Modern Physics

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Contents

Basic related concept:

- **heat**: thermal energy transmitted from one body to another(energy in transit)
- **thermal energy**: due to random motion of molecules
- **temperature**: measure of concentration of internal energy

1 Temperature

Two units for temperature:

- degree Celsius($^\circ C$): water freeze at $0^\circ C$, and boils at $100^\circ C$ in standard condition
- kelvins(K): absolute temperature scale
- Fahrenheit is almost ignored in physics

The relationship between these two measures:

$$T(K) = T(^\circ C) + 273$$

Triple point is the temperature that 3 phase(liquid, solid and vapor) of a substance that coexist.

2 Heat Transfer

2.1 Heat Transfer Due to Temperature Change

The relationship is:

$$Q = mc\Delta T$$

where

- Q is the heat transfered during the process, positive Q represent heat coming and temperature increasing
- m is the mass of sample
- c is the specific heat(intrinsic property of an object)
- ΔT is the temperature change

Two contacted objects will finally reach thermal equilibrium, meaning they have the same temperature.

2.2 Heat Transfer Due to Phase Change

The relationship is:

$$Q = mL$$

where

- Q is the heat transfered during phase change, note that temperature is constant in this process
- m is the mass of sample
- L is **latent heat of transformation**, could be latent heat of fusion, vaporization, etc

Summary of phase changes:

- solid to liquid: **melting**, reverse: **freezing**
- liquid to gas: **vaporization**, reverse: **condensation**
- solid to gas: **sublimation**, reverse: **deposition**

2.3 Ways of Heat Transfer

There are three ways for heat transfer:

- **conduction**: by contact
- **convection**: by motion of fluid
- **radiation**: by EM waves

When crystal absorbs of gives off heat, either temperature of phase changes.

3 Thermal Expansion

Change in temperature may lead to change in size, usually size expanded when temperature increases and shrinks as temperature goes lower. Relationship in change of length is:

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

or in simpler form:

$$\Delta L = \alpha L_i \Delta T$$

where

- L: length, sub i represents initial and sub f represents final
- α: coefficient of linear expansion

Similarly, relationship in change of volume is:

$$\Delta V = \beta V_i \Delta T$$

where β is the **coefficient of volume expansion**. For most solid $\beta \approxeq 3\alpha$. Most substance have positive β, one exception is water from $0°C$ to $4°C$(maximum density).

4 Kinetic Theory of Gases

Pressure(P) is defined as:

$$P = \frac{F}{A}$$

Avogadro's constant(number of atoms or molecules in 1 **mole**) is:

$$N_A = 6.02 \times 10^{23}$$

The molar mass(M) of an object is:

$$M = mN_A \quad \text{where } m \text{ is th } \textbf{unit mass}$$

Idea gas law can be expressed as equation:

$$PV = nRT$$

where

- n: number of moles of gas
- R: universal gas constant which is 8.314 in SI
- T: temperature in kelvins

Average translational kinetic energy of gas molecules is directly proportional to the absolute temperature:

$$K_{avg} = \frac{3}{2}k_B T$$

where

$$k_B = \frac{R}{N_A}$$

By root-mean-square speed:

$$\frac{1}{2}mv^2 = \frac{3}{2}k_B T$$

RMS speed is:

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

5 Laws of Thermodynamics

5.1 Zeroth Law of Thermodynamics

If object 1 and 2 are each in thermal equilibrium with object 3, then object 1 and 2 are in thermal equilibrium with each other.

5.2 First Law of Thermodynamics

Energy is neither created nor destroyed in any thermodynamic system, mathematically:

$$\Delta U = Q - W$$

where

- ΔU is the change in internal energy of the system
- Q is heat added to the system
- W is work done by the system

Work done by gas(assume gas has constant pressure) is:

$$W = P\Delta V \quad \text{or differntial form} \quad dW = PdV$$

Two types of process:

- isothermal process: temperature remains constant($P - V$ graph is reciprocal function)
- adiabatic process: no heat exchange between system and surrounding($P - V$ graph is steeper)

5.3 Second Law of Thermodynamics

The total **entropy** of a system plus its surrounding will never decrease. Which implies:

- heat spontaneously go from hot to cold
- a heat engine can never operate at 100% efficiency

A heat engine is a device that use heat to produce useful work. Its efficiency(e) is:

$$e = \frac{Q_H - |Q_C|}{Q_H} = 1 - \frac{|Q_C|}{Q_H}$$

The most efficient heat engine follows **Carnot** cycle:

1. isothermal expansion
2. adiabatic expansion
3. isothermal compression
4. adiabatic compression

it has efficiency:

$$e = \frac{T_H - T_C}{T_H} = 1 - \frac{T_C}{T_H}$$