

TEACHING INSTRUCTIONAL DESIGN (BRP)

COURSE

QUANTUM PHYSICS 2

by

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Undergraduate Program in Physics Faculty of Mathematics and Natural Sciences Universitas Indonesia Depok September 2020



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			Relativistic				
Relation to Curriculum	Compulsory Course	3	Quantum Physics 1	Quantum Mechanics,	None			
Semester	5 th	5		Quantum Field Theory	None			
Lecturer(s)	Prof. Dr. Drs. Terry Mart							
Course Description	This course discusses the advance capability in understanding and ap between charged particles and a scattering due to electromagnetic	pplying those conce an electromagnetic	pts to related proble	ems in physics, such	as the interaction			
Online Class Link	https://emas.ui.ac.id/course/view.p	ohp?id=2923						
Program Learning Outcome (PLO)							
PLO-1	Apply concepts in physics in solv	ing general problen	ns in physics.					
PLO-2	Formulate problems and solutions in mechanics, electrodynamics, electricity, and magnetism that involve quantum effects.							
PLO-3	Derive specific equations for adva	nced quantum prob	olems, obtain their s	olution, and analyze	e it.			

Course Learning Outco	ome (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 Magnetic moment of a particle with spin-½ Paramagnetic resonance

	– Summation of two spin
	- Summation of spin- ¹ / ₂ 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
D H H	[1] S. Gasiorowicz, <i>Quantum Physics</i> 3rd Ed., John Wiley & Sons, Inc., 2003.
Reading List	[2] A. Goswami, <i>Quantum Mechanics</i> 2nd Ed., Wm. C. Brown Publishers, 1997.

I. Teaching Plan

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

		- Effects of a strong	Structured		Teams.	material to	materials, and doing	
		magnetic field by	individual		i camb.	answer	problem sets,	
		using the Schrödinger	learning		F (30%)	questions in the	students can derive	
		equation	1. Reading study		· · · ·	problem set.	and analyze the	
		•			Synchronous:	problem set.	•	
		- Effects of a magnetic	materials and		Question and		effects of the	
		field on simple cases:	deriving		answer session	Asynchronous:	interaction between	
		Landau levels, Hall	formulas from		during the	Problem set.	an electron and an	
		effect, and Aharanov-	the textbook.		lecture		electromagnetic	
		Bohm effect	(50 minutes)				field.	
			2. Doing problem					
			sets in the book.				Specific Indicator:	
			(50 minutes)				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	Face-to-face	Synchronous	O (40%)	E (30%)	General Indicator:	100
		operator in matrix	lecture and	MS Teams	Synchronous:	Asynchronous:	After the	
		form	discussion		Face-to-face	Students find	synchronous lecture,	
		- Orbital angular	(50 minutes)	Asynchronous	lecture via MS	reference	reading study	
		momentum operator in		_	Teams.	material to	materials, and doing	

