Foundations of Physics 2B/3C 2019-2020

Thermodynamics – Lecture 1 Aims

- To introduce the course;
- To give an overview of the syllabus and provide a motivation for studying this important topic;
- To introduce the correct terminology for describing thermodynamics;
- To re-cap the zeroth Law of thermodynamics and temperature.

1. Motivation

Second law of central importance in science – why changes occur. Not only the basis for why engines run/chemical reaction happen; it also tells us the why, foundation of the chemical reaction consequences (thoughts, creativity – music, drama, physics...)

Classical thermo – looks at a few basic bulk properties of materials, and their behaviour (Macroscopic picture). Quite general + no why. Emerged before atoms, when atoms discovered people realised could describe the microscopic picture, very detailed (1 mole $\sim 10^{24}$ atoms) Need to treat statistically.

2. Overview

Subject came about in 19th Century – engineers wanted to develop efficient machines – convert heat to work. Statisical mechanics developed (Boltzmann + Gibbs) took at underlying molecular interpretation, much richer understanding.

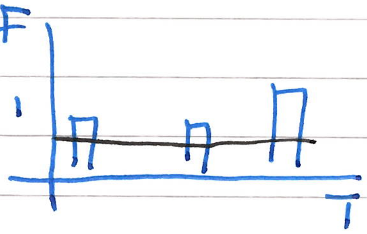
Example 2.1 : Lecture theatre $\sim 3\times10^6$ litres of air
$(20\times10\times15)\,m^3 \sim 10^{24}$ molecules

Count using 10GHz processor, 1 molecule/cycle, count 3×10^{17} molecules/year $\Longrightarrow$ Average desktop 3×10^{11} yrs to count all molecules $> T_H \sim 10^{10}$ yrs

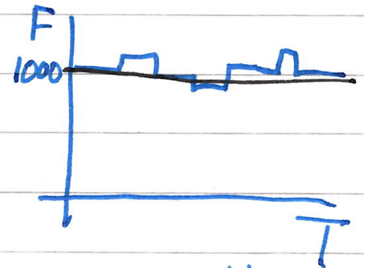
In thermal equilibrium, most atoms behave as average, with no small scale fluctuations. As atoms increases, average is constant and fluctuations smooth → thermodynamic limit
particles → ∞, thermo behaviour asymptotically ~~approaches~~ approximated by Statisical Mechanics. Material properties are constant

Example 2.2   Consider hitting roof of various sizes

Small, odd droplets hit → impulse



Large roof Many drops hit



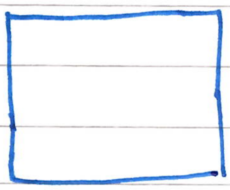
Higher force on large roof, less fluctuation. Average smooths

$$\text{pressure} = \frac{\text{Force}}{\text{Area}}$$, for both roofs — the same

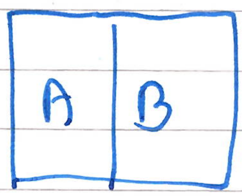
As area → ∞ $p \to p_0$, thermodynamic limit

Example 2.3   Definition of terms

Extensive – System Extent   Intensive – Independent of size

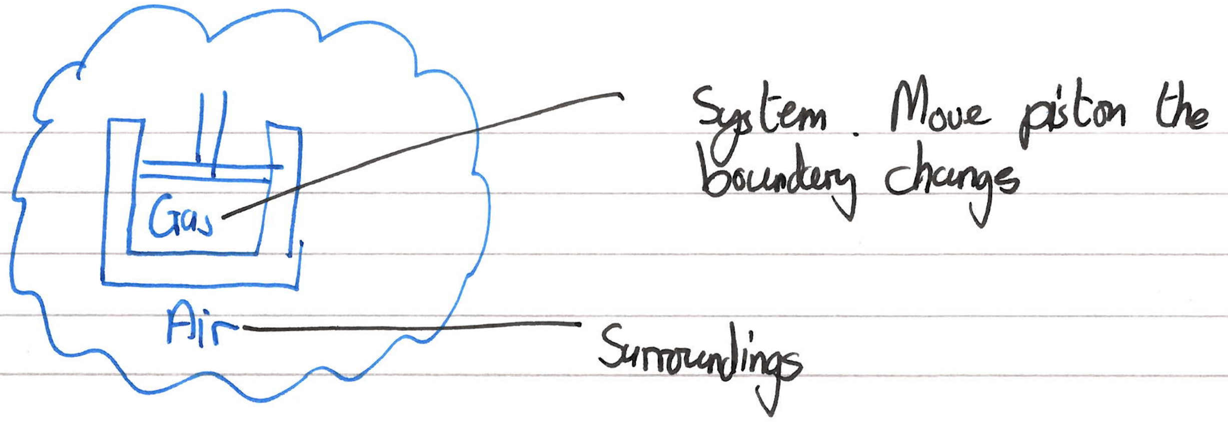


Volume, V Temperature, T
Internal Energy, U pressure, p

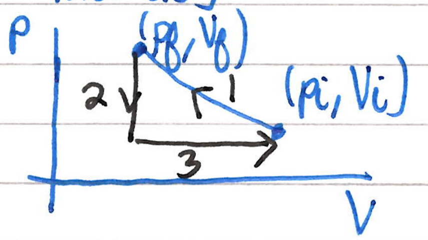


$V^* = V_A = V_B = V/2$ $T^* = T_A = T_B = T$
$U^* = U_A = U_B = U/2$ $p^* = p_A = p_B = p$

System properties related by an equation of state
$f(p, V, T, U) = 0$
Ideal gas $pV = RT$, $pV - RT = 0$



Change boundary, system state changes along path.
Shut piston, volume decreases (at constant temperature) so pressure increases



System changes along path

$1 \to 2 \to 3$ returns to our initial state.

