PORTFOLIO FOR
STATISTICAL PHYSICS COURSE

SEMESTER 5 ACADEMIC YEAR 2020-2021

Course Coordinator:
Prof. Tjipto Prastowo, Ph.D

Teaching Team:
Dr. Zainul Arifin Imam Supardi, M.Si
Utama Alan Deta, M.Si

PHYSICS DEPARTMENT
FACULTY OF MATHEMATICS AND NATURAL SCIENCES
THE STATE UNIVERSITY OF SURABAYA
2021

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A. SEMESTER LEARNING ACTIVITY PLAN

A.1 COURSE IDENTITY

Module Name	Statistical Physics
Module Level	Bachelor Degree
Course Code	N/A
Subheading	N/A
Course contained	N/A
Semester/Year	5/3
Module Coordinator	Prof. Tjipto Prastowo, Ph.D
Lecturers	1. Prof. Tjipto Prastowo, Ph.D 2. Dr. Zainul Imam Supardi, M.Si 3. Utama Alan Deta, M.Si
Language	Bahasa Indonesia
Course Classification	Compulsory
Teaching format/ The number of hours per week during semester	A weekly meeting in class for 3 ‘hours’ of teaching (1 ‘hour’ of teaching = 50 minutes)
Course Load	1 Course Unit = 3 workhours per week or 170 minutes per week with various activities as follows: • Class Activity: 50 minutes • Structured Learning: 60 minutes • Independent Learning: 60 minutes **3 Course Units = 9 workhours per week = 510 minutes per week**
Course Credit	3 Course Units
Pre-requisites	Modern Physics
Course Learning Outcome	1. Demonstrating independent, creative and honest characters in doing student assignments, mid and final exams. 2. Understanding theoretical concepts of Statistical Physics in general and Classical Statistics (Maxwell-Boltzmann distribution) and Quantum Statistics (Bose-Einstein and Fermi-Dirac distributions) comprehensively. 3. Being able to formulate problem solving for procedural problems relevant to the applications of both Classical and Quantum Statistics to some statistical phenomena found in microscopic systems.
Course Content	Statistical Physics examines the behaviour of microscopic systems having extremely huge number of constituting particles through an approach of both classical distribution of Maxwell-Boltzmann Statistics and quantum distribution of Bose-Einstein and Fermi-Dirac Statistics. During class discussion, differences among the three statistical distribution are explained. The applications of the classical and quantum statistical distribution are discusssed that

	include ideal and real gases, boson and fermion gases, classical and semi-classical gases, Gibbs paradox, entropy of classical and semi-classical gases, monoatomic and diatomic gases, the specific heat of monoatomic and diatomic gases, the specific heat of solids based on classical and quantum calculations, and total partition function in the presence of molecular interaction, and the introduction of concepts of micro canonical, canonical and grand canonical ensembles.
Attributed soft skill	Collaborative work in a group of students
References and sources	1. Prastowo, T. 2014. Lecture Notes on Statistical Physics. Unpublished work. 2. Pointon, A. J. 1978. An Introduction to Statistical Physics. London, UK: Longmann. 3. Beiser, A. 1988. Perspective of Modern Physics. London, UK: McGraw-Hill. 4. Serway, R. A. et al. 2005. Modern Physics. California, US: Thomson Learning Inc. 5. Kittel, C. and H. Kroemer. 1980. Thermal Physics. New York, US: W. H. Freeman and Co. 6. Some power point files and/or course materials relevant to Statistical Physics from the internet.

A.2 COURSE TOPICS

Class discussions involve the following learning materials:

1. General consideration: statistical distribution function, phase space, scopes of Statistical Physics
2. Velocity, momentum and kinetic energy distribution functions, the applications of Maxwell-Boltzmann Statistics, equipartition principle and the specific heat of gases, Boltzmann partition function
3. Boson system and its population, Bose-Einstein gas, the applications of Bose-Einstein Statistics, thermal radiation of the black-body, photon as boson, Planks' radiation law
4. Boson system and its population, Bose-Einstein gas, the applications of Bose-Einstein Statistics, calculations of the specific heat of solids, phonon as boson, Einstein theory, Debye theory
5. Fermion system and its population, Fermi-Dirac gas, the applications of Fermi-Dirac Statistics, conduction electrons as fermion, Fermi theory
6. Fermion system and its population, Fermi-Dirac gas, the applications of Fermi-Dirac Statistics, calculations of the specific heat of metals
7. Thermodynamics of gases based on classical and quantum statistical distributions, concepts of entropy, open and closed systems
8. Concepts of entropy, a change in entropy, classical and semi-classical gases, Gibbs paradox
9. Diatomic gases, quantum model of translational, rotational and vibrational motions, total partition function for diatomic gases
10. Ensembles of micro canonical, canonical, grand canonical systems, total partition functions of classical and semi-classical systems, total partition function in the presence of molecular interaction

A.3 COURSE PROGRAM

	THE STATE UNIVERSITY OF SURABAYA **FACULTY OF MATHEMATICS AND NATURAL SCIENCES** **PHYSICS STUDY PROGRAM**	**Document Code**

SEMESTER LESSON PLAN

NAME OF COURSE	**COURSE CODE**	**DISCIPLINE**	**COURSE UNIT**		**SEMESTER**	**DATE CREATED**
STATISTICAL PHYSICS		PHYSICS	**T= 3 units**	**P=?**	5 (five)	2 August 2020

AUTHORISATION	**AUTHOR**	**COURSE COORDINATOR**	**HEAD OF PHYSICS STUDY PROGRAM**
PHYSICS DEPARTMENT	Prof. Tjipto Prastowo, Ph.D	Prof. Tjipto Prastowo, Ph.D	Prof. Dr. Munasir, M.Si

Learning Achievement	**Program Learning Outcome (PLO)**	
	PLO1	Students are able to demonstrate knowledge of Classical Physics and Modern Physics.
	PLO2	Students are able to formulate a physical systems as physical model by using mathematics.
	PLO6	Students are able to improve their knowledge and continue their study in a higher education.
	PLO9	Student are able to work as an individual as well as a team effectively, have entrepreneurship skill and awareness of environmental issues.
	Course Learning Outcome (CLO)	
	CLO-1	Demonstrating independent, creative and honest characters in doing student assignments, mid and final exams.
	CLO-2	Understanding theoretical concepts of Statistical Physics in general and Classical Statistics (Maxwell-Boltzmann distribution) and Quantum Statistics (Bose-Einstein and Fermi-Dirac distributions) comprehensively.
	CLO-3	Being able to formulate problem solving for procedural problems relevant to the applications of both Classical and Quantum Statistics to some statistical phenomena found in microscopic systems.
	Final competence in each step of learning (Sub-CLO)	
	Sub-CLO1	Being able to understand differences between microscopic and macroscopic systems as well as laws of physics control the two.
	Sub-CLO2	Being able to understand basic principles of Maxwell-Boltzmann Statistics to derive some physical distribution function and its applications to the structure of an ideal gas in general, equipartition principle and the specific heat of gases.
	Sub-CLO3	Being able to understand basic principles of Bose-Einstein Statistics and its applications to black-body radiation.
	Sub-CLO4	Being able to understand basic principles of Bose-Einstein Statistics and its applications to the specific heat of solids.
	Sub-CLO5	Being able to understand basic principles of Fermi-Dirac Statistics and its applications to conduction electrons on metals.

	Sub-CLO6	Being able to understand basic principles of Fermi-Dirac Statistics and its applications to the specific heat of metals.
	Sub-CLO7	Being able to understand basic principles of thermodynamics of gases based on classical and quantum statistics, concepts of entropy for open and closed systems.
	Sub-CLO8	Being able to understand basic principles of thermodynamics of gases based on classical and quantum statistics, concepts of entropy and a change in entropy of a system, classical gases, Gibbs paradox, semi-classical gases.
	Sub-CLO9	Being able to understand basic principles of quantum model of diatomic gases, a combined motion of molecular translation, rotation and vibration, total partition function for diatomic gases.
	Sub-CLO10	Being able to understand ensemble model for description of microscopic systems, the role of total partition function in formulation of Helmholtz energy to derive the equation of state and total energy of gases with or without the presence of molecular interaction.
Course Description	Statistical Physics examines the behaviour of microscopic systems having extremely huge number of constituting particles through an approach of both classical distribution of Maxwell-Boltzmann Statistics and quantum distribution of Bose-Einstein and Fermi-Dirac Statistics. During class discussion, differences among the three statistical distribution are explained. The applications of the classical and quantum statistical distribution are discusssed that include ideal and real gases, boson and fermion gases, classical and semi-classical gases, Gibbs paradox, entropy of classical and semi-classical gases, monoatomic and diatomic gases, the specific heat of monoatomic and diatomic gases, the specific heat of solids based on classical and quantum calculations, and total partition function in the presence of molecular interaction, and the introduction of concepts of micro canonical, canonical and grand canonical ensembles.	
Topic Discussions: Learning Materials	1. General consideration: statistical distribution function, phase space, scopes of Statistical Physics 2. Velocity, momentum and kinetic energy distribution functions, the applications of Maxwell-Boltzmann Statistics, equipartition principle and the specific heat of gases, Boltzmann partition function 3. Boson system and its population, Bose-Einstein gas, the applications of Bose-Einstein Statistics, thermal radiation of the black-body, photon as boson, Planks' radiation law 4. Boson system and its population, Bose-Einstein gas, the applications of Bose-Einstein Statistics, calculations of the specific heat of solids, phonon as boson, Einstein theory, Debye theory 5. Fermion system and its population, Fermi-Dirac gas, the applications of Fermi-Dirac Statistics, conduction electrons as fermion, Fermi theory 6. Fermion system and its population, Fermi-Dirac gas, the applications of Fermi-Dirac Statistics, calculations of the specific heat of metals 7. Thermodynamics of gases based on classical and quantum statistical distributions, concepts of entropy, open and closed systems 8. Concepts of entropy, a change in entropy, classical and semi-classical gases, Gibbs paradox 9. Diatomic gases, quantum model of translational, rotational and vibrational motions, total partition function for diatomic gases 10. Ensembles of micro canonical, canonical, grand canonical systems, total partition functions of classical and semi-classical systems, total partition function in the presence of molecular interaction	
References	**Primary:**	
	1. Prastowo, T. 2014. Lecture Notes on Statistical Physics. Unpublished work. 2. Pointon, A. J. 1978. An Introduction to Statistical Physics. London, UK: Longmann.	

	3. Beiser, A. 1988. Perspective of Modern Physics. London, UK: McGraw-Hill. 4. Serway, R. A. et al. 2005. Modern Physics. California, US: Thomson Learning Inc. 5. Kittel, C. and H. Kroemer. 1980. Thermal Physics. New York, US: W. H. Freeman and Co.
	Secondary:
	Some power point files and/or course materials relevant to Statistical Physics from the internet
Lecturers	1. Prof. Tjipto Prastowo, Ph.D 2. Dr. Z.A. Imam Supardi, M.Si 3. Utama Alan Deta, M.Si
Pre-requisites	Modern Physics

Week	**Final competence in each learning step (Sub-CLO)**	**Assessment**		**Learning Format, Methods, Instruction, (Time Allocation)**		**Learning Materials**	**Proportion (%)**
		Indicator	**Criteria & Format**	**Luring (*offline*)**	**Daring (*online*)**		
(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**	**(8)**
1	Being able to understand differences between microscopic and macroscopic systems as well as laws of physics control the two systems	Students can explain differences between microscopic and macroscopic systems as well as laws of physics control the two systems			Contextual Learning Class discussion Q & A	• General consideration • Statistical distribution function • Phase space • Scopes of Statistical Physics	
2	Being able to understand basic principles of Maxwell-Boltzmann Statistics to derive some physical distribution function and its applications to the structure of an ideal gas in general, equipartition	Students can explain basic principles of Maxwell-Boltzmann Statistics to derive some physical			Contextual Learning Class discussion Q & A	• Velocity, momentum and kinetic energy distribution functions • The applications of Maxwell-Boltzmann	

	principle and the specific heat of gases	distribution function and its applications to the structure of an ideal gas in general, equipartition principle and the specific heat of gases				Statistics • Equipartition principle • The specific heat of gases	
3	Being able to understand basic principles of Maxwell-Boltzmann Statistics to derive some physical distribution function and its applications to the structure of an ideal gas in general, equipartition principle and the specific heat of gases	Students can explain basic principles of Maxwell-Boltzmann Statistics to derive some physical distribution function and its applications to the structure of an ideal gas in general, equipartition principle and the specific heat of gases			Contextual Learning Class discussion Q & A	• Velocity, momentum and kinetic energy distribution functions • The applications of Maxwell-Boltzmann Statistics • Equipartition principle • The specific heat of gases	
4	Being able to understand basic principles of Maxwell-Boltzmann Statistics to derive some physical distribution function and its applications to the	Students can explain basic principles of Maxwell-Boltzmann Statistics to	Exercise on Chap. 2, Lecture Notes on Satistical Physics (Assignment 1)		Contextual Learning Class discussion Q & A	• The applications of Maxwell-Boltzmann Statistics • Equipartition principle	**10%**

	structure of an ideal gas in general, equipartition principle and the specific heat of gases	derive some physical distribution function and its applications to the structure of an ideal gas in general, equipartition principle and the specific heat of gases, solve problems relevant to Maxwell-Boltzmann Statistics				• The specific heat of gases • Boltzmann partition function	
5	Being able to understand basic principles of Bose-Einstein Statistics and its applications to black-body radiation	Students can explain basic principles of Bose-Einstein Statistics and its applications to black-body radiation			Contextual Learning Class discussion Q & A	• Boson system and its population • Bose-Einstein gas • The applications of Bose-Einstein Statistics • Thermal radiation of the black-body • Photon as boson • Planks’ radiation law	
6	Being able to understand basic principles of Bose-Einstein Statistics and its applications to the specific heat of solids	Students can explain basic principles of Bose-Einstein Statistics and its applications to			Contextual Learning Class discussion Q & A	• Boson system and its populatioN • Bose-Einstein gas • The applications of Bose-Einstein Statistics	

		the specific heat of solids				• Calculations of the specific heat of solids • phonon as boson • Einstein theory • Debye theory	
7	Being able to understand basic principles of Bose-Einstein Statistics and its applications to the specific heat of solids	Students can explain basic principles of Bose-Einstein Statistics and its applications to the specific heat of solids, solve problems relevant to Bose-Einstein Statistics	Exercise on Chap. 3, Lecture Notes on Statistical Physics (Assignment 2)		Contextual Learning Class discussion Q & A	• Boson system and its population • Bose-Einstein gas • The applications of Bose-Einstein Statistics • Calculations of the specific heat of solids • phonon as boson • Einstein theory • Debye theory	**10%**
8	**Mid Semester Exam**						**30%**
9	Being able to understand basic principles of Fermi-Dirac Statistics and its applications to conduction electrons on metals	Students can explain basic principles of Fermi-Dirac Statistics and its applications to conduction electrons on metals			Contextual Learning Class discussion Q & A	• Fermion system and its population • Fermi-Dirac gas • The applications of Fermi-Dirac Statistics • Conduction electrons as fermion • Fermi theory	
10	Being able to understand basic principles of Fermi-Dirac Statistics and its applications to the specific heat of metals	Students can explain basic principles of Fermi-Dirac Statistics and its	Exercise on Chap. 4, Lecture Notes on Statistical Physics (Assignment 3)		Contextual Learning Class discussion Q & A	• Fermion system and its population • Fermi-Dirac gas • The applications of Fermi-Dirac	**10%**

		applications to the specific heat of metals, solve problems relevant to Fermi-Dirac Statistics				Statistics • Calculations of the specific heat of metals	
11	Being able to understand basic principles of thermodynamics of gases based on classical and quantum statistics, concepts of entropy for open and closed system	Students can basic principles of thermodynamics of gases based on classical and quantum statistics, concepts of entropy for open and closed system			Contextual Learning Class discussion Q & A	• Thermodynamics of gases based on classical and quantum statistical distributions • Concepts of entropy • Open and closed systems	
12	Being able to understand basic principles of thermodynamics of gases based on classical and quantum statistics, concepts of entropy for open and closed system	Students can basic principles of thermodynamics of gases based on classical and quantum statistics, concepts of entropy for open and closed system			Contextual Learning Class discussion Q & A	• Thermodynamics of gases based on classical and quantum statistical distributions • Concepts of entropy • Open and closed systems	
13	Being able to understand basic principles of thermodynamics of gases	basic principles of thermodynamic			Contextual Learning Class discussion Q & A	• Concepts of entropy • A change in	

	based on classical and quantum statistics, concepts of entropy and a change in entropy of a system, classical gases, Gibbs paradox, semi-classical gases	s of gases based on classical and quantum statistics, concepts of entropy and a change in entropy of a system, classical gases, Gibbs paradox, semi-classical gases				entropy • Classical and semi-classical gases • Gibbs paradox	
14	Being able to understand basic principles of quantum model of diatomic gases, a combined motion of molecular translation, rotation and vibration, total partition function for diatomic gases	Students can explain basic principles of quantum model of diatomic gases, a combined motion of molecular translation, rotation and vibration, total partition function for diatomic gases			Contextual Learning Class discussion Q & A	• Diatomic gases • Quantum model of translational, rotational and vibrational motions • Total partition function for diatomic gases	
15	Being able to understand ensemble model for description of microscopic systems, the role of total partition function in formulation of Helmholtz energy to derive the	Students can explain ensemble model for description of microscopic systems, the			Contextual Learning Class discussion Q & A	• Ensembles of micro canonical, canonical, grand canonical systems • Total partition functions of classical and semi-	

	equation of state and total energy of gases with or without the presence of molecular interaction	role of total partition function in formulation of Helmholtz energy to derive the equation of state and total energy of gases with or without the presence of molecular interaction				classical systems • Total partition function in the presence of molecular interaction	
16	**Final Exam**						**40%**

