Introduction to Aerospace Propulsion

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Lecture No -   5

In this lecture ...

- Quasi-static processes
- Concept of energy and its various forms
- Internal energy
- Total energy
- Enthalpy
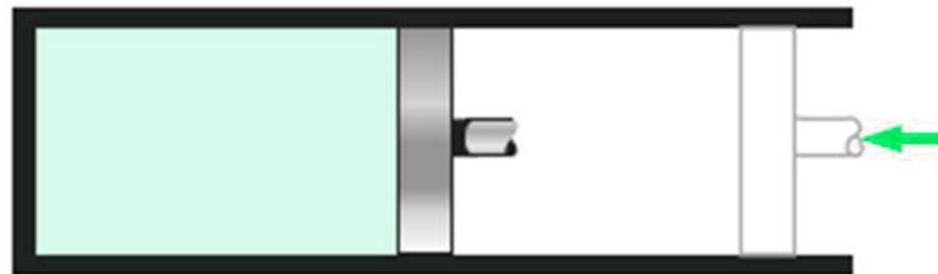- Zeroth law of thermodynamics and temperature

Quasi-static processes

- When a process proceeds in such a manner that the system remains infinitesimally close to an equilibrium state at all times: Quasi-static or Quasi-equilibrium process

- The process proceeds slow enough to allow the system to the system to adjust itself internally so that properties in one part of the system do not change any faster than those at other parts.
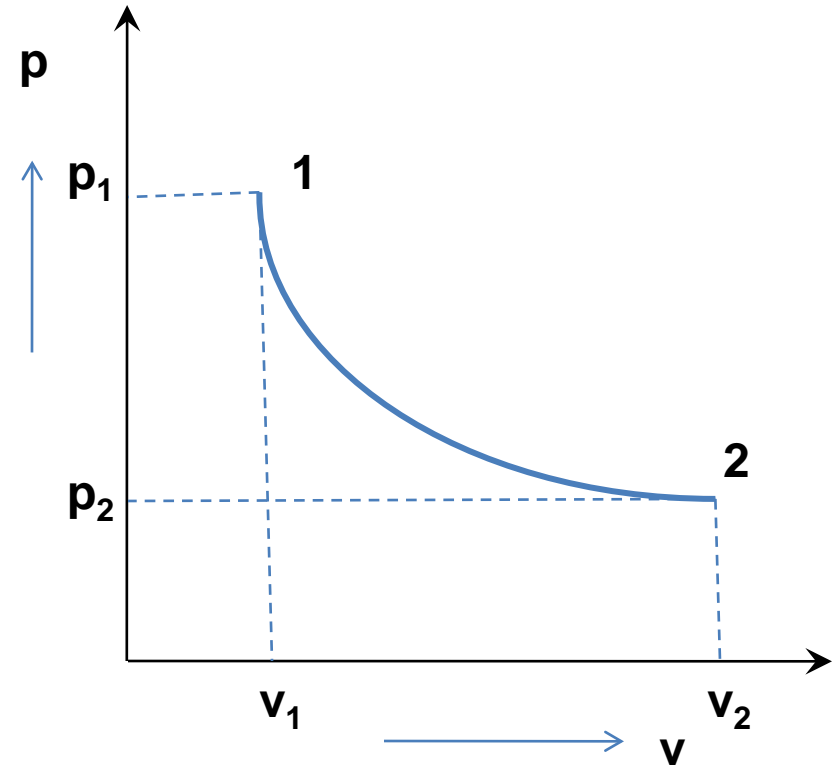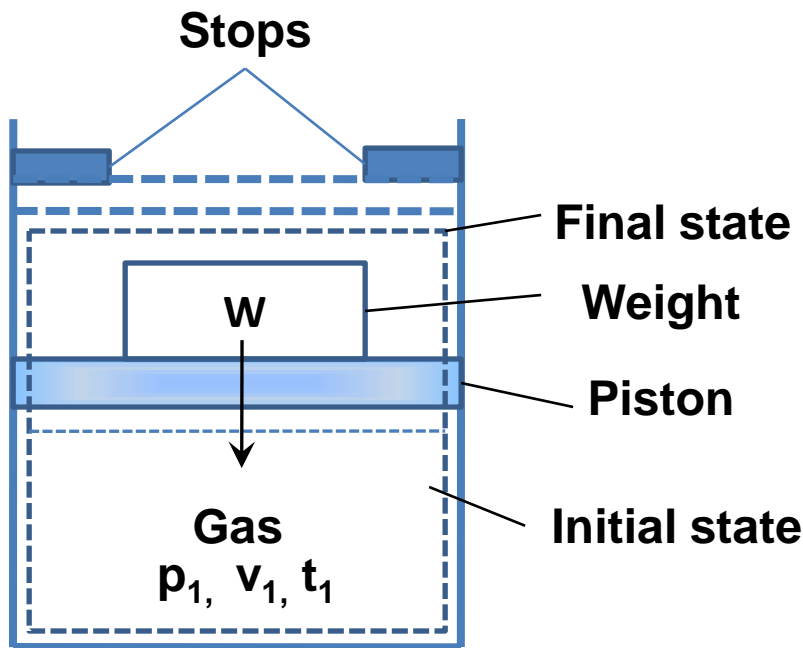
Quasi-static processes

