Chapter 18 Temperature, Thermal Expansion, and the Ideal Gas Law

Zeroth law of thermodynamics: thermal equilibrium.

What is temperature? How to define temperature scale?

First law of thermodynamics: conservation of energy to include heat.

What is heat? How heat does work?

Second law of thermodynamics: the direction where nature processes evolve.

What is entropy? Why does the entropy always increase?

18.1 Temperature & 18.2 Temperature Scales

The concept of temperature is based on our sense of hot and cold. However, our perception of the hotness or coldness of a body is deceptive.

A **thermometer** is an instrument that measures temperature. Any property of a substance or a device that changes when it is heated or cooled may be used as the basis of thermometer.

The **Celsius** scale and the **Fahrenheit** scale: Freezing point of water is assigned $0^{o}C$ or $32^{o}F$; boiling point of water is assigned $100^{o}C$ or $212^{o}F$.

How to measure extremely high temperature or extremely low temperature?

18.3 The Zeroth Law of Thermodynamics

State variable: The state of any system, such as a gas in a flask, may be specified by a certain number of macroscopic state variables, such as temperature, mass, pressure, and volume.

Thermal equilibrium: When all its state variables are constant in time, the system is said to be in thermal equilibrium. In this condition, the state variables have single values that characterize the whole system.

Two system are in thermal equilibrium with each other if their temperature are the same.

Zeroth law: Two bodies in thermal equilibrium with a third are also in thermal equilibrium with each other.

18.4 The Equation of State of an Ideal Gas (I)

In 1662, Boyle found that the volume of a gas kept at constant temperature is inversely proportional to the pressure:

$$\boxed{\text{(Boyle)} \qquad PV = \text{constant at fixed } T}$$

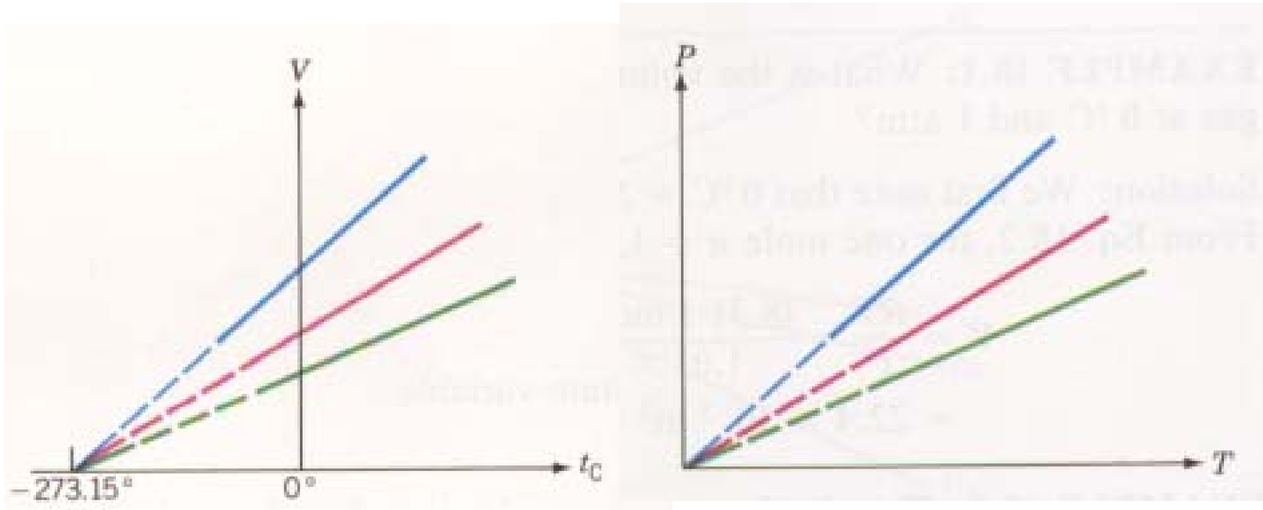
In 1800, Charles and Gay-Lussac independently found that at a fixed pressure found that the volume of a gas is proportional to the change in temperature.

$$\boxed{\text{(Charles and Gay-Lussac)} \qquad V \propto T \text{ at fixed } P}$$

Gay-Lussac also found that at fixed volume, the change in pressure is proportional to the change in temperature.

$$\boxed{\text{(Gay-Lussac)} \qquad P \propto T \text{ at fixed } V}$$

18.4 The Equation of State of an Ideal Gas: **The Kelvin temperature**



18.4 The Equation of State of an Ideal Gas (II)

The value of *PV* depends on the number of molecules *N* of the gas that are present. At a given pressure and temperature $V \propto N$. Thus $PV \propto N$. Combining this with $PV \propto T$, we obtain **the equation of state for an ideal gas**.

$$PV = NkT$$

Where *k* is a constant of proportionality called **Boltzmann's constant**: $k = 1.38 \times 10^{-23}$ J/K

18.4 The Equation of State of an Ideal Gas (II)

Instead of specifying the large number of molecules in a sample, it is often convenient to specify the number of **moles**.