	motiv form	Stand			0.00000	nuchlam cata	
				E (200/)		•	
				, ,	*		
	•	0		-	problem set.	*	
		e .		-		-	
	U				•	matrix form.	
		e		during the	Problem set.		
	- Paramagnetic			lecture		-	
	resonance	the textbook.				Students can derive	
		(50 minutes)				harmonic oscillator,	
		2. Doing problem				orbital angular	
		sets in the book.				momentum, and spin	
		(50 minutes)				angular momentum	
						operators in matrix	
						form, the magnetic	
						moment of a particle	
						with spin- ¹ /2, and	
						apply them to cases	
						involving	
						paramagnetic	
						resonance	
3	- Summation of two	Face-to-face	Synchronous	O (40%)	E (30%)	General Indicator:	50
	spin	lecture and	MS Teams	Synchronous:	Asynchronous:	After the	
	- Summation of spin- ¹ / ₂	discussion		Face-to-face	Students find	synchronous lecture,	
	with orbital angular	(50 minutes)	Asynchronous	lecture via MS	reference	reading study	
	momentum		-	Teams.	material to	materials, and doing	
	- Summation of angular	Structured			answer	problem sets,	
	momenta and its	individual		F (30%)	questions in the	students can	
	application on cases	learning		· /	^	calculate the	
		0		Question and		summation of	
	e e	materials and		answer session	Asynchronous:	angular momenta.	
					Problem set.		
		formulas from		lecture		Specific Indicator:	
	3	 3 - Summation of two spin - Summation of spin-¹/₂ with orbital angular momentum - Summation of angular 	 Spin angular momentum operator in matrix form Magnetic moment of a particle with spin-½ Paramagnetic resonance Paramagnetic resonance Summation of two spin Summation of spin-½ with orbital angular momenta and its application on cases involving identical particles 	-Spin angular momentum operator in matrix formindividual learning-Magnetic moment of a particle with spin-½ - Paramagnetic resonance1. Reading study materials and deriving formulas from the textbook. (50 minutes)-Paramagnetic resonanceformulas from the textbook. (50 minutes)2. Doing problem sets in the book. (50 minutes)2. Doing problem sets in the book. (50 minutes)3-Summation of two spin-Summation of spin-½ with orbital angular momentumFace-to-face lecture and discussion (50 minutes)-Summation of angular momentum-Summation of angular momenta and its application on cases involving identical particlesStructured individual learning-Summation of angular momenta and its application on cases involving identical particlesStructured individual learning	- Spin angular individual F (30%) momentum operator in matrix form I. Reading study Question and - Magnetic moment of a particle with spin-½ - Paramagnetic formulas from utring the - Paramagnetic formulas from the textbook. (50 minutes) I. Composition - Paramagnetic formulas from the textbook. (50 minutes) I. Doing problem - Summation of two sets in the book. (50 minutes) I. Spin Synchronous: - Summation of spin Face-to-face Synchronous Synchronous: - Summation of spin formutes) MS Teams Synchronous: - Summation of angular Structured MS Teams. Face-to-face Iscussion Structured individual F (30%) Teams. - Summation of angular Structured Synchronous: Face-to-face involving identical particles Individual F (30%)	3- Spin angular momentum operator in matrix form - Magnetic moment of a particle with spin-1/2 - Paramagnetic resonanceindividual 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 lecturequestions in the problem set.3- Summation of two spin - Summation of spin-1/2 with orbital angular momentumFace-to-face individual discussion (50 minutes)Synchronous MS TeamsO (40%) Synchronous: Face-to-face lecture and discussion (50 minutes)E (30%) Asynchronous: Face-to-face lecture and discussion (50 minutes)Synchronous MS TeamsE (30%) Synchronous: Face-to-face lecture via MS Teams3- Summation of spin-1/2 with orbital angular momentumFace-to-face individual learning 1. Reading study materials and derivingSynchronous MS TeamsC (40%) Synchronous: Face-to-face lecture via MS Teams.E (30%) synchronous: Face-to-face lecture via MS Teams.E (30%) synchronous: Face-to-face lecture via MS Teams.3- Summation of angular momentumStructured individual learning 1. Reading study materials and derivingMS Teams Asynchronous: F (30%) Synchronous: Problem set.F (30%) synchronous: Problem set.	- Spin angular momentum operator in matrix formindividual learning 1. Reading studyF (30%) Synchronous: Question and answer session during the lecturequestions in the problem set.students can derive operator representations in matrix form Magnetic particle with spin-½ - Paramagnetic resonanceformulas from the textbook. (50 minutes) 2. Doing problem sets in the book. (50 minutes)F (30%) Spin formulasquestions in the problem set.students can derive operator representations in matrix form.3- Summation of two spinFace-to-face lecture and with orbital angular momentum of spin-½Synchronous the textbook. (50 minutes)O (40%)E (30%) spin -½E (30%) Asynchronous angular momentum operators in matrix form, the magnetic resonance3- Summation of two spinFace-to-face lecture and with orbital angular momentum operatorsSynchronous momenta form, the magnetic resonanceC (40%)E (30%) materials and apply them to cases involving paramagnetic resonance3- Summation of spin-½ with orbital angular momentumSynchronous for inutes)Synchronous AsynchronousAsynchronous students fand question in the synchronousAsynchronous form, the magnetic resonance3- Summation of angular momentumStructured individualMs Teams formulas formulasE (30%) question in the synchronousE (30%) materials and doing answer answer application on cases involving identical particlesStructured individual