SLOW COMPRESSION
(QUASI-EQUILIBRIUM)

VERY FAST EQUILIBRIUM
(NON QUASI-EQILIBRIUM)

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Quasi-static processes

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Quasi-static processes

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Quasi-static processes

- Engineers are interested in quasi-static processes because
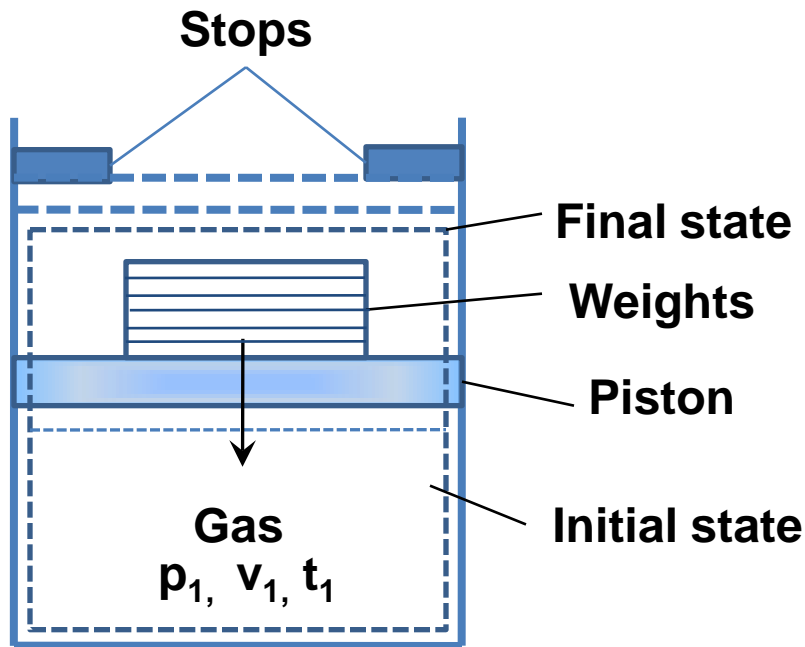 - they are easy to analyse
  - work-producing devices deliver maximum work when they operate on quasi-static processes
- Quasi-static processes serve as standards to which actual processes can be compared
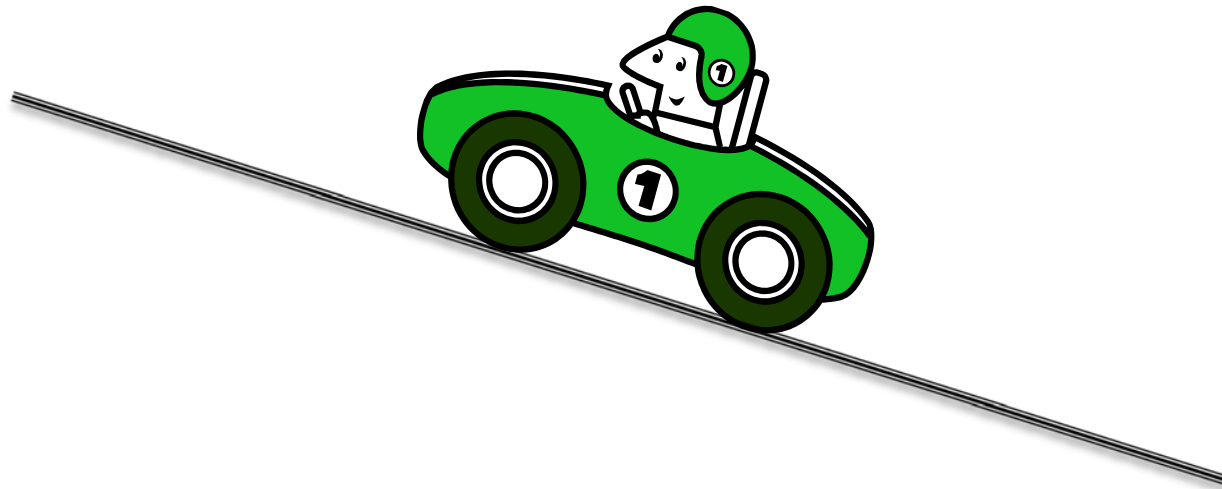
Energy

