Physics 207, Review, Dec. 15

- Semi-cumulative
- Early material, relatively simple calculations and more conceptual problems
- Most recent material comparable to previous exams
- Approx. 12 MC questions and 8 conventional.

Assignments:

- Problem Set 11, Ch. 22: 6, 7, 17, 37, 46 (Due, tonight at 11:59 PM)

Entropy and the 2nd Law

$$dS \equiv \frac{dQ_r}{T}$$

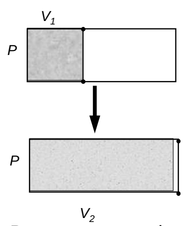
- In a reversible process the total entropy remains constant, ΔS=0!
- In a process involving heat transfer the change in entropy ΔS between the starting and final state is given by the heat transferred *Q* divided by the absolute temperature *T* of the system (if T is constant).

$$\Delta S = \frac{Q}{T}$$

- The 2nd Law of Thermodynamics
  "There is a quantity known as entropy that in a closed system always remains the same (reversible) or increases (irreversible)."
- Entropy, when constructed from a microscopic model, is a measure of disorder in a system.

Exercise

Free Expansion and the 2nd Law



You have an ideal gas in a box of volume V_1. Suddenly you remove the partition and the gas now occupies a larger volume V_2.

Does the entropy of the system increase and by how much?

$\Delta S = nC_v \ln (T_f / T_i) + nR \ln (V_f / V_i)$

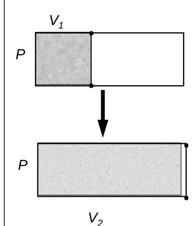
Because entropy is a state variable we can choose any path that get us between the initial and final state.

(1) Adiabatic reversible expansion (as above)

(2) Heat transfer from a thermal reservoir to get back to T_i

Exercise

Free Expansion and the 2nd Law



You have an ideal gas in a box of volume V_1. Suddenly you remove the partition and the gas now occupies a larger volume V_2.

Does the entropy of the system increase and by how much?

$\Delta S_1 = nC_v \ln (T_f / T_i) + nR \ln (V_f / V_i)$

(1) Heat transfer from a thermal reservoir to get to T_i

$\Delta S_2 = \int_i^f dQ/T = \int_i^f (dU + PdV) / T = \int_{T_f}^{T_i} nC_v \, dT/T = nC_v \ln(T_i / T_f)$

$\Delta S = \Delta S_1 + \Delta S_2 =$ ~~$nC_v \ln (T_f / T_i)$~~ $+ nR \ln (V_f / V_i)$ ~~$- nC_v \ln (T_f / T_i)$~~

The Laws of Thermodynamics

- First Law
  Q = U + W
- dQ = δU + δW = δU – P dV
- Second Law
  ΔS ≥ 0 and ΔS = 0 for a reversible process.
- **Do not forget: Entropy, S, is a <u>state variable</u> just like P, V and T!**

Recap , Lecture 29

- Agenda: Finish Ch. 22, Start review, Evaluations
  - Heat engines and Second Law of thermodynamics
  - Reversible/irreversible processes and Entropy

Assignments:

- Problem Set 11, Ch. 22: 6, 7, 17, 37, 46 (Due, Friday, Dec. 15, 11:59 PM)
- Friday, Review

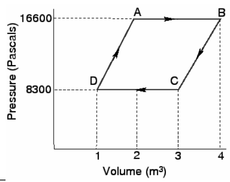
Review problem

- Important issues:
  - ❖ Process: What are the Qs and W ? (These reflects efficiency)
  - ❖ What is the change in entropy (ΔS) ?
  - ❖ State: What are P, V, T and S

Five moles of an ideal monoatomic gas are taken through the cycle shown using just two thermal reservoirs. (Take R to be 8.3 J/K mol)

(a) What is the internal energy of the gas at point C (in joules)?

(b) What is work done in moving from A to B (in joules)?



Review problem

- Five moles of an ideal monoatomic gas are taken through the cycle shown using just two thermal reservoirs. (Take R to be 8.3 J / K mol)

(a) What is the internal energy of the gas at point C (in joules)?

Working fluid: Ideal gas ($\gamma = 5/3$).

$PV = nRT$ and $U = 3/2\ nRT$

$U_C = 3/2\ P_C V_C = 1.5 \times 8300 \times 3$ J

(b) What is work done in moving from A to B (in joules)?