A.4 MAPPING OF LEARNING OUTCOME-COURSE OUTCOME

A.4.1 Program Learning Outcome (PLO) of UPP

Competency of SSC-ASIIN	Component	Code	Programme Learning Outcome (PLO)
Specific competences	**Knowledge**	KNO-1 (PLO1)	Able to **demonstrate** knowledge of Classical Physics and Modern Physics
		KNO-2 (PLO2)	Able to **formulate** a physical systems as physical model by using mathematics
		KNO-3 (PLO3)	Able to **solve problems** in physical systems comprehensively by using mathematics and computational tools
	Skill	SKI-1 (PLO4)	Able to **analyze** a physical system by applying mathematics and computational tools/ICT
		SKI-2 (PLO5)	Able to **design and conduct** experiments in learning physics by applying the scientific methods
		SKI-3 (PLO6)	Able to **improve their knowledge** and be able to continue their study in a higher education
		SKI-4 (PLO7)	Able to **communicate** their ideas and/or research results in academic writing and speaking effectively
Social and attitude competences	**Social**	SOC-1 (PLO8)	Able to **make a decision** based on the data and information in order to fulfil and evaluate their task responsibility
		SOC-2 (PLO9)	Able to **work as an individual as well as a team** effectively, **have entrepreneurship skill** and awareness of environmental issues
	Attitude	ATT-1 (PLO10)	Able to **demonstrate good scientist's manners**, critical thinking and innovation skills in research and professional fields; and willing to do lifelong learning
		ATT-2 (PLO11)	Able to **demonstrate the appreciation** of **religious values, and nationalism as citizens** as well as conducting their tasks professionally

A.4.2 Program Educational Objective (PEO) of UPP

1. Produce Bachelor of Physics who are able to use physics knowledge and methodology to solve problems in their work field.
2. Produce Bachelor of Physics who have a strong commitment to developing knowledge, whether by studying in a higher-level degree working in a formal institution and entrepreneurs.
3. Produce Bachelor of Physics who master the scientific method to observe, analyze and understand physical phenomena, and produce scientific work and contribute according to their expertise.
4. Produce Bachelor of Physics who masteries physics that is able to apply their knowledge, expertise in various fields of work, and develop themselves in their career environment.
5. Produce Bachelor of Physics who can communicate orally and/ in writing effectively, creatively, innovatively, and collaboratively, as well as working in teams.

A.4.3 Mapping of PLO-PEO

Outcomes	**Objectives**				
	Produce Bachelor of Physics who are able to use physics knowledge and methodology to solve problems in their work field.	Produce Bachelor of Physics who have a strong commitment to developing knowledge, whether by studying in a higher-level degree working in a formal institution and entrepreneurs.	Produce Bachelor of Physics who master the scientific method to observe, analyze and understand physical phenomena, and produce scientific work and contribute according to their expertise.	Produce Bachelor of Physics who masteries physics that is able to apply their knowledge, expertise in various fields of work, and develop themselves in their career environment.	Produce Bachelor of Physics who can communicate orally and/ in writing effectively, creatively, innovatively, and collaboratively, as well as working in teams.
PLO-1	S	S	S	S	S
PLO-2	S	S	S	S	S
PLO-3	S	S	S	S	S
PLO-4	S	S	S	S	S
PLO-5	S	M	S	M	S
PLO-6	S	M	S	S	M
PLO-7	S	S	S	M	S
PLO-8	S	M	S	M	S
PLO-9	S	M	S	M	S
PLO-10	M	M	M	M	S
PLO-11	M	M	M	S	S

Notes:

S = Strong, M = Moderate, L = Low

B. COURSE ASSESSMENT

B.1 ASSESSMENT RUBRICS

N/A.

B.2 ASSESSMENT SYSTEM

Final grade for each student is obtained from each component of assessment below,

Assignments 1 and 2 : 30%
Mid Exam : 30%
Final Exam (Assignment 3) : 40%

B.3 WEIGHT DISTRIBUTION OF ASSESSMENT

Component	CLO-1	CLO-2	CLO-3	TOTAL
Assignments 1 and 2	20	40	40	100
Mid Exam	40	40	20	100
Final Exam	20	30	50	100

Notice that all numerical data in the above table are given in per cent.

B.4 STUDENT GRADE SYSTEM

Final grade for each student is classified below according to a total score obtained,

Excellent : if a total score is greater than or equal to 80
Good : if a total score is greater than or equal to 70
Satisfactory : if a total score is greater than or equal to 55
Failed : if a total score is less than 55

Grade	Interval
A	85 ≤ A < 100
A-	80 ≤ A- < 85
B+	75 ≤ B+ < 80
B	70 ≤ B < 75
B-	65 ≤ B- < 70
C+	60 ≤ C+ < 65
C	55 ≤ C < 60
D	40 ≤ D < 55
E	0 ≤ E < 40

C. COURSE DEVELOPMENT

C.1 A BRIEF REPORT FOR CLASS RESULTS

The following table reports student academic achievement during the course.

Parameter	N	N in per cent
The number of students taking the subject	34	100
The number of students who has passed the course during a normal time	34	100
The number of students who has passed the course by a remedial treatment	-	-
The number of students who has failed the course after taking a remedial treatment	-	-

C.2 ANALYSIS OF CLASS PROBLEMS

Class achievement is recorded successful with three students scored between 55 and 70, classified as satisfactory, 19 students scored between 70 and 80, classified as good and other 12 students scored greater than 80, classified as excellent. The final scores were distributed to grades C, B-, B, B+, A- and A.

C.3 STRATEGY FOR ALTERNATIF SOLUTIONS

N/A. All the students have passed the course.

D. APPENDICES

D.1 DOCUMENTS OF CLASS ACTIVITIES

D.1.1 Weekly Journal

7/20/2021 SIAKADU: Cetak Jurnal Perkuliahan

KEMENTERIAN RISET, TEKNOLOGI, DAN PENDIDIKAN TINGGI

UNIVERSITAS NEGERI SURABAYA

UNESA

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F: +6231-8293484
laman: unesa.ac.id
email : bakpk@unesa.ac.id

Aktivitas Perkuliahan

Nama Matakuliah : Fisika Statistik

Kelas : 2018E

Jadwal & Ruang : C03.03.02 (14.40 - 17.10) R.

Dosen : TJIPTO PRASTOWO (196702031995021001)
UTAMA ALAN DETA (198903172015041002)

No.	Tanggal	Pertemuan	Topik	Peserta	Status	Dosen
1	**16-09-2020**	Pertemuan ke 1	1. Penjelasan RPS Fisika Statistik 2. Penjelasan tugas, sistem evaluasi dan asesmen perkuliahan Fisika Statistik 3. Materi Bab 1 Lecture Notes on Statistical Physics 4. Sistem makroskopis vs sistem mikroskopis 5. Besaran empiris vs besaran mikroskopis 6. Pengertian Ruang Fasa 7. Distribusi Statistik Klasik vs Distribusi Statistik Kuantum	34	Terjadwal	Tjipto Prastowo
2	**23-09-2020**	Pertemuan ke 2	1. Fungsi distribusi statistik 2. Statistik Maxwell-Boltzmann 3. Fungsi distribusi kecepatan, momentum, energi 4. Kecepatan rata-rata, kecepatan rms, kecepatan yang paling mungkin 5. Teori ekipartisi	34	Terjadwal	Tjipto Prastowo
3	**30-09-2020**	Pertemuan ke 3	1. Aplikasi statistik Maxwell-Boltzmann 2. Teori ekipartisi 3. Kalor jenis gas ideal 4. Persamaan keadaan gas ideal 5. Penjelasan PR	34	Terjadwal	Tjipto Prastowo
4	**07-10-2020**	Pertemuan	1. Sistem Boson	34	Terjadwal	Tjipto Prastowo

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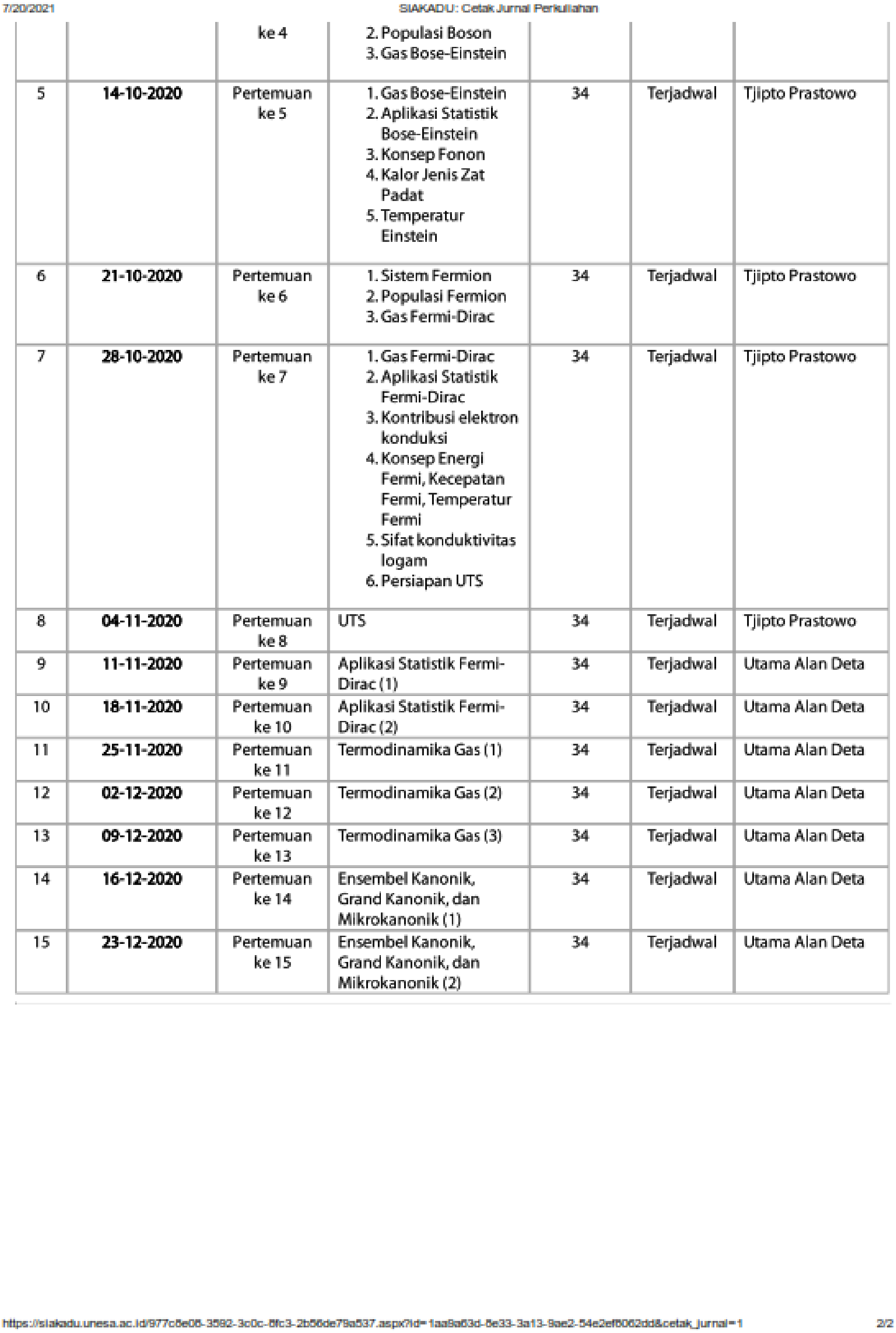
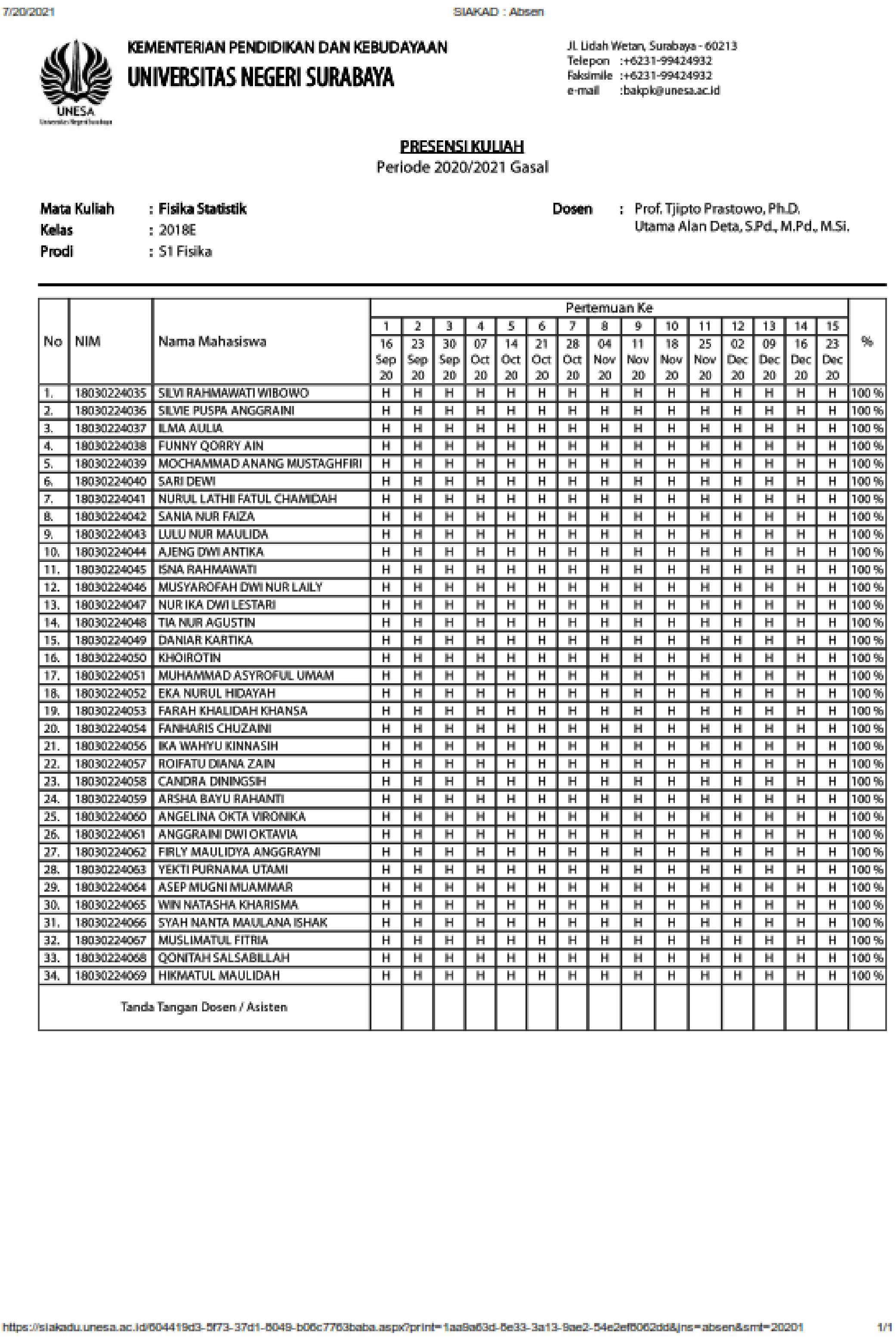