- Energy can exist in numerous forms such as thermal, mechanical, kinetic, potential, electric, magnetic, chemical, and nuclear

- The sum total of the above: total energy, E

$$e = E/m \ kJ/kg$$

- Thermodynamics provides no information about the absolute value of the total energy.

- It deals only with the change of the total energy, which is what matters in engineering problems.

Energy

- Forms of energy:
  - Macroscopic energy: energy that a system possesses as a whole with respect to some outside reference frame, eg: KE, PE

  - Microscopic energy: those related to the molecular structure of a system and the degree of the molecular activity and are independent of outside reference frames

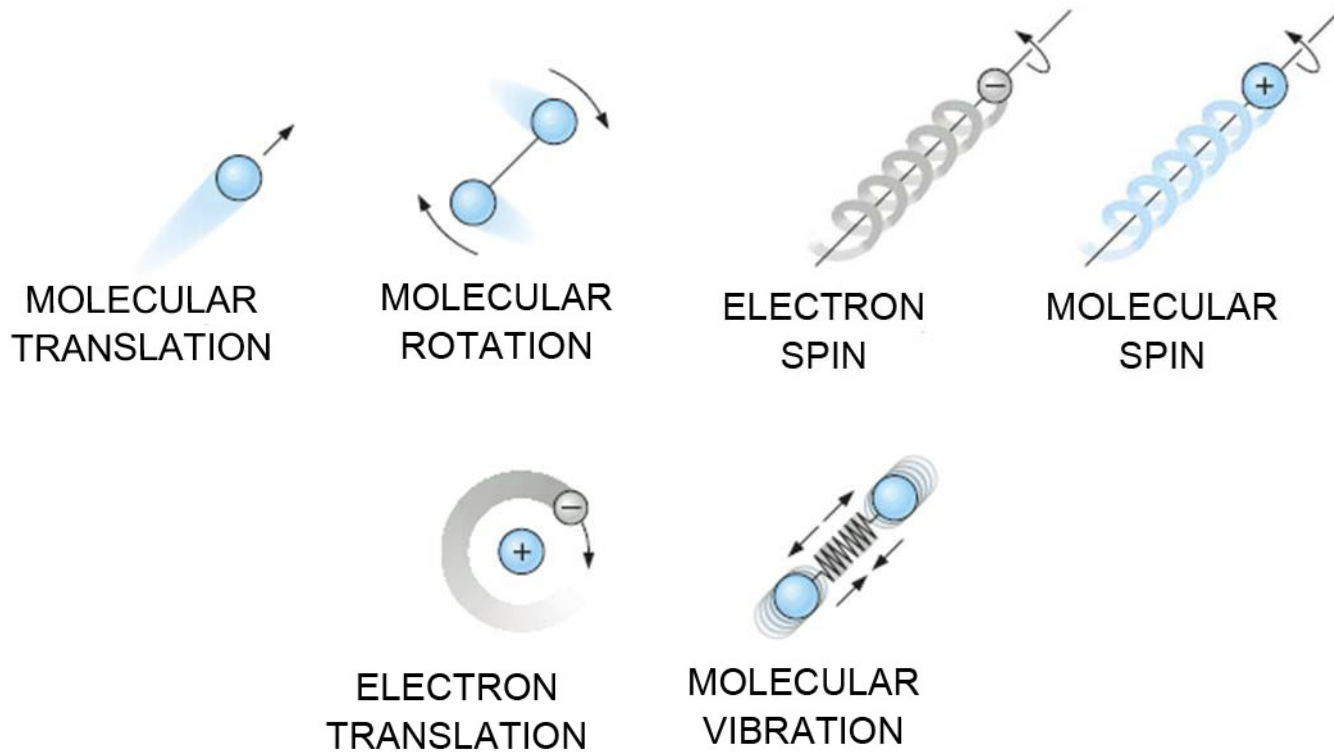 - Sum of all microscopic forms of energy of a system: Internal energy, U (kJ) or u (kJ/kg)

Macroscopic energy

The macroscopic energy, KE and PE, of an object changes with velocity and elevation.