One **mole** (mol) of any substance contains as many elementary units (such as atoms or molecules) as the number of atoms in 12 g of the isotope carbon-12. This number is called **Avogadro's number**: $N_A = 6.02 \times 10^{23}$ mol^{-1}.

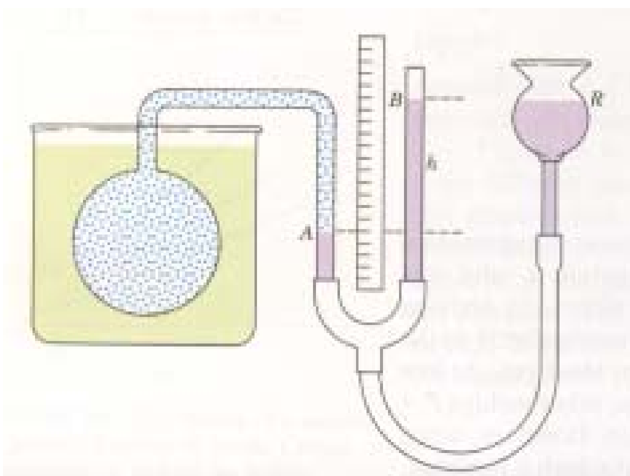
$$PV = nRT$$

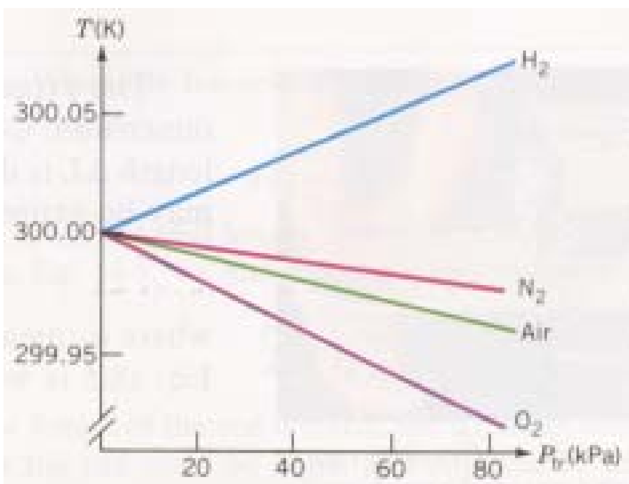
Where $R = kN_A = 8.314$ J/mol·k is called the universal gas constant.

TABLE 18.1
MOLECULAR MASSES (g/mol)

Hydrogen	2.02
Helium	4
Nitrogen	28
Oxygen	32
Carbon dioxide	44

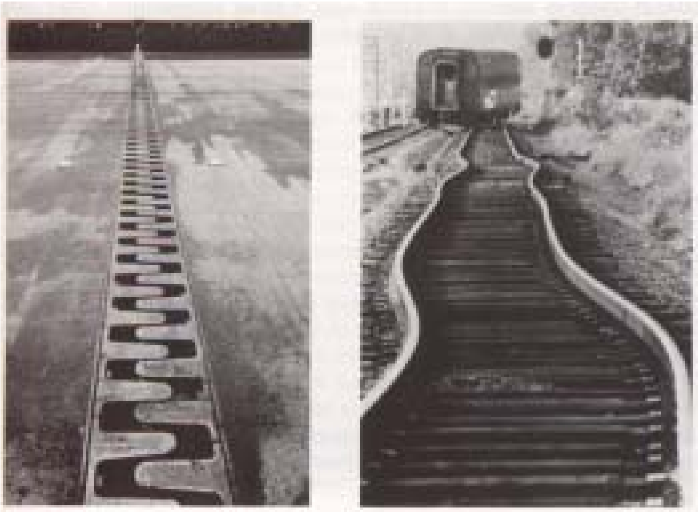
18.5 Constant-Volume Gas Thermometer

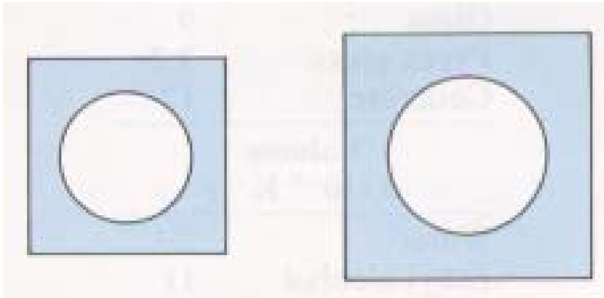




18.6 Thermal Expansion

Most materials expand when their temperature is increased.





