PHY101: Introduction to Physics I

Monsoon Semester 2024

Lecture 32

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Previous Lectures

Different speeds related to kinetic theory of gases

This Lecture

Introduction to thermodynamics

Introduction to thermodynamics

Thermodynamics

- Thermodynamics concerns with the determination of the relationships among the various properties (macroscopic variables) of materials, which can be worked out without consideration of the detailed structure (microscopic) of the materials.

- Thermodynamics describes the average behavior of very large numbers of microscopic constituents, and its laws can be derived from statistical mechanics.

- Historically, thermodynamics developed out of a desire to increase the efficiency of early steam engines, particularly through the work of French engineer Nicolas Léonard Sadi Carnot (1824). He is regarded as the Father of Thermodynamics.

Scientists who contributed to this field

Thermodynamics Pioneers

Image Source: http://en.wikipedia.org/wiki/File:Eight_founding_schools.png

Significance of the topic

Thermodynamics

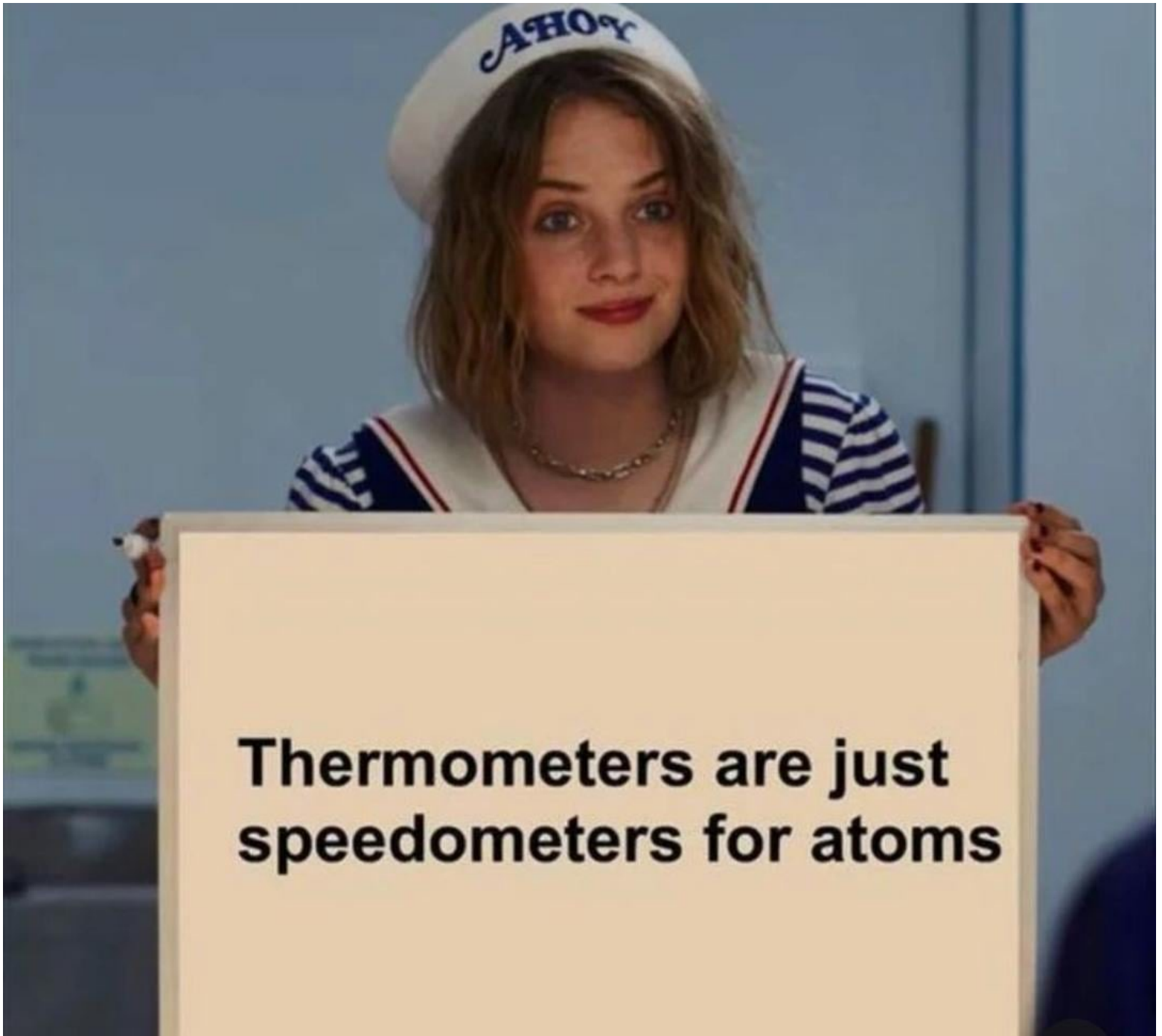
- A practical science concerned with economics, industry, real life problems.
- A thermodynamic system is any macroscopic system, with measurable macroscopic quantities (thermodynamic parameters) associated with the system.
- DYNAMICS in Thermodynamics signifies the concepts of energy *transfer* between a system and its environment and the resulting temperature variations.
- It also concerns itself with the physical and chemical transformations of matter in all of its forms: solid, liquid, and gas.
- It takes into account the processes which “violate” conservation of mechanical energy -- friction -- via the conversion between mechanical and thermal energy.

