

COURSE CODE: PHS 105 (Part II: Heat & Thermodynamics)
COURSE TITLE: General Physics for Non-majors
NUMBER OF UNITS: 3 Units
COURSE DURATION: Three hours per week

COURSE DETAILS:

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COURSE CONTENT:

Temperature, heat, thermometers, internal energy and Mechanical Equivalence of heat, Elementary treatment of the contents of the laws of thermodynamics.

COURSE REQUIEREMENTS:

This course is compulsory for all Agricultural and Biological Sciences in the University. In this light, students are expected to participate in all the course activities and obtain minimum of 75% attendance to be able to write the final examination.

READING LIST:

1. Sears, W., University Physics, Addison-Willey Publishing company, Singapore, 1974

2. Nelkon, M and Parker, P., Advance level Physics, Heinemann Educational Books, London, 1982
3. Serway, R.A., Faughn, J.S., Vuille, C., College Physics Solutions, Harcourt Brace College Publishers, 1997.
4. Halliday, D., Resnick, R. and J. Walker, Fundamentals of Physics, John Wiley and Sons, 1993.
5. O. Ajaja, First-Year University Physics (Mechanics, Heat and Sound), Lamiad Nigeria Ltd., 1993.

LECTURE NOTES:

CHAPTER ONE

1.0 THERMODYNAMIC SYSTEMS & THERMAL EQUILIBRIUM

Thermodynamics involve the study of the relationship between heat and other forms of energy. It often involves production of heat from work or work from heat. The former occurs when we rub our palms together (i.e. mechanical work) to generate heat and the later when fuel is burnt (heat from automobile engine to generate motion of the wheels (mechanical work).

Chemical thermodynamics deals mainly with equilibrium states i.e. with systems which are in the thermodynamic equilibrium. To be in thermodynamic equilibrium, a system must be in mechanical, chemical and thermal equilibrium. This means that mechanical properties (e.g. pressured, chemical properties (e.g. composition) and thermal properties and thermal properties (e.g. temperature) must all be at “steady-state” i.e. they must not change with time.

If two systems A and B which are initially at different thermal states are brought into thermal contact, energy exchange will occur between the two systems until eventually both attain the same thermal state. At this point the then properties of A and B no longer vary with time and they are in thermal equilibrium.

The Zeroth law of thermodynamics states that two systems which are in their equilibrium with a third system are also in thermal equilibrium with each other.

1.1 FIRST LAW OF THERMODYNAMICS

The first law of thermodynamics is essentially the law of conservation of energy. It states that if a closed system absorbs a net amount of energy (heat) Q from its surroundings and does an amount of work (W), the quantity $(Q-W)$ is used in raising the internal energy (μ) of the system.

Mathematically, first law of thermodynamic can be expressed as

$$Q - W = \Delta u \quad \text{_____} \quad (1)$$

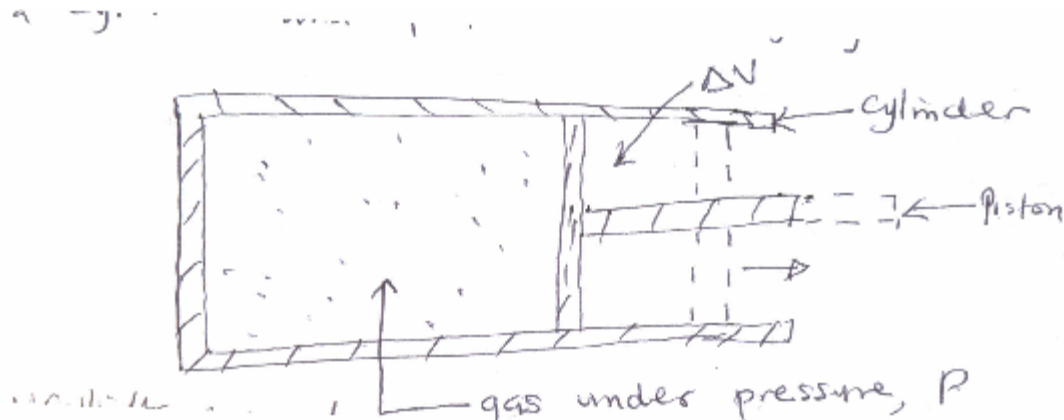
Where Δu is the change in internal energy of the system.

