College Of Engineering
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كليــة الهندسة
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Dept. of Chem. & Petrochemical Engineering
Subject : Physics
First Stage

Physics

Chapter 7– Temperature and Thermodynamics

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Thermodynamics

Thermodynamics involves situations in which the temperature or state of a system changes due to energy transfers.

Thermodynamics is very successful in explaining the bulk properties of matter.

Also successful in explaining the correlation between these properties and the mechanics of atoms and molecules.

Historically, the development of thermodynamics paralleled the development of atomic theory.

To describe thermal phenomena, careful definitions are needed:

- Temperature
- Heat
- Internal energy

Thermal Contact and Thermal Equilibrium

Two objects are in **thermal contact** with each other if energy can be exchanged between them.

- The exchanges we will focus on will be in the form of heat or electromagnetic radiation.

The energy is exchanged due to a temperature difference.

Thermal equilibrium is a situation in which two objects would not exchange energy by heat or electromagnetic radiation if they were placed in thermal contact.

- The thermal contact does not have to also be physical contact.

Zeroth Law of Thermodynamics

If objects A and B are separately in thermal equilibrium with a third object C, then A and B are in thermal equilibrium with each other.

- Let object C be the thermometer
- Since they are in thermal equilibrium with each other, there is no energy exchanged among them.

Temperature – Definition

We associate the concept of temperature with how hot or cold an object feels.

Our senses provide us with a qualitative indication of temperature.

We need a reliable and reproducible method for measuring the relative hotness or coldness of objects.

- We need a technical definition of temperature.

Temperature can be thought of as the property that determines whether an object is in thermal equilibrium with other objects.

Two objects in thermal equilibrium with each other are at the same temperature.

- If two objects have different temperatures, they are not in thermal equilibrium with each other.

A **thermometer** is a device that is used to measure the temperature of a system.

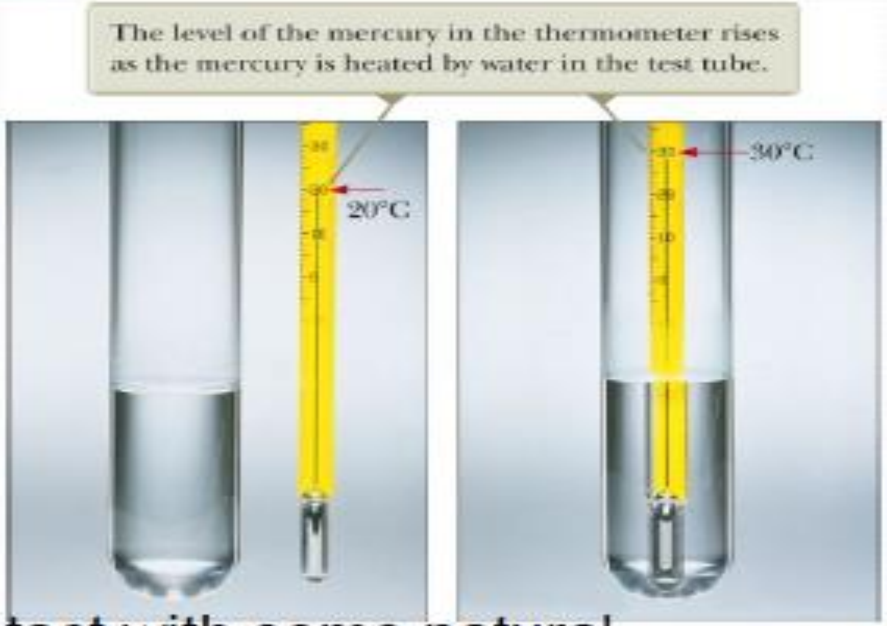
Thermometers are based on the principle that some physical property of a system changes as the system's temperature changes.

Thermometer, Liquid in Glass

A common type of thermometer is a liquid-in-glass.

The material in the capillary tube expands as it is heated.

The liquid is usually mercury or alcohol.



Calibrating a Thermometer

A thermometer can be calibrated by placing it in contact with some natural systems that remain at constant temperature.

