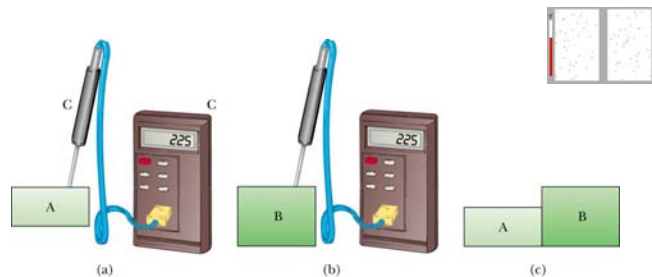


Chapter 13: Temperature, Kinetic Theory and Gas Laws

Zeroth Law of Thermodynamics (law of equilibrium):

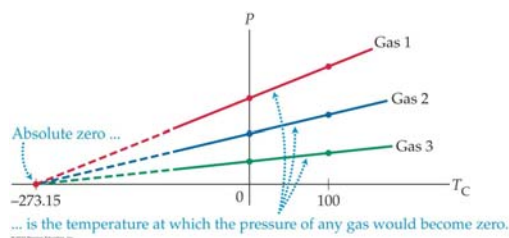
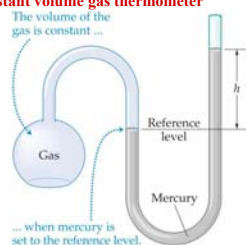
If objects A and B are separately in thermal equilibrium with a third object C, then A and B are in thermal equilibrium with each other.

Objects in thermal equilibrium with each other are at the same **temperature**.



Thermometers and Temperature Scales

constant volume gas thermometer



Any physical property which changes sensitively with the temperature can be used as thermometer. For example, the pressure of gas at a constant volume is an indicator of temperature. Celsius and Fahrenheit are artificially defined temperature scales. The absolute temperature (Kelvin) scale defines an absolute zero as a lower bound for physical processes.

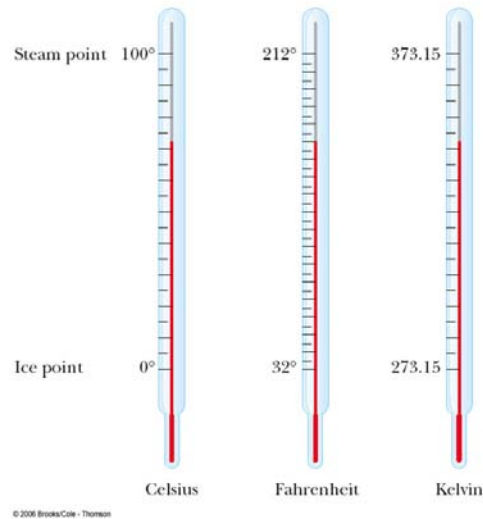
$$T = T_C + 273.15$$



Temperature Scales

$$T_C = T - 273.15$$

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



Ideal Gases

One mole of any substance contains as many particles as there are atoms in 12 g of the carbon-12 isotope. (Avogadro's number $N_A = 6.02 \times 10^{23}$)

IDEAL GASES

An ideal gas is a collection of atoms or molecules that move randomly, exert no long-range forces on one another, and occupy a negligible fraction of the volume of their container. For any ideal gas:

$$PV = nRT ,$$

where n is the number of moles, T is the absolute temperature, the universal gas constant $R = 8.31 \text{ J/mol-K} = 0.0821 \text{ L}\cdot\text{atm} / \text{mol-K}$

Macroscopic Description of An Ideal Gas

$$PV = nRT$$

Ideal gas

The volume occupied by 1 mole of any gas at atmospheric pressure and at 0°C is 22.4 L. (Equal volumes of gas at the same temperature and pressure contain the same number of molecules.)

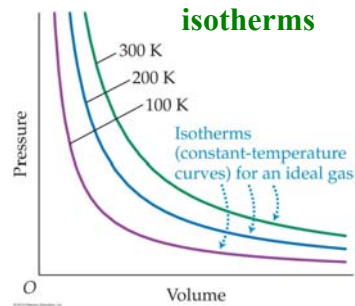
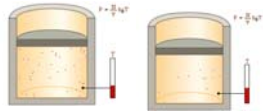
$$R = N_A k_B$$

$$PV = nRT = Nk_B T$$

N: number of molecules;

k_B : Boltzmann's constant

$$k_B = R / N_A = 1.38 \times 10^{-23} \text{ J / K}$$



The Kinetic Theory of Gases

Assumptions:

1. The number of molecules in the gas is large. However, the average separation of molecules is large compared with their dimensions.
2. The molecules obey Newton's law of motion, but as a whole they move randomly.
3. Molecules interact only through short-range forces during elastic collisions.
4. The molecules make elastic collisions with the walls.
5. All molecules in the gas are identical.

The Kinetic Theory of Gases

Assume N molecules of an ideal gas are inside a cubic container of volume V ($d^3=V$). Let's figure out the impulse exerted by one particular molecule in one collision with the wall at $x=d$.

$$\Delta p_x = mv_x - (-mv_x) = 2mv_x$$

How often does this molecule collide with this wall?