		ke 4	2. Populasi Boson 3. Gas Bose-Einstein			
5	**14-10-2020**	Pertemuan ke 5	1. Gas Bose-Einstein 2. Aplikasi Statistik Bose-Einstein 3. Konsep Fonon 4. Kalor Jenis Zat Padat 5. Temperatur Einstein	34	Terjadwal	Tjipto Prastowo
6	**21-10-2020**	Pertemuan ke 6	1. Sistem Fermion 2. Populasi Fermion 3. Gas Fermi-Dirac	34	Terjadwal	Tjipto Prastowo
7	**28-10-2020**	Pertemuan ke 7	1. Gas Fermi-Dirac 2. Aplikasi Statistik Fermi-Dirac 3. Kontribusi elektron konduksi 4. Konsep Energi Fermi, Kecepatan Fermi, Temperatur Fermi 5. Sifat konduktivitas logam 6. Persiapan UTS	34	Terjadwal	Tjipto Prastowo
8	**04-11-2020**	Pertemuan ke 8	UTS	34	Terjadwal	Tjipto Prastowo
9	**11-11-2020**	Pertemuan ke 9	Aplikasi Statistik Fermi-Dirac (1)	34	Terjadwal	Utama Alan Deta
10	**18-11-2020**	Pertemuan ke 10	Aplikasi Statistik Fermi-Dirac (2)	34	Terjadwal	Utama Alan Deta
11	**25-11-2020**	Pertemuan ke 11	Termodinamika Gas (1)	34	Terjadwal	Utama Alan Deta
12	**02-12-2020**	Pertemuan ke 12	Termodinamika Gas (2)	34	Terjadwal	Utama Alan Deta
13	**09-12-2020**	Pertemuan ke 13	Termodinamika Gas (3)	34	Terjadwal	Utama Alan Deta
14	**16-12-2020**	Pertemuan ke 14	Ensembel Kanonik, Grand Kanonik, dan Mikrokanonik (1)	34	Terjadwal	Utama Alan Deta
15	**23-12-2020**	Pertemuan ke 15	Ensembel Kanonik, Grand Kanonik, dan Mikrokanonik (2)	34	Terjadwal	Utama Alan Deta

D.1.2 Student Attendance



7/20/2021 SIAKAD : Absen

KEMENTERIAN PENDIDIKAN DAN KEBUDAYAAN
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PRESENSI KULIAH
Periode 2020/2021 Gasal

Mata Kuliah : **Fisika Statistik**
Kelas : 2018E
Prodi : S1 Fisika

Dosen : Prof. Tjipto Prastowo, Ph.D.
Utama Alan Deta, S.Pd., M.Pd., M.Si.

No	NIM	Nama Mahasiswa	Pertemuan Ke															%
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
			16 Sep 20	23 Sep 20	30 Sep 20	07 Oct 20	14 Oct 20	21 Oct 20	28 Oct 20	04 Nov 20	11 Nov 20	18 Nov 20	25 Nov 20	02 Dec 20	09 Dec 20	16 Dec 20	23 Dec 20	
1.	18030224035	SILVI RAHMAWATI WIBOWO	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	100 %
2.	18030224036	SILVIE PUSPA ANGGRAINI	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	100 %
3.	18030224037	ILMA AULIA	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	100 %
4.	18030224038	FUNNY QORRY AIN	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	100 %
5.	18030224039	MOCHAMMAD ANANG MUSTAGHFIRI	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	100 %
6.	18030224040	SARI DEWI	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	100 %
7.	18030224041	NURUL LATHII FATUL CHAMIDAH	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	100 %
8.	18030224042	SANIA NUR FAIZA	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	100 %
9.	18030224043	LULU NUR MAULIDA	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	100 %
10.	18030224044	AJENG DWI ANTIKA	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	100 %
11.	18030224045	ISNA RAHMAWATI	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	100 %
12.	18030224046	MUSYAROFAH DWI NUR LAILY	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	100 %
13.	18030224047	NUR IKA DWI LESTARI	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	100 %
14.	18030224048	TIA NUR AGUSTIN	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	100 %
15.	18030224049	DANIAR KARTIKA	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	100 %
16.	18030224050	KHOIROTIN	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	100 %
17.	18030224051	MUHAMMAD ASYROFUL UMAM	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	100 %
18.	18030224052	EKA NURUL HIDAYAH	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	100 %
19.	18030224053	FARAH KHALIDAH KHANSA	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	100 %
20.	18030224054	FANHARIS CHUZAINI	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	100 %
21.	18030224056	IKA WAHYU KINNASIH	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	100 %
22.	18030224057	ROIFATU DIANA ZAIN	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	100 %
23.	18030224058	CANDRA DININGSIH	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	100 %
24.	18030224059	ARSHA BAYU RAHANTI	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	100 %
25.	18030224060	ANGELINA OKTA VIRONIKA	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	100 %
26.	18030224061	ANGGRAINI DWI OKTAVIA	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	100 %
27.	18030224062	FIRLY MAULIDYA ANGGRAYNI	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	100 %
28.	18030224063	YEKTI PURNAMA UTAMI	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	100 %
29.	18030224064	ASEP MUGNI MUAMMAR	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	100 %
30.	18030224065	WIN NATASHA KHARISMA	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	100 %
31.	18030224066	SYAH NANTA MAULANA ISHAK	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	100 %
32.	18030224067	MUSLIMATUL FITRIA	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	100 %
33.	18030224068	QONITAH SALSABILLAH	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	100 %
34.	18030224069	HIKMATUL MAULIDAH	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	100 %
Tanda Tangan Dosen / Asisten																		

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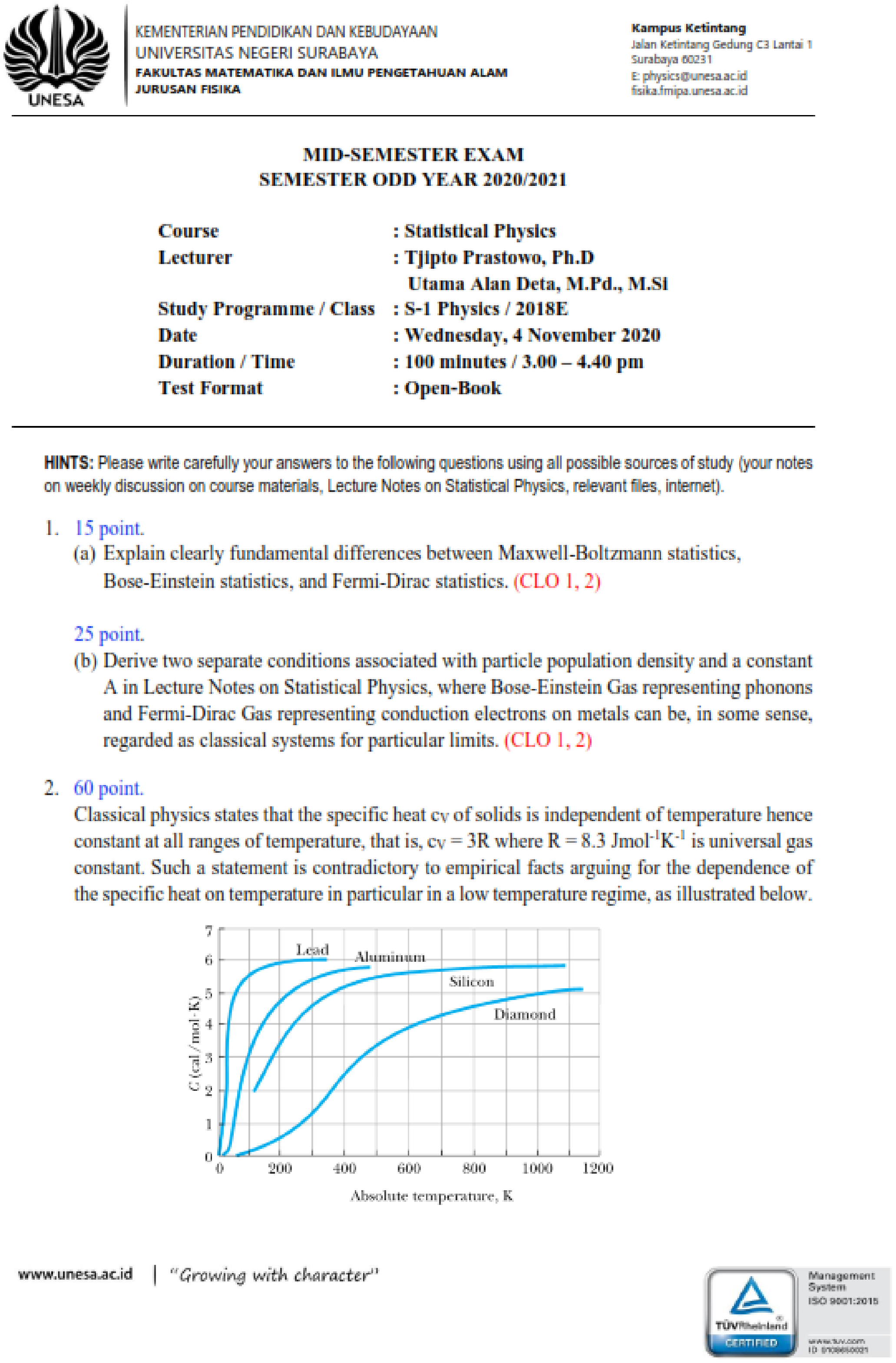
D.2 DOCUMENTS OF EXAMS

D.2.1 Mid Exam



KEMENTERIAN PENDIDIKAN DAN KEBUDAYAAN
UNIVERSITAS NEGERI SURABAYA
FAKULTAS MATEMATIKA DAN ILMU PENGETAHUAN ALAM
JURUSAN FISIKA

Kampus Ketintang
Jalan Ketintang Gedung C3 Lantai 1
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MID-SEMESTER EXAM
SEMESTER ODD YEAR 2020/2021

Course : **Statistical Physics**
Lecturer : **Tjipto Prastowo, Ph.D**
Utama Alan Deta, M.Pd., M.Si
Study Programme / Class : **S-1 Physics / 2018E**
Date : **Wednesday, 4 November 2020**
Duration / Time : **100 minutes / 3.00 – 4.40 pm**
Test Format : **Open-Book**

HINTS: Please write carefully your answers to the following questions using all possible sources of study (your notes on weekly discussion on course materials, Lecture Notes on Statistical Physics, relevant files, internet).

1. 15 point.
   (a) Explain clearly fundamental differences between Maxwell-Boltzmann statistics, Bose-Einstein statistics, and Fermi-Dirac statistics. (CLO 1, 2)

   25 point.
   (b) Derive two separate conditions associated with particle population density and a constant A in Lecture Notes on Statistical Physics, where Bose-Einstein Gas representing phonons and Fermi-Dirac Gas representing conduction electrons on metals can be, in some sense, regarded as classical systems for particular limits. (CLO 1, 2)

2. 60 point.
   Classical physics states that the specific heat c_V of solids is independent of temperature hence constant at all ranges of temperature, that is, $c_V = 3R$ where $R = 8.3\ \text{Jmol}^{-1}\text{K}^{-1}$ is universal gas constant. Such a statement is contradictory to empirical facts arguing for the dependence of the specific heat on temperature in particular in a low temperature regime, as illustrated below.

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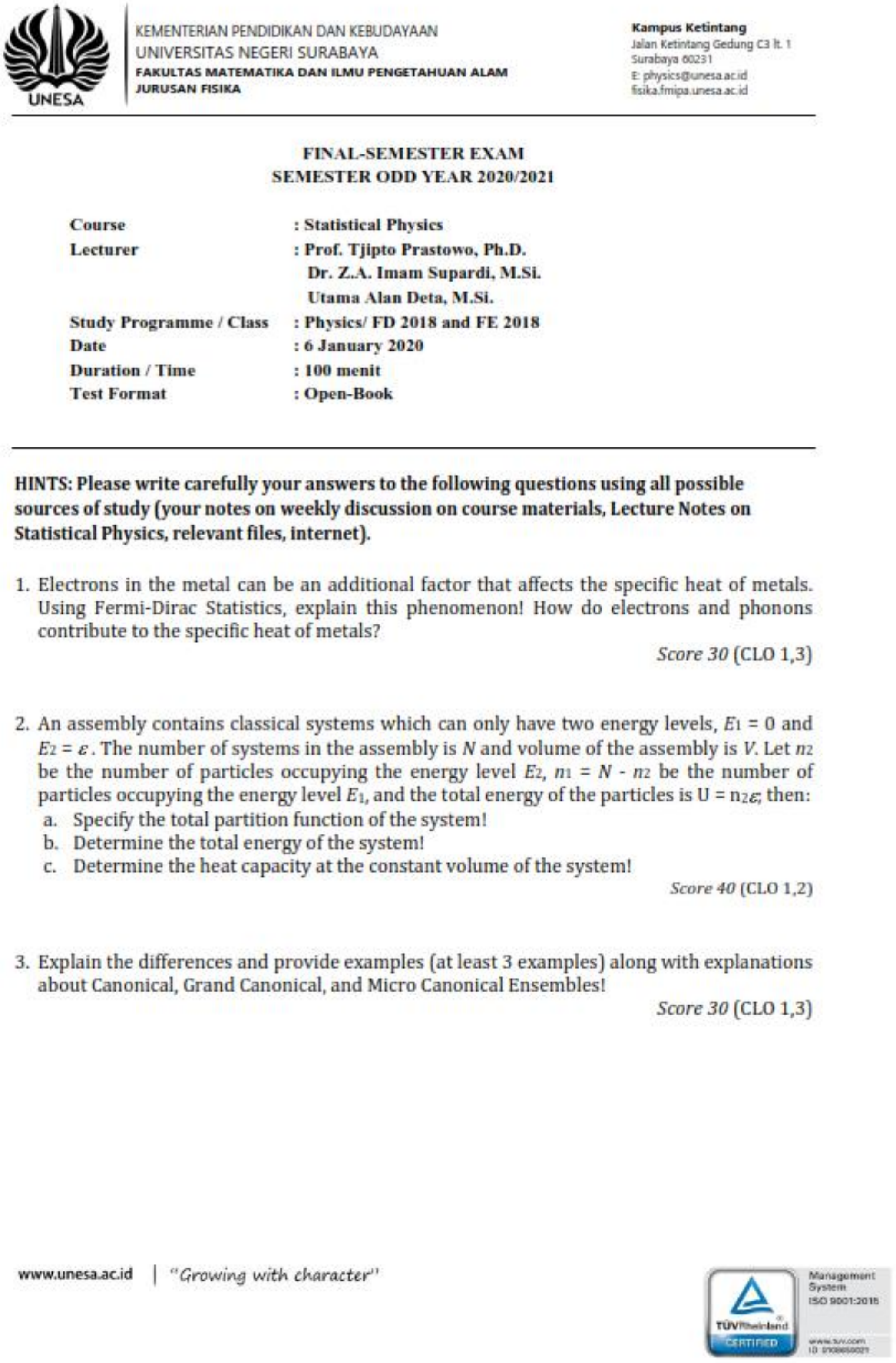
(a) Show that the specific heat c_V of solids according to Einstein model for atomic vibration in solids is 5.5 kal $mol^{-1}K^{-1}$ at temperature of $T=T_E$ where T_E is Einstein temperature.
(b) Determine Einstein temperatures T_E for lead, aluminum, and silicon.
(c) Calculate the gap in energy for lead, aluminum, and silicon.
(d) Calculate the oscillator mean energy for lead, aluminum, and silicon at temperature 300 K.
(CLO 1, 2, 3)

D.2.2 Final Exam



KEMENTERIAN PENDIDIKAN DAN KEBUDAYAAN
UNIVERSITAS NEGERI SURABAYA
FAKULTAS MATEMATIKA DAN ILMU PENGETAHUAN ALAM
JURUSAN FISIKA

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FINAL-SEMESTER EXAM
SEMESTER ODD YEAR 2020/2021

Course : **Statistical Physics**
Lecturer : **Prof. Tjipto Prastowo, Ph.D.**
Dr. Z.A. Imam Supardi, M.Si.
Utama Alan Deta, M.Si.
Study Programme / Class : **Physics/ FD 2018 and FE 2018**
Date : **6 January 2020**
Duration / Time : **100 menit**
Test Format : **Open-Book**

HINTS: Please write carefully your answers to the following questions using all possible sources of study (your notes on weekly discussion on course materials, Lecture Notes on Statistical Physics, relevant files, internet).