Common systems involve water

- A mixture of ice and water at atmospheric pressure
  - Called the *ice point* of water
- A mixture of water and steam in equilibrium
  - Called the *steam point* of water

Once these points are established, the length between them can be divided into a number of segments.

Celsius Scale

The ice point of water is defined to be 0° C.

The steam point of water is defined to be 100° C.

The length of the column between these two points is divided into 100 increments, called degrees.

Problems with Liquid-in-Glass Thermometers

An alcohol thermometer and a mercury thermometer may agree only at the calibration points.

The discrepancies between thermometers are especially large when the temperatures being measured are far from the calibration points.

The thermometers also have a limited range of values that can be measured.

- Mercury cannot be used under –39° C
- Alcohol cannot be used above 85° C

Absolute Zero

The thermometer readings are virtually independent of the gas used.

If the lines for various gases are extended, the pressure is always zero when the temperature is –273.15° C.

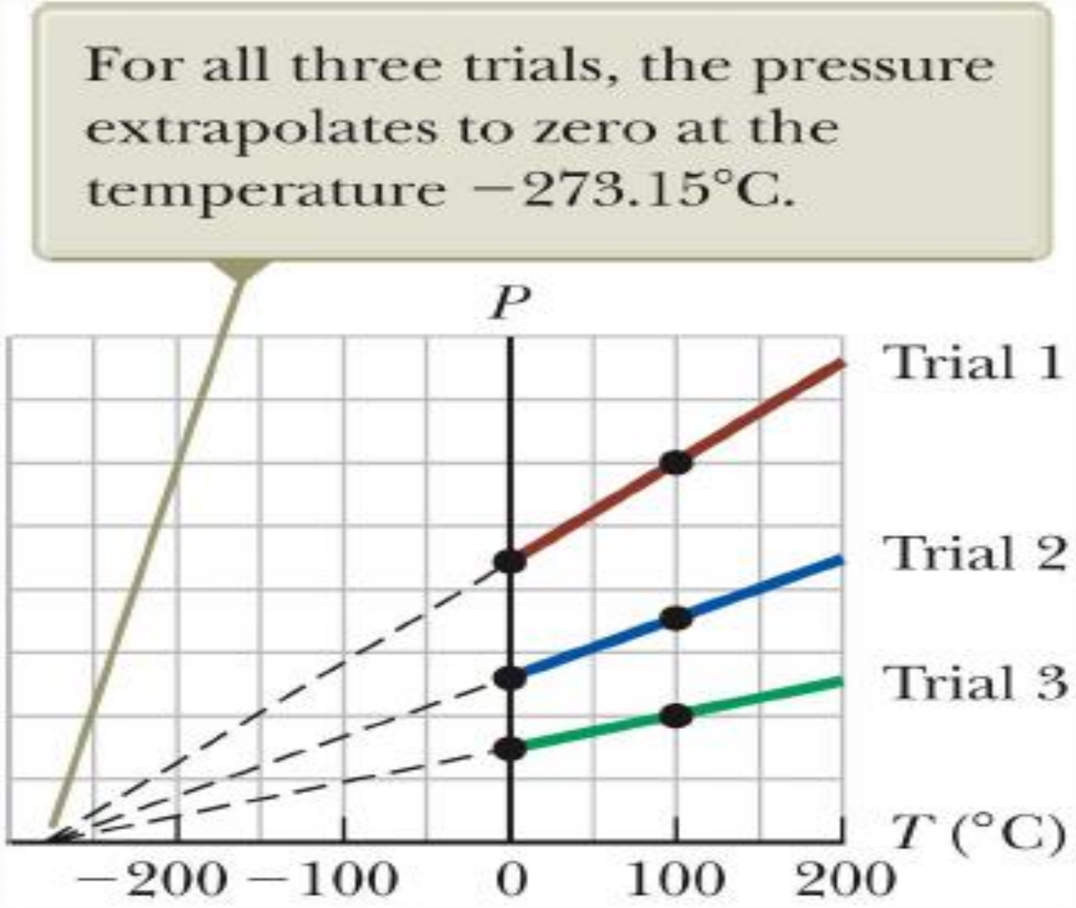
This temperature is called **absolute zero.**

Absolute zero is used as the basis of the **absolute temperature scale.**

The size of the degree on the absolute scale is the same as the size of the degree on the Celsius scale.

