Thermodynamics   state   of a system
(or what changing temperature can do)

Ways to characterize a system

Macroscopic parameters (describes the system as whole)	Microscopic parameters (describes elementary component)
Temperature T	Number of molecules N
Pressure P	Chemical decomposition
Volume V	(atomic/molecular mass) m
Density ϱ	degrees of freedom
	velocity/energy distributions
Thermodynamics	Statistical mechanics/physics

| Temperature characterizes the direction of energy flow from hot to cold	Temperature characterize the kinetic energy of (often chaotic) motion of atoms / molecules.

What happens when the temperature changes?

To really understand what is going on, one has to use microscopic description. But the more complex the system is, the harder it is!

| Most complex Solids ordered strong- interacting particles often anisotropic	Little better liquids strongly interacting free particles	Simplest gas free-moving non-interacting* particles (* ideally)

Phenomenological description

thermal expansion

Thermal expansion of solid/liquids
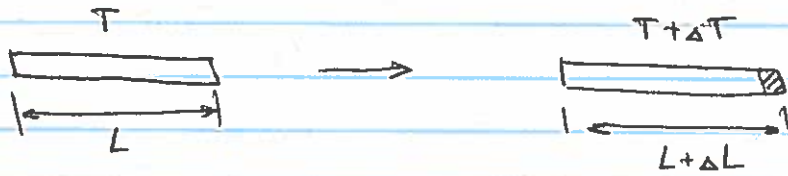
$$\frac{\Delta L}{L} = \alpha \Delta T$$ All complicated microscopic physics is hidden in α

α - coefficient of linear expansion

β - volume expansion coefficient
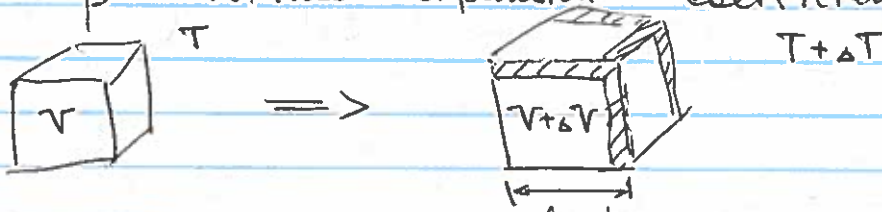
$V = L^3$

$V + \Delta V = (L + \Delta L)^3 \approx L^3 + 3L^2 \Delta L$

since $\Delta L / L \ll 1$

$\Delta V = 3L^2 \Delta L$

$$\frac{\Delta V}{V} = \frac{3L^2 \Delta L}{L^3} = 3\frac{\Delta L}{L}$$

for isotropic solids

$$\beta \Delta T = 3\alpha \Delta T$$

$$\underline{\beta = 3\alpha}$$

Since change in length/volume is proportional to the change in temperature, we cannot use it to reliably set a temperature standard (or T=0) → many experimental temperature scales

Ideal (non-interacting) gasses are much easier to describe

Historically: Robert Boyle's Law (1627-1691)

$PV \propto T$ {

at a constant T: $V \propto 1/P$

Jacques Charles' Law (1746-1823)

at constant pressure P: $V \propto T$

Joseph Gay-Lussac's Law (1778-1850)

at constant volume V: $P \propto T$

Amadeo Avogadro (1776-1856) hypothesis
Two gasses with same (P, V, T) have same number of molecules

$N_A = 6.02214154 \cdot 10^{23}$ number of molecules in one mole of gas

Universal gas law

$$PV = n \cdot RT \qquad \text{or} \qquad PV = N \cdot k_B T$$

(macroscopic)   (microscopic)

n – number of moles N – number of molecules
$R = 8.314 \; J/mol \cdot K$ $k_B = 1.38 \cdot 10^{-23} \; J/K$
universal gas constant   Boltzmann constant

$$n \cdot R = \frac{N}{N_a} \cdot R = N \cdot \frac{R}{N_a} = N \cdot k_B$$

$$k_B = R/N_a$$

Important   small   print
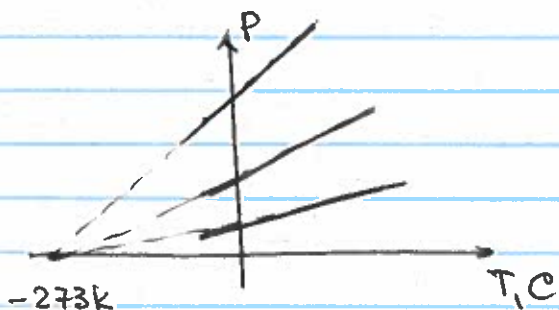
$PN = nRT$ works   only   if T is in Kelvins!

~~then~~ We   can   also   use this   for   figuring
out   the   absolute   zero

$$\text{if } V \text{ is constant}$$
$$P = \boxed{\frac{nR}{V}} \cdot T$$

slope   of the   curve

$-273k$

↑
~~check~~   at   what   temperature   P = 0

extrapolate