	2		the textbook. (50 minutes) 2. Doing problem sets in the book. (50 minutes)				Students can calculate the summation of two spins, spin-1/2 with orbital angular momentum, and angular momenta along with its application on cases involving identical particles	70
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

				Taama	motorial to	materials and doing	
		Structured		Teams.		Ű,	
				E (200/)		*	
				· · · ·	•		
		0			problem set.		
				-			
					•	angular momenta.	
		-		-	Problem set.		
				lecture		-	
		the textbook.					
		(50 minutes)				calculate the	
		2. Doing				Clebsch-Gordan	
		problem sets				coefficient use its	
		in the book.				notation, and apply it	
		(50 minutes)					
4	- Perturbation theory for	Face-to-face	Synchronous	O (40%)	E (30%)	General Indicator:	50
	degenerate cases	lecture and	MS Teams	Synchronous:	Asynchronous:	After the	
	- Stark effect	discussion		Face-to-face	Students find	synchronous lecture,	
		(50 minutes)	Asynchronous	lecture via MS	reference	reading study	
				Teams.	material to	materials, and doing	
		Structured			answer	problem sets,	
		individual		F (30%)	questions in the	students can derive	
		learning		Synchronous:	problem set.	the formula for time-	
		1. Reading study		Question and		independent	
		materials and		answer session	Asynchronous:	perturbation theory	
		deriving		during the	Problem set.	and analyze its	
		formulas from		lecture		applications.	
		the textbook.					
		(50 minutes)				Specific Indicator:	
		· · · · · ·					
		sets in the book.					
		(50 minutes)				•	
						for degenerate cases	
	4	degenerate cases	4- Perturbation theory for degenerate cases - Stark effect2. Doing problem sets in the book. (50 minutes)4- Perturbation theory for degenerate cases - Stark effectFace-to-face lecture and discussion (50 minutes)4- Perturbation theory for degenerate cases - Stark effectFace-to-face lecture and discussion (50 minutes)5Structured individual learning 1. Reading study materials and deriving formulas from the textbook. (50 minutes)6Image: Construct of the textbook (50 minutes)7Image: Construct of the textbook (50 minutes)8Image: Construct of the textbook (50 minutes)9Image: Construct of the textbook (50 minutes)9Image: Construct of the textbook (50 minutes)9Image: Construct of the textbook (50 minutes)	individual learningindividual learning1. Reading study materials and deriving formulas from the textbook. (50 minutes)individual deriving formulas from the textbook. (50 minutes)4- Perturbation theory for degenerate cases - Stark effectFace-to-face lecture and discussion (50 minutes)Synchronous4- Perturbation theory for degenerate cases - Stark effectFace-to-face lecture and discussion (50 minutes)Synchronous5Structured individual learning 1. Reading study materials and deriving formulas from the textbook. (50 minutes)Asynchronous	4- Perturbation theory for degenerate cases - Stark effectFace-to-face lecture and discussion (50 minutes)Synchronous: Question and answer session during the lecture4- Perturbation theory for degenerate cases - Stark effectFace-to-face discussion (50 minutes)Synchronous (50 minutes)5Stark effectStructured individual lecture and (50 minutes)MS Teams AsynchronousO (40%) Synchronous: Face-to-face lecture