CARE PHYS 213 Quiz 1 Review Session

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Welcome to the Center for Academic Resources in Engineering (CARE) P

Final Exam Review Schedule:

- Monday, 4/1, 6-8 pm in CIF 4039 |-----| Tutors: Wesley, David, Apar

Worksheet

Solutions

Slides

Worksheets and solutions for past exams can be found on the Exam Rev

Additionally, here is a Jupyter Notebook file giving examples of things y n
your computer, you can open the file on Google Colab.

Jupyter Notebook file

Good luck on your exam!

https://queue.illinois.edu/q/queue/713

This queue is closed. Check back later!

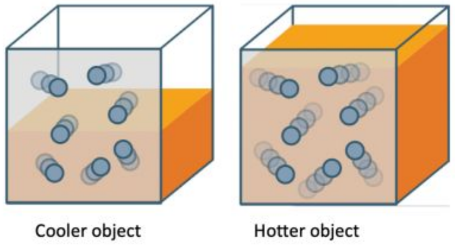
Internal Energy

- Total energy is always conserved
- **Positive work on a system increases its internal energy (contracting volume).**
- First law of thermodynamics:

$$\underbrace{\Delta U}_{\text{Change in internal energy}} = \underbrace{W_{on}}_{\text{Work done on the system}} + \underbrace{Q}_{\text{Heat added to the system}}$$

Temperature, Heat Capacity

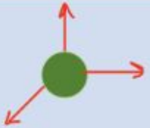
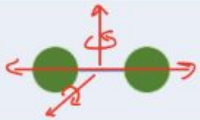
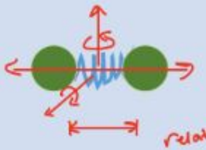
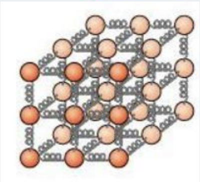
- Heat capacity (C) - how much the heat energy of a system increases per unit temperature (Kelvin)
  - Larger heat capacity = more energy is required to increase the temperature
- Higher temperature = more internal energy



Heat Capacity (Molar/Specific)

- **Heat Capacity:** The amount of heat required to raise the temperature of **an (entire) object** by 1 K – units are Joules / Kelvin (J/K)
  - Defined for an object (at constant volume) with internal energy U as:
    - $C = \mathrm{d}U/\mathrm{d}T$
- **Molar Heat Capacity:** The amount of heat required to raise the temperature of **1 mole** of something by 1 K - units are Joules / mole Kelvin (J / mol K)
  - Simply divide C by number of moles
- **Specific Heat Capacity:** The amount of heat required to raise the temperature of **1 kg** of something by 1 K - units are Joules / kilogram Kelvin (J / kg K)

Equipartition

	Molecule	Degrees of freedom	U	C_V
Monatomic: DOF = 3		$N_{DOF} = 3$ x, y, z momentum	$U = \frac{3}{2}NkT$	$C_V = \frac{3}{2}Nk$
Diatomic: DOF = 5		$N_{DOF} = 5$ x, y, z momentum 2 rotation axes	$U = \frac{(3+2)}{2}NkT$	$C_V = \frac{5}{2}Nk$
Vibrational: DOF = 7	 relative	x, y, z momentum 2 rotation axes vibration mode (momentum+potential) $N_{DOF} = 7$	$U = \frac{(3+2+2)}{2}NkT$	$C_V = \frac{7}{2}Nk$
Solid: DOF = 6		x, y, z momentum x, y, z spring modes	$U = \frac{(3+3)}{2}NkT$	$C_V = 3Nk$

← don't need to know this one

Equipartition and Heat Capacity

- Only need to memorize DOFs for monatomic gas, diatomic gas, and solids (3, 5, and 6, respectively)
  - # DOFs is able to increase as temperature increase (but you don't need to memorize and "special" cases)
- For objects under the <u>equipartition assumption</u>:

$$U = \frac{N_{\mathrm{DOF}}}{2} NkT \implies C = \frac{\mathrm{d}U}{\mathrm{d}T} = \frac{N_{\mathrm{DOF}}}{2} Nk$$

Entropy

- Microstate vs. Macrostate
  - Microstate: individual, **specific** arrangement
  - Macrostate: properties that arise from the microstate
  - **Many microstates can lead to same macrostate**
    - Two people have same weight (macrostate), but the distribution of weight can be different (microstate)

Entropy, cont'd

- The degree of "diversity" associated with a macrostate
- A measure of the number of microstates associated with a macrostate
  - $S = k\ln(\Omega)$ where Ω is the number of microstates
  - $\Delta S \geq 0$
- Equilibrium
  - Occurs when the macrostate of the system ceases to change
  - The most probable macrostate is the one with the **highest entropy**
  - In other words, **equilibrium is achieved when S, entropy, is maximized**

The Binomial Coefficient

If I have N coins and am looking for the macrostate with q heads, the number of microstates:

$$\binom{N}{q} = \frac{N!}{q!(N-q)!}$$

Example: If I have 20 coins, how many microstates are associated with the macrostate of having **7 heads**?