NOTES:

- (i) Heat added to the system is positive

(ii) Heat released by the system is negative

Work is said to be done when any boundary of a system undergoes a displacement under the action of a force. Let us consider a system consisting of a gas under pressure P enclosed in a cylinder and piston unit [see Fig. 1]



The work (dW) done by the gas when the piston moves to the right under pressure P such that the volume of the gas increases by dV is

$$dW = PdV \quad \text{_____} (2)$$

If the piston moves through a finite distance, then the work done is given as

$$W = \int_{v_1}^{v_2} PdV \quad \text{_____} (3)$$

NOTES:

- (1) Work done by the system is positive
- (2) Work done on the system is negative

1.2 HEAT ENGINES

A heat engine as a device which produce work from a supply of heat. A common example of heat engine is the PEDRO (oil Gasoline) engine.

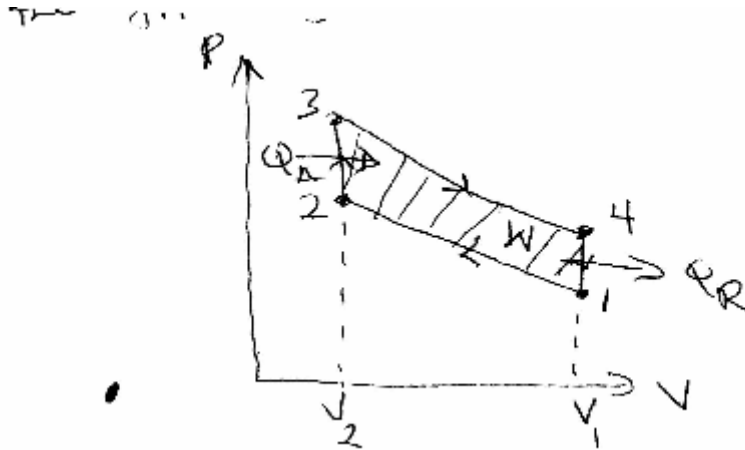
The working cycle for the petrol can be closely approximated by OTTO cycle which consists of four main processes,

- 1-2 Adrabetic compression of air-petrol mix

2-3 Heating at constant volume to state 3

2-4 Adiabatic expansion to state 4

The above four processes can be represented by the following figure.



The term “reservoir” is used to represent any part of a system which can absorb or release a large amount/quantity of heat without showing an appreciable change in temperature.

Based on the 2nd law of thermodynamic it is impossible to build an engine with low efficiency, however, it is of interest that can be attained. The Carnot engine is an idealized engine that can produce above 100% efficiency. It consists of four REVERSIBLE processes (i.e. a process that can be made to reverse itself without external aid); these processes include:

1-2: Reversible adiabatic compression

2-3; Reversible isothermal expansion during which, heat Q_A is absorbed

From heat reservoir, T_H

3-4 Reversible adiabatic expansion from T_H to T_c

4-1 Reversible isothermal compression during which heat, Q_R is rejected.

For a Carnot engine

$$\frac{T_C}{T_H} = \frac{Q_R}{Q_A} \quad \text{_____} \quad (6)$$

The efficiency of a Carnot engine is given by

$$e_c = 1 - \frac{T_c}{T_H}$$

$$T_H \text{ _____} (7)$$

1.4 HEAT CAPACITY

The heat capacity of a body, such as a lump of metal, is the quantity of heat required to raise the temperature of such body by 1K. It is measure in J/K.