Role of temperature

Temperature

- Temperature, as we already saw, is related to the average kinetic energy of constituents of a system. It is a standardized measure of the average motion of the individual atoms and molecules in a gas, liquid, or solid.

- High temperature: The constituents are moving around energetically
  - In a gas at high temperature the individual gas molecules are moving about independently at high speeds.
  - In a solid at high temperature the individual atoms of the solid are vibrating energetically around their stable lattice positions.
- Low temperature: The converse is true for a "cold" object.
  - In a gas at low temperature the individual gas molecules are moving about sluggishly.
  - In a solid at low temperature the vibrations of the individual atoms are small.


AHOY
Thermometers are just
speedometers for atoms

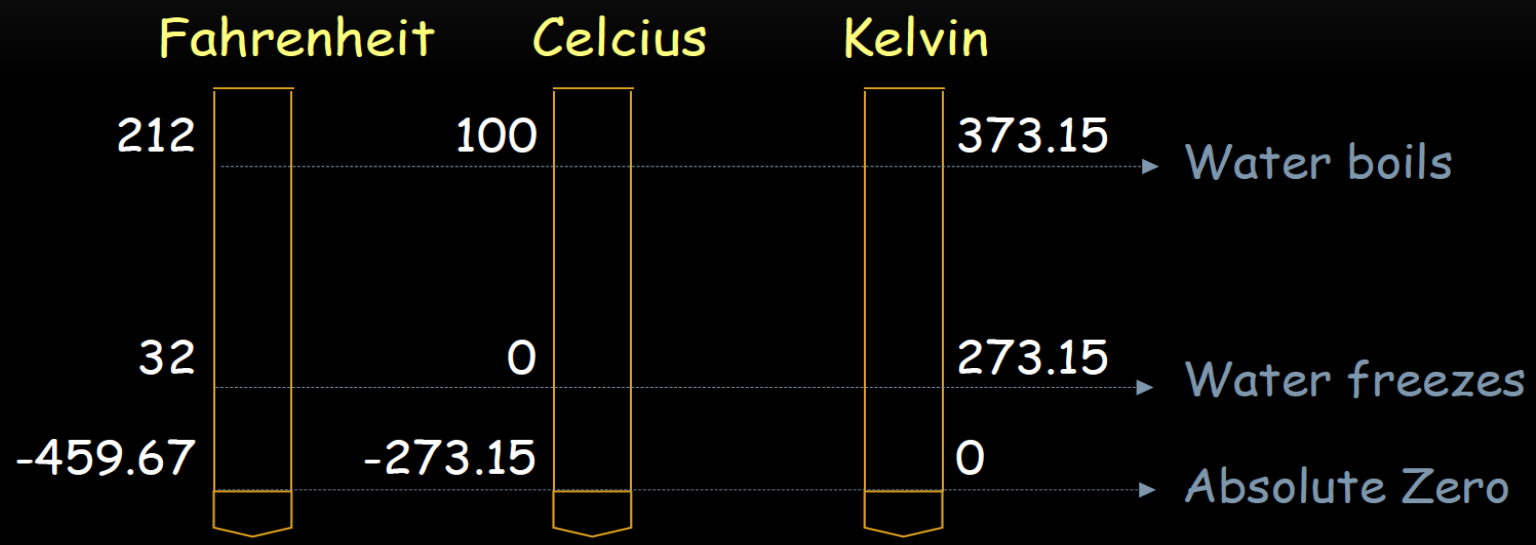
What is absolute zero?