1. Electrons in the metal can be an additional factor that affects the specific heat of metals. Using Fermi-Dirac Statistics, explain this phenomenon! How do electrons and phonons contribute to the specific heat of metals?

Score 30 (CLO 1,3)

2. An assembly contains classical systems which can only have two energy levels, $E_1 = 0$ and $E_2 = \varepsilon$. The number of systems in the assembly is N and volume of the assembly is V. Let n_2 be the number of particles occupying the energy level E_2, $n_1 = N - n_2$ be the number of particles occupying the energy level E_1, and the total energy of the particles is $U = n_2\varepsilon$; then:
   a. Specify the total partition function of the system!
   b. Determine the total energy of the system!
   c. Determine the heat capacity at the constant volume of the system!

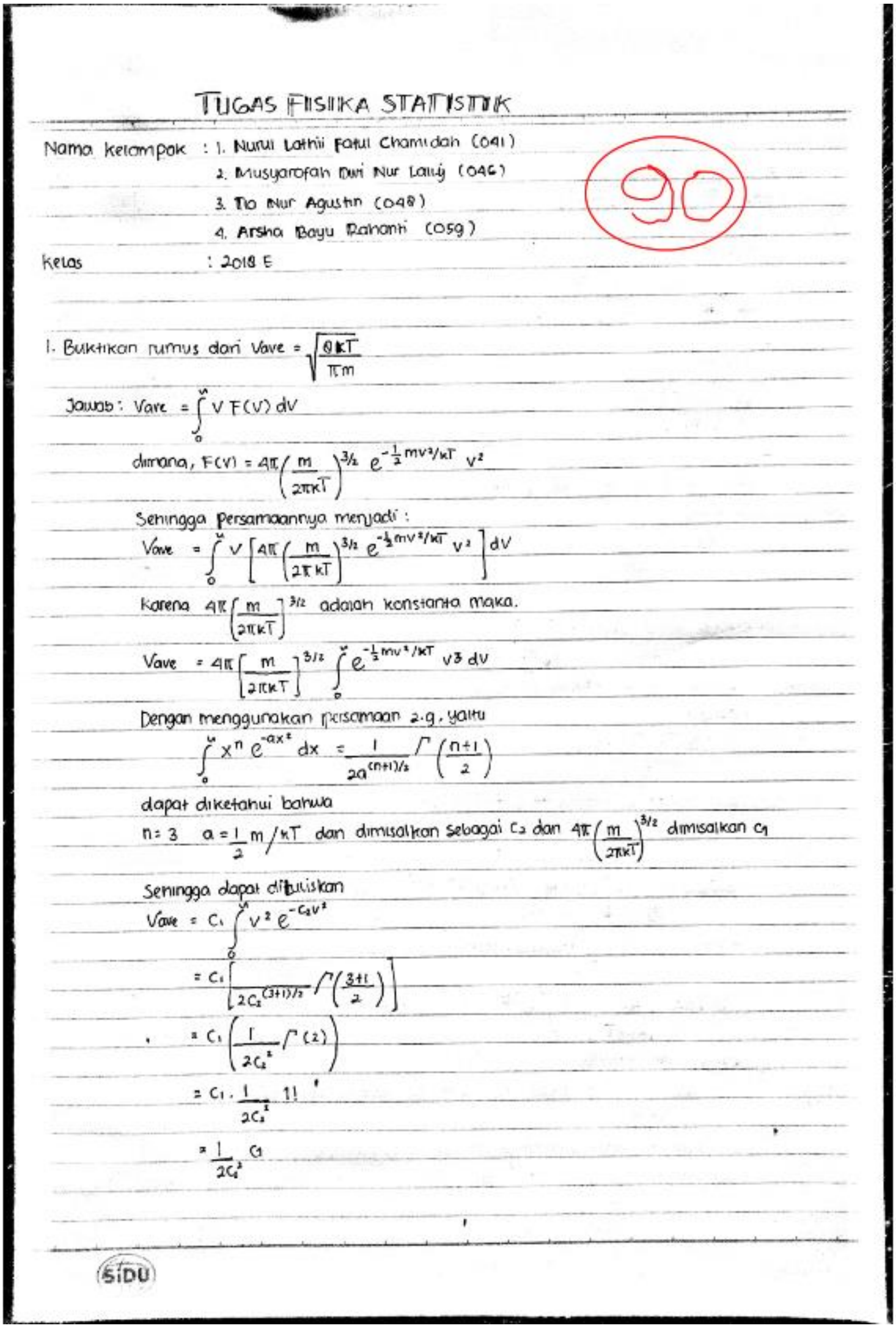
Score 40 (CLO 1,2)

3. Explain the differences and provide examples (at least 3 examples) along with explanations about Canonical, Grand Canonical, and Micro Canonical Ensembles!

Score 30 (CLO 1,3)

D.3 SAMPLES OF STUDENT PERFORMANCE

D.3.1 Assignment 1



TUGAS FISIKA STATISTIK

Nama kelompok : 1. Nurul Lathii Fatul Chamidah (041)
2. Musyarofah Dwi Nur Laily (046)
3. Tio Nur Agustin (048)
4. Arsha Bayu Rahanti (059)

Kelas : 2018 E

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1. Buktikan rumus dari $V_{ave} = \sqrt{\frac{8kT}{\pi m}}$

Jawab: $V_{ave} = \int_0^\infty V\, F(V)\, dV$

dimana, $F(V) = 4\pi\left(\frac{m}{2\pi kT}\right)^{3/2} e^{-\frac{1}{2}mv^2/kT}\, v^2$

Sehingga persamaannya menjadi :

$$V_{ave} = \int_0^\infty V \left[4\pi\left(\frac{m}{2\pi kT}\right)^{3/2} e^{-\frac{1}{2}mv^2/kT}\, v^2\right] dV$$

Karena $4\pi\left(\frac{m}{2\pi kT}\right]^{3/2}$ adalah konstanta maka.

$$V_{ave} = 4\pi\left[\frac{m}{2\pi kT}\right]^{3/2} \int_0^\infty e^{-\frac{1}{2}mv^2/kT}\, v3\, dV$$

Dengan menggunakan persamaan 2.9, yaitu

$$\int_0^\infty x^n e^{-ax^2}\, dx = \frac{1}{2a^{(n+1)/2}}\, \Gamma\left(\frac{n+1}{2}\right)$$

dapat diketahui bahwa

$n = 3$ $a = \frac{1}{2}m/kT$ dan dimisalkan sebagai c_2 dan $4\pi\left(\frac{m}{2\pi kT}\right)^{3/2}$ dimisalkan c_1

Sehingga dapat dituliskan

$$V_{ave} = C_1 \int_0^\infty v^2 e^{-C_2 v^2}$$

$$= C_1\left[\frac{1}{2C_2^{(3+1)/2}}\, \Gamma\left(\frac{3+1}{2}\right)\right]$$

$$= C_1\left(\frac{1}{2C_2^2}\, \Gamma(2)\right)$$

$$= C_1 \cdot \frac{1}{2C_2^2}\, 1!$$

$$= \frac{1}{2C_2^2}\, C_1$$

Mensubtitusikan kembali C_1 dan C_2 ke dalam persamaan, sehingga menjadi

$$V_{ave} = \frac{1}{2}\left(\frac{2kT}{m}\right)^2 \cdot 4\pi\left(\frac{m}{2\pi kT}\right)^{3/2}$$

$$= \frac{\frac{1}{2}\left(\frac{2kT}{m}\right)^2}{\frac{1}{4\cancel{\pi}}\cancel{\sqrt{\pi}}\cancel{\sqrt{\pi}}\sqrt{\pi}\left(\frac{2kT}{m}\right)^{3/2}}$$

$$= \frac{\frac{1}{2}\left(\frac{2kT}{m}\right)^2}{\frac{\sqrt{\pi}}{4}\left(\frac{2kT}{m}\right)^{3/2}}$$

$$= \frac{2}{\sqrt{\pi}}\left(\frac{2kT}{m}\right)^{1/2} \quad \text{atau} \quad \frac{2}{\sqrt{\pi}}\sqrt{\frac{2kT}{m}}$$

Dan persamaan menjadi

$$V_{ave} = \sqrt{\frac{8kT}{\pi m}} \;//$$

2. Buktikan bahwa rumus $V_{rms} = \sqrt{\frac{3kT}{m}}$

Jawab : Dimana V_{rms} adalah $\sqrt{(V^2)_{ave}}$

dengan,

$$(V)^2_{ave} = \int_0^\infty V^2 F(V)\, dV$$

Dan $F(V) = 4\pi\left(\frac{m}{2\pi kT}\right)^{3/2} e^{-\frac{1}{2}mV^2/kT} V^2$

Sehingga persamaan menjadi

$$(V)^2_{ave} = \int_0^\infty V^2\left[4\pi\left(\frac{m}{2\pi kT}\right)^{3/2} e^{-\frac{1}{2}mV/kT} V^2\right] dV$$

karena $4\pi\left(\frac{m}{2\pi kT}\right)^{3/2}$ adalah konstanta, maka

$$(V)^2_{ave} = \left(\frac{4\pi}{2\pi kT}\right)^{3/2} \int_0^\infty e^{-\frac{1}{2}mV^2/kT}\; V^4\, dV$$

Dimisalkan bahwa

$4\pi\left(\frac{m}{2\pi kT}\right)^{3/2}$ adalah C_1 dan C_2 adalah $\frac{1}{2}m/kT$

Diselesaikan menggunakan persamaan 2.g, sehingga

$$(V^2)_{ave} = C_1\int_0^\infty V^4 e^{-C_2V^2}\; dV$$

$$= C_1 \left(\frac{1}{2C_2^{(4+1)/2}} \Gamma\left(\frac{4+1}{2}\right) \right)$$

$$= C_1 \left(\frac{1}{2C_2^{5/2}} \cdot \frac{3}{2} \cdot \frac{1}{2} \Gamma\left(\frac{1}{2}\right) \right)$$

$$= C_1 \cdot \frac{1}{2C_2^{5/2}} \; \frac{3.\sqrt{\pi}}{4}$$

Mensubtitusikan C_1 dan C_2 ke dalam persamaan, sehingga

$$(v)^2{}_{ave} = 4\pi \left(\frac{m}{2\pi kT}\right)^{3/2} \cdot \left(\frac{1}{2} \left(\frac{2kT}{m}\right)^{5/2} \cdot \frac{3\sqrt{\pi}}{4} \right)$$

$$= \frac{\frac{3}{8} \sqrt{\pi} \left(\frac{2kT}{m}\right)^{5/2}}{\frac{1}{4\cancel{\pi}} \sqrt{\pi} \cdot \sqrt{\pi} \sqrt{\pi} \left(\frac{2kT}{m}\right)^{3/2}}$$

$$= \frac{\frac{3}{8} \cancel{\sqrt{\pi}} \left(\frac{2kT}{m}\right)^{5/2}}{\frac{1}{4} \cancel{\sqrt{\pi}} \left(\frac{2kT}{m}\right)^{3/2}}$$

$$= \frac{3}{\cancel{8}} \cdot \cancel{4} \cdot \frac{\cancel{2}kT}{m}$$

$$(v^2)_{ave} = \frac{3kT}{m}$$

Dimana V_{rms} adalah $\sqrt{(v^2)_{ave}}$, sehingga

$$V_{rms} = \sqrt{\frac{3kT}{m}} \; //$$

3. Buktikan bahwa rumus $E_{ave} = \frac{3}{2} kT$

Jawab: $E_{ave} = \int_0^{\infty} E \, F(E) \, dE$

Dimana $F(E) = 2\pi \left(\frac{1}{\pi kT}\right)^{3/2} e^{-E/kT} \, E^{1/2}$

Sehingga persamaan menjadi

$$E_{ave} = \int_0^{\infty} E \left[2\pi \left(\frac{1}{\pi kT}\right)^{3/2} e^{-E/kT} \, E^{1/2} \right] dE$$

Karena $2\pi \left(\frac{1}{\pi kT}\right)^{3/2}$ adalah konstanta, maka

$$E_{ave} = 2\pi \left(\frac{1}{\pi kT}\right)^{3/2} E^{3/2} e^{-E/kT} \, dE$$

Dimisalkan bahwa

$2\pi\left(\frac{1}{\pi kT}\right)^{3/2}$ adalah c_1 dan $\frac{1}{kT}$ adalah c_2

Dengan menggunakan persamaan 2.35, yaitu

$$\int_0^{\infty} x^n e^{-ax}\, dx = \frac{1}{a^{n+1}}\Gamma(n+1)$$

Sehingga

$$\begin{aligned}
\varepsilon_{ave} &= c_1 \int_0^{\infty} \varepsilon^{3/2} e^{-c_2\varepsilon}\, d\varepsilon \\
&= c_1\left(\frac{1}{c_2^{3/2+1}}\Gamma\left(\frac{3}{2}+1\right)\right) \\
&= c_1\left(\frac{1}{c_2^{5/2}}\Gamma\left(\frac{5}{2}\right)\right) \\
&= c_1 \cdot \frac{1}{c_2^{3/2}}\,\frac{3\sqrt{\pi}}{4}
\end{aligned}$$

Mensubtitusikan kembali c_1 dan c_2 ke dalam persamaan

$$\begin{aligned}
\varepsilon_{ave} &= c_1 \cdot \frac{1}{c_2^{5/2}}\,\frac{3\sqrt{\pi}}{4} \\
&= 2\pi\left(\frac{1}{\pi kT}\right)^{3/2} \cdot (kT)^{5/2} \cdot \frac{3\sqrt{\pi}}{4} \\
&= \frac{(kT)^{5/2}\,\frac{3.\sqrt{\pi}}{4}}{\frac{1}{\cancel{2\pi}} \cdot \sqrt{\pi}\cancel{\sqrt{\pi}}\sqrt{\pi}\ (kT)^{3/2}} \\
&= \frac{(kT)^{5/2}\,\frac{3.\sqrt{\pi}}{4}}{\frac{\sqrt{\pi}}{2}(kT)^{3/2}} \\
&= \frac{3\cancel{\sqrt{\pi}}}{\cancel{4}_2} \cdot \frac{\cancel{2}}{\cancel{\sqrt{\pi}}} \cdot kT \\
&= \frac{3}{2}kT \quad //
\end{aligned}$$

kita perlu belajar fisika statistik untuk mempelajari sistem mikroskopis beranggota sangat banyak dalam orde bilangan Avogrado yang tidak mungkin mengkarakterisasi masing-masing individu anggota sistem tersebut. Sifat sistem kemudian diturunkan dari perataan sifat individu anggota sistem tersebut.

4. a) Mengapa kita perlu belajar fisika statistik ?

Jawab : Karena statistika pada umumnya tidak dapat menjangkau ukuran mikro, hanya ukuran makro saja. Untuk itu perlu adanya fisika statistik. Fisika statistik mampu membahas atau menghitung sistem fisis berukuran mikro yang berada di alam, dimana sistem mikro ini tidak dapat dilihat secara langsung seperti molekul, atom dan lain-lain.

Ruang fasa merupakan kombinasi dari ruang spasial dan ruang momentum atau kecepatan. Oleh karena atom-atom sistem mikroskopis selalu bergerak dan bergerak itu berarti posisinya berpindah, maka dinamika sistem mikroskopis dapat didiskripsikan dengan baik dan lengkap melalui pergerakan atom-atom sistem mikroskopis tersebut dalam

b) Mengapa perlu ada ruang fasa untuk sistem mikroskopik ?