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Internal energy

- Sensible energy: part of the internal energy associated with kinetic energy of molecules
  – Rotational KE, translational KE, vibrational KE

- Latent energy: internal energy associated with phase change of a system

- Chemical energy: internal energy associated with the atomic bonds in a molecule

- Nuclear energy: tremendous amount of energy associated with the strong bonds within the nucleus of the atom

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The various forms of microscopic energies that make up sensible energy.

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SENSIBLE
AND
LATENT
ENERGY

CHEMICAL
ENERGY

NUCLEAR
ENERGY
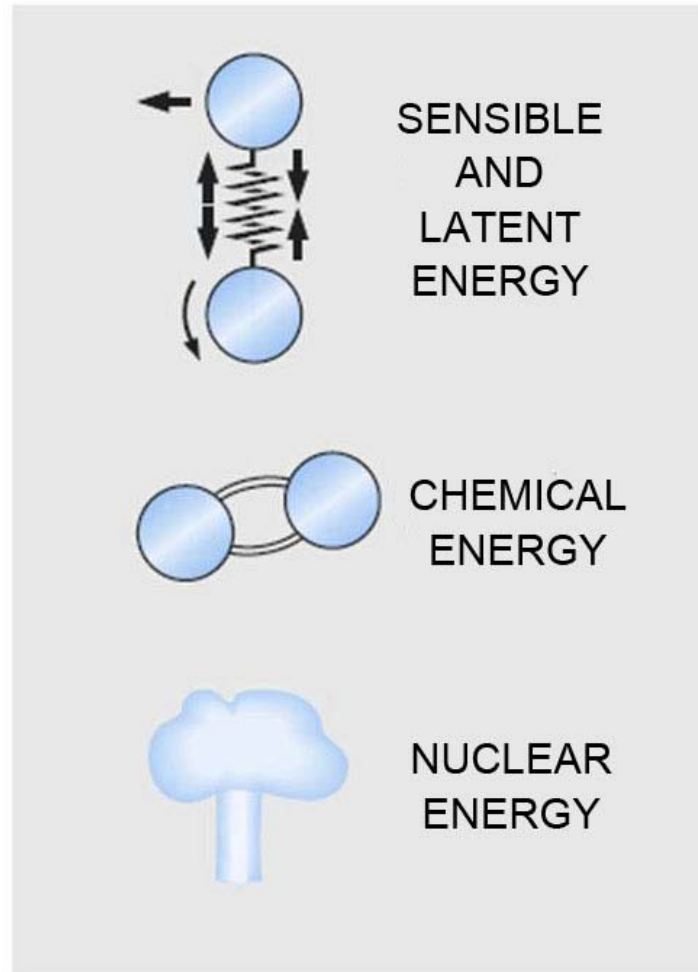
The internal energy of a system is the sum of all forms of the microscopic energies.

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MICROSCOPIC KINETIC ENERGY OF THE MOLECULES (Does not turn the wheel)

