## EBONYI STATE UNIVERSITY, ABAKALIKI

DEPARTMENT OF INDUSTRIAL PHYSICS

SECOND SEMESTER 2021/2022 EXAMINATION

COURSE CODE: PHY 412 Title: Statistical and Thermal Physics

Date: 20/10/2022

Instruction: Answer Any Four Questions

Time: 2 Hours, Credit Unit: 3

1. (a) Why we study statistical mechanics (3 areas)
We study it to link microscopic particles to macroscopic laws and predict bulk properties.
- Gases/Thermodynamics: From molecular motion we derive pV=nkT, internal energy, entropy, heat capacities.
- Solids (electrons & phonons): Explains heat capacity of crystals (Debye model), electron behavior in metals, Fermi energy.
- Radiation/Light: Gives Planck’s black-body law from photon statistics.

(b) Microstate (two approaches)
A microstate is one exact specification of the system at the microscopic level.
- Classical view: A point in phase space (all particle positions and momenta).
- Quantum view: A specific set of quantum numbers (occupation of energy eigenstates).

(c) Equilibrium macrostate vs microstates
A macrostate is defined by bulk variables (e.g., E,V,N). The number of microstates compatible with it is its multiplicity W. Systems move toward the macrostate with maximum W (maximum entropy S=k ln W), which is the most stable equilibrium. So equilibrium macrostate ↔ overwhelmingly many microstates.

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2. (a) System definition via the three ensembles
- Microcanonical: Isolated system; fixed E,V,N. All accessible microstates have equal probability.
- Canonical: Closed to heat bath; fixed T,V,N (energy can fluctuate). Boltzmann weight e^{-βE}.
- Grand Canonical: Open system; fixed T,V,μ (energy and particles can exchange). Weight e^{-β(E-μN)}.

(b) Distinguishability
Particles are distinguishable if swapping two changes the microstate (classical labeled particles). They are indistinguishable when exchange does not create a new state (quantum identical particles: bosons/fermions). Distinguishability affects counting and entropy (Gibbs correction).

(c) Partition function for distinguishable particles
For one particle with levels {ε\_i}: z\_1 = Σ\_i e^{-βε\_i}.
For N distinguishable non-interacting particles: Z\_N = (z\_1)^N.
(We do not divide by N! here because particles are labeled/distinguishable.)

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3. (a) Why particles are indistinguishable
Identical quantum particles have no individual identity; measurements cannot tell which is which. Their total wavefunction must be symmetric (bosons) or antisymmetric (fermions). When de Broglie wavelengths overlap, classical labels fail—indistinguishability is required.

(b) Linear combination of ψ
Yes. By the superposition principle, any linear combination of allowed solutions is also a solution (if boundary conditions hold).
Example: particle in an infinite well 0<x<L: ψ\_n(x)=sin(nπx/L).
Ψ(x,t)=c1ψ1 e^{-iE1t/ħ}+c2ψ2 e^{-iE2t/ħ} is a valid physical state, normalizable and satisfying the boundary conditions. Different c\_i give different measurable probabilities.

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4. (a) Prediction of Fermi–Dirac distribution
f(E)=1/[e^{(E-μ)/kT}+1].
At T=0, all states with E<E\_F are filled and those with E>E\_F are empty (step function). At T>0, the step smears around μ≈E\_F. Explains electron filling in metals and many solid-state properties.

(b) Applications of transport phenomena
Describe flow of charge, heat, and matter: electrical conductivity and thermoelectric effects in metals/semiconductors, thermal conduction, viscosity of fluids, diffusion, plasma transport, and device noise/relaxation times.

(c) Scattering probability
For random scattering with mean time τ=20s, probability to scatter within time t=10.5s:
P=1-e^{-t/τ}=1-e^{-10.5/20}≈1-e^{-0.525}≈0.408 (≈41%).

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5. (a) Occupancy 0.25 at 300 K — energy gap to the “maximum filled energy”
For Fermi–Dirac:
f=1/[e^{(E-μ)/kT}+1]=0.25 → e^{(E-μ)/kT}=3.
So E-μ = kT ln 3.
With k=1.38×10^{-23} J/K, T=300K: ΔE=4.55×10^{-21} J (≈0.0284 eV).
Here μ is the “maximum energy of the filled state” (≈Fermi level).

(b) Pauli Exclusion Principle
No two identical fermions can occupy the same quantum state (same set of quantum numbers) simultaneously.

(c) Fermi energy
The energy of the highest occupied electron state at T=0K; sets the scale for electron properties in a metal.

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6. (a) Fermi temperature and velocity for sodium (E\_F=3.3 eV)
Convert E\_F to joules: E\_F=3.3×1.602×10^{-19}=5.2866×10^{-19} J.
- Fermi temperature: T\_F=E\_F/k\_B=5.2866×10^{-19}/1.38×10^{-23}≈3.83×10^4 K.
- Fermi velocity: v\_F=√(2E\_F/m\_e)=√[2(5.2866×10^{-19})/9.11×10^{-31}]≈1.08×10^6 m/s.

(b) Successes of Drude theory
- Gives Ohm’s law and σ=ne^2τ/m; explains why conductivity scales with carrier density and relaxation time.
- Explains Wiedemann–Franz trend (link between electrical and thermal conductivities).
- Predicts qualitative temperature dependence of resistivity and AC response σ(ω).
- Provides basic picture for Hall effect magnitude and sign (with refinements by Sommerfeld).

(c) Applications of fluctuation phenomena
Thermal (Johnson–Nyquist) noise in resistors, Brownian motion and diffusion, shot noise in electronics, critical opalescence near phase transitions, and random-walk models used in soft matter and semiconductor device physics.