via MS Teams4- Perturbation theory for degenerate cases - Stark effectSynchronous Heatman (50 minutes)Synchronous Heatman (50 minutes)Face-to-face lecture and discussion (50 minutes)O (40%) Synchronous: Face-to-face lecture via MS Teams.5Heatman (50 minutes)MS Teams (50 minutes)Face-to-face lecture via MS Teams.6Commutes (50 minutes)Synchronous: (50 minutes)Face-to-face lecture via MS Teams.1Reading study materials and deriving formulas from the textbook. (50 minutes)Synchronous: Question and answer session during the lecture2Doing problem sets in the book.Commutes lectureSynchronous: lecture	4Perturbation theory for degenerate casesSame factor individual learning formulas from the textbook. (50 minutes)Synchronous: answer session during the lectureanswer question and answer session during the lectureE (30%) synchronous: Problem set.4- Perturbation theory for degenerate casesFace-to-face (50 minutes)Synchronous: (50 minutes)Synchronous: (50 minutes)Synchronous: (50 minutes)4- Perturbation theory for degenerate casesFace-to-face (50 minutes)Synchronous: (50 minutes)Synchronous: (50 minutes)Synchronous: (50 minutes)5Stark effectStructured individual learning (50 minutes)Synchronous: (50 minutes)Synchronous: (50 minutes)Synchronous: (50 minutes)4- Perturbation theory for discussion (50 minutes)Synchronous: (50 minutes)Synchronous: (50 minutes)Synchronous: (50 minutes)Synchronous: (50 minutes)5Structured individual (50 minutes)Synchronous: (50 minutes)Synchronous: (50 minutes)Synchronous: (50 minutes)6Structured individual (60 minutes)Synchronous: (50 minutes)F (30%) (30%)Synchronous: (50 minutes)7Synchronous: (50 minutes)Synchronous: (50 minutes)Synchronous: (50 minutes)Synchronous: (50 minutes)8Structured (50 minutes)Synchronous: (So minutes)Synchronous: (So minutes)Synchronous: (So minutes)9Synchronous: (So minutes)Synchronous	4Perturbation theory for degenerate cases - Stark effectStructured individual learning formulas from the textbook. (50 minutes)Synchronous: Ouestion and answer session during the lectureanswer asswer problem set.problem set. students can calculate the summation of angular momenta.4- Perturbation theory for degenerate cases - Stark effectFeac-to-face individual iscussion (50 minutes)Synchronous MS TeamsO (40%) Synchronous Face-to-face lecture via MS reams.E (30%)General Indicator: Asynchronous reams.4- Perturbation theory for degenerate cases - Stark effectFace-to-face individual learningSynchronous MS TeamsO (40%) Synchronous Face-to-face lecture via MS reams.E (30%)General Indicator: Asynchronous: problem sets, individual individual learningAsynchronous: material to answer synchronous: Face-to-face lecture via MS reams.Students find reference reference problem sets, students can derive the formula for time- independent materials and deriving formulas from the textbook. (50 minutes)Synchronous: synchronous question and answer session during the lectureF (30%) synchronous: problem set.Synchronous: problem set.4- Perturbation file individual terving formulas from the textbook. (50 minutes)Synchronous: problem set.Synchronous: problem set.4- Perturbation file individual terving formulas from the textbook. (50 minutes)Synchronous: problem set.Synchronous: prob