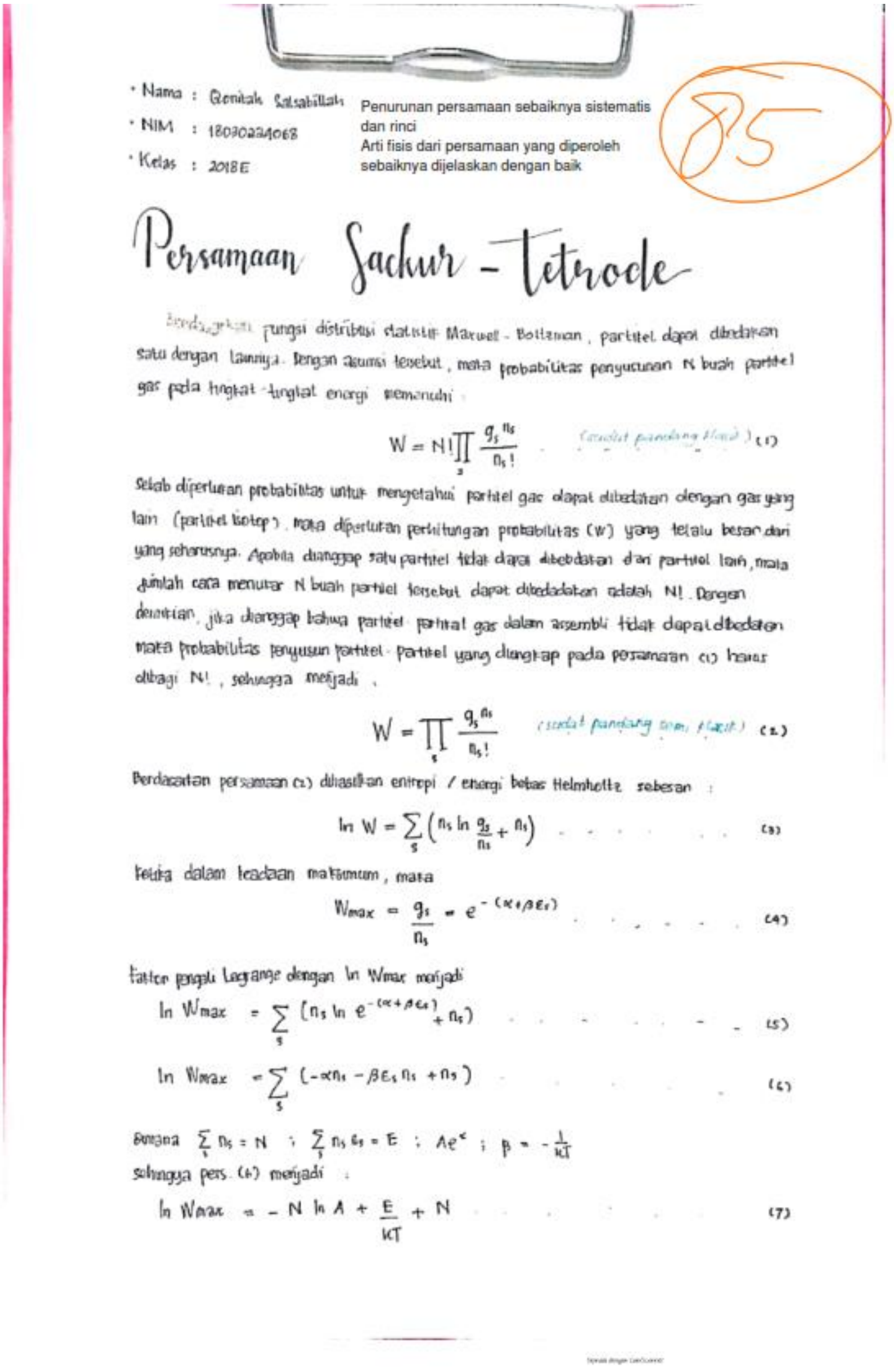
Jawab : Ruang fasa adalah kombinasi antara ruang spasial dan ruang momentom. Sistem mikroskopik yang kita tahu adalah sistem fisis yang berukuran mikro (kecil) dimana sistem ini selalu bergerak, serta memiliki massa dan juga momentum. Sehingga perlulah ruang fasa tersebut untuk menghitung gerak-gerak yang ada pada ruangan atau partikel-partikel dalam benda.

c) Mengapa semua fungsi distribusi memiliki bentuk sebagai fungsi eksponensial pangkat negatif ?

Jawab : Agar kurva distribusi dapat berbentuk seperti kurva peluruhan radioaktif. Dimana kurva tersebut melengkung dari kiri ke kanan bawah menunjukkan bahwa zat radioaktif semakin lama semakin menyusut dan berkurang.

Sebagian besar fungsi distribusi yang mendiskripsikan sifat dan perilaku alamiah sistem fisis apapun biasanya merupakan fungsi Gaussian yang memiliki ciri sebagai fungsi eksponensial berpangkat negatif. Hal ini untuk memberikan batasan terhadap kemungkinan nilai teoritis variabel dinamik dalam fungsi distribusi tersebut berharga tak hingga. Misalnya, fungsi distribusi kecepatan dan energi, seandainya kecepatan dan energi berharga tak hingga maka secara otomatis fungsi distribusinya berharga nol. Dengan kata lain, secara fisis tidaklah mungkin menjumpai situasi dimana kecepatan dan energi sistem berharga tak hingga karena hal itu berarti fungsi distribusinya berharga nol. Apabila fungsi distribusi berharga nol, maka sistem fisis tersebut tidak eksis.

D.3.2 Assignment 2



- Nama : Qonitah Salsabillah
- NIM : 18030234068
- Kelas : 2018E

Penurunan persamaan sebaiknya sistematis dan rinci
Arti fisis dari persamaan yang diperoleh sebaiknya dijelaskan dengan baik

85

Persamaan Sackur - Tetrode

Berdasarkan fungsi distribusi statistik Maxwell - Boltzman, partikel dapat dibedakan satu dengan lainnya. Dengan asumsi tersebut, maka probabilitas penyusunan N buah partikel gas pada tingkat-tingkat energi memenuhi :

$$W = N!\prod_s \frac{g_s^{n_s}}{n_s!} \qquad \text{(sudut pandang klasik)} \quad (1)$$

Sebab diperlukan probabilitas untuk mengetahui partikel gas dapat dibedakan dengan gas yang lain (partikel isotop), maka diperlukan perhitungan probabilitas (W) yang terlalu besar dari yang seharusnya. Apabila dianggap satu partikel tidak dapat dibedakan dari partikel lain, maka jumlah cara menukar N buah partikel tersebut dapat dibedakan adalah N!. Dengan demikian, jika dianggap bahwa partikel-partikel gas dalam assembli tidak dapat dibedakan maka probabilitas penyusun partikel-partikel yang dianggap pada persamaan (1) harus dibagi N!, sehingga menjadi :

$$W = \prod_s \frac{g_s^{n_s}}{n_s!} \qquad \text{(sudut pandang semi klasik)} \quad (2)$$

Berdasarkan persamaan (2) dihasilkan entropi / energi bebas Helmholtz sebesar :

$$\ln W = \sum_s \left(n_s \ln \frac{g_s}{n_s} + n_s\right) \quad (3)$$

Ketika dalam keadaan maksimum, maka

$$W_{max} = \frac{g_s}{n_s} = e^{-(\alpha+\beta\varepsilon_s)} \quad (4)$$

Faktor pengali Lagrange dengan ln Wmax menjadi

$$\ln W_{max} = \sum_s \left(n_s \ln e^{-(\alpha+\beta\varepsilon_s)} + n_s\right) \quad (5)$$

$$\ln W_{max} = \sum_s \left(-\alpha n_s - \beta\varepsilon_s n_s + n_s\right) \quad (6)$$

Dimana $\sum_s n_s = N$; $\sum_s n_s \varepsilon_s = E$; Ae^{α} ; $\beta = -\frac{1}{kT}$
sehingga pers. (6) menjadi :

$$\ln W_{max} = -N \ln A + \frac{E}{kT} + N \quad (7)$$

fungsi partisi $z = \frac{N}{A}$, diperoleh nilai ln Wmax

$$\ln W_{max} = N \ln \frac{z}{N} + \frac{E}{kT} + N \quad (8)$$

dengan nilai $z = BV\,(2\pi mkT)^{3/2}$. Parameter B dalam fungsi partisi menyatakan rapat keadaan dalam ruang fasa, maka dengan menggunakan prinsip ketidakpastian Heisenberg $\Delta p_x \Delta x \approx h$ diperoleh volume pada ruang fasa minimum.

$$\Delta \Gamma_{min} = \Delta p_x \Delta p_y \Delta p_z \Delta x \Delta y \Delta z$$

$$\Delta \Gamma_{min} \approx h \cdot h \cdot h$$

$$\Delta \Gamma_{min} \approx h^3 \quad (9)$$

Parameter B bergantung keadaan fasa maksimum, maka

$$B = \frac{1}{\Delta \Gamma_{min}} = \frac{1}{h^3} \quad \text{(sudut pandang semi klasik)} \quad (10)$$

Nilai z yang digunakan untuk menurunkan persamaan keadaan termodinamika yaitu :

$$Z = \frac{V}{h^3}(2\pi mkT)^{3/2} \quad (11)$$

Maka energi totalnya :

$$E = NkT^2 \frac{d\ln z}{dT}$$

$$E = NkT^2 \frac{d}{dT} \ln \frac{V}{h^3}(2\pi mk)^{3/2}\, T^{3/2}$$

$$E = NkT^2 \frac{d}{dT}\left(\ln \frac{V}{h^3}(2\pi mk)^{3/2} + \frac{3}{2}\ln T\right)$$

$$E = NkT^2 \left(0 + \frac{3}{2} \cdot \frac{1}{T}\right)$$

$$E = \frac{3}{2} NkT \quad (12)$$

Nilai entropinya :

$$S = k \ln W_{max}$$

$$S = \frac{E}{T} + Nk\left(\ln \frac{z}{N} + 1\right)$$

$$S = \frac{(3/2\, Nk\cancel{T})}{\cancel{T}} + Nk\left(\ln \frac{V}{Nh^3}(2\pi mkT)^{3/2}\right) + Nk$$

$$S = \frac{5}{2}Nk + Nk\left(\ln \frac{V}{Nh^3}(2\pi mkT)^{3/2}\right)$$

$$S = Nk\left(\frac{5}{2} + \ln\left\{\frac{V(2\pi mkT)^{3/2}}{Nh^3}\right\}\right) \quad (13)$$

Persamaan tersebut dikenal dengan persamaan Sackur - Tetrode yang berlaku untuk entropi gas yang menempati volume (V) tersusun oleh partikel (N) yang tidak berstruktur pada suhu (T).

Kalor jenis cv gas diatomik

Diketahui bahwa energi molekul gas diatomik sebesar :

$$U \cong NkT^2\left[\frac{3}{2T} + \frac{\partial}{\partial T}\ln\left\{\sum_j (2j+1)e^{-j(j+1)h^2/8\pi^2 IkT}\right\} + \frac{\partial}{\partial T}\ln\left\{\frac{e^{-\hbar\omega/2kT}}{1-e^{-\hbar\omega/kT}}\right\} + \frac{\partial}{\partial T}\ln\left\{g_0 + g_1 e^{-U_1/kT}\right\}\right] \quad (1)$$

Didefinisikan suhunya menjadi :

$$\Theta_r = \frac{h^2}{8\pi^2 Ik} \quad ; \quad \Theta_v = \frac{\hbar\omega}{k} \quad ; \quad \Theta_e = \frac{U_1}{k}$$

Dengan definisi tersebut, maka persamaan (1) menjadi :

$$U \cong NkT^3\left[\frac{3}{2T} + \frac{\partial}{\partial T}\ln\left\{\sum_j (2j+1)e^{-j(j+1)\Theta_r/T}\right\} + \frac{\partial}{\partial T}\ln\left\{\frac{e^{-\Theta_v/2T}}{1-e^{-\Theta_v/T}}\right\} + \frac{\partial}{\partial T}\ln\left\{g_0 + g_1 e^{-\Theta_e/T}\right\}\right] \quad (2)$$

Kasus I → Dimana $T \ll \Theta_r$. Karena $\Theta_r \ll \Theta_v \ll \Theta_e$ maka
$(\Theta_r/T \; ; \; \Theta_v/T \; ; \; \Theta_e/T) \to \infty$

Sehingga persamaan (2) menjadi

$$U \approx NkT^2\left[\frac{3}{2T} + \frac{\partial}{\partial T}\ln\left\{\sum_j (2j+1)e^{-j(j+1)\infty}\right\} + \frac{\partial}{\partial T}\ln\left\{\frac{e^{-\infty}}{1+e^{-\infty}}\right\} + \frac{\partial}{\partial T}\ln\left\{g_0 + g_1 e^{-\infty}\right\}\right]$$

$$U = NkT^2\left[\frac{3}{2T} + 0 + 0 + 0\right]$$

$$U = \frac{3}{2}NkT \rightarrow U = \frac{3}{2}nN_0kT = \frac{3}{2}nRT$$

Berdasarkan persamaan energi dapat dihitung kapasitas kalor dan kalor jenisnya

- $C_v = \frac{dU}{dT} = \frac{d}{dT}\left(\frac{3}{2}nRT\right) = \frac{3}{2}nR$
- $c_v = \frac{C_v}{n} = \frac{3}{2}R$

Kasus ii $\rightsquigarrow$ Dimana $\theta_r \ll T \ll \theta_v$. Pada jangkauan ini maka $\theta_v / T \to \infty$, dan $\theta_e / T \to \infty$.

Sehingga persamaan (2) menjadi

$$U \approx NkT^2 \left[\frac{3}{2T} + \frac{\partial}{\partial T} \ln \left\{ \sum_j (2j+1) e^{-j(j+1)\theta_r/T} \right\} + \frac{\partial}{\partial T} \ln \left\{ \frac{e^{-\infty}}{1-e^{-\infty}} \right\} + \frac{\partial}{\partial T} \ln \left\{ g_0 + g_1 e^{-\infty} \right\} \right]$$

$$U = NkT^2 \left[\frac{3}{2T} + \frac{\partial}{\partial T} \ln \left\{ \sum_j (2j+1) e^{-j(j+1)\theta_r/T} \right\} \right]$$

Sebagai pendekatan

$$\sum_j (2j+1) e^{-j(j+1)\theta_r/T} = \int_0^\infty (2j+1) e^{-j(j+1)\theta_r/T} \, dj$$

$$= \int_0^\infty (2j+1) e^{-j(j+1)\theta_r/T} \, d(j+\tfrac{1}{2})$$

$$= 2e^{\theta_r/4T} \int_0^\infty (j+\tfrac{1}{2}) e^{-(j+1/2)^2 \theta_r/T} \, d(j+1/2)$$

misalkan $j + 1/2 = y$, maka

$$= 2e^{\theta_r/4T} \int_0^\infty x e^{-x^2\theta_r/T} \, dx$$

$$= e^{\theta_r/4T} \int_0^\infty \frac{T}{\theta_r} e^{-y} \, dy$$

$$= e^{\theta_r/4T} \frac{T}{\theta_r}$$

Energi pada jangkauan $\theta_r \ll T \ll \theta_v$

$$U \approx NkT^2 \left[\frac{3}{2T} + \frac{\partial}{\partial T} \ln \left\{ e^{\theta_r/4T} \frac{T}{\theta_r} \right\} \right]$$

$$U = NkT^2 \left[\frac{3}{2T} + \frac{\partial}{\partial T} \ln \left\{ \frac{T}{\theta_r} \right\} \right]$$

$$U = NkT^2 \left[\frac{3}{2T} + \frac{\partial}{\partial T} \ln T - \frac{\partial}{\partial T} \ln \theta_r \right]$$

$$U = NkT \left[\frac{3}{2T} + \frac{1}{T} - 0 \right]$$

$$U = \frac{5}{2} NkT \longrightarrow U = \frac{5}{2} n N_0 kT = \frac{5}{2} nRT \; //$$

Kapasitas kalor dan kalor jenisnya adalah :

- $C_v = \frac{dU}{dT} = \frac{d}{dT}\frac{5}{2}nRT = \frac{5}{2}nR$
- $c_v = \frac{C_v}{n} = \frac{5}{2}R$