$W = \int PdV = P(V_B - V_A) = 16600 \times 2$ J

(c) Additional points:

$T_A, T_B, T_C, T_D = ???$

$T_A = P_A V_A/nR = 2000 \times 2/5 = 800$ K

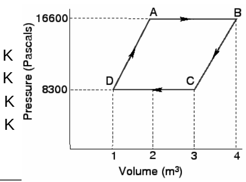
$T_B = P_B V_B/nR = 2000 \times 4/5 = 1600$ K

$T_C = P_C V_C/nR = 1000 \times 3/5 = 600$ K

$T_D = P_D V_D/nR = 1000 \times 1/5 = 200$ K

So A→B Q in, B→C Q out,

C→D Q out, D→A Q in



Review problem

- And what of these Q's? ($U = 3/2\ nRT = 3/2\ PV$) Let 1 m³ = V, P = 8300 Pa

$Q = \Delta U - W$ (on gas) $= \Delta U + W$ (by gas)

$U_A = 1.5 P_A V_A = 1.5\ nR\ T_A$ and so on.

$Q_{A\to B} = 1.5 P_A (V_B - V_A) + P_A (V_B - V_A) = 2.5 P_A (V_B - V_A) = 10$ PV

$Q_{B\to C} = 1.5 (P_C V_C - P_B V_B) + 0.5 (P_C + P_B)(V_C - V_B) = -7.5$ PV – 1.5 PV

$Q_{C\to D} = 1.5 P_C (V_D - V_C) + P_A (V_D - V_C) = 2.5 P_C (V_D - V_C) = -5$ PV

$Q_{D\to A} = 1.5 (P_A V_A - P_D V_D) + 0.5 (P_A + P_D)(V_A - V_D) = 4.5$ PV + 1.5 PV

$Q_{cold} = 14$ PV

$Q_{hot} = 16$ PV

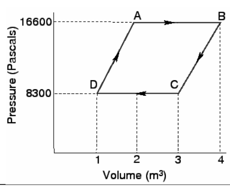
W = 2 PV

$\varepsilon = 1 - 14/16 = 0.125$

$\varepsilon_{Carnot} = 1 - 200\text{ K}/1600\text{ K} = 0.875$!!!

(best case scenario)

Suggestion: Don't build this engine!



Review problem

- And what of these ΔS?

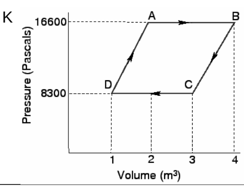
- If we start at A and end at A, $\Delta S_{engine} = 0$, still there has been Q's transferred between the high and low temperature reservoirs. These we need to know in order to determine ΔS. Let them be 1600 K and 200 K respectively (best case scenario). So

$\Delta S = Q_{high}/T_{high} + Q_{low}/T_{low}$

$\Delta S = -16$ PV J / 1600 K + 14 PV / 200 K

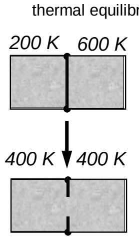
$\Delta S = -10$ nR + 70 nR = 60x8.3x5 J/T

(and we can't go back, $\Delta S > 0$)



Review problem

- An adiabatic (no thermal contact with the outside world), two compartment container, each container having a 10 liter capacity, is filled with 0.5 mole (per compartment) of an *identical* monoatomic idea gas with temperatures of 200 K and 600 K respectively. By how much does the entropy change if the gas in each chamber is allowed to mix and reestablish thermodynamic equilibrium? (Hint: Mixing and thermal equilibrium may be done separately.)



Adiabatic worked expansion

$\Delta S = nC_v \ln (T_f / T_i) + nR \ln (V_f / V_i)$

Heat transfer from a thermal reservoir

$\Delta S = nC_v \ln (T_f / T_i)$ for the ideal gas

($\Delta S_{res} = -Q/T_f$ for a fixed T reservoir)

Here only the temperature change matters

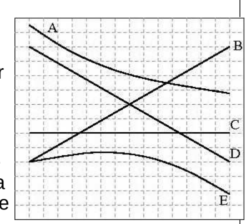
$\Delta S = nC_v \ln (T_f / T_1) + nC_v \ln (T_f / T_2)$

$\Delta S = 3nR/2\ [\ln (400/200) + \ln (400/600)] > 0$

Concept problem

- You can vary the efficiency of a Carnot engine by varying the temperature of the cold reservoir while maintaining the hot reservoir at constant temperature.

The curve that best represents the efficiency of such an engine as a function of the temperature of the cold reservoir is ___?



Review problem

- If an engine operates at half of its theoretical maximum efficiency (ε_{max}) and does work at the rate of W J/s, then, in terms of these quantities, how much heat must be discharged per second.
- This problem is about process (Q and W), specifically Q_C?