Answer: 20 “choose” 7:

$$\binom{20}{7} = 77520$$

Tip: scipy.special module

(special.binom() also works)

```
[ ]  from scipy import special

     # Known quantities:
     N = 20 # total number of coins
     q = 7 # number of heads
     # The first way of doing this is using the factorial function within special:
     omega = special.factorial(N) / (special.factorial(q) * special.factorial(N - q))
     print('Number of microstates:', omega)
     # The second (easier) way of doing this is just using special.comb():
     omega = special.comb(N,q)
     print('Number of microstates:', omega)

     Number of microstates: 77520.0
     Number of microstates: 77520.0
```

Dice Example

- **Microstate:** set of individual die values
- **Macrostate:** sum of die values
- What is the most likely macrostate?
  - 7: has the largest number of microstates associated with it
  - Probability = 6 / 36 = ⅙
- What is the macrostate with the *highest entropy?*
  - Again, 7: *has the largest number of microstates associated with it*
- **Entropy of a macrostate is simply a measure of the number of microstates associated with it**
- **More microstates → higher probability**

	2	3	4	5	6	7
	3	4	5	6	7	8
	4	5	6	7	8	9
	5	6	7	8	9	10
	6	7	8	9	10	11
	7	8	9	10	11	12

Entropy

$$\frac{1}{T} \equiv \left(\frac{dS}{dU}\right)_{V,N}$$

Temperature is defined as the derivative of entropy. When two systems can exchange energy, equilibrium occurs when the temperatures are equal. (maximizes entropy)

$$C_V = \left(\frac{dQ}{dT}\right)_{V,N}$$

Heat capacity is how much heat it takes to change the temperature of a system.

$$\Delta S = \int_{T_i}^{T_f} \frac{C_V(T)}{T} dT$$

$$\Delta U = \int_{T_i}^{T_f} C_V(T) dT$$

Measure heat capacity **as a function of temperature** to find change in entropy and internal energy.

Differential Manipulation

- Know these tricks!
- Heat capacity is the link between $\mathrm{d}U$ and $\mathrm{d}T$
  - **If you know the heat capacity and the temperature change, you can find the change in internal energy and the change in entropy**

$$C = \frac{\partial U}{\partial T} \implies \Delta U = \int_{T_i}^{T_f} C \mathrm{d}T$$

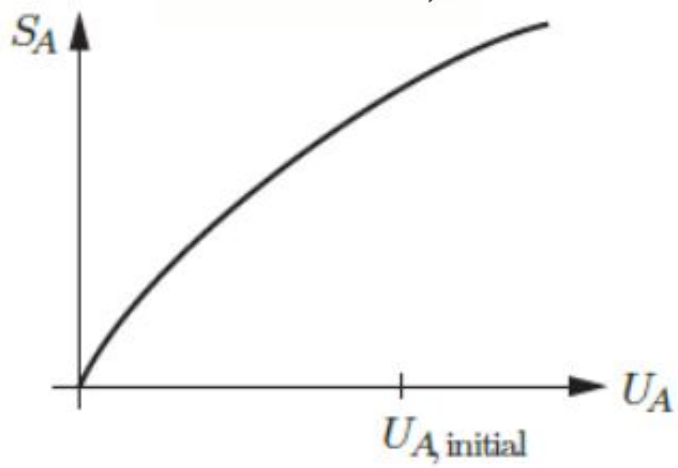
$$\frac{\partial S}{\partial U} = \frac{1}{T} \implies \Delta S = \int \frac{\mathrm{d}U}{T} = \int_{T_i}^{T_f} \frac{C \mathrm{d}T}{T}$$

Entropy vs. Internal Energy

What does this tell us?

- Since the slope is always positive, temperature is always positive
- More energy = greater entropy
- Diminishing returns: it gets harder and harder to increase entropy as you increase energy
- Decreasing slope = increasing temperature. More energy means greater temperature

$$\frac{1}{T} \equiv \left(\frac{dS}{dU}\right)_{V,N}$$



Good Luck!

Feel free to ask any questions you may have!

You got this!!!

Queue QR Code: Please sign in!

Ask us for our drop-in tutoring hours!

Check CARE website for more information!