Kasus (ii) $\rightsquigarrow T \gg \Theta_v$ dan $\Theta_c / T \to \infty$

Sehingga persamaan (2) menjadi

$$U \approx NkT^2 \left[\frac{3}{2T} + \frac{\partial}{\partial T}\ln\left\{e^{\Theta r/4T}\frac{T}{\Theta r}\right\} + \frac{\partial}{\partial T}\ln\left\{\frac{e^{-\Theta v/2T}}{1-e^{-\Theta v/T}}\right\}\right]$$

karena $T \gg \Theta_v$ maka $\Theta v / T \to 0$ dan $\Theta r / T \to 0$ sehingga

$$U = NkT^2\left[\frac{3}{2T} + \frac{\partial}{\partial T}\ln\left\{\frac{T}{\Theta r}\right\} + \frac{\partial}{\partial T}\ln\left\{\frac{T}{\Theta v}\right\}\right]$$

$$U = NkT^2\left[\frac{3}{2T} + \frac{1}{T} + \frac{1}{T}\right]$$

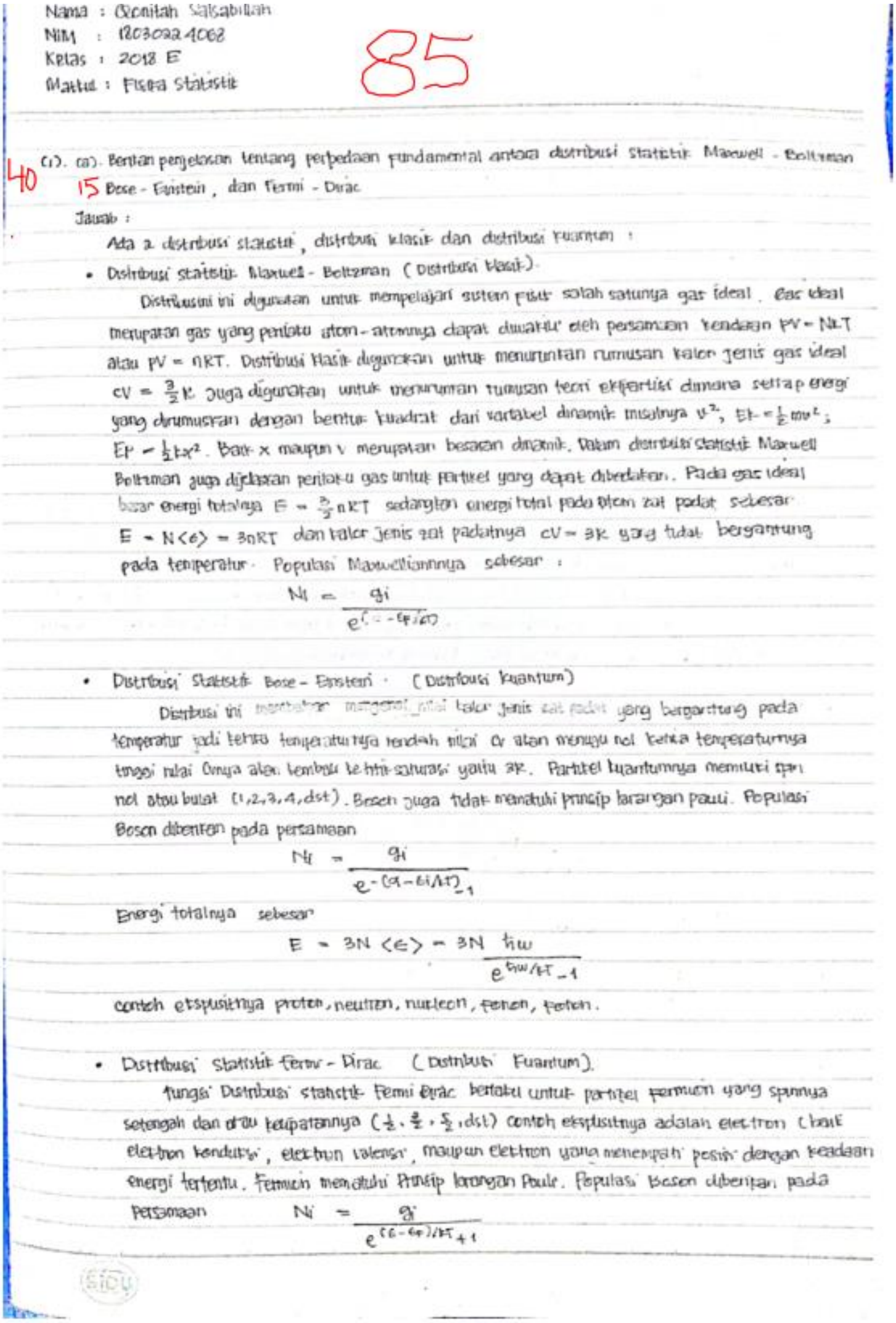
$$U = \frac{7}{2}NkT \rightarrow U = \frac{7}{2}nRT$$

Kapasitas kalor dan kalor jenisnya adalah :

- $C_v = \frac{dU}{dT} = \frac{d}{dT}\left(\frac{7}{2}nRT\right) = \frac{7}{2}nR$
- $c_v = \frac{C_v}{n} = \frac{7}{2}R$

Dari hasil tersebut tampak bahwa kapasitas kalor gas mengalami perubahan ketika suhu diubah dari sangat rendah ke sangat tinggi. Suhu sangat rendah dan sangat tinggi tersebut sangat relatif dan bergantung pada jenis gas.

D.3.3 Student Work on Mid Exam



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Matkul : Fisika Statistik

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40 (1). (a). Berikan penjelasan tentang perbedaan fundamental antara distribusi statistik Maxwell - Boltzman
15 Bose - Einstein, dan Fermi - Dirac

Jawab :

Ada 2 distribusi statistik, distribusi klasik dan distribusi kuantum :

- Distribusi statistik Maxwel - Boltzman (Distribusi klasik).

Distribusi ini digunakan untuk mempelajari sistem fisik salah satunya gas ideal. Gas ideal merupakan gas yang perilaku atom-atomnya dapat diwakili oleh persamaan keadaan $PV = NkT$ atau $PV = nRT$. Distribusi klasik digunakan untuk menurunkan rumusan kalor jenis gas ideal $cV = \frac{3}{2}k$. Juga digunakan untuk menurunkan rumusan teori ekipartisi dimana setiap energi yang dirumuskan dengan bentuk kuadrat dari variabel dinamik misalnya v^2, $Ek = \frac{1}{2}mv^2$; $Ep = \frac{1}{2}kx^2$. Baik x maupun v merupakan besaran dinamik. Dalam distribusi statistik Maxwell Boltzman juga dijelaskan perilaku gas untuk partikel yang dapat dibedakan. Pada gas ideal besar energi totalnya $E = \frac{3}{2}nkT$ sedangkan energi total pada sistem zat padat sebesar $E = N\langle \epsilon \rangle = 3nRT$ dan kalor jenis zat padatnya $cV = 3k$ yang tidak bergantung pada temperatur. Populasi Maxwellianmnya sebesar :

$$Ni = \frac{gi}{e^{(\alpha - \epsilon i/kT)}}$$

- Distribusi Statistik Bose - Einstein (Distribusi kuantum)

Distribusi ini membahas mengenai nilai kalor jenis zat padat yang bergantung pada temperatur jadi ketika temperaturnya rendah nilai Cv akan menuju nol ketika temperaturnya tinggi nilai Cvnya akan kembali ke titik saturasi yaitu 3k. Partikel kuantumnya memiliki spin nol atau bulat (1,2,3,4,dst). Boson juga tidak mematuhi prinsip larangan pauli. Populasi Boson diberikan pada persamaan

$$Ni = \frac{gi}{e^{-(\alpha - \epsilon i/kT)} - 1}$$

Energi totalnya sebesar

$$E = 3N\langle \epsilon \rangle = 3N \frac{\hbar w}{e^{\hbar w/kT} - 1}$$

contoh eksplisitnya proton, neutron, nukleon, fonon, foton.

- Distribusi Statistik Fermi - Dirac (Distribusi Kuantum).

Fungsi Distribusi statistik Femi Dirac berlaku untuk partikel fermion yang spinnya setengah dan atau kelipatannya $(\frac{1}{2}, \frac{3}{2}, \frac{5}{2}, dst)$ contoh eksplisitnya adalah elektron (baik elektron konduksi, elektron valensi, maupun elektron yang menempati posisi dengan keadaan energi tertentu. Fermion mematuhi Prinsip larangan Pauli. Populasi Boson diberikan pada persamaan

$$Ni = \frac{gi}{e^{(\epsilon - \epsilon_F)/kT} + 1}$$

Distribusi fermi-Dirac menjelaskan fenomena konduksi logam dan perbedaan sifatnya. Persamaan energi ferminya

$$\epsilon_F = \frac{h^2}{2m}\left(\frac{n_v \pi}{L}\right)^2 = \frac{\hbar^2}{2m}\left(\frac{N\pi}{2L}\right)^2$$

(b). Bentuk distrib populasi fermion

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$$N_i = \frac{g_i}{e^{(\epsilon-\epsilon_F)/kT}+1}$$

Rumus populasi ini bermanfaat sekali untuk menjelaskan fenomena mengapa gas Bose-Einstein berperilaku sebagai sistem klasik atau gas elektron / elektron konduksi logam

$$N_i = \frac{g_i}{e^{(\epsilon-\epsilon_F)/kT}+1}$$

$$e^{(\epsilon-\epsilon_F)/kT}+1 = \frac{g_i}{N_i}$$

$$e^{(\epsilon-\epsilon_F)/kT} = \frac{g_i}{N_i}-1$$

$$\left\{ \frac{g_i}{N_i}-1 = \frac{g_i}{N_i} \rightsquigarrow \right.$$ jika dan hanya jika pembilangnya jauh lebih besar dari penyebut.

$$e^{(\epsilon-\epsilon_F)/kT} = \frac{g_i}{N_i}$$

$$N_i = \frac{g_i}{e^{(\epsilon-\epsilon_F)/kT}}$$ (Populasi Maxwellian)

Dengan demikian proses diatas merupakan proses berubahnya distribusi statistik kuantum Fermi-Dirac menjadi fungsi distribusi statistik Maxwell-Boltzman. Dengan kata lain proses tersebut mendeskripsikan proses berubahnya sistem kuantum menjadi sistem klasik. Itu berarti, syarat agar sistem kuantum dalam halini sistem fermion berubah menjadi sistem klasik (maxwellian) dengan mengasumsikan g jauh lebih besar dari N. Dalam bahasa Fisika, g adalah jumlah keadaan dengan tingkat energi tertentu, N adalah jumlah partikel.

Sistem Kuantum Boson ⟶ Sistem Klasik Maxwellian

$$N_i = \frac{g_i}{e^{(\epsilon-\epsilon_F)/kT}-1}$$

$$e^{(\epsilon-\epsilon_F)/kT}-1 = \frac{g_i}{N_i}$$

$$e^{(\epsilon-\epsilon_F)/kT} = \frac{g_i}{N_i}+1$$

$$\left\{ \frac{g_i}{N_i}+1 = \frac{g_i}{N_i} \rightsquigarrow \right.$$ jika dan hanya jika pembilangnya jauh lebih besar dari penyebutnya.

$$e^{(\epsilon-\epsilon_F)/kT} = \frac{g_i}{N_i}$$

$$N_i = \frac{g_i}{e^{(\epsilon-\epsilon_F)/kT}}.$$

Sistem kuantum, baik boson maupun fermion berubah menjadi sistem klasik jika dan hanya jika jumlah $g_i \gg N_i$

Fungsi Partisi Boltzman ·

$$Z = \int_0^\infty g(\epsilon) e^{-\epsilon/kT} \, d\epsilon = BV(2\pi mkT)^{3/2}.$$

Epsilon (energi) yang tidak mungkin berharga negatif oleh karena itu, batas integralnya dimulai dari nol sampai tak hingga

B = Konstanta ; V = Volume

$$\underset{g=1}{①} = B \underbrace{\Delta x \Delta p_x}_{h} \underbrace{\Delta y \Delta p_y}_{h} \underbrace{\Delta z \Delta p_z}_{h}$$

Δx = ketidakpastian Heisenberg

$$1 = Bh^3$$

$$Z = \frac{V}{h^3}(2\pi mkT)^{3/2} \; ; \; \frac{N}{Z} = \frac{Nh^3}{V(2\pi mkT)^{3/2}} = e^{\alpha} = A$$

ternyata ada rumusan $\frac{N}{Z}$ yang dikarakteristikan dengan A, yang menjadi kriteria apakah suatu sistem fisis tertentu dapat dikategorikan sebagai sistem klasik atau bukan. A sebanding dengan kerapatan gas N/V, gas ideal adalah gas yang atomnya berjauhan. Kerapatan hanya ditentukan oleh 2 variabel N dan V bukan oleh cara bagaimana atom-atom berinteraksi. Sehingga N/V untuk gas ideal rendah, apabila ada sistem fisis yang A nya kecil atau N/V nya rendah, maka sistem fisis itu adalah sistem fisis klasik Maxwell Boltzman.

(2). a). Diketahui = $C_V = 3R$ ($R = 8,3 \text{ Jmol}^{-1}\text{K}^{-1}$). $c_V = 5,5$

45 15

$$C_V = \frac{1}{n}\left(\frac{\partial E}{\partial T}\right)_V$$

$$= 3\frac{N_A}{k}\frac{\hbar^2\omega^2}{T^2}\frac{e^{\hbar\omega/kT}}{(e^{\hbar\omega/kT}-1)^2}$$

$$= 3N_A k\left(\frac{\hbar^2\omega^2}{kT}\right)\frac{e^{\hbar\omega/kT}}{(e^{\hbar\omega/kT}-1)^2}$$

$$= 3R\left(\frac{\hbar^2\omega}{kT}\right)\frac{e^{\hbar\omega/kT}}{(e^{\hbar\omega/kT}-1)^2}$$

- ketika $\hbar\omega \gg kT$ maka $e^{\hbar\omega/kT} - 1 \approx e^{\hbar\omega/kT}$

  maka dapat ditulis $C_V = 3R\left(\frac{\hbar\omega}{kT}\right)^2 e^{-\hbar\omega/kT} \approx 0$

- ketika $\hbar\omega \ll kT$ maka $e^{\hbar\omega/kT} \approx 1 + \frac{\hbar\omega}{kT}$

  Persamaan menjadi $C_V = 3R\left(1 + \frac{\hbar\omega}{kT}\right)$ karena suhu terlampau besar, maka

  $C_V \approx 3R.$

$C_V \approx 3R$

$C_V \approx 3 \cdot \frac{8,314}{4,2} \longrightarrow C_V \approx 5,9$ kal/mol K $\rightsquigarrow C_V \approx 6$ kal/mol K.

(b). T_E lead = 300 K

15 T_E Al = 450 K

T_E Si = 900 K.