Assume that a small quantity of heat, dQ , is transferred between a system of mass m and its surrounding. If the system undergoes a small temperature change, dT , the specific heat capacity, c , of the system is defined as

$$c = \frac{1}{m} \frac{dQ}{dt} \text{ _____} (8)$$

From Eq. 8, we can conclude that the heat dQ needed to increase/raise the temperature of mass, m , of material by an amount dT is

$$dQ = mcdT \text{ _____} (9)$$

c is measured in J/Kg/K or $\text{Jkg}^{-1}\text{K}^{-1}$ e-g

c for water is $4200\text{J/kg}^{-1}\text{k}^{-1}$, or $4.2 \text{Jg}^{-1}\text{K}^{-1}$

CHAPTER TWO

2.1 The Concept of Temperature

The concept of temperature plays an important role in both biological and physical sciences because the temperature of an object is directly related to average k.e of the atoms and molecules composing the object. The temperature of a body is therefore define as the property of the body that determines whether or not the body/system is in thermal equilibrium with another body.

2.2 Temperature Scales

Some of the commonly encountered temperature scale include: Fahrenheit scale,; O°C and 100°C on the Celsius scale; and 273.15k and 373.15 on the Kelvin scale.

The Celcius temperature T_c , is related to Fahrenheit, T_F , according to the equation:

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

The Kelvin temperature, T_k is an absorbent temperature scale, it is related to the celcius temperature, T_F , by the equation.

$$T_k = T_c + 273.15 \text{ _____} (2)$$

Furthermore, the Fahrenheit temperature is related to the Celcius temperature according to the equation.

$$T_F = \frac{9}{5} (T_c) + 32 \text{ _____} (3)$$

NOTE: In order to convert from Fahrenheit to Kelvin temperature scale, one needs to convert the °F to °C and finally from °C to K.

2.3 WORKED EXAMPPLES

(1) Calculate the equivalent of 98.6°F in °C.

Solution: $T_F = 98.6^\circ\text{F}$, $T_c = ?$

We know that $T_c = \frac{5}{9} (T_F - 32)$

$$= \frac{5}{9} (98.6 - 32)$$

$$= \frac{5}{9} * 66.6^\circ\text{F}$$

$$= 37.0^\circ\text{C}.$$

(2) The reading on the pressure scale at steam and ice points are 800mm and 200mm respectively. Determine the equivalent Temperature (in °C) when it reads 450mm.

Solution. $P_{\theta} = 300$, $P_{100} = 800$, $P = 450$ mm

The temperature θ in °C is given by

$$\begin{aligned}\theta &= \frac{P_{\theta} - P_0}{P_{100} - P_0} \times 100 \text{ } ^\circ\text{C} \\ &= \frac{450 - 300}{800 - 300} \times 100 \\ &= 30^\circ\text{C}\end{aligned}$$

2.4 THERMOMETRIC LIQUID

For a liquid to be used in a thermometer, it must have the following properties:

- It must be colorless
- It must be a good conductor of heat
- It must be able to expand and contract uniformly
- It must have high coefficient of expansion
- It must have low specific heat capacity

Water is not used as thermometric liquid because of the following reasons:

- It does not expand uniformly
- It has small range of expansion
- It has lower meniscus
- It wets glass

2.5 PRACTICAL THERMOMETERS

Some of the practical thermometers of interest are the liquid-in-glass thermometers, clinical thermometer, maximum and minimum thermometers and constant-volume gas thermometers.

2.5.1. Clinical Thermometer

It is mainly used to determine the temperature of human body. The range of the thermometer is between 35°C and 43°C. It is made up of a short tube with a bore through

which a finite mercury thread moves. The Clinical Thermometer is highly sensitive to temperature changes.

2.5.2 Maximum & Minimum Thermometers

The thermometer is used to determine the maximum temperature during the day and minimum temperature in the night. It is commonly called farmers thermometer.

It consists of U-shaped stem connected to larger bulbs as shown below. Both bulb contain alcohol and was separated by a column of mercury in the bend of the U-stem.