ABSOLUTE SCALE OF TEMPERATURE

- There is an absolute zero temperature at which the classical motions of atoms and molecules ceases.
- *Quantum mechanically, however, the substance still has a zero point energy. (Heisenberg's uncertainty relation: Planck's constant is not zero.)*

Conversion between the temperature scales

TEMPERATURE SCALES



$$\frac{T_c}{100} = \frac{T_F - 32}{180} = \frac{T - 273.15}{100}$$

T: Temperature in K, T_c: Temperature in °C, T_F: Temperature in °F

What is definition of Kelvin?

MODERN DEFINITION OF KELVIN

- The temperature of the triple point on the Kelvin scale is 273.16 K
- Therefore, the current definition of the 1 Kelvin is 1/273.16 of the temperature of the triple point of water

The triple point of water occurs at 0.01° C and 4.58 mm of Hg (0.061 atm or 610 Pa).

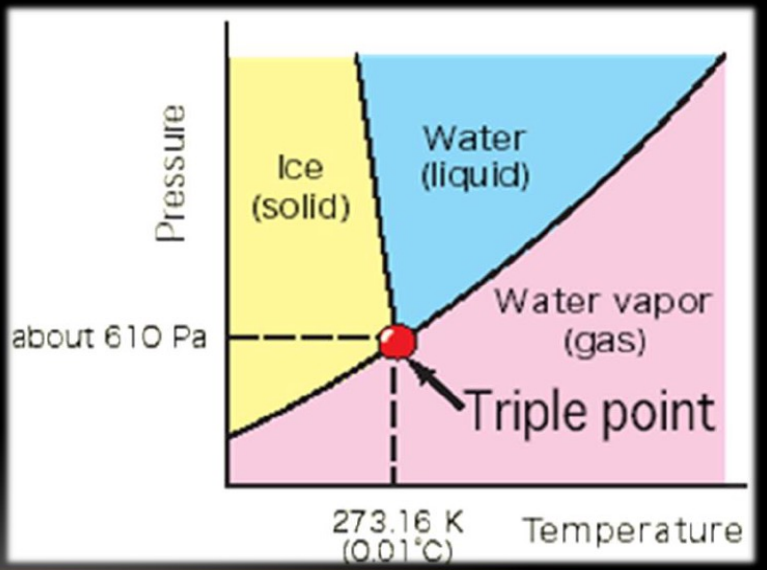
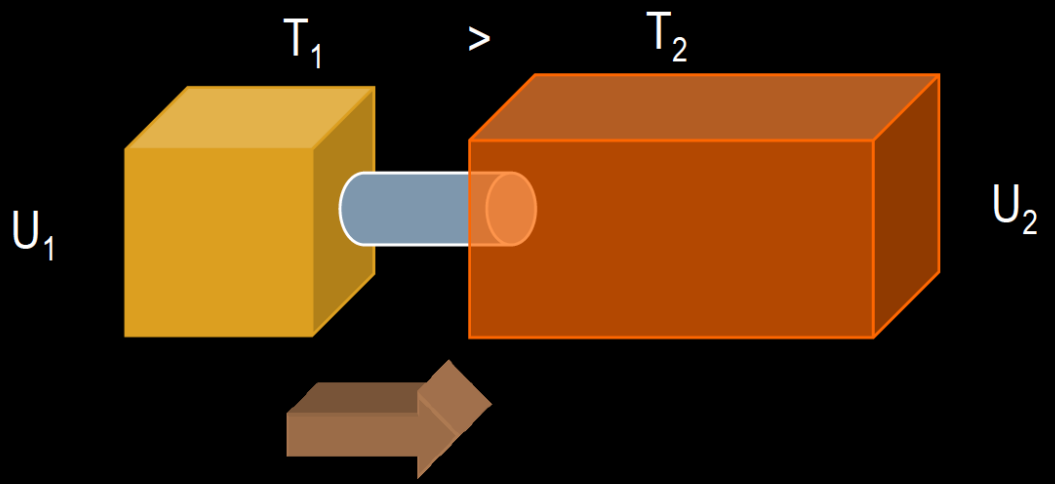


