Unit Six Quiz Solutions and Unit Seven Goals

Mechanical Engineering 370
Thermodynamics

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Quiz Six Solution

- To be added following quiz

Outline

- Introduction to the Second Law of Thermodynamics
- Physical background for second law
- Mathematical statement of second law
- Use of entropy as determination of maximum efficiency
- Deriving other common forms of the second law

Unit Seven Goals

- As a result of studying this unit you should be able to
  - recognize that there is a thermodynamic property, called entropy, s, defined as follows: ds = (du + Pdv) / T
  - understand the inequality that dS   dQ/T
  - understand that dS   0 for isolated systems
  - recognize that entropy is a property

More Unit Seven Goals

- understand the definitions of engine and refrigeration cycles
- apply the definitions of work and heat flow for these cycles
- compute the efficiency of an engine cycle
- compute the coefficient of performance (COP) for a refrigeration cycle
- perform Carnot cycle computations

Why the Second Law?

- Encapsulates the phenomenon that certain process in nature flow one way
  - Water flows downhill
  - Heat flows from high to low temperatures
- We know that we can reverse these processes with an external effect (pump water, use refrigerator)

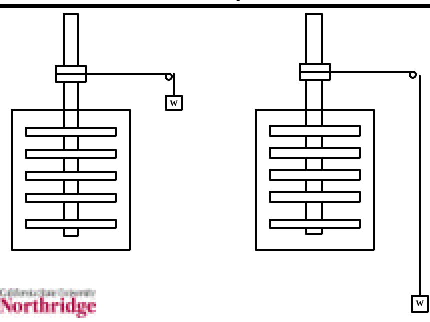
Second Law Application

- Based on entropy, a thermodynamic property
- Used to define ideal (reversible) processes
- Provides calculations to show if processes are possible
- Get equations for maximum efficiency of conversion of heat to work

Approach to Second Law

- Developed around 1850 by consideration of engine and refrigeration cycles
- Text considers similar derivation
- Important idea is in result using entropy
- Class notes will start at this point
  - Provide focus on ultimate calculations
  - Show equivalence to text derivation

Joule's Experiment



Joule's Experiment Explained

- The falling weight, W, turns the paddle wheels increasing the energy
- For an insulated system $Q = \Delta U + W = 0$ so that $\Delta U = -W = mg(z_{initial} - z_{final})$
- For falling weight, $z_{initial} - z_{final} > 0$, so $\Delta U > 0$, corresponding to water heating.
- What about process where weight rises and water cools?

Another Example

- Two identical blocks
  - Same mass and heat capacity
  - Block A at 300 K, block B at 500 K
  - Blocks placed in contact each reaching a final temperature of 400 K
  - No heat or work external to blocks
  - $\Delta U = \Delta U_A + \Delta U_B = 0$ or $\Delta U_A = -\Delta U_B$
- Can $T_{A,Final} = 200$ K and $T_{B,Final} = 600$ K?

General Idea

- Some processes in nature are observed to only proceed in one direction
- First law does not prohibit these processes going in the opposite direction
- Is there any general rule that shows the one-directional nature of processes
- Yes, it is the second law

The Second Law

- There exists an extensive thermo-dynamic property called the entropy, S, defined as follows:

$$dS = (dU + PdV)/T$$

- For any process dS   dQ/T
- For an isolated system dS   0
- T must be absolute temperature

Entropy as a Property

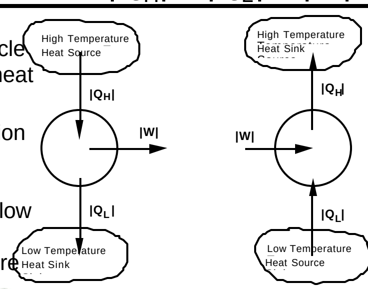
- Have total entropy, S, and specific entropy, s = S/m
- Dimensions of entropy are energy divided by temperature
- For S, typical units are kJ/K or Btu/R
  - units for s: kJ/kg•K or Btu/lb_m • R
  - s in tables is similar to v
  - in mixed region, $s = s_f + x\, s_{fg}$

Cyclic Processes

- In a cycle, the initial and final states of the system are the same
- Since the states are the same, the properties are the same
- Thus, for a cycle, $\Delta u = \Delta s = 0$
- Since heat and work depend on path, these may be nonzero, but $Q = \Delta U + W$ means that Q = W for a cycle