2.5.3 Gas Thermometer

A constant volume gas thermometer consists of a large bulb, D, which contain a gas such as hydrogen or helium. It operates based on the fact that at constant volume, the pressure of a gas increases linearly with temperature.

- (ii) It is accurate
- (iii) It is constant

It has a wide range of temperature reading.

CHAPTER THREE

3.0 THERMAL EXPANSION

It is well that most materials expand when heated and contract when cooled. Expansion in such materials is as a result of temperature difference.

3.1 Thermal expansion in Solids

Most solids expand in length when they are warmed. The increase in any one dimension (ID) of such a solid is called a LINEAR EXPANSION.

Assume that a rod of material has a length L_0 at some initial temperature, and that when the temperature increases by an amount ΔT , the length increases by ΔL . Experiments have shown that if T is not too large, then change in length, ΔL , is proportional to the original length and to the change in temperature mathematically.

$$\Delta L \propto L_0 \Delta T$$
$$\longrightarrow \Delta L = \alpha L_0 \Delta T \quad (1)$$

Where α is known as the coefficient of linear expansivity. It is measured in $(C^\circ)^{-1}$ or K^{-1} .

For any temperature, we can define the coefficient of linear expansion as

$$\alpha = \frac{1}{L} \frac{dL}{dT} \quad (2)$$

Where L is the length of the bar at temperature T .

Suppose a rod of material of length, L_0 , at temperature θ_0 , increases to L_1 as a result of increase in temperature to θ_1 , then, from Eq. 1

$$L_1 = L_0 [1 + \alpha(\theta_1 - \theta_0)] \quad (3)$$

Where L_1 is the new length at temperature θ_1

3.2 Expansion in Liquids

The temperature of a liquid determines its volume, but its vessel determines shape. The expansion in liquids is characterized by CUBIC EXPANSIVITY, γ . Most liquids do not expand uniformly and γ is not constant over a wide range of temperature, the coefficient of cubic or volume expansivity is given as:

$$\gamma = \frac{V_2 - V_1}{V_1(\theta_2 - \theta_1)} \quad (4)$$

where V_1 and V_2 are the volumes of a given mass, liquid at the temperatures θ_1 and θ_2 .

From EQ (4)

$$V_2 = V_1 (1 + \gamma (\theta_2 - \theta_1)) \quad (5)$$

NOTE: The coefficient of cubic expansivity is three times the coefficient of linear expansivity.

The densities of the liquid at the two temperatures are

$$\rho_1 = 1/V_1 \quad \rho_2 = 1/V_2 \quad (6)$$

Using (6) in (5) we have

$$\text{or } \rho_2 = \frac{\rho_1}{1 + \gamma (\theta_2 - \theta_1)} \quad (7)$$

3.3 WORKED EXAMPLES

(1) A steel tape measuring 5m long is calibrated at a temperature of 20°C. What is the length on a hot summer day when the temperature is 35°C. ($\alpha_{\text{steel}} = 1.2 \times 10^{-5} (\text{C}^\circ)^{-1}$)

Solution: $\alpha = 1.2 \times 10^{-5}$, $T = T_2 - T_1 = 35 - 20$
 $= 15^\circ\text{C}$, $L_0 = 5\text{m}$

We know that

$$\begin{aligned}
L_1 &= L_0 [1 + \alpha \Delta T] \\
&= 5 (1 + 1.2 \times 10^{-5}(15)) \\
&= 5.0009\text{m}
\end{aligned}$$

(2) A glass flask of volume 200 cm^3 filled with mercury at 20°C . How much mercury overflows when the temperature of the system is raised to 100°C ? (The coefficient of volume expansion of the glass is $1.2 \times 10^{-5}(\text{C}^\circ)^{-1}$ for the liquid $= 1.8 \times 10^{-5}(\text{C}^\circ)^{-1}$)