To convert: $T_C = T - 273.15$

The units of the absolute scale are **kelvins.** The absolute scale is also called the Kelvin scale. Named for William Thomson, Lord Kelvin



Fahrenheit Scale

A common scale in everyday use in the US. Named for Daniel Fahrenheit

Temperature of the ice point is 32°F.

Temperature of the steam point is 212°.

There are 180 divisions (degrees) between the two reference points.

$$\Delta T_C = \Delta T = \frac{5}{9}\Delta T_F$$

Comparison of Scales

Celsius and Kelvin have the same size degrees, but different starting points.

- $T_C = T - 273.15$

Celsius and Fahrenheit have different sized degrees and different starting points.

$$T_F = \frac{9}{5}T_C + 32^\circ F$$

To compare changes in temperature

Ice point temperatures 0°C = 273.15 K = 32° F

Steam point temperatures 100°C = 373.15 K = 212° F

Thermal Expansion

Thermal expansion is the increase in the size of an object with an increase in its temperature.

Linear Expansion

Assume an object has an initial length L.

That length increases by ΔL as the temperature changes by ΔT.

We define the **coefficient of linear expansion** as

$$\alpha = \frac{\Delta L / L_i}{\Delta T}$$

A convenient form is $\Delta L = \alpha L_i \Delta T$

This equation can be written in terms of the initial and final conditions of the object:

- $L_f - L_i = \alpha L_i (T_f - T_i)$

The coefficient of linear expansion, α, has units of $(^\circ C)^{-1}$

Some materials expand along one dimension, but contract along another as the temperature increases. Since the linear dimensions change, it follows that the surface area and volume also change with a change in temperature.

Some Coefficients

TABLE 19.1 *Average Expansion Coefficients for Some Materials Near Room Temperature*

Material (Solids)	Average Linear Expansion Coefficient $(\alpha)(°C)^{-1}$	Material (Liquids and Gases)	Average Volume Expansion Coefficient $(\beta)(°C)^{-1}$
Aluminum	24×10^{-6}	Acetone	1.5×10^{-4}
Brass and bronze	19×10^{-6}	Alcohol, ethyl	1.12×10^{-4}
Concrete	12×10^{-6}	Benzene	1.24×10^{-4}
Copper	17×10^{-6}	Gasoline	9.6×10^{-4}
Glass (ordinary)	9×10^{-6}	Glycerin	4.85×10^{-4}
Glass (Pyrex)	3.2×10^{-6}	Mercury	1.82×10^{-4}
Invar (Ni–Fe alloy)	0.9×10^{-6}	Turpentine	9.0×10^{-4}
Lead	29×10^{-6}	Air[a] at 0°C	3.67×10^{-3}
Steel	11×10^{-6}	Helium[a]	3.665×10^{-3}

[a]Gases do not have a specific value for the volume expansion coefficient because the amount of expansion depends on the type of process through which the gas is taken. The values given here assume the gas undergoes an expansion at constant pressure.

Example: Expansion of a railroad track

(a) A steel railroad track has a length of 30.0 m when the temperature is 0 °C. What is the length on a hot day when the temperature is 40.0 °C?

(b) (b) What is the stress caused by this expansion?

Solution:

(a) The change in length due to the temperature change,

$$\begin{aligned}\Delta L &= \alpha L_0 \Delta T \\ \Delta L &= (11 \times 10^{-6}\ /^{\circ}\mathrm{C})(30.0\ \mathrm{m})(40.0\ ^{\circ}\mathrm{C}) \\ \Delta L &= 0.013\ \mathrm{m}.\end{aligned}$$

So the new length is 30.013 m.

(b) The railroad undergoes a linear expansion, so this is a tensile strain,

$$\begin{aligned}\frac{F}{A} &= Y\frac{\Delta L}{L} \\ \frac{F}{A} &= (2.0 \times 10^{11}\ \mathrm{Pa}\left(\frac{0.013\ \mathrm{m}}{30.0\ \mathrm{m}}\right) \\ \frac{F}{A} &= 8.7 \times 10^{7}\ \mathrm{Pa}.\end{aligned}$$