Individual homework	1 week	Uploaded answer in EMAS

III. 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
Mid-Term Exam	1, 2, 3, 4	Written exam via EMAS	1	30
Final Exam	5, 6, 7, 8, 9	Written exam via EMAS	1	40
			Total:	100

IV. Rubric(s)

This rubric is used as a guideline for assessing or giving levels of student performance results. a rubric usually consists of assessment criteria that include the dimensions / aspects that are assessed based on indicators of learning achievement. This assessment rubric is useful for clarifying the basics and aspects of the assessment so that students and lecturers can be guided by the same thing regarding the expected performance demands. Lecturers can choose the type of rubric according to the assessment given.

A. Conversion of the student's final score

Score	Grade	Equivalent
85 - 100	A	4.00
80 - < 85	A-	3.70
75 - < 80	B+	3.30
70 - < 75	B	3.00
65 - < 70	B-	2.70
60 - < 65	C+	2.30
55 - < 60	C	2.00
40 - < 50	D	1.00
< 40	E	0.00

B. Assessment rubric

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