DAM

Water

MACROSCOPIC KINETIC ENERGY (Turns the wheel)
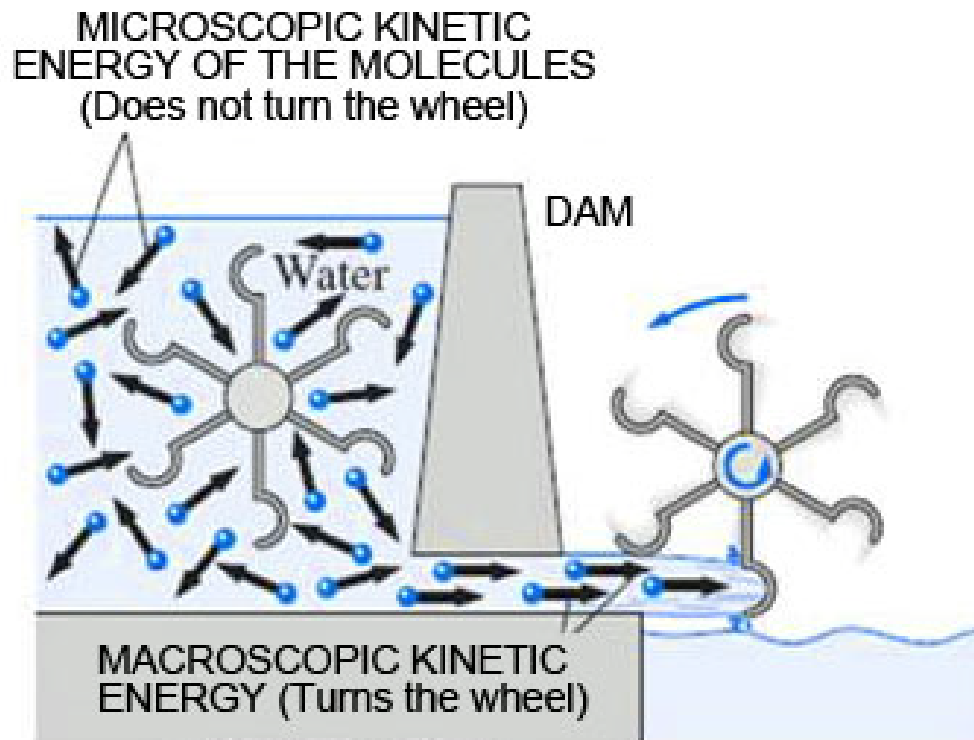
The *macroscopic* kinetic energy is an organised form of energy and more useful than the disorganised *microscopic* kinetic energies of the molecules

Kinetic and Potential energies

- Kinetic energy, KE, of a system:

$$KE = \frac{mV^2}{2} \text{ (kJ)} \quad \text{or,} \quad ke = \frac{V^2}{2} \text{ (kJ/kg) on a unit mass basis}$$

- Potential energy, PE, of a system:

$$PE = mgz \text{ (kJ)} \quad \text{or,} \quad pe = gz \text{ (kJ/kg) on a unit mass basis}$$

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Total energy of a system

- In the absence of magnetic, electric, and surface tension effects, the total energy of a system consists of the kinetic, potential, and internal energies

$$E = U + KE + PE = U + \frac{mV^2}{2} + mgz \quad \text{(kJ)}$$

or, on a unit mass basis

$$e = u + ke + pe = u + \frac{V^2}{2} + gz \quad \text{(kJ/kg)}$$

Total energy of a system

- Closed systems whose velocity and elevation of the center of gravity remain constant during a process are frequently referred to as stationary systems.

- The change in the total energy E of a stationary system is identical to the change in its internal energy U.

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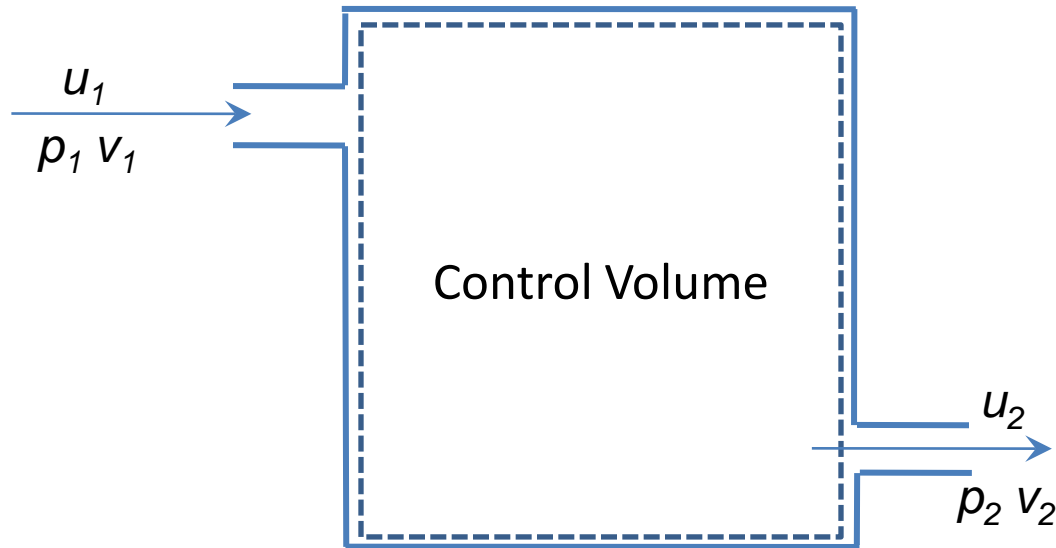
Enthalpy