Solution: For flask, $\Delta V = \alpha V_0 \Delta T$

$$\begin{aligned}
&= (1.2 \times 10^{-5}) (200) (100-20) \\
&= 0.192\text{cm}^3
\end{aligned}$$

For the liquid

$$\begin{aligned}
\Delta V &= (1.8 \times 10^{-5}) (200) (100-20) \\
&= 2.88\text{cm}^3
\end{aligned}$$

The volume of the liquid that overflows to

$$2.88 - 0.192$$

A brass plate which measures $5\text{cm} \times 5\text{cm}$ is heated from 40°C to 70°C . What is the change in area (in m^2) of the plate? ($\alpha_{\text{Brass}} = 1.8 \times 10^{-5}(\text{C}^\circ)^{-1}$).

Solution 7: $A_0 = 5\text{cm} \times 5\text{cm} = 25\text{cm}^2 = 25 \times 10^{-4}\text{m}^2$

$$= 1.8 \times 10^{-5}(\text{C}^\circ)^{-1}, \Delta T = (7-4)^\circ\text{C} = 3^\circ\text{C}$$

We know that

$$\Delta A = \beta A_0 \Delta T$$

$$\beta = 2 \alpha = 3.6 \times 10^{-5}(\text{C}^\circ)^{-1}$$

$$\begin{aligned}
\therefore \Delta A &= (3.6 \times 25 \times 10^{-4} \times 3) \text{m}^2 \\
&= 2.70 \times 10^{-2} \text{m}^2
\end{aligned}$$

3.4 THE ANOMALOUS BEHAVIOUR OF WATER

Water is an example of substance that do not equal when heated. For instance, within the temperature of 0°C and 4°C , water decreases in volume with increase in temperature. This is contrary to the behaviour of most substances (see the figure below). Water has the maximum density at 4°C because it has the minimum volume at this temperature.

Above 40C, water behaves normally, and the volume increases with temperature. This regular behaviour is otherwise referred to as anomalous behaviour of water. This behaviour has an important effect in plant and animal life in lakes.

CHAPTER FOUR

4.0 THE IDEAL GAS LAW

This law relates pressure, the Kelvin temperature, the volume and the number of moles of an ideal gas together. An ideal gas is an idealized model of real. At a sufficiently low temperature, a real gas behaves as an ideal gas.

In a constant volume gas thermometer, the gas behaves as an ideal gas because it is kept at a sufficiently low density. Experiment reveals that a plot of the pressure of the gas versus temperature is a straight line, thus, indicating that the absolute pressure, P , is directly proportional to the Kelvin temperature, T , for a fixed volume and a fixed number of molecules of an ideal gas.

Furthermore, experience indicates that when the volume and temperature of a low-density gas are kept constant, doubling the number of molecules doubles the pressure, tripling the number triples the pressure. Hence, under the condition of constant volume and constant temperature, the absolute pressure, P , of an ideal gas is proportional to the number of molecules or number of moles.

In order to study the variation of absolute pressure with volume of an ideal gas, let us consider a partially filled balloon. This balloon will be “soft”, because the pressure of the air is too low to expand the balloon to its maximum size. However, if all of the air in the balloon is squeezed into a small “bubble”, the “bubble” will have a tight feel indicating that the pressure in the smaller space is high. Thus, it is possible to increase the pressure of a gas by reducing its volume (i.e. $P \propto 1/v$).

The three relationship explained above can be summed up as the ideal gas law which states that “the absolute pressure, P , of an ideal gas is directly proportional to the Kelvin temperature, T , and the of moles, n , of the gas and is inversely proportional to the volume, v of the gas.

Mathematically

$$P \propto \frac{nT}{V}$$

$$P = \frac{nRT}{V}$$

$$\longrightarrow PV = nRT \quad \text{_____} \quad (1)$$

Where R is called the universal gas.

