Thermal Physics Notes

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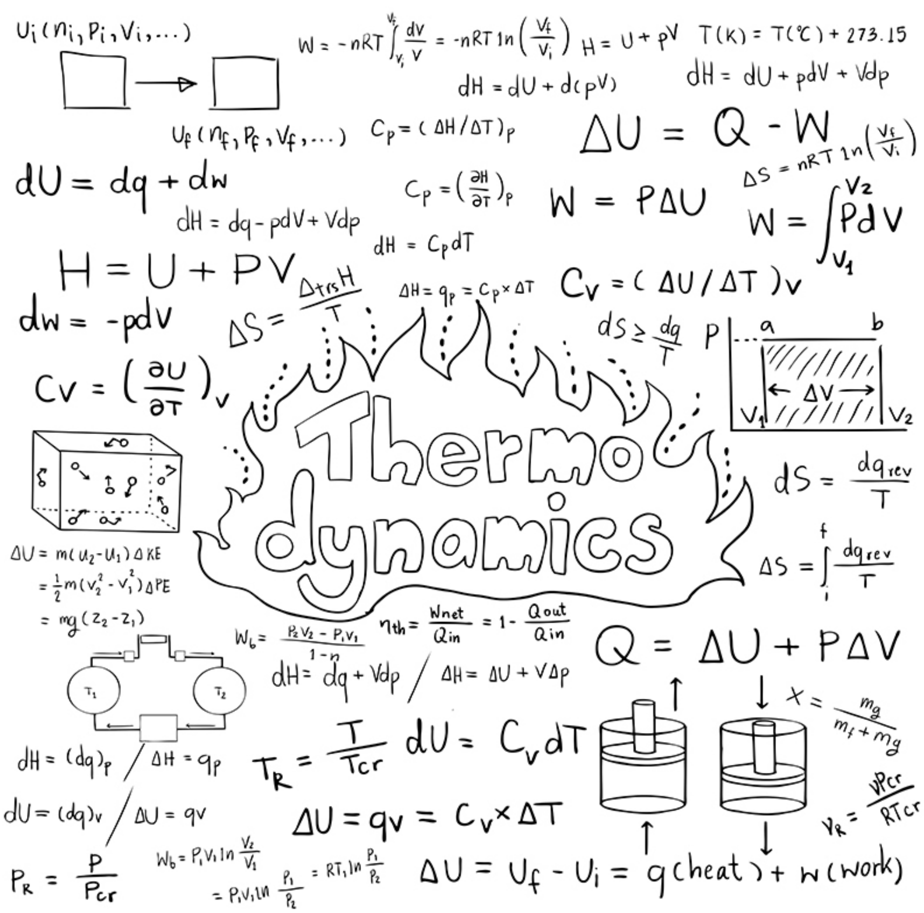

Contents

1 Introduction

Reference book: Herbert B. Callen - Thermodynamics and Thermostatistics - https://drive.google.com/file/d/11ygKClITZgF4yU05_UyhQ4CKt7QYX9wQ/view?usp=sharing
Let's get started!

- Laws of thermodynamics apply to macroscopic objects/collections of particles $\rightarrow$ systems with many interactions
- For Newton's Laws, you need the positions, velocities and the model/type of interparticle forces present in order to predict the evolution of the system.
- Macroscopic systems $\rightarrow$ General Laws $\rightarrow$ Universal in nature (applicable to a wide variety of systems)
- These laws are not fundamental $\rightarrow$ Emerge from microscopic laws $\rightarrow$ But they make the analysis of macroscopic properties simple
- Example: Consider a box with N ideal gas particles $\rightarrow$ We need 6N coordinates, i.e., 3-spatial coordinates and 3-velocity components for each particle $\rightarrow$ Law: $\vec{F_i} = m_i \vec{a_i}$ (3 second-order differential equations).

  Let's try to find what *coordinates* describe macroscopic systems $\rightarrow$ Thermodynamic variable

  Consider a 1-D lattice (say a metal rod) with separation between adjacent particles $= a$. The particles are held together so they are vibrating about their mean position. Plot the displacement of i^{th} particle Δx_i against i. As N (total number of particle) is very large we can look ath the scenario wherein $N \rightarrow \infty$, i.e., the particle number-axis becomes approximately continuous. We will see "collective behaviour" because there motions are connected. At a later time, the curve shifts forward $\rightarrow$ analogy: wave that is propagating forward.

$k = \frac{2\pi}{\lambda}$
$\omega(k)$: dispersion relation

Modes:

1. Slow mode:
   (a) Small k modes
   (b) Large λ modes
   (c) Small ω modes

   "Long distance modes" $\rightarrow \lambda >> a$
2. Fast mode:
   (a) Large k modes
   (b) Small λ modes
   (c) Large ω modes - oscillate rapidly

   "Short distance modes" $\rightarrow \lambda \approx a$

When we observe time average, the high frequency modes are unobservable $\rightarrow$ "Things that don't change over long time interval are macroscopic observables". Take the limits $\lambda \rightarrow \infty$ and $T \rightarrow \infty$, the states that emerge are called "Thermodynamic States"/ "Static States".

When we take into account the extremely large wavelength modes, we see that particles on one side move in a certain direction (say left) and particles on the other side move in the opposite direction (right). Overall effect: Length of the rod appears to be increasing $\rightarrow$ Macroscopic effect $\rightarrow$ Length of rod: macroscopic variable $\rightarrow$ Volume of solid: thermodynamic coordinate

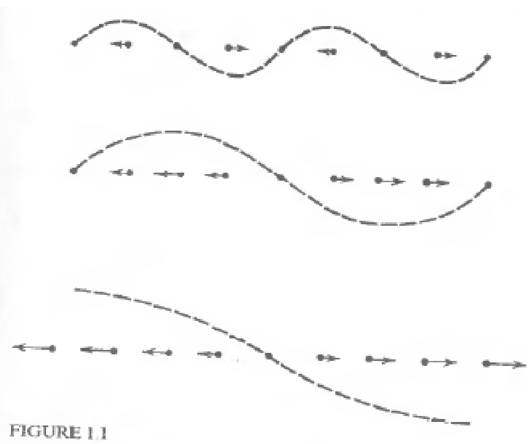

FIGURE 1.1
Three normal modes of oscillation in a nine-atom model system. The wave lengths of the three modes are four, eight and sixteen interatomic distances. The dotted curves are a transverse representation of the longitudinal displacements.

- Some examples of macroscopic variables:
  1. Electrostatics: Macroscopic variable $\rightarrow$ Net charge (Q)
  2. Magnetostatics: Macroscopic value $\rightarrow$ net magnetic dipole moment ($\vec{\mu}$)
- Speciality of thermodynamics $\rightarrow$ Takes into account "hidden coordinates". Tells us energy is distributed among the modes which are invisible to us at a macroscopic level!