Cycles with $|Q_H| = |Q_L| + |W|$

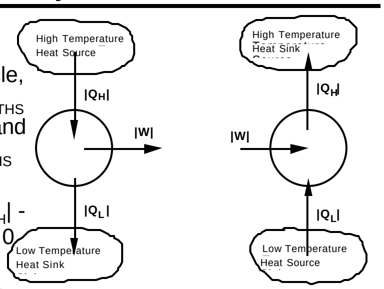
- Engine cycle converts heat to work
- Refrigeration cycle transfers heat from low to high temperature



Engine Cycle   Refrigeration Cycle

Engine Cycle Heat and Work

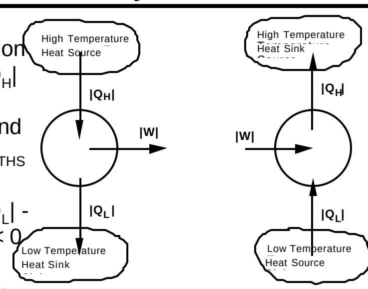
- For the engine cycle, $|Q_H| = -Q_{HTHS} = Q_{H,Cycle}$ and $|Q_L| = Q_{LTHS} = -Q_{L,Cycle}$
- $Q_{cycle} = |Q_H| - |Q_L| = W > 0$



Engine Cycle   Refrigeration Cycle

Refrigeration Cycle Heat/ Work

- Refrigeration engine, $|Q_H| = Q_{HTHS} = -Q_{H,Cycle}$ and $|Q_L| = -Q_{LTHS} = Q_{L,Cycle}$
- $Q_{cycle} = |Q_L| - |Q_H| = W < 0$



Engine Cycle   Refrigeration Cycle

Cycle Parameters

- Engine cycle efficiency $\eta = \frac{|W|}{|Q_H|}$
- Refrigeration cycle COP (coefficient of performance) $\beta = \frac{|Q_L|}{|W|}$
- General definitions, valid for any cycle
- Engine efficiency always less than one
- COP can be greater than one

Reversible Process

- In a reversible process it is possible to return a system to its initial state with no changes in the surroundings
- Idealization, cannot do better than a reversible process
  - This is the = part of the sign in dS dQ/T and $dS_{\text{isolated system}}$ 0
- For a reversible process $dS = dQ/T$ and $dS_{\text{isolated system}} = 0$

Temperature Reservoir

- A body that transfers heat with no change in its temperature
- Two-phase fluid is best example
- Reservoir usually envisioned as very large body such that $\Delta T = Q/(mc_v) \approx 0$
- Basic idea is that instead of $dS = dQ/T$ we can write $\Delta S = \int dq/T = Q/T$

Carnot Cycle

- Cycle with only two temperature reservoirs, HTR at T_H and LTR at T_L
- $\Delta S_{\text{isol syst}} = \Delta S_{HTR} + \Delta S_{cycle} + \Delta S_{LTR}$ 0
- $\Delta S_{\text{isol syst}} = Q_{HTR}/T_H + 0 + Q_{LTR}/T_L$ 0
- For the engine cycle $Q_{HTR} = -|Q_H|$ and $Q_{LTR} = |Q_L|$, so $-|Q_H|/T_H + |Q_L|/T_L$ 0
- Refrigeration cycle $Q_{HTR} = |Q_H|$ and $Q_{LTR} = -|Q_L|$, so $|Q_H|/T_H - |Q_L|/T_L$ 0

Carnot Cycle Continued

- For both cycles, $|Q_H| = |Q_L| + |W|$
- For the engine cycle
  - $-|Q_H|/T_H + |Q_L|/T_L$ 0 so that $-|Q_H|/T_H + (|Q_H| - |W|)/T_L$ 0
  - Rearrange to get $|Q_H|(1/T_L - 1/T_H)$ $|W|/T_L$
  - $\eta = |W| / |Q_H| \le 1 - T_L / T_H = \eta_{Carnot}$
- It is impossible to construct an engine cycle without heat rejection

Carnot Cycle Concluded

- For both cycles, $|Q_H| = |Q_L| + |W|$
- For the refrigeration cycle
  - $|Q_H|/T_H - |Q_L|/T_L$ 0 so that $(|Q_L| + |W|)/T_H - |Q_L|/T_L$ 0 or $(|Q_L| + |W|)/T_H$ $|Q_L|/T_L$
  - Divide by $|W|$ and rearrange to get
  - $\beta = |Q_L| / |W| \le T_L / (T_H - T_L) = \beta_{Carnot}$
- It is impossible to transfer heat from low to high temperature without work input