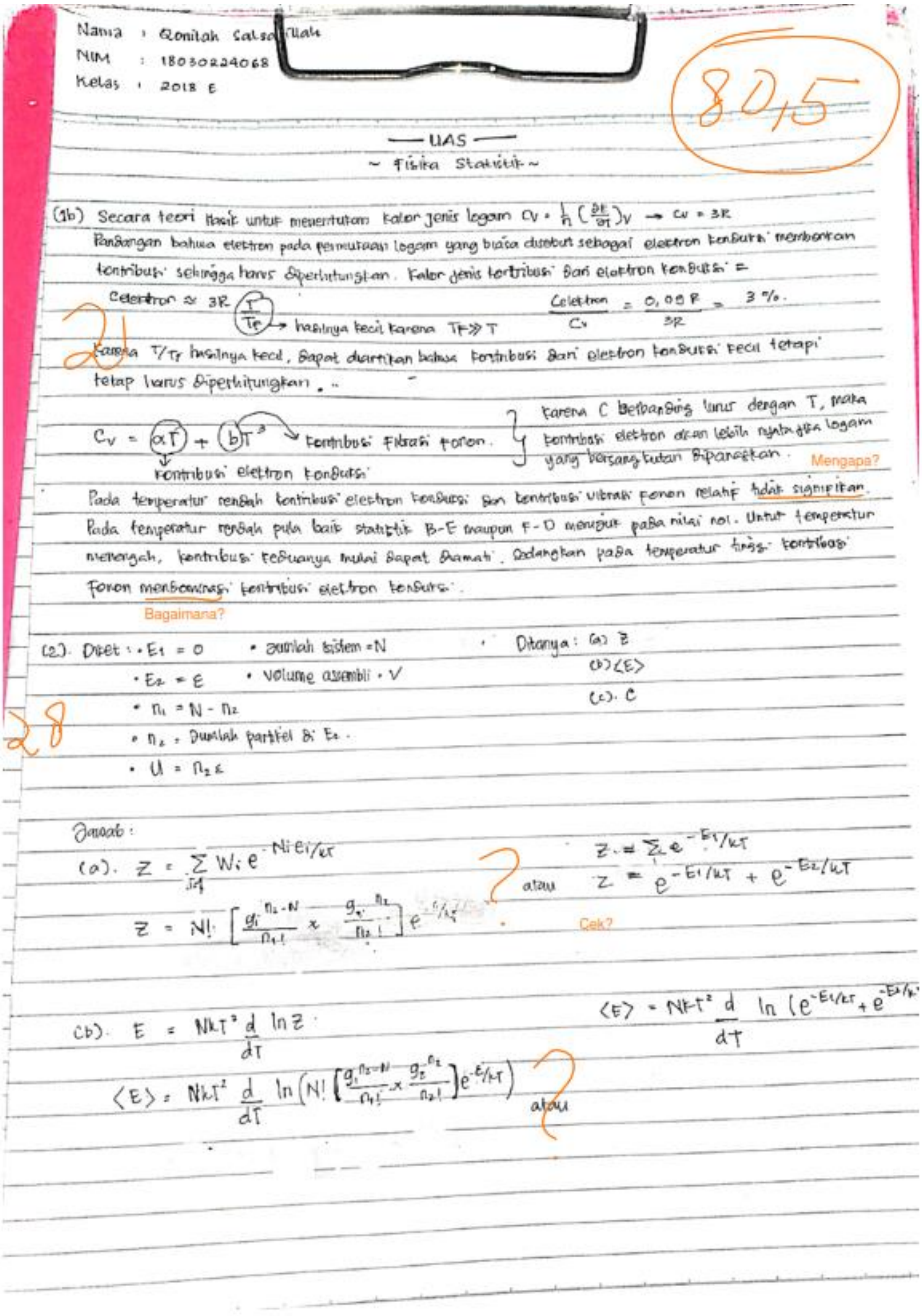
(c). $\hbar\omega_L = k_B T_E = 8,62 \times 10^{-5}$ eV/K × 300 K = $2,586 \times 10^{-2}$ eV

15 $\hbar\omega_{Al} = k_B T_E = 8,62 \times 10^{-5}$ eV/K × 450 K = $3,879 \times 10^{-2}$ eV

$\hbar_{Si} = k_B T_E = 8,62 \times 10^{-5}$ eV/K × 900 K = $7,758 \times 10^{-2}$ eV

(d). •

D.3.4 Student Work on Final Exam



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Kelas : 2018 E

80,5

— UAS —
~ Fisika Statistik ~

(1b) Secara teori klasik untuk menentukan kalor jenis logam $C_V = \frac{1}{n}\left(\frac{\partial E}{\partial T}\right)_V \rightarrow C_V = 3R$
Pandangan bahwa elektron pada permukaan logam yang biasa disebut sebagai elektron konduksi memberikan kontribusi sehingga harus diperhitungkan. Kalor jenis kontribusi dari elektron konduksi =

$C_{elektron} \approx 3R \boxed{\frac{T}{T_F}} \rightarrow$ hasilnya kecil karena $T_F \gg T$ $\qquad \frac{C_{elektron}}{C_V} = \frac{0,09R}{3R} = 3\%$.

21

Karena T/T_F hasilnya kecil, dapat diartikan bahwa kontribusi dari elektron konduksi kecil tetapi tetap harus diperhitungkan.

$C_V = \underbrace{\boxed{\alpha T}}_{\text{kontribusi elektron konduksi}} + \boxed{b} T^3 \rightarrow$ kontribusi vibrasi fonon.

} karena C berbanding lurus dengan T, maka kontribusi elektron akan lebih nyata jika logam yang bersangkutan dipanaskan. Mengapa?

Pada temperatur rendah kontribusi elektron konduksi dan kontribusi vibrasi fonon relatif tidak signifikan. Pada temperatur rendah pula baik statistik B-E maupun F-D menuju pada nilai nol. Untuk temperatur menengah, kontribusi keduanya mulai dapat diamati. Sedangkan pada temperatur tinggi kontribusi fonon mendominasi kontribusi elektron konduksi.
Bagaimana?

(2). Diket : • $E_1 = 0$ • Jumlah sistem = N · Ditanya : (a) Z
• $E_2 = \varepsilon$ • Volume assembli = V (b) ⟨E⟩
• $n_1 = N - n_2$ (c). C
• n_2 = Jumlah partikel di E_2.
• $U = n_2 \varepsilon$

28

Jawab :

(a). $Z = \sum_{i=1} W_i e^{-N_i \varepsilon_i / kT}$

$Z = N! \left[\frac{g_1^{n_2 - N}}{n_1!} \times \frac{g_2^{n_2}}{n_2!}\right] e^{-\varepsilon/kT}$

? atau $Z = \sum_i e^{-E_i/kT}$

$Z = e^{-E_1/kT} + e^{-E_2/kT}$

Cek?

(b). $E = NkT^2 \frac{d}{dT} \ln Z$

$\langle E \rangle = NkT^2 \frac{d}{dT} \ln\left(N! \left[\frac{g_1^{n_2 - N}}{n_1!} \times \frac{g_2^{n_2}}{n_2!}\right] e^{-\varepsilon/kT}\right)$

? atau $\langle E \rangle = NkT^2 \frac{d}{dT} \ln\left(e^{-E_1/kT} + e^{-E_2/kT}\right.$

$$C_v = \frac{d}{dT}\left(NkT^2 \frac{d}{dT} \ln Z\right)$$

$$= 2NkT \frac{d}{dT} \ln Z + NkT^2 \frac{d^2}{dT^2} \ln Z$$

$$= Nk \left(2T \frac{d}{dT} \ln Z + T^2 \frac{d^2}{dT^2} (\ln Z)\right).$$

$$= Nk \left(2T \frac{d}{dT} \ln \left(e^{-E_1/kT} + e^{-E_2/kT}\right) + T^2 \frac{d^2}{dT^2} \ln \left(e^{-E_1/kT} + e^{-E_2/kT}\right)\right.$$

Cek?

(3). Canonical Ensembel → Ensembel yang asembli-asemblinya memiliki dinding yang tidak dapat ditembus sistem tetapi dapat ditembus oleh energi. Dalam ensembel ini jumlah sistem dalam semua assembli sama banyaknya tetapi energinya berbeda. Namun jumlah total assembli dalam ensembelnya konstan, karena tidak terjadi pertukaran partikel (dN = 0).

Contoh : (1) Air mineral dalam botol yang terkena sinar matahari

25,5

(2) Refrigeran dalam mesin pendingin

(3) Besi yang dipanaskan dari satu ujung, ujung yang lain juga akan panas.

?

Grand Kanonical Ensembel → Ensembel yang asembli-asemblinya memiliki dinding yang dapat ditembus sistem maupun energi sehingga terjadi pertukaran partikel (dN ≠ 0) dan terjadi pertukaran energi (dE ≠ 0). Dalam sistem termodinamika disebut sistem terbuka.

Contoh : (1) Air Conditioner (AC), terjadi pertukaran energi (kalor). terjadi pertukaran partikel (udara)

(2) Kopi Panas yang menjadi dingin.

(3) Kulkas, terjadi pertukaran energi dari panas menjadi dingin.

?

Micro Kanonikal Ensembel → Ensembel yang asembli-asemblinya memiliki dinding yang tidak dapat ditembus sistem maupun energi sehingga tidak terjadi pertukaran partikel dan tidak terjadi pertukaran energi. Dalam sistem termodinamika disebut sistem terisolasi

Contoh : (1) Air dalam termos → menjaga suhu air tetap dan dilapisi dinding isolator

(2) Kalorimeter. → memiliki sifat yang sama dengan sistem termos.

(3) Gas Ideal.

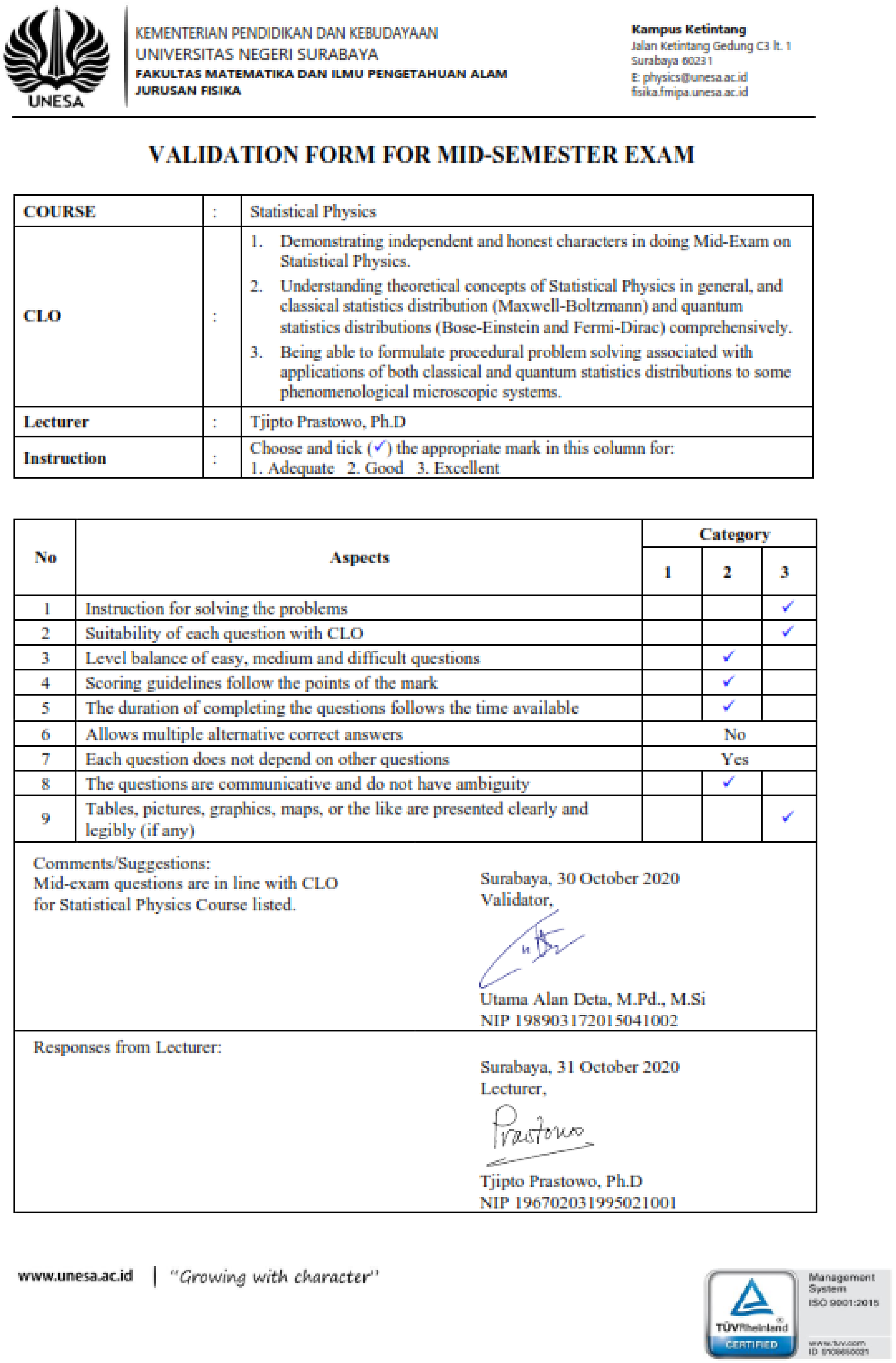
?

Demi Allah, saya akan mengerjakan UAS dengan bersungguh-sungguh sesuai dengan hasil pemikiran saya pribadi tanpa melakukan kecurangan dalam bentuk apapun.

RONITAH S.

D.4 VALIDATION TEST

D.4.1 Validation Test of Mid Exam



UNESA

KEMENTERIAN PENDIDIKAN DAN KEBUDAYAAN
UNIVERSITAS NEGERI SURABAYA
FAKULTAS MATEMATIKA DAN ILMU PENGETAHUAN ALAM
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VALIDATION FORM FOR MID-SEMESTER EXAM

COURSE	:	Statistical Physics
CLO	:	1. Demonstrating independent and honest characters in doing Mid-Exam on Statistical Physics. 2. Understanding theoretical concepts of Statistical Physics in general, and classical statistics distribution (Maxwell-Boltzmann) and quantum statistics distributions (Bose-Einstein and Fermi-Dirac) comprehensively. 3. Being able to formulate procedural problem solving associated with applications of both classical and quantum statistics distributions to some phenomenological microscopic systems.
Lecturer	:	Tjipto Prastowo, Ph.D
Instruction	:	Choose and tick (✓) the appropriate mark in this column for: 1. Adequate 2. Good 3. Excellent

No	**Aspects**	**Category**		
		1	**2**	**3**
1	Instruction for solving the problems			✓
2	Suitability of each question with CLO			✓
3	Level balance of easy, medium and difficult questions		✓	
4	Scoring guidelines follow the points of the mark		✓	
5	The duration of completing the questions follows the time available		✓	
6	Allows multiple alternative correct answers	No		
7	Each question does not depend on other questions	Yes		
8	The questions are communicative and do not have ambiguity		✓	
9	Tables, pictures, graphics, maps, or the like are presented clearly and legibly (if any)			✓

Comments/Suggestions:
Mid-exam questions are in line with CLO
for Statistical Physics Course listed.

Surabaya, 30 October 2020
Validator,

Utama Alan Deta, M.Pd., M.Si
NIP 198903172015041002

Responses from Lecturer:

Surabaya, 31 October 2020
Lecturer,

Prastowo

Tjipto Prastowo, Ph.D
NIP 196702031995021001

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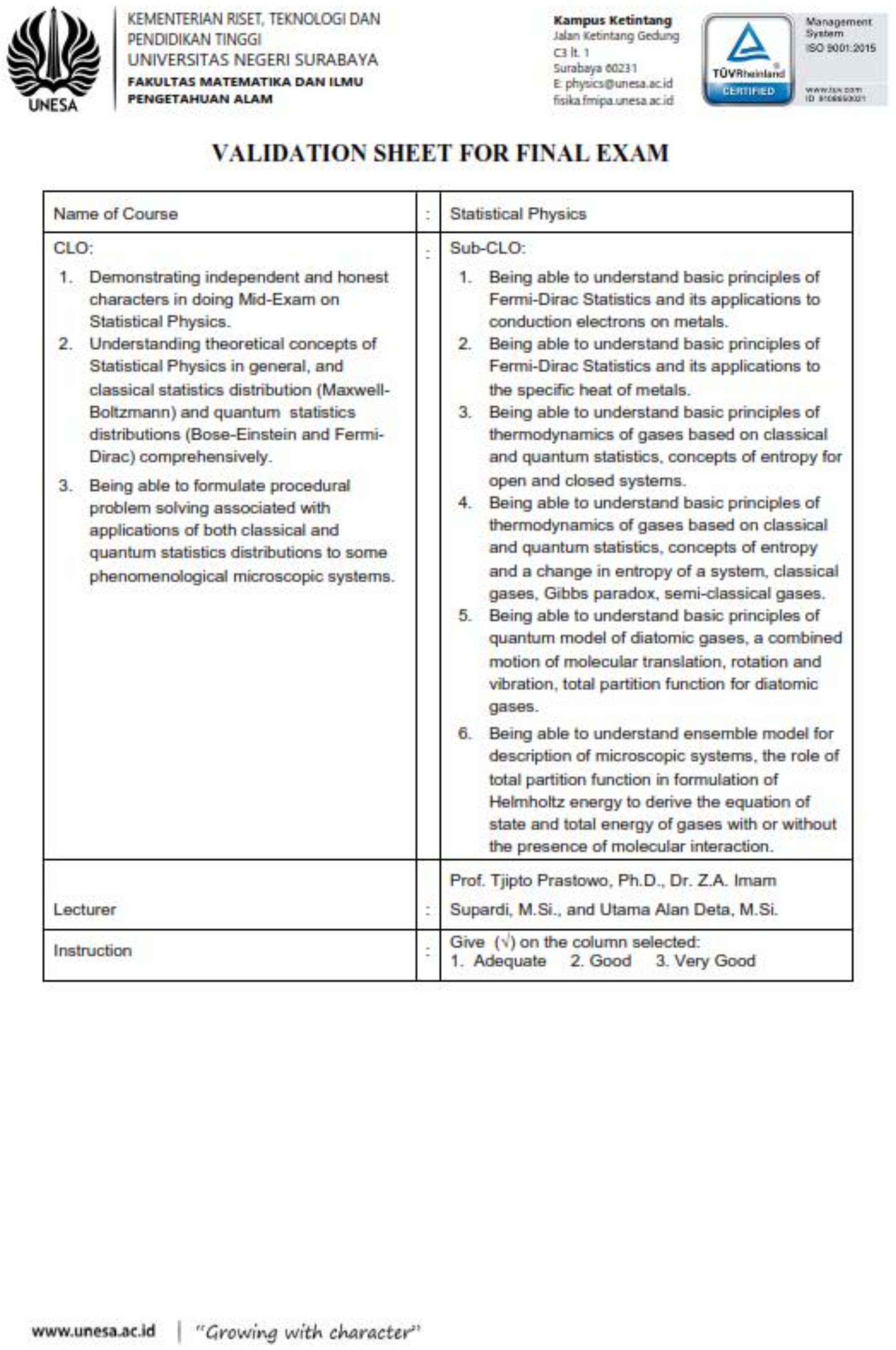
D.4.2 Validation Test of Final Exam



