



Physics Thermodynamics

The study of the thermal energy of objects, how it is exchanged between objects, and how it relates to work

Introduction

KEY VARIABLES

Variable	Description	Units
P	Pressure	Pa (N/m ²)
V	Volume	m ³
T	Temperature	K
n	Number of moles in a system	
N	Number of particles in a system	
f	Degrees of freedom	
U	Internal energy of a system	J
Q	Heat added to a system ($Q > 0$)	J
E_{th}	Thermal energy of a system	J
W	Work done by a system ($W > 0$)	J
S	Entropy	J/K
H	Enthalpy	J
F	Helmholtz free energy	J
G	Gibbs free energy	J
ρ	Density	kg/m ³

CONSTANTS

Constant	Symbol & Value
Universal gas constant	$R = 8.31 \text{ J mol}^{-1} \text{ K}^{-1}$
Avogadro's number	$N_A = 6.02 \times 10^{23} \text{ mol}^{-1}$
Boltzmann constant	$k_B = R / N_A = 1.38 \times 10^{-23} \text{ J/K}$
Standard temperature	0°C
Standard pressure	10 ⁵ Pa
Planck's constant	$h = 6.626 \times 10^{-34} \text{ J} \cdot \text{s}$
Speed of light	$c = 3.00 \times 10^8 \text{ m/s}$
Unit of electric charge	$e = 1.60 \times 10^{-19} \text{ C}$

Conventions

- **Italic subscript:** Indicate which variable is held constant (e.g., C_p means that pressure is held constant to calculate C_p)
- **Roman subscript:** Specify special cases for variables.
- **Subscripts i and f:** Indicate initial and final values for a given variable

Extensive vs. Intensive Properties

- **Extensive properties:** Properties of a system proportional to the extent of the system

EX: Double system size re-volume and mass are doubled. These are extensive variables.

- **Intensive properties:** Properties of a system independent of the extent of the system

EX: Double system size re-pressure and temperature remain the same. These are intensive variables.

Moles

- **A mole of ¹²C atoms** has a mass of 1 g.
 - 1 mole = 6.022×10^{23}
- **Atomic number:** Number of protons in an atom
- **Mass number:** Number of protons and neutrons in an atom
- **Atomic mass:** The weighted average mass of a given atom at rest based on the relative natural abundance of isotopes of that atom
- **Molar mass (M):** Number of grams per mole of an atom or molecule
 - Mass (g) = Mn
- **Molar volume:** Volume occupied by one mole of substance; depends on pressure and temperature

Thermal Energy & Temperature

Definitions

Thermal vs. Internal Energy

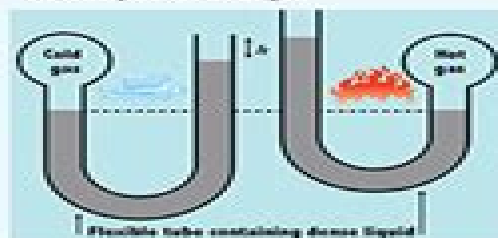
- **Thermal energy (E_{th}):** Energy contained in the random (incoherent) motion of the particles that make up matter
 - Motion can be translational, rotational, and/or vibrational.
 - Nonrandom (coherent) motion does not contribute to thermal energy.
- **Internal energy (U):** Thermal energy plus other forms of energy stored in particles that make up a system (e.g., energy in chemical bonds, nuclei, and mass)

"Heat" vs. "To Heat"

- **Heat:** Thermal energy that is transferred from one system to another
- **To heat:** To increase the temperature of a system

Temperature (T)

- Directly proportional to thermal energy
 - A higher temperature corresponds to higher thermal energy, and vice versa.
 - In layman's terms, higher temperatures correspond to hotter objects and lower temperatures to colder objects.
- **Ideal gas thermometer:** Measures temperature accurately; see image below
 - An ideal gas contains point-like particles that interact only through elastic collisions.
 - The volume of cold gas is heated and the flexible tube is raised so that the hot gas occupies the same volume as the cold gas.
 - The hot gas is at a higher pressure than the cold gas and forces the liquid at height h higher up the tube. This height is proportional to the absolute temperature of the gas.



Thermodynamic State Variables (P , V , T & n)

- Functions of these variables are also thermodynamic state variables.
- The value of state variables does not depend on how the system got into the particular state.

Temperature Scales

"Absolute zero" temperature is the temperature of minimum possible thermal energy.

Arbitrary Scales

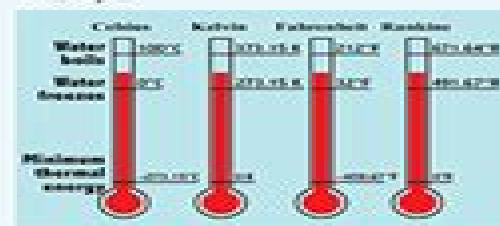
- **Celsius:** Defines absolute zero to be -273.15°C and the triple point of pure water to be 273.16°C .
 - The freezing (boiling) point of water at 1 standard atmosphere of pressure is very close to 0°C (100°C).
- **Fahrenheit:** Defines absolute zero to be -459.67°F and the triple point of pure water to be 32.018°F .
 - The freezing (boiling) point of water at 1 standard atmosphere of pressure is very close to 32°F (212°F).

Absolute Scales

- **Kelvin:** Assigns 0°K as the temperature of minimum possible thermal energy
 - $1^\circ\text{K} = 1^\circ\text{C}$
 - The degree sign is not used for the Kelvin scale.
- **Rankine:** Assigns 0°R as the temperature of minimum possible thermal energy
 - $1^\circ\text{R} = 1^\circ\text{F}$
 - NIST recommends against using the Rankine scale.

Conversion between Temperature Scales

- $T_C = \frac{5}{9}(T_F - 32^\circ)$
- $T_F = \frac{9}{5}T_C + 32^\circ$
- $T_K = T_C + 273.15$
- $T_R = T_F + 459.67$
- $T_K = \frac{5}{9}T_R$



Laws of Thermodynamics

Zeroth Law of Thermodynamics

- Two systems in thermal contact at the same temperature are in thermal equilibrium.
- Two systems in thermal equilibrium with a third system are in thermal equilibrium with each other.

First Law of Thermodynamics

- The energy of a system is conserved.
- $\Delta U = Q - W$
 - The change in the internal energy (ΔU) of a system is the difference between the amount of heat (Q) supplied to the system and the amount of work (W) done by the system.

Second Law of Thermodynamics

Entropy

- **Entropy:** The quantitative measure of the ability of thermal energy to do work per unit temperature
 - Entropy (S) is a state variable.
 - A high-entropy system can do more work than a low-entropy system at the same temperature.
 - Entropy cannot be measured, only calculated.
 - Entropy is an extensive property, so the entropy of two systems A and B is the sum of entropies: $S_{total} = S_A + S_B$
- **Macrostate:** State of a system described by state variables T , P , V , and n

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Siddappa N.Byrareddy



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