Image Source: https://www.nmij.jp/english/library/units/temperature/img/triple-chart_en.gif

Heat: Transfer of energy due to temperature difference

HEAT

- Heat concerns with the transfer of energy from one object to another as a result of their different temperatures.
- When we say two objects are in Thermal contact, that means heat, and hence energy can flow between objects

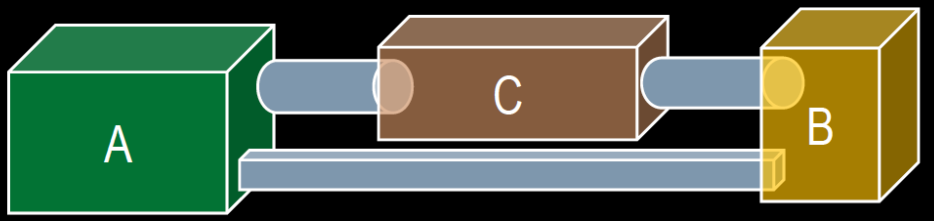


- Thermal equilibrium is established when objects in thermal contact cease heat transfer: They are said to be at the same temperature.

Laws of thermodynamics

ZEROTH LAW OF THERMODYNAMICS

- The **zeroth law of thermodynamics** states that if two systems (A and B) are each in thermal equilibrium with a third system (C), they (A and B) are also in thermal equilibrium with each other.



Next lectures: First law, second law and third law

Work done: A mechanical form of energy

THE CONCEPT OF WORK

Work is a Mechanical form of Energy: It's the product of Force and displacement in the direction of the applied force.

$$\Delta W = F\ \Delta x$$

Recalling the definition of pressure (Force per unit area), we obtain

$$\Delta W = P\ \Delta V$$

Thus work done is associated with volume change.

Work of expansion

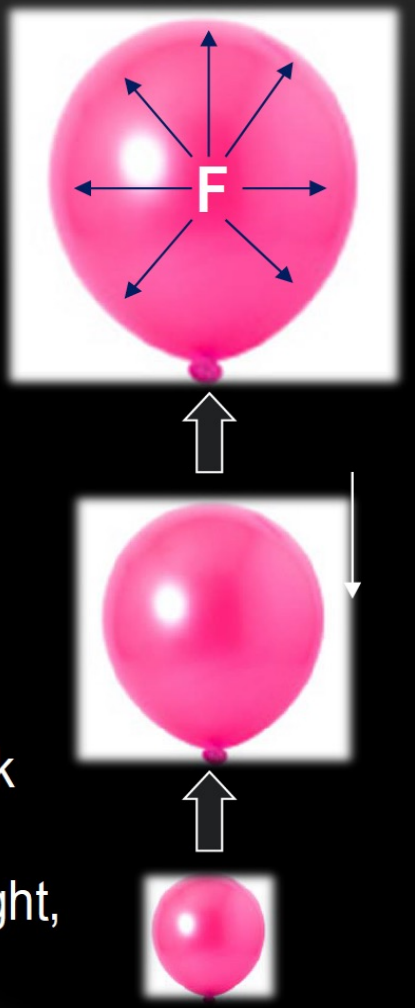
THE CONCEPT OF WORK

Changes in Volume Cause Work:

- Work is performed when air expands

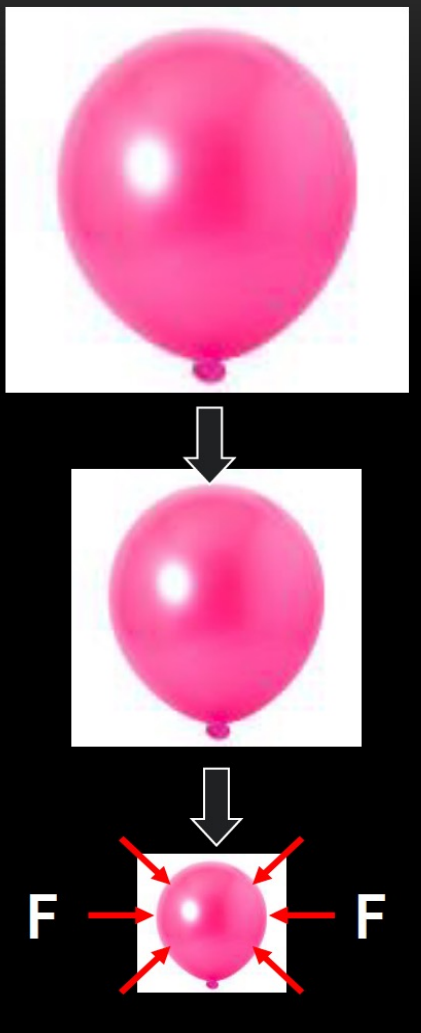
Work of Expansion: $dW > 0$

- Occurs when a system performs work (or exerts a force) on its environment.
- Rising air parcels (or balloons) involve expansion work
- Since the environmental pressure decreases with height, with height a rising parcel must expand to maintain an equivalent pressure



Work of contraction

THE CONCEPT OF WORK



Changes in Volume Cause Work:

- Work is performed when air contracts

Work of Contraction: $dW < 0$

- Occurs when an environment performs work (or exerts a force) on a system

- Sinking air parcels (or balloons) involve contraction work

- Since the environmental pressure decreases with height, with height a sinking parcel must contract to maintain an equivalent pressure

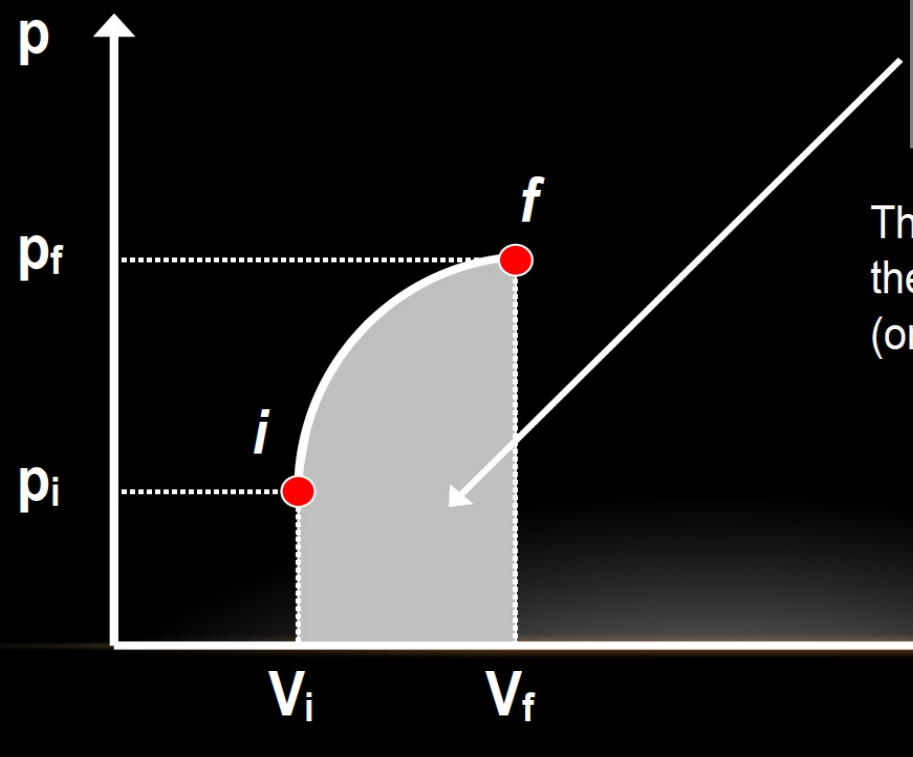
PV diagrams

PV DIAGRAMS

The work done can be found using area under the curve.

$$dW = p\,dV$$

$$W = \int_i^f p\,dV$$



The work done is the area under the i ⟶ f curve (or gray area)