$\varepsilon_{max} = 1 - Q_C/Q_H$ and $\varepsilon = ½\, \varepsilon_{max} = ½(1 - Q_C/Q_H)$

also $W = \varepsilon\, Q_H = ½\, \varepsilon_{max} Q_H \rightarrow 2W / \varepsilon_{max} = Q_H$

$-Q_H (\varepsilon_{max} - 1) = Q_C \rightarrow Q_C = 2W / \varepsilon_{max} (1 - \varepsilon_{max})$

Review problem

- A thin sheet of metal 3.14 m long, 2.00 m wide & 0.0001 m thick is rolled into a hollow tube 2.00 m long and 0.50 m in radius. The coefficient of thermal expansion is $1.0\text{x}10^{-6}$ /C. If the temperature increases by 100 C, what is the approximate fractional change in the overall tube volume.
- Here the change in thickness is unlikely to matter.

Review problem

- An aluminum bar (1.000000 m long, 0.10 m^2 cross-sectional area) just slides into the 1.000000 m gap of a press. The temperature is now raised 10 ℃. How much pressure must be applied to keep the gap at exactly 1.000000 m. (Possibly useful information: Linear expansion coefficient $20.\text{x}10^{-6}$ /C, Young's Modulus $7.0\text{x}10^{10}$ N/m and Bulk Modulus $10\text{x}10^{10}$ N/m)
- $\Delta L/L$ from a compressive force must equal the $\Delta L/L$ from the temperature increase to be offsetting.
- $F/A / \Delta L/L = Y$ and $\Delta L/L = \alpha\, \Delta T \rightarrow F/(AY) + \alpha\, \Delta T = 0$

$F = -\alpha\, \Delta T\, A\, Y = -20\text{x}10^{-6} \text{x}10 \text{x} (0.10)\, 7.0\text{x}10^{10}$ N

$F = 1.4 \text{x}10^{6}$ N

Concept problem

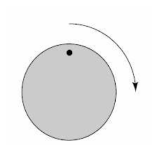
- Which of the following wavelengths could NOT be present as a harmonic on a 2 m long string:

(A) 4.00 m
(B) 2.00 m
(C) 1.00 m
(D) 0.89 m
(E) 0.50 m

Concept problem

- The circular object pictured here is made to rotate clockwise at 29 revolutions per second. It is filmed with a camera that takes 30 frames per second. Compared to its actual motion, the dot on the film appears to move

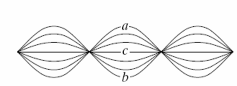
A. clockwise at a very slow rate.
B. counterclockwise at a very slow rate.
C. clockwise at a very fast rate.
D. counterclockwise at a very fast rate.
E. in a random fashion.



Concept problem

- A string is clamped at both ends and plucked so it vibrates in a standing mode between two extreme positions *a* and *b*. Let upward motion correspond to positive velocities. When the string is in position *c*, the instantaneous velocity of points along the string:

(A) is zero everywhere.
(B) is positive everywhere.
(C) is negative everywhere.
(D) depends on location.



Concept problem

An airplane mechanic notices that the sound from a twin-engine aircraft rapidly varies in loudness when both engines are running. What could be causing this variation from loud to soft?

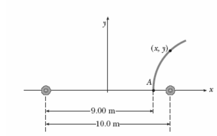
(A) superposition
(B) beats
(C) resonance
(D) interference

Review problem

- Two identical speakers 10 m apart are driven by the same oscillator with a frequency of $f = 21.5$ Hz

  (a) Does a receiver placed at point *A* record a minimum in sound intensity from the two speakers? Take the speed of sound to be 344 m/s.

  $f\,\lambda = v \rightarrow \lambda = v / f = 16.0$ m
- $\phi_1 = 2\pi\,(d_1/\lambda)$ and $\phi_2 = 2\pi\,(d_2/\lambda)$
- Path difference → phase difference



Review problem

- A violin string has a length of 0.350 m and is tuned to concert G, with $f_G = 392$ Hz. Where must the violinist place her finger to play concert A, with $f_A = 420$ Hz?

  $\lambda_G / 2 = 0.350 \text{ m} \rightarrow 0.700$ m

  $f_G\,\lambda_G = v \rightarrow v = 392 \times 0.700$ m/s

  $f_A\,\lambda_A = v \rightarrow \lambda_A = 392 \times 0.700 / 420 = 0.653$ m

  d = 0.350-(λ_A/2) = 0.350 – 0.327 = 0.023 m from end

  but 0.350 m– 0.023 m or 32.7 cm from the bridge

Review problem

- Two wires are welded together end to end. The wires are made of the same material, but the diameter of one is twice that of the other. They are subjected to a tension of 4.10 N. The thin wire has a length of 30.0 cm and a linear mass density of 2.00 g/m. The combination is fixed at both ends and vibrated in such a way that two antinodes are present with the node between them being right at the weld.

(a) What is the frequency of vibration?

(b) How long is the thick wire?

Recap , Lecture 29

- Agenda: Finish Ch. 22, Start review, Evaluations
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  - ❖ Reversible/irreversible processes and Entropy

Almost everyone, I'm sure, is looking forward to a break after a hard semester. You've earned it.

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