18.6 Thermal Expansion:
Coefficients of Linear and volume Expansion

The coefficient of linear expansion:

$$\alpha = \frac{\Delta L / L_0}{\Delta T}$$

The coefficient of volume expansion:

$$\beta = \frac{\Delta V / V_0}{\Delta T}$$

TABLE 18.2
COEFFICIENTS OF EXPANSION (20°C)

Linear α (10^{-6} K^{-1})	
Aluminum	24
Brass	18.7
Copper	17
Steel	11.7
Glass	9
Pyrex glass	3.2
Concrete	12
Volume β (10^{-4} K^{-1})	
Water	2.1
Ethyl alcohol	11
Mercury	1.8
Gasoline	9.5

Example 18.3

What is the relation between α and β for an isotropic solid ---one whose properties do not depend on direction?

Solution:

Consider a cube of side *L*.

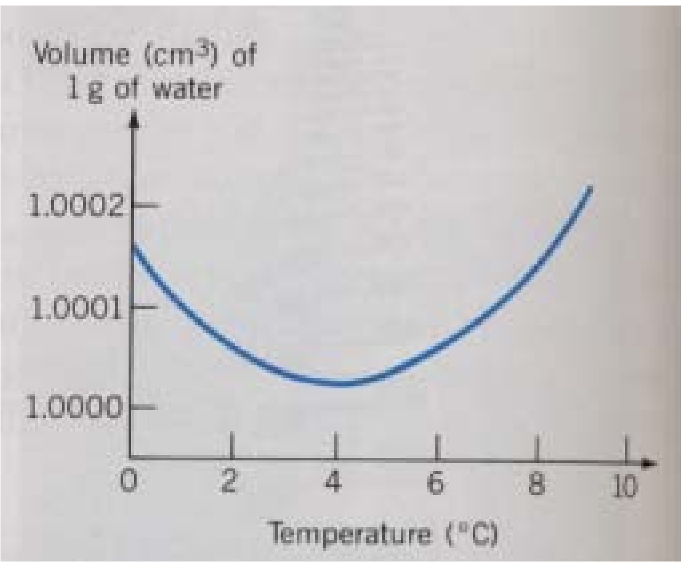
$$V = L^3 \Rightarrow dV = 3L^2 dL$$

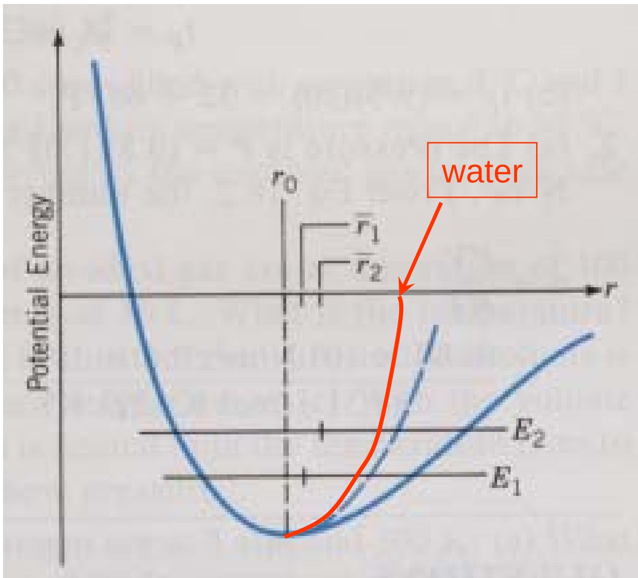
$$\frac{dV}{V} = 3\frac{dL}{L}$$

For a given ΔT

$$\beta = \frac{\Delta V / V}{\Delta T} = 3\frac{\Delta L / L}{\Delta T} = 3\alpha$$

Thermal Expansion of Water: Anomalous Expansion Between 0-4ºC





Exercises and Problems

Ch.18:

Prob. 2, 3, 6, 7, 12