3. Thermal Equilibrium, Heat + Temperature

Heat is energy in transit — Can add heat, but can't say object contains a quantity of heat.

Heat moves (spontaneously) from hot to cold — energy must be supplied to move heat cold $\to$ hot.

Thermal equilibrium — no heat transfer.

Example 3.1 Prepare a gas, a range of pressures / volumes

$$p_1 V_1 = a > b = p_2 V_2$$

Empirically find sample 1 is hotter

$pV = f(T)$, equation of state.

Heat capacity — the amount that must be supplied / removed to change an objects temperature

$$\Delta Q = mc\Delta T$$

A small change dT in an objects temperature requires the addition/removal of a differential amount of heat δQ

Heat capacity, capital C [whole object]
Specific heat capacity, lower case c [per unit mass (mole)]

$$C = mc$$

How much heat is required to change an objects temp $T_1 \to T_2$?

$$\Delta Q = \int \delta Q = \int_{T_1}^{T_2} C\,dT = C(T_2 - T_1)$$

If C is independent of temperature

Most changes happen when some condition is constant (volume, pressure)

$$C_V = \left(\frac{\partial Q}{\partial T}\right)_V \quad ; \quad C_p = \left(\frac{\partial Q}{\partial T}\right)_p$$

4. <u>Zeroth Law</u> - Establishes Temperature

Two bodies at same temperature, in thermal equilibrium
Heat goes hot $\to$ cold under action, irreversible, as move to thermal equilibrium define an arrow of time

If two bodies are separately in thermal equilibrium with a third body, the original two bodies must be in thermal equilibrium with eachother.

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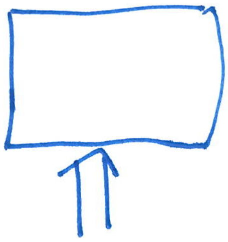
Thermodynamics – Handout 1

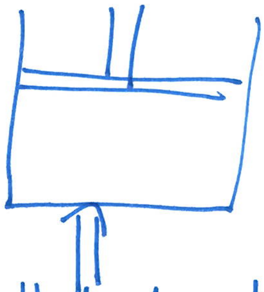
Exercise 1

Which is bigger, the heat capacity at constant pressure, C_P or the heat capacity at constant volume, C_V?

1) Heat capacity at constant pressure is larger: $C_p > C_V$.
2) All heat capacities are equal: $C_p = C_V$.
3) Heat capacity at constant volume is larger: $C_V > C_p$



Heat at constant V
pressure increases



Heat at constant pressure
Volume changes — requires work

$C_p > C_V$

Zeroth Law of Thermodynamics

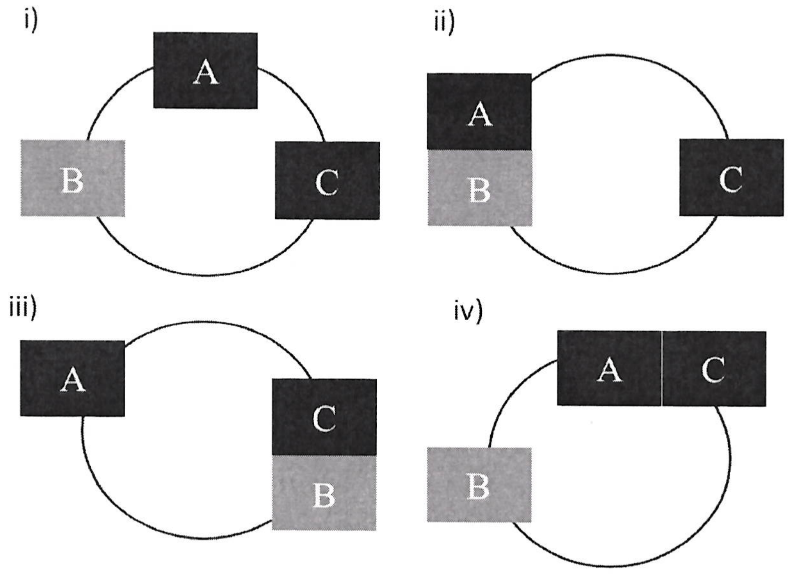


Figure 1: Representation of the Zeroth Law of Thermodynamics.

B is the thermometer

Put A in contact with B, and B takes some value (ii)

Put C in contact with B and value of B doesn't change (iii)

A and C must be in thermal equilibrium without doing the experiment (iv)

2nd Law gives temperature scale.