- The combination of internal energy *u* and *pv* is often encountered in the analysis of control volumes

- Enthalpy is a combination property

$$\text{Enthalpy}, h = u + pv \ \ (\text{kJ/kg})$$

$$H = U + PV \ \ (\text{kJ})$$

- Enthalpy is also often referred to as heat content

- Process in which enthalpy is constant: isenthalpic process

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Enthalpy

The combination $u+pv$ is frequently encountered in the analysis of control volumes

Zeroth law of thermodynamics

- States that "if two bodies are in thermal equilibrium with a third body, they are also in thermal equilibrium with each other".

- It serves as a basis for the validity of temperature measurement.

- By replacing the third body with a thermometer, the zeroth law can be restated as two bodies are in thermal equilibrium if both have the same temperature reading even if they are not in contact.

Zeroth law of thermodynamics

Let us say T_A, T_B and T_C are the temperatures of A, B and C, respectively.
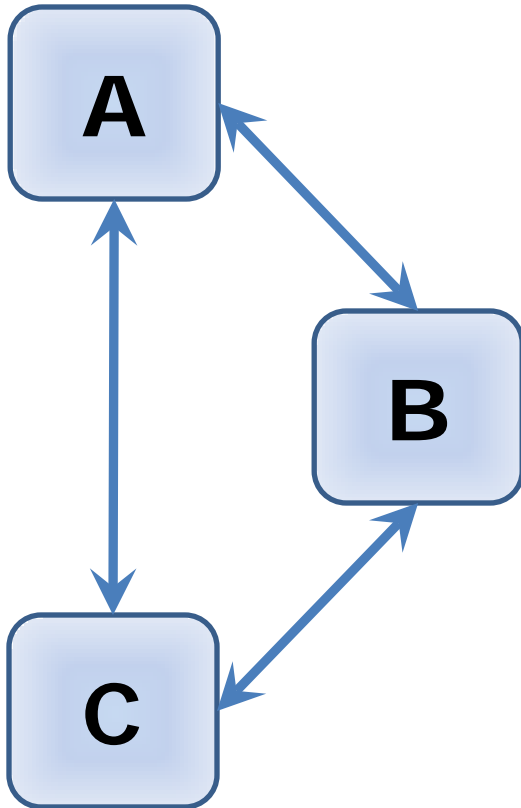
A and C are in thermal equilibrium: $T_A = T_C$

B and C are in thermal equilibrium: $T_B = T_C$

Consequence of Zeroth law: $T_A = T_B$

Zeroth law of thermodynamics

- It was named the zeroth law since it should have preceded (proposed in 1931) the first and the second laws of thermodynamics that were defined in late 1800s.

- All temperature scales based on reproducible states: freezing point (ice point) or boiling point of water (steam point).

- On the Celsius scale, ice and steam points were assigned 0^oC and 100^oC respectively.

Temperature scales

- In thermodynamics, it is desirable to have a temperature scale that is independent of any property of a substance.

- Thermodynamic temperature scale or the Kelvin scale

- The lowest temperature on this scale is 0 K.

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Temperature scales

- A temperature scale that turns out to be nearly identical to the Kelvin scale: ideal gas temperature scale

- Measured using a constant volume thermometer

- Filled with hydrogen or helium

- At low pressures, the temperature of a gas is proportional to its pressure at constant volume

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Ideal gas temperature scales

- The temperature of a gas of fixed volume varies linearly with pressure at sufficiently low pressures.

- The relationship between the temperature and the pressure of the gas in the vessel can be expressed as