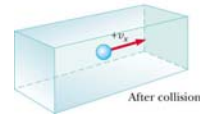
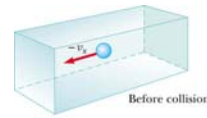
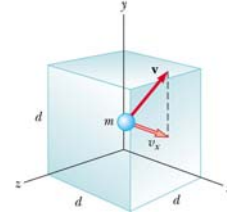
$$\Delta t = 2d / v_x$$

In unit time, the total impulse received by the wall from this molecule is

$$\frac{\Delta p_x}{\Delta t} = \frac{2mv_x}{2d / v_x} = mv_x^2 / d$$

In unit time, the total impulse received by the wall from ALL THE MOLECULES is

$$\frac{I}{t} = Nm \overline{v_x^2} / d$$



The Kinetic Theory of Gases

The average force received by the wall from the molecules is

$$F = \frac{I}{t} = Nm \overline{v_x^2} / d$$

$$P = \frac{F}{A} = \frac{Nm \overline{v_x^2} / d}{d^2} = \frac{N}{V} m \overline{v_x^2}$$

Because space is isotropic, $\overline{v_x^2} = \overline{v_z^2} = \overline{v_y^2} = \frac{1}{3} \overline{v^2}$

$$PV = \frac{2}{3} N \left(\frac{1}{2} m \overline{v^2} \right)$$

But we also know that $PV=Nk_B T$. Therefore,

$$\frac{1}{2} m \overline{v^2} = \frac{3}{2} k_B T$$

<http://www.phy.ntnu.edu.tw/ntnujava/viewtopic.php?t=42>

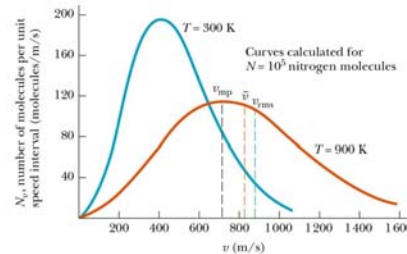
Molecular Interpretation of Temperature

$$\frac{1}{2} m \bar{v}^2 = \frac{3}{2} k_B T$$

$$KE_{total} = N \left(\frac{1}{2} m \bar{v}^2 \right) = \frac{3}{2} N k_B T = \frac{3}{2} nRT$$

$$U = \frac{3}{2} nRT$$

$$v_{rms} = \sqrt{\frac{3k_B T}{m}} = \sqrt{\frac{3RT}{M}}$$



Maxwell velocity distribution N₂

$$f(v) = 4\pi \left(\frac{m}{2\pi k_B T} \right)^{3/2} v^2 e^{-\frac{mv^2}{2k_B T}}$$

Maxwell - Boltzmann

For hydrogen molecules at RT, the rms velocity ~ 1.9 km/s!



$$v_{esc} = \sqrt{\frac{2GM_E}{R_E}} \approx 11.2 \text{ km/s}$$

Thermal Expansion

The length of a solid object (with an initial length L₀ at temperature T₀) changes by ΔL for a change ΔT in temperature:

$$\Delta L = \alpha L_0 \Delta T$$

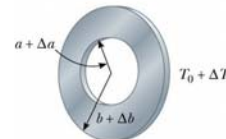
$$L - L_0 = \Delta L = \alpha L_0 (T - T_0)$$

α is the coefficient of linear expansion.

The volume change of an object with a change in temperature is

$$\Delta V = \beta V_0 \Delta T$$

β is the coefficient of volume expansion. Usually, β = 3 α .



Thermal expansion



Examples

19. It is desired to slip an aluminum ring over a steel bar. At 10.00°C the inside diameter of the ring is 4.000 cm and the diameter of the rod is 4.040 cm. Find the temperature of the ring at which the ring just fits over the bar. The bar remains at 10.00°C.

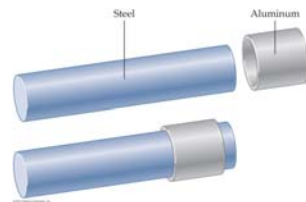


TABLE 16–1 Coefficients of Thermal Expansion near 20 °C

| Substance | Coefficient of linear expansion, α (K^{-1}) |
|--------------|--|
| Lead | 29×10^{-6} |
| Aluminum | 24×10^{-6} |
| Brass | 19×10^{-6} |
| Copper | 17×10^{-6} |
| Iron (steel) | 12×10^{-6} |
| Concrete | 12×10^{-6} |
| Window glass | 11×10^{-6} |
| Pyrex glass | 3.3×10^{-6} |
| Quartz | 0.50×10^{-6} |

| Substance | Coefficient of volume expansion, β (K^{-1}) |
|----------------------|---|
| Ether | 1.51×10^{-3} |
| Carbon tetrachloride | 1.18×10^{-3} |
| Alcohol | 1.01×10^{-3} |
| Gasoline | 0.95×10^{-3} |
| Olive oil | 0.68×10^{-3} |
| Water | 0.21×10^{-3} |
| Mercury | 0.18×10^{-3} |

© 2010 Pearson Education, Inc.

Summary of Chapter 13

- Temperature determines whether two objects will be in thermal equilibrium.

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

- Temperature scale conversions:

$$T_C = \frac{5}{9}(T_F - 32)$$

- Linear expansion: $\Delta L = \alpha L_0 \Delta T$ $T = T_C + 273.15$

- Volume expansion: $\Delta V = \beta V \Delta T$

Ideal gas

Average (translational) kinetic energy per molecule:
proportional to T