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

		exclusion principle	Structured		F (30%)	questions in the	students can analyze	
			individual		Synchronous:	problem set.	the characteristics of	
			learning		Question and	•	a Helium atom.	
			1. Reading study		answer session	Asynchronous:		
			materials and		during the	Problem set.	Specific Indicator:	
			deriving		lecture		Students can	
			formulas from				calculate the	
			the textbook.				ionization energy of	
			(50 minutes)				a Helium atom,	
			2. Doing problem				analyze the effects of	
			sets in the book.				the repulsive force	
			(50 minutes)				between electrons,	
							and the impact of	
							Pauli's exclusion	
							principle.	
11	7	- Molecule orbitals	Face-to-face	Synchronous	O (40%)	E (30%)	General Indicator:	100
		- Expected energy value	lecture and	MS Teams	Synchronous:	Asynchronous:	After the	
		of an H ₂ molecule	discussion		Face-to-face	Students find	synchronous lecture,	
		- Molecule rotational	(50 minutes)	Asynchronous	lecture via MS	reference	reading study	
		and vibrational energy			Teams.	material to	materials, and doing	
			Structured			answer	problem sets,	
			individual		F (30%)	questions in the	students can analyze	
			learning		Synchronous:	problem set.	simple molecules	
			1. Reading study		Question and		such as H ₂ Hydrogen	
			materials and		answer session	Asynchronous:	molecules.	
			deriving		during the	Problem set.		
			formulas from		lecture		Specific Indicator:	
			the textbook.				Students can	
			(50 minutes)				calculate molecule	
			2. Doing problem				orbitals, the expected	
			sets in the book.				energy value of an	
			(50 minutes)				H ₂ molecule, and the	

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

1. Reading study Question and dependent materials and answer session Asynchronous: perturbation deriving deriving during the Problem set. and apply it is formulas from lecture several cases physics.	n
deriving formulas fromduring the lectureProblem set.and apply it is several cases	n
formulas from lecture several cases	
the textbook. Drivsics.	1n
(50 minutes)	
2. Doing problem Specific Ind	
sets in the book. Students can	** •
(50 minutes) time-depende	
perturbation	•
for cases with	
coupling with	
electromagne	
fields, analyz	e phase
space, and ca	lculate
matrix eleme	nts
based on sele	ction
rules.	
149- Scattering cross-Face-to-faceSynchronousO (40%)E (30%)General Ind	icator: 50
section lecture and MS Teams Synchronous: Asynchronous: After the	
- Elastic and inelastic discussion Face-to-face Students find synchronous	lecture,
scattering (50 minutes) Asynchronous lecture via MS reference reading study	7
- Low energy cross- Teams. material to materials, and	d doing
section Structured answer problem sets,	
individual F (30%) questions in the students can	derive
learning Synchronous: problem set. the general for	ormula
1. Reading study Question and for scattering	theory.
materials and answer session Asynchronous:	
deriving during the Problem set. Specific Ind	cator:
formulas from lecture Students can	
the textbook. calculate scar	ttering
(50 minutes) cross-section	s in

			2. Doing problem				general, in cases with	
			sets in the book.				elastic scattering and	
			(50 minutes)				inelastic scattering, and the cross-section	
1.7					0 (100())	F (200())	for low energy.	-0
15	9	- Breit-Wigner formula	Face-to-face	Synchronous	O (40%)	E (30%)	General Indicator:	50
		and S-wave scattering	lecture and	MS Teams	Synchronous:	Asynchronous:	After the	
		in cases involving a	discussion		Face-to-face	Students find	synchronous lecture,	
		square well	(50 minutes)	Asynchronous	lecture via MS	reference	reading study	
		- Formulation of the			Teams.	material to	materials, and doing	
		Born approximation	Structured			answer	problem sets,	
		- Scattering in general	individual		F (30%)	questions in the	students can derive	
		in cases involving	learning		Synchronous:	problem set.	the general formula	
		identical particles	1. Reading study		Question and		for scattering theory.	
			materials and		answer session	Asynchronous:		
			deriving		during the	Problem set.	Specific Indicator:	
			formulas from		lecture		Students can analyze	
			the textbook.				the Breit-Wigner	
			(50 minutes)				formula and S-wave	
			2. Doing problem				scattering for cases	
			sets in the book.				involving a square	
			(50 minutes)				well, derive the	
							formulation for the	
							Born approximation	
							and apply scattering	
							formulas in general	
							for cases involving	
							identical particles.	
16				Fina	l 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-¹/₂ Paramagnetic resonance 	Individual homework	1 week	Uploaded answer in EMAS
4	Exercise 4	2	Problem set	 Summation of two spin Summation of spin-¹/₂ 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 H₂ 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)	
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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.

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

A. Conversion of the student's final score

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