Lecture 1, Sep 8, 2022

Fundamental Concepts

- Energy: the capacity to do work
- Work: a transfer of energy
- Energy is a *fundamental concept*
- Fundamental concepts include:
  - Mass
  - Volume
  - Time
  - Energy
  - Entropy
- Fundamental concepts cannot be measured directly
  - e.g. you can't directly measure mass, instead you have to measure weight (force)
- A system has energy if it can lift a mass
- Heat Q is also a form of energy

The Heat Engine

- A heat engine converts heat into work
- From heat engines came the science of thermodynamics
- A heat engine takes heat Q_H from a high temperature source T_H, and produces work W
  - Heat engines necessarily have to dump heat Q_C into a heat sink at temperature T_C
- To maximize efficiency, we need to maximize w and minimize Q_H
  - The First Law of Thermodynamics says that in a heat engine, $Q_H = Q_C + W$, i.e. energy in equals energy out

Definition

The First Law of Thermodynamics: Energy is conserved

Definition

The thermal efficiency of a heat engine: $\eta_{th} = \dfrac{W}{Q_H}$

Entropy

- Early steam engines had $\eta = 4\%$, engines today only have $\eta = 30\%$
  - What is the maximum efficiency we can achieve?
- The cooling wastes energy, so is it really necessary?
  - Carnot: it's not possible to eliminate the heat sink, so efficiency can never truly be 100%
- To make sense of this, Clausius proposed the new property *entropy* S
- Entropy is similar to energy
- When you add heat to a system, the energy change is $\Delta E = Q$; the entropy change is $\Delta S = \dfrac{Q}{T}$

Definition

Entropy $\Delta S = \dfrac{Q}{T}$, the heat added to a system divided by its temperature

- Consider an object A with temperature $T + \Delta T$, and object B with temperature T
  - When they're brought into contact they will exchange heat, so $\Delta E_A = -Q, \Delta E_B = Q$

  - The entropy change is $\Delta S_A = -\dfrac{Q}{T+\Delta T}, \Delta S_B = \dfrac{Q}{T}$
  - $|\Delta S_A| < |\Delta S_B|$, so the total $\Delta S = \Delta S_A + \Delta S_B > 0$
  - Entropy has been generated, but energy is conserved
- In order to destroy entropy, we'd need the heat to go from the colder object to the hotter object
- Entropy can only be created, never destroyed

Definition

The Second Law of Thermodynamics: The entropy of an isolated system always increases: $\Delta S > 0$

- The second law determines what processes happen spontaneously
- To understand what entropy really means, we need to get down to the molecular level
  - S is related to the distribution of energies, whereas E is the sum of energies