Constant with R = 8.314J / mol. K

Sometimes it is convenient to express the ideal gas law in terms of the total number of particles, N, instead of number of moles, n. To apply this method, we introduce the Avogadro number, NA = 6.022 x 10²³ particles per mole to the R. H. s. of

eg. (1) above i.e.

$$PV = nN_A \left(\frac{R}{N_A}\right) T \quad \text{_____} \quad (2)$$

By definition, $N = nN_A \quad \text{_____} \quad (3)$

and $K = \frac{R}{N_A} \quad \text{_____} \quad (4)$

where K = 1.38 x 10⁻²³ J/K in the Boltzenon constant.

Using eqs. (3) and (4) in (2), we have

$$PV = NKT \quad \text{_____} \quad (5)$$

4.1 BOYLE'S LAW

Robert Boyle (1627-1691) discovered that the absolute pressure of a fixed mass a low density gas at constant temperature is inversely proportional to its volume. This important discovery is referred to as Boyle's law and can be derived from the Ideal gas law. For instance, if a system changes from initial pressure and volume (Pi, vi) to a final state (Pf, vf) it D possible to express the ideal gas equation otherwisely called the equation of state as

$$P_i V_i = nRT \quad \text{_____} \quad (6) \quad \text{(for the initial state)}$$

$$P_f V_f = nRT \quad \text{_____} \quad (7) \quad \text{(for the final state)}$$

Combining (6) and (7), we have

$$P_i V_i = P_f V_f \quad \text{_____} \quad (8)$$

Eqn. (8) is a concise way of stating Boyle's law.

The fig below is a geographical illustration of Boyle's law.

Fig. 4.1: Variation of Pressure with Volume (Boyle's law)

Based on the figure above, it can be easily induced that volume decreases as pressure increases for a constant temperature system (i.e. isotherm).

4.2 CHARLES' LAW

A French scientist Jacques Charles (1740-1823) showed that the volume of a fixed mass of gas at constant volume pressure is directly proportional to the Kelvin temperature (i.e. V & T). This relationship is referred to as Charles' law and it can be derived from the ideal gas.

In a simple mathematical form, we note that when an Ideal gas of constant pressure at initial volume and temperature v_i, T_i , changes to final states v_f, T_f , than from the ideal gas law.

$$\frac{V_i}{T_i} = \frac{nR}{p} \quad (9) \quad (\text{for state } v_f, T_f)$$

$$\frac{V_f}{T_f} = \frac{nR}{P} \quad (10) \quad (\text{for state } v_f, T_f)$$

Combining (9) & (10)

$$\frac{V_i}{T_i} = \frac{V_f}{T_f} \quad \text{_____} (11)$$

4.3 DALTON'S LAW OF PARTIAL PRESSURE

In a mixture of gases, two or more different gases are present at the same time. For instance, fresh air is a mixture of approximately 78.1% Nitrogen (N₂), 21.0% oxygen (O₂) and 0.9% argon (Ar). The law that deals with such mixture of gases is the “Dalton’s law of partial pressure” which states that “the total pressure of a gas mixture is equal to the sum of the partial pressures of component gases.”

NOTE: The partial pressure of a gas is the pressure it would expect if it were present by itself in the container at the same temperature as the mixture.

CHAPTER FIVE

5.0 KINETIC THEORY

Let us consider an ideal gas composed of N identical particles (infinitesimally small particles – i.e. point particles) contained in cubical container whose sides have length, L . Apart from elastic collisions, these particles do not interact. The figure below shows a particle of mass, m , as it strikes the right wall perpendicularly and rebounds elastically. While approaching the wall, the particle has a velocity $+V$ and linear momentum $+mV$. The particle rebounds with velocity $-v$ and momentum $-mV$ as it travels to the left wall, rebounds from it and heads back toward the right wall. The time, t , between collisions with the right wall is

$$t = \frac{2L}{v}$$

Applying the Newton's second law of motion in the form of impulse-momentum theorem, the average force on the particle by the wall is

$$F = \frac{\text{final momentum} - \text{initial momentum}}{\text{Time between successive collisions}} \\ = \frac{(-mv) - (+mv)}{T} \quad (2)$$