$$T = a + bP$$

  where the values of the constants a and b for a gas thermometer are determined experimentally.
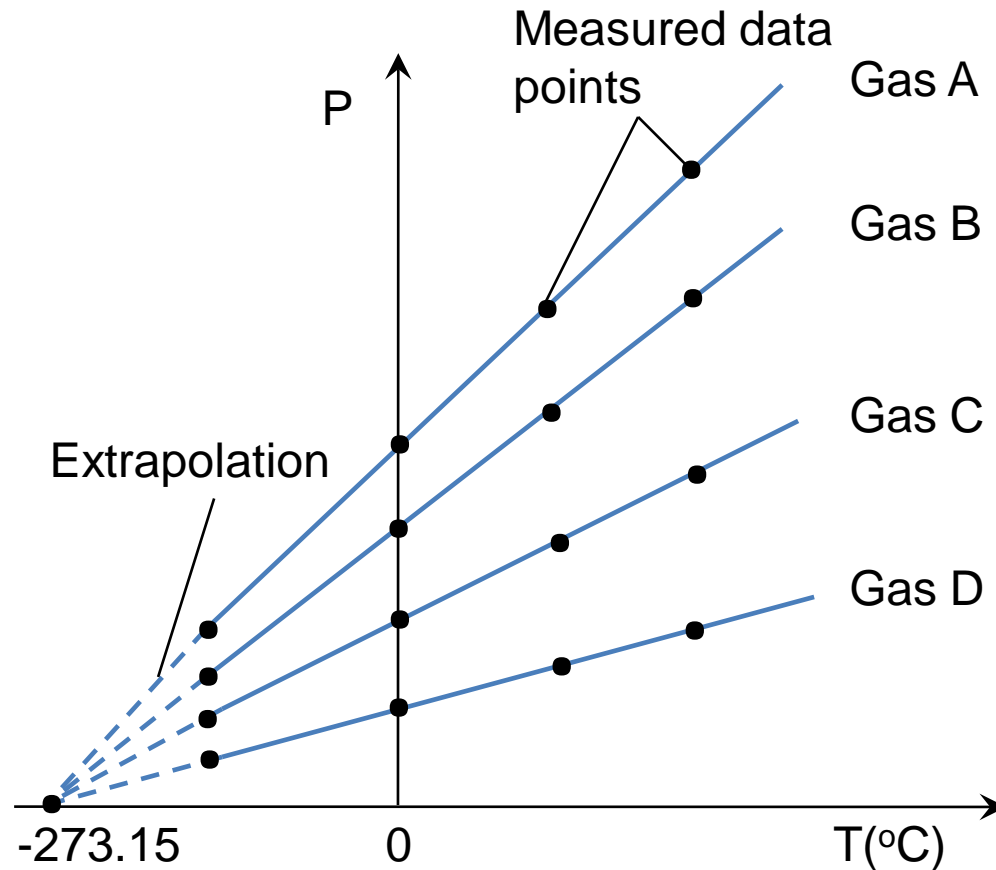
Ideal gas temperature scale

- Measuring the pressures of the gas in the vessel at two reproducible points (such as the ice and the steam points) and assigning suitable values to temperatures at those two points.

- These two measurements are sufficient to determine the constants *a* and *b*

- Then the unknown temperature *T* of a medium corresponding to a pressure reading *P* can be determined from that equation by a simple calculation.

Ideal gas temperature scale

- If the ice and steam points are assigned the values 0°C and 100°C, respectively, then the gas temperature scale will be identical to the Celsius scale.

- In this case the value of the constant *a* (which corresponds to an absolute pressure of zero) is determined to be -273.15°C regardless of the type and the amount of the gas in the vessel of the gas thermometer.

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Ideal gas temperature scale

P vs.T plots of the experimental data obtained from a constant-volume gas thermometer using four different gases at different (but low) pressures.

Ideal gas temperature scale

- -273.15°C: is the lowest temperature that can be obtained by a gas thermometer, and thus we can obtain an absolute gas temperature scale by assigning a value of zero to the constant *a*.

- In this case, we need to specify the temperature at only one point to define an absolute gas temperature scale.

- Standard fixed point for temperature scale: Triple point of water: 0.01°C or 273.16K (for Celsius scale)

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Ideal gas temperature scale

- The absolute gas temperature scale is not a thermodynamic temperature scale, since it cannot be used at very low temperatures (due to condensation) and at very high temperatures (due to dissociation and ionization).

- However, absolute gas temperature is identical to the thermodynamic temperature in the temperature range in which the gas thermometer can be used.

Recap of this lecture

- Quasi-static processes
- Concept of energy and its various forms
- Internal energy
- Total energy
- Enthalpy
- Zeroth law of thermodynamics and temperature

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In the next lecture …

- ## Specific heat
  - At constant pressure and constant volume

- ## Heat transfer
  - Meaning of heat transfer
  - Types of heat transfer

- ## Work
  - Thermodynamic meaning of work
  - Different types of work