KEMENTERIAN RISET, TEKNOLOGI DAN PENDIDIKAN TINGGI
UNIVERSITAS NEGERI SURABAYA
FAKULTAS MATEMATIKA DAN ILMU PENGETAHUAN ALAM

Kampus Ketintang
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Surabaya 60231
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VALIDATION SHEET FOR FINAL EXAM

Name of Course	:	Statistical Physics
CLO: 1. Demonstrating independent and honest characters in doing Mid-Exam on Statistical Physics. 2. Understanding theoretical concepts of Statistical Physics in general, and classical statistics distribution (Maxwell-Boltzmann) and quantum statistics distributions (Bose-Einstein and Fermi-Dirac) comprehensively. 3. Being able to formulate procedural problem solving associated with applications of both classical and quantum statistics distributions to some phenomenological microscopic systems.	:	Sub-CLO: 1. Being able to understand basic principles of Fermi-Dirac Statistics and its applications to conduction electrons on metals. 2. Being able to understand basic principles of Fermi-Dirac Statistics and its applications to the specific heat of metals. 3. Being able to understand basic principles of thermodynamics of gases based on classical and quantum statistics, concepts of entropy for open and closed systems. 4. Being able to understand basic principles of thermodynamics of gases based on classical and quantum statistics, concepts of entropy and a change in entropy of a system, classical gases, Gibbs paradox, semi-classical gases. 5. Being able to understand basic principles of quantum model of diatomic gases, a combined motion of molecular translation, rotation and vibration, total partition function for diatomic gases. 6. Being able to understand ensemble model for description of microscopic systems, the role of total partition function in formulation of Helmholtz energy to derive the equation of state and total energy of gases with or without the presence of molecular interaction.
Lecturer	:	Prof. Tjipto Prastowo, Ph.D., Dr. Z.A. Imam Supardi, M.Si., and Utama Alan Deta, M.Si.
Instruction	:	Give (√) on the column selected: 1. Adequate 2. Good 3. Very Good

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No	Aspects	Category		
		1	2	3
1	Instruction for solving the problems			✓
2	Suitability of each question with CLO		✓	
3	Level balance of easy, medium and difficult questions			✓
4	Scoring guidelines follow the points of the mark		✓	
5	The duration of completing the questions follows the time available			✓
6	Allows multiple alternative correct answers	No		
7	Each question does not depend on other questions	Yes		
8	The questions are communicative and do not have ambiguity		✓	
9	Tables, pictures, graphics, maps, or the like are presented clearly and legibly (if any)			✓

Comments/Suggestions:
Final-exam questions are in line with CLO
for Statistical Physics Course listed.

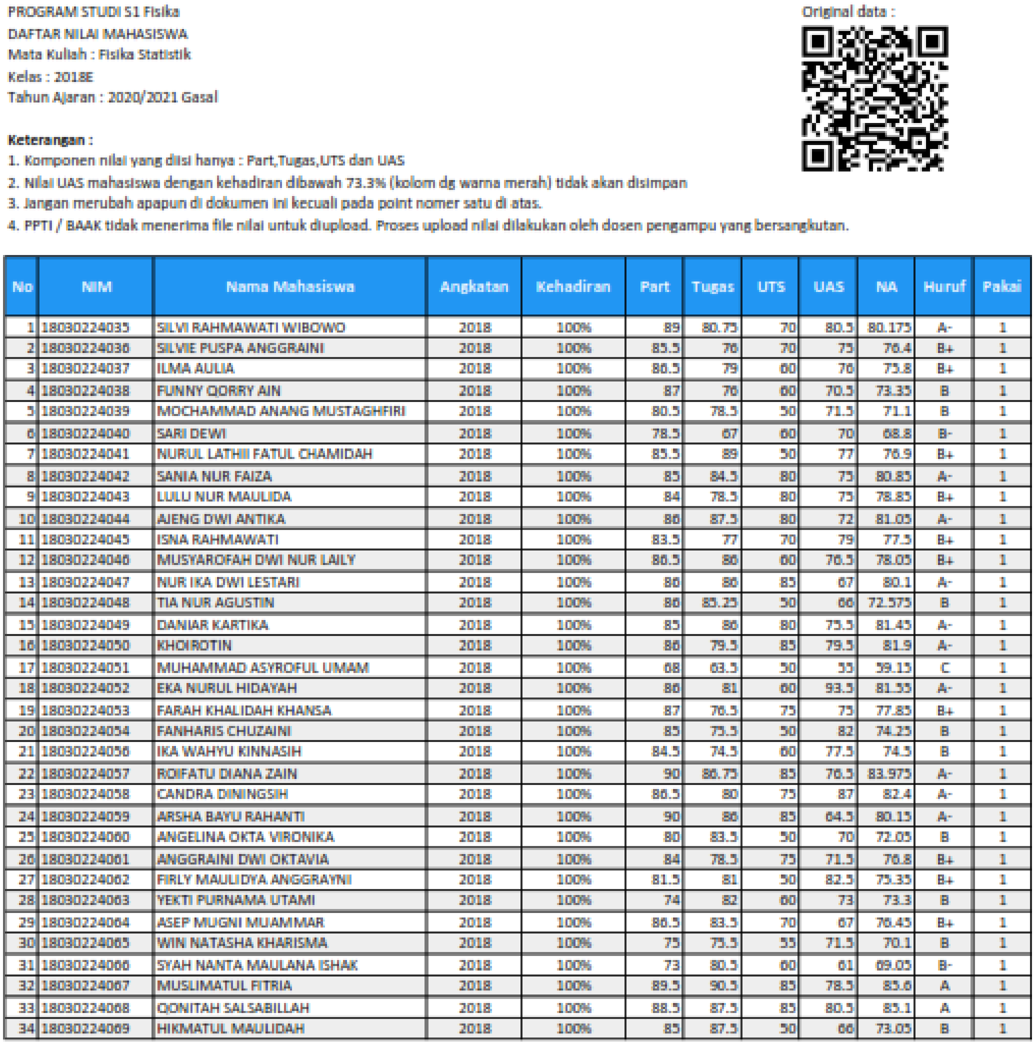
Surabaya, 4 January 2020
Validator,
Prastowo
Tjipto Prastowo, Ph.D
NIP 196702031995021001

Response from Lecturer:

Surabaya, 5 January 2020
Lecturer,

Utama Alan Deta, M.Pd., M.Si
NIP 198903172015041002

D.5 CLASS ACADEMIC ACHIEVEMENT



PROGRAM STUDI S1 Fisika
DAFTAR NILAI MAHASISWA
Mata Kuliah : Fisika Statistik
Kelas : 2018E
Tahun Ajaran : 2020/2021 Gasal

Original data :

Keterangan :

1. Komponen nilai yang diisi hanya : Part,Tugas,UTS dan UAS
2. Nilai UAS mahasiswa dengan kehadiran dibawah 73.3% (kolom dg warna merah) tidak akan disimpan
3. Jangan merubah apapun di dokumen ini kecuali pada point nomer satu di atas.
4. PPTI / BAAK tidak menerima file nilai untuk diupload. Proses upload nilai dilakukan oleh dosen pengampu yang bersangkutan.

No	NIM	Nama Mahasiswa	Angkatan	Kehadiran	Part	Tugas	UTS	UAS	NA	Huruf	Pakai
1	18030224035	SILVI RAHMAWATI WIBOWO	2018	100%	89	80.75	70	80.5	80.175	A-	1
2	18030224036	SILVIE PUSPA ANGGRAINI	2018	100%	85.5	76	70	75	76.4	B+	1
3	18030224037	ILMA AULIA	2018	100%	86.5	79	60	76	75.8	B+	1
4	18030224038	FUNNY QORRY AIN	2018	100%	87	76	60	70.5	73.35	B	1
5	18030224039	MOCHAMMAD ANANG MUSTAGHFIRI	2018	100%	80.5	78.5	50	71.5	71.1	B	1
6	18030224040	SARI DEWI	2018	100%	78.5	67	60	70	68.8	B-	1
7	18030224041	NURUL LATHII FATUL CHAMIDAH	2018	100%	85.5	89	50	77	76.9	B+	1
8	18030224042	SANIA NUR FAIZA	2018	100%	85	84.5	80	75	80.85	A-	1
9	18030224043	LULU NUR MAULIDA	2018	100%	84	78.5	80	75	78.85	B+	1
10	18030224044	AJENG DWI ANTIKA	2018	100%	86	87.5	80	72	81.05	A-	1
11	18030224045	ISNA RAHMAWATI	2018	100%	83.5	77	70	79	77.5	B+	1
12	18030224046	MUSYAROFAH DWI NUR LAILY	2018	100%	86.5	86	60	76.5	78.05	B+	1
13	18030224047	NUR IKA DWI LESTARI	2018	100%	86	86	85	67	80.1	A-	1
14	18030224048	TIA NUR AGUSTIN	2018	100%	86	85.25	50	66	72.575	B	1
15	18030224049	DANIAR KARTIKA	2018	100%	85	86	80	75.5	81.45	A-	1
16	18030224050	KHOIROTIN	2018	100%	86	79.5	85	79.5	81.9	A-	1
17	18030224051	MUHAMMAD ASYROFUL UMAM	2018	100%	68	63.5	50	55	59.15	C	1
18	18030224052	EKA NURUL HIDAYAH	2018	100%	86	81	60	93.5	81.55	A-	1
19	18030224053	FARAH KHALIDAH KHANSA	2018	100%	87	76.5	75	75	77.85	B+	1
20	18030224054	FANHARIS CHUZAINI	2018	100%	85	75.5	50	82	74.25	B	1
21	18030224056	IKA WAHYU KINNASIH	2018	100%	84.5	74.5	60	77.5	74.5	B	1
22	18030224057	ROIFATU DIANA ZAIN	2018	100%	90	86.75	85	76.5	83.975	A-	1
23	18030224058	CANDRA DININGSIH	2018	100%	86.5	80	75	87	82.4	A-	1
24	18030224059	ARSHA BAYU RAHANTI	2018	100%	90	86	85	64.5	80.15	A-	1
25	18030224060	ANGELINA OKTA VIRONIKA	2018	100%	80	83.5	50	70	72.05	B	1
26	18030224061	ANGGRAINI DWI OKTAVIA	2018	100%	84	78.5	75	71.5	76.8	B+	1
27	18030224062	FIRLY MAULIDYA ANGGRAYNI	2018	100%	81.5	81	50	82.5	75.35	B+	1
28	18030224063	YEKTI PURNAMA UTAMI	2018	100%	74	82	60	73	73.3	B	1
29	18030224064	ASEP MUGNI MUAMMAR	2018	100%	86.5	83.5	70	67	76.45	B+	1
30	18030224065	WIN NATASHA KHARISMA	2018	100%	75	75.5	55	71.5	70.1	B	1
31	18030224066	SYAH NANTA MAULANA ISHAK	2018	100%	73	80.5	60	61	69.05	B-	1
32	18030224067	MUSLIMATUL FITRIA	2018	100%	89.5	90.5	85	78.5	85.6	A	1
33	18030224068	QONITAH SALSABILLAH	2018	100%	88.5	87.5	85	80.5	85.1	A	1
34	18030224069	HIKMATUL MAULIDAH	2018	100%	85	87.5	50	66	73.05	B	1

D.6 ASSESSMENT OF PLO-CLO AND CLASS PERFORMANCE

ASSESSMENT OF PROGRAM LEARNING OUTCOMES (PLO)

COURSE : Statistical Physics
CREDIT : 3
STUDY PROGRAM : Undergraduate Programme of Physics
PERIOD : 2020/2021 (Odd Semester)
CLASS : 2018E
PARTICIPANTS : 34

PROGRAM LEARNING OUTCOMES:

PLO 1. Able to demonstrate knowledge of Classical Physics and Modern Physics.

PLO 2. Able to formulate a physical systems as physical model by using mathematics.

PLO 6. Able to improve their knowledge and be able to continue their study in a higher education.

PLO 9. Able to work as an individual as well as a team effectively, have entrepreneurship skill and awareness of environmental issues.

COURSE LEARNING OUTCOMES:

1. Demonstrating independent, creative and honest characters in doing student assignments, mid and final exams.

2. Understanding theoretical concepts of Statistical Physics in general and Classical Statistics (Maxwell-Boltzmann distribution) and Quantum Statistics (Bose-Einstein and Fermi-Dirac distributions) comprehensively.

3. Being able to formulate problem solving for procedural problems relevant to the applications of both Classical and Quantum Statistics to some statistical phenomena found in microscopic systems.

CLO-PLO CORRELATION:

	PLO1	PLO2	PLO3	PLO4	PLO5	PLO6	PLO7	PLO8	PLO9	PLO10	PLO11
CLO1	✓	✓	0	0	0	✓	0	0	✓	0	0
CLO2	✓	✓	0	0	0	✓	0	0	✓	0	0
CLO3	✓	✓	0	0	0	✓	0	0	✓	0	0

ASSESSMENT PLAN:

	PLO1	PLO2	PLO3	PLO4	PLO5	PLO6	PLO7	PLO8	PLO9	PLO10	PLO11
CLO1	Participation, Assignment, Mid Exam, Final Exam	Participation, Assignment, Mid Exam, Final Exam	0	0	0	Participation, Assignment, Mid Exam, Final Exam	0	0	Participation, Assignment, Mid Exam, Final Exam	0	0
CLO2	Participation, Assignment, Mid Exam, Final Exam	Participation, Assignment, Mid Exam, Final Exam	0	0	0	Participation, Assignment, Mid Exam, Final Exam	0	0	Participation, Assignment, Mid Exam, Final Exam	0	0
CLO3	Participation, Assignment, Mid Exam, Final Exam	Participation, Assignment, Mid Exam, Final Exam	0	0	0	Participation, Assignment, Mid Exam, Final Exam	0	0	Participation, Assignment, Mid Exam, Final Exam	0	0

STUDENTS' PERFORMANCE:

	PLO1	PLO2	PLO3	PLO4	PLO5	PLO6	PLO7	PLO8	PLO9	PLO10	PLO11
Excellent	29%	29%	#DIV/0!	#DIV/0!	#DIV/0!	25%	#DIV/0!	#DIV/0!	29%	#DIV/0!	#DIV/0!
Good	67%	67%	#DIV/0!	#DIV/0!	#DIV/0!	50%	#DIV/0!	#DIV/0!	67%	#DIV/0!	#DIV/0!
Satisfy	4%	4%	#DIV/0!	#DIV/0!	#DIV/0!	25%	#DIV/0!	#DIV/0!	4%	#DIV/0!	#DIV/0!
Fail	0%	0%	#DIV/0!	#DIV/0!	#DIV/0!	0%	#DIV/0!	#DIV/0!	0%	#DIV/0!	#DIV/0!

GRAPHICAL CLASS OR STUDENTS PERFORMANCE