Chapter 8

Thermodynamics

8.1 The Law of Conservation of Energy

8.1.1 Thermal Equilibrium

Principle 16: The Law of Thermal Equilibrium (Zeroth' Law)

> Two objects in thermal equilibrium with a third one are in thermal equilibrium with each other as well

Question The room temperature is 22°C. You leave a cup of water for 10 min. What will be the temperature of the cup? The water?

8.1.2 Internal Energy of Ideal Gas

The energy of the gas. For ideal gas it comes from the kinetic energy of the molecules and is directly related to the velocity of the molecules:

Formula 34: Internal Energy of Ideal Gas.

$$\text{Internal Energy} = \frac{5}{2}\left(\text{Boltzmann's constant}\right)\left(\text{Temperature}\right)$$

$$U = \frac{5}{2}kT$$

Notes.

1. Temperature must be in Kelvin
2. Formula is valid only for diatomic gases (molecules comprising two atoms)
3. $k_{\mathrm{b}} = 1.38 \times 10^{-23}$ J/K

Question Can you convert 25°C into Kelvin? Can you convert 300 K into °C?

8.1.3 First Law of Thermodynamics

Question How does the internal energy of a gas change?

Principle 17: The First Law of Thermodynamics

$$\text{Change in Energy} = \text{Heat Transfered} - \text{Work "spent" by Gas}$$

$$\triangle U = Q - W$$

Example: You have been pedaling the exercise bike steadily for 20 min at a power of 200 W. How much energy have you transfered to the bike and in what manner (work or heat?). How much energy has the bike released into the room?

You have transfered the energy in the form of mechanical work (if it were heat, the energy must have flown from your hot body to the cold bike rather than having your muscles pedal the bike!).

- In 20 min, you have transfered $200 \times (20 \times 60) = 240,000$ Joules to the bike.
- As the bike remains at the same temperature as before, it must have the same internal energy as before. Temperature is an indicator of the internal energy.
- Therefore, the bike must have released in the form of heat everything that has gained in the form of work
- The bike releases 240,000 Joules into the room

Question Can you harness that energy? The energy not that disordered when it is being transferred to the bike through work. So, we should be able to harness it!!!

8.1.4 Puzzles

*P*8.1.1 The molecular oxygen in air has a mass of 2.7×10^{-26} kg. How fast do Oxygen molecules move at room temperature of 25°C?

*P*8.1.2 An ideal gas absorbs 100 kcal of heat and does 30 kcal of work on its environment. By how much has its internal energy changed?

Ans. increased by 70 kcal

*P*8.1.3 an ideal gas releases 100 kcal of heat and does 30 kcal of work on its environment. By how much has its internal energy changed?

Ans. decreased by 130 kcal

*P*8.1.4 An ideal gas absorbes 100 kcal of heat and the environment does 30 kcal of work on the gas by compressing it. By how much has its internal energy changed?

Ans. incresed by 130 kcal

8.2 Engines, Heat Pumps, and Refrigerators

8.2.1 Ordered vs. Disordered Energy

Observation

1. It is easy to convert ordered energy into disordered (scattered randomly to many particles in the surrounding environment)

2. It is difficult to convert disordered energy into ordered

Entropy Entropy is a quantity that measures the total disorder of an object.

Example: Large Disorder - Large Entropy **Example:** Low Disorder -

Low Entropy

Question What happens to the Entropy as your computer's hardrive ages?

Question What happens to the Entropy as you stir your coffee with cream and sugar?

Question Compare your independent research project report with a report that has been typed by a bunch of monkeys typing randomly. Which report has high entropy? Which one has low entropy?

Principle 18: Second Law of Thermodynamics

The entropy of a thermally isolated system of objects never decreases

Note The Laws of Thermodynamics lead to interesting consequences:

1. You can create order at one place, but the disorder at another place will increase even more so

2. We cannot have perpetual motion machine!!! If the system is thermally isolated, it violages the fist law. If it is not thermally isolated it violates the second law - you cannot take disordered energy and converted into to ordered as such a machine will eventually lead to decrease in order

8.2.2 Engines, Refrigerators, and Heat Pumps

Formula 35: Efficiency

$$\text{efficiency} = \frac{\text{useful energy}}{\text{energy for which we pay}}$$

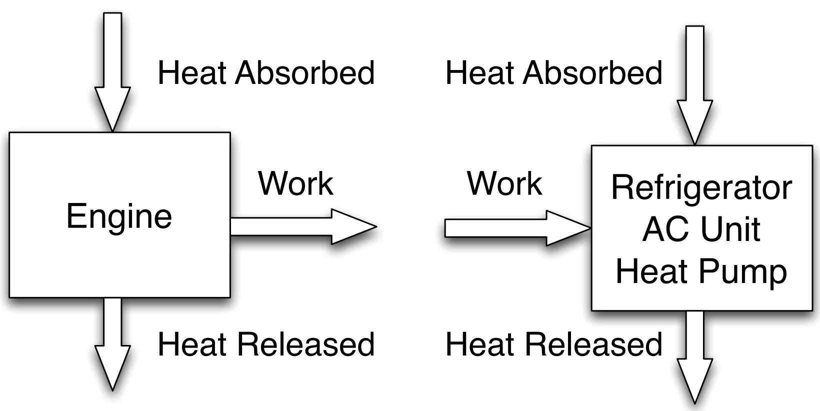

Figure 8.1: Engines, Heat Pumps and Refrigerators: Energy Flow

Formula 36: Efficiency of Engine

$$e = \frac{\text{Work performed by the engine}}{\text{Heat Absorbed}}$$

Example: An engine absorbs 100 kJ and releases 80 kJ. How much is its eficiency?

$$\text{Work} = 100 \text{ kJ} - 80 \text{ kJ} = 20 \text{ kJ}$$

$$e = \frac{20}{100} = 20\%$$

The best (theoretical) efficiency for an engine

If an engine operates between a lowest T_L and a highest T_H temperatures, its efficiency CANNOT exceed:

Formula 37: Max Efficiency of an Engine

$$e_{\max} = \frac{T_H - T_L}{T_H}$$

Formula 38: Coefficient of Performance of a refrigerator

$$C.P. = \frac{\text{Heat Absorbed}}{\text{Work by the electricity}}$$

8.2.3 Puzzles

*P*8.2.1 If your refrigerator removes 1 kcal of energy from the food inside its compartment and releases 1.2 kcal of energy back into your kitchen, how much was the work done by the electricity?

A. 1.2 kcal

B. 0.2 kcal

C. 2.2 kcal

*P*8.2.2 A person approaches you to invest in his upstart business. He claims that he has invented a super-efficient engine that operates between 300 and 400 K and has an efficiency of 85%. Do his claims make physical sense?

*P*8.2.3 In the following pairs, mark which system is at lower entropy

A. Messy room vs. Clean room

B. The hard drive of a brand new computer vs. the hard drive of an 10-yr old computer

C. Your research project write-up vs. the letters of a scrabble box

D. Frozen ice vs. Melted water

E. Warm soup vs. cold soup

F. The Universe at the time of Big Bang vs. The Universe Now

*P*8.2.4 The North Anna Nuclear Reactors Units can generate approximately 900 MW of energy while at the same time they release about 2,100 MW of energy into the nearby river. What is the efficiency of the reactors?