Chapter 18

Thermodynamics

Main points

- Absolute Zero: Lowest possible temperature
  (No kinetic energy left to take away.)
- 1st Law of Thermodynamics: $\Delta E_{int} = Q - W$
  (Cons. of E to include thermal phenomena.)
- Adiabatic Processes: $Q = 0$
  (No heat enters or leaves the system.)
- 2nd Law of Thermodynamics:
  (Governs the direction of natural events.)

Absolute Zero & The Kelvin Scale

The lowest possible temperature occurs at –273 ^{o}C.

Define the Kelvin temperature scale such that 0 K corresponds to the absolute zero of temperature.

The intervals on the Kelvin scale are the same as the Celsius scale. So…

$T_K = T_C + 273$ “degrees” and $\Delta T_K = \Delta T_C$

Examples: Water freezes at 273 K.

Water boils at 373 K.

The 1st Law of Thermodynamics

...is just "conservation of energy" to include thermal phenomena.

$$\Delta E_{int} = Q - W$$

where E_{int} = the internal energy of the system,

Q = heat added to the system, and

W = work done BY the system being investigated.

The 1st Law Sign Conventions

$$\Delta E_{int} = Q - W$$

$Q > 0$ when heat enters the system, and

$Q < 0$ when heat leaves the system.

$W > 0$ when the system does work on its environment. (That is, when system expands.)

$W < 0$ when the environment does work on the system. (That is, when system contracts.)

The 1st Law Example

A gas in a cylinder with a piston is placed over a flame causing the system to absorb 50 J heat. At the same time, the piston is push inward squeezing the gas. The work done to compress the gas was 30 J. Calculate the change in the internal energy of the system.

Q = +50 J (heat enters the system)

W = –30 J (system contracted)

$$\Delta E_{int} = +50\text{ J} - (-30\text{ J}) = 80\text{ J}$$

The 2nd Law of Thermodynamics

...governs the direction of natural events. While it is possible to convert work completely into heat, it is impossible to convert heat into work with no other changes taking place.

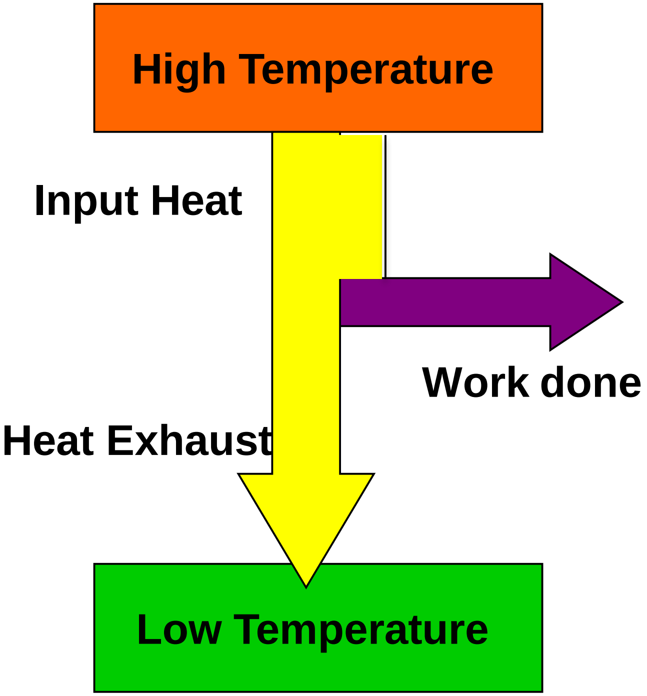
For example: An metal rod that is hot on one end and cold on the other will eventually reach a common temperature throughout, but a rod at a given temperature will not spontaneously get hot on one end and cold on the other (even though this does not violate conservation of energy). In other words, energy tends to disperse.

Heat Engines

“Heat naturally flows from hot to cold.” (2nd law)

An *engine* taps some of this heat to do some useful work.

However, not all the heat in can be converted into useful work. There must be some waste heat exhausted to the low temperature region.



Heat Engines (cont’d)

Heat enters the engine from the high temperature side. The engine converts some of this heat into useful work and exhausts the rest into the low temperature side.

A perfect engine would convert 100% of the heat enter at high temperature into useful work, but this is impossible according to the 2^{nd} law of thermodynamics.

Heat Engine Efficiency

Efficiency, e = Work Out / Heat Input

Since the heat input cannot be converted completely into work, what is the best we can do ?

Ideal (Carnot) efficiency = $\frac{T_H - T_C}{T_H} = 1 - \frac{T_C}{T_H}$

where T_H and T_C are the temperatures* of hot side and cold side of the engine, respectively.

*Must use absolute (Kelvin) temperature scale when applying this formula for ideal efficiency.

Example

Calculate the ideal efficiency of a heat engine operating between the freezing point and boiling point of water.

Since we must use the Kelvin temperature scale,

$$T_H = 373 \text{ K and } T_C = 273 \text{ K.}$$

Then, $e_{ideal} = 1 - \frac{T_C}{T_H} = 1 - \frac{273 \text{ K}}{373 \text{ K}} = 0.26 \text{ or } 26\ \%$

To increase efficiency, increase T_H, and/or decrease T_C.

Refrigerators

- Even though heat will not spontaneously flow from cold to hot, you can MAKE heat flow “uphill” if you do some mechanical work.
- Success Measure: Coefficient of Performance
- COP = Heat removed / Work Input
- Ideal (Carnot) COP* = $T_C / (T_H - T_C)$

*Must use absolute (Kelvin) temperature scale.

Example

Calculate the ideal COP of a refrigerator operating between the freezing point and boiling point of water.

Since we must use the Kelvin temperature scale,

$$T_H = 373\text{ K and } T_C = 273\text{ K.}$$

Then, $COP_{ideal} = \frac{T_C}{T_H - T_C} = \frac{273\text{ K}}{373\text{ K} - 273\text{ K}} = 2.73$

To increase COP, decrease T_H, and/or increase T_C.

2nd Law of Thermodynamics

- Heat will not spontaneously flow from a cold place to a hot place.
- There are no perfect engines.
- Your refrigerator will not work if you don’t plug it in.
- It is easier to make an omelet out of an egg than it is to make an egg out of an omelet.
- The entropy of the universe tends to increase.

Entropy

- A measure of disorder in a system. (This is a crude definition.) A better description is that entropy is a measure of the *spread of energy*.

Energy tends to transform from more useful forms into less useful forms.

Distributions of molecular positions, velocities, energies, etc. are based on probabilities. There are more ways to have disorder than order.