Substituting (i) into (2)

$$F = -2mv \div 2L$$

$$= -\frac{mV^2}{L} \quad (3)$$

The magnitude of the total force exerted on the right wall is equal to the number of particles that collide with the wall during the time t multiplied by the average force produced by one particle i.e.

$$F = \frac{(N)}{(3)} \frac{(mV^2)}{(L)} \quad (4)$$

The collection of particles possesses a Maxwellian distribution of speeds, so an average value V^2 must be used, rather than a value for any individual particle. It is important to note that the squared speed is not equal to the value of

Mean squared speed i.e

$$V^2 + (V^2) \quad (5)$$

Often the square root of the quantity V^2 may be required, this quantity is called ROOT-MEAN-SQUARE-SPEED (i.e. r.m.s. speed), where

$$V_{r.m.s} = \sqrt{V^2} \quad (6)$$

By substituting (6) into (4), we have

$$F = \frac{(N)}{(3)} \frac{(mv^2)}{(L)} \quad (7)$$

By definition, pressure is given by

$$P = \frac{F}{L^2} = \frac{1}{L^2} \frac{N}{3} \frac{mV_{rms}^2}{L}$$

Volume, $v = L^3$, hence, eq. (8) because

$$P = \frac{1}{V} \frac{N}{3} \frac{mv^2}{r.m.s}$$

$$i.e pV = \frac{2}{3}N (\frac{1}{2}mv_{r.m.s}^2) - 91$$

Eq. (9) relates the macroscopic properties of the gas (i.e. pressure and volume) to the microscopic quantities /properties (i.e. mass and speed).

From Eq. (9), the quantity $\frac{1}{2} m v_{\text{r.m.s.}}^2$ is the average translational kinetic energy of the system i.e.

$$\text{K. E.} = \frac{1}{2} m v_{\text{r.m.s.}}^2 \quad (10)$$

By substituting (10) into (a), one readily obtains

$$PB = \frac{2}{3} N (\text{K.E.}) \quad (11)$$

From the ideal gas law,

$$PV = NKT \quad (12)$$

By combining (11) of (12), we have

$$\begin{aligned} NKT &= \frac{2}{3} N (\text{K.E.}) \\ = \text{K.E.} &= \frac{3}{2} KT \quad (13) \end{aligned}$$

Based on eq. (13) we conclude that the Kelvin temperature is directly proportional to the average translational kinetic energy of an individual ideal gas no matter what the pressure and the volume are.

5.1 SOLVED PROBLEMS

Fresh air is primarily a mixture of nitrogen (N_2) with molecular mass = 28.0u, oxygen, (O_2) with molecular mass of 32.0u and argon, Ar, with molecule mass 39.9u. Assume that each gas behaves as an ideal gas. At a temperature of 293k, find:

- (a) the average translational kinetic energy;
- (b) the r.m.s speed for each type of molecule

$$(k = 1.38 \times 10^{-23} \text{J/K})$$

Sol2:

- (a) From the kinetic theory, the particle in each gas have the same translational kinetic energy given as

$$\text{K-E} = \frac{3}{2} KT$$

$$K=1.38 \times 10^{-23} \text{ J/K, } T = 293\text{k}$$

$$\text{K.E} = (1.38 \times 10^{-23}) (293) \left(\frac{3}{2}\right)$$

$$= 6.07 \times 10^{-22} \text{ J}$$

- (b) We need to compute the mass of each particle by using the fact that one mole or Avogadro's number of particles has a mass in grams equal to the atomic or molecular mass of the substance.

