CARE PHYS 213 Review Session - Quiz 2

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Welcome to the Center for Academic Resources in Engineering (CARE) PHYS 213 Quiz 2 Review Session!

This session will be lead by Jonah and Wesley on Nov. 12 from 3-5pm in CIF!

Tutors are available to answer questions, review problems, and help you feel prepared for your final. The worksheet can be found under the PHYS 213 section here:

https://care.grainger.illinois.edu/programs/exam-review-sessions

Solutions and slides will be posted after the session. Let us know if you have any questions!
Topic breakdown for the Exam 2

Unit 5: Thermodynamic Processes

Unit 6: Reversible Processes

Unit 7: Boltzmann Factor

Unit 8: Boltzmann Examples

Boltzmann Constant

The Boltzmann constant $k$ is a physical constant that relates average kinetic energy of a gas particle to its temperature.

$$\frac{PV}{TN} = k$$

Boyle, Charles, Gay-Lussac, Avogadro

$$k = \frac{R}{N_A} = \frac{nR}{N}$$

$$k = 1.380649 \times 10^{-23} \text{ J/K}$$
Unit 5: Thermodynamics Processes

Four Main processes:

- Isochoric: Constant Volume
- Isobaric: Constant Pressure
- Isothermal: Constant Temperature
- Adiabatic: Constant Heat ($dQ = 0$)
Unit 6: Reversible Processes

- Processes which keep the system in equilibrium
  - Isothermal + Adiabatic
- Must be slow
- $dS = 0$ (no change in entropy)
- For adiabatic processes: $PV^\gamma = \text{constant}$
Unit 7: Boltzmann Factor

- \( \exp(-E / k_B T) \)  
  Boltzmann factor for state \( i \)

- Uses:
  - Finding energies of states
  - Probability of an energy state: \( P(i) \)
  - Counting Microstates

- Probability of state \( i \)

\[
f_i = e^{-E_i/kT}
\]

\[
P(i) = \frac{f_i}{\sum_j f_j}
\]

\[
U = \sum_i P_i E_i
\]

- \( q \) quanta in \( N \) oscillators:

\[
\binom{N - 1 + q}{q} = \frac{(N - 1 + q)!}{q! (N - 1)!}
\]
Boltzmann Example: Two State System

Suppose we have a system with two possible energies:

- \( E_a = 5 \times 10^{-22} \) J
- \( E_b = 12 \times 10^{-22} \) J

One distinct microstate corresponds to \( E_a \), but two distinct microstates correspond to \( E_b \). The system is in an environment at 300 K.

What is the probability that the particle has energy \( E_a \)?

Answer: \[ P(E_a) = \frac{\exp(-E_a/k_B T)}{\exp(-E_a/k_B T) + 2\exp(-E_b/k_B T)} = 0.372 \]
- The Helmholtz Free Energy is a useful expression to describe systems which can transfer heat but not particles or volume with the environment (i.e. constant volume).
- Defined as: \( F_{\text{system}} = U_{\text{system}} - T_{\text{environ}} S_{\text{system}} \)
- Equilibrium occurs when \( F \) is minimized.
- For an engine using a brick: \( W_{\text{max}} = F_{\text{initial}} - F_{\text{equilibrium}} \).
Example: Hot Brick

We have a hot brick \((T_H = 800 \text{ K})\) powering an engine in contact with a cold reservoir \(T_C = 200 \text{ K}\). The heat capacity of the brick is \(C_b = 1 \text{ J/K}\).

To what temperature will the brick have cooled when the engine stops doing work?

What do you expect the maximum amount work that could be extracted from the brick to be?

In general, when a system is colder than the temperature of the environment \((T_{sys} < T_{env})\) its free energy is:
Chemical Equilibria

- $\mu = \frac{dF}{dN}$, at constant temperature and volume
- At Equilibrium:
  - Total entropy (S of system and env) maximized
  - Free Energy (F) minimized
  - Chemical Potentials must be equal
Conceptual Check: Chemical Equilibrium

How does free energy relate to chemical potential?

- $F/N = dF/dN = \mu$

- It's the amount of free energy per particle!

What does chemical potential represent?

- the energy absorbed or released due to a change of the particle number of the given species
Good Luck!!!

Feel free to ask any questions you may have!

You got this!!!