For nitrogen, $m = 28.0 \text{ g/mole}$

$$\begin{aligned} & 6.022 \times 10^{23} \text{ mole}^{-1} \\ & = 4.65 \times 10^{-26} \text{ kg} \end{aligned}$$

For oxygen, $m = 32.0 \text{ g/mole}$

$$\begin{aligned} & 6.022 \times 10^{23} \text{ mole}^{-1} \\ & = 5.31 \times 10^{-26} \text{ kg} \end{aligned}$$

For argon, $m = 39.9 \text{ g/mol}$

$$\begin{aligned} & 6.022 \times 10^{23} \text{ mol}^{-1} \\ & = 6.63 \times 10^{-26} \text{ kg} \end{aligned}$$

Now, we compute the r.m.s speed of each particle as

$$\text{K.E} = \frac{1}{2} M v_{\text{r.m.s}}^2$$

$$\text{For nitrogen, } v_{\text{rms}} = \sqrt{\frac{2 \text{K.E}}{M}} = \sqrt{\frac{2(6.07 \times 10^{-21})}{4.65 \times 10^{-26}}}$$

$$= 511 \text{ m/s}$$

$$\text{For oxygen, } v_{\text{rms}} = \sqrt{\frac{2 \times 6.07 \times 10^{-21}}{5.31 \times 10^{-26}}} = 478 \text{ m/s}$$

$$\text{For argon, } v_{\text{rms}} = \sqrt{\frac{2 \times 6.07 \times 10^{-21}}{6.63 \times 10^{-26}}} = 428 \text{ m/s}$$

$e = 0.95$ for a most black surface. Equation (4) is known as STEFAN'S LAW

All bodies absorb, to varying degrees, part of the thermal radiation which is incident upon them. The net rate at which is incident upon them. The net rate at which heat is radiated by the body at temperatures T_1 and T_2 can be expressed as

$$Q = e \alpha A (T_1^4 - T_2^4) \quad (5)$$

A body which absorbs all the radiation incident upon it would appear black since radiation is reflected from it. Such a body is an ideal substance and ideal emitter with $e=1$. It is called a “black surface” and such a body with such surface is a “BLACKBODY”.

CHAPTER SIX

6.0 HEAT TRANSFER

If two bodies initially at different temperatures brought into thermal contact, thermal equilibrium can be attained only if heat is able to flow from the hotter body to the cooler body. The three processes by which heat is transferred between two regions at different temperatures are conduction, convection and radiation.

6.1 CONDUCTION

Conduction is the transfer of energy from one part of a body to another part without the actual movement of any part of the body. The figure below shows a rod whose ends are in thermal contact with a hot reservoir at temperature, T_H and a cold reservoir at temperature, T_c . The sides of the rod are covered with insulating material so that the transfer of heat is along the rod not through the sides. Metal generally have high values of k and are thus considered as GOOD CONDUCTORS of heat while non-metals are poor heat conductors and they are called INSULATORS with low values of K . Heat conduction is essentially due to the vibration of molecules within the material.

It has been shown that the rate of transfer of heat through conduction, dQ , is proportional to the cross-sectional area of the rod and to the temperature gradients, cIT

Dx

Mathematically

$$dQ = -k A \frac{dT}{dX} \text{ (1)}$$

k is measured in $dtJ/s.m.co$ or $W/m.co$

where k is known as “thermal conductivity” i.e. measure of the ability of a material to conduct heat. Since T decreases as x increases (see the fig. below), dT is negative, and Q is positive. If the rod has length, L , and the temperature decreases from T_H to T_c , then $\frac{dT}{dx} = \frac{\Delta T}{\Delta L} = \frac{T_c - T_H}{L}$, hence Eq. Q becomes

6.2 CONVECTION

Convection is the transfer of heat from one region to another by the actual motion of the heated / medium. Hence, this mode of heat transfer is only applicable to fluids (i.e. liquids and gases). For a liquid flowing over a solid surface (see d fig. below), the rate of heat flow by convection, Q_c , from the surface to the fluid (or vice-versa) is given by

$$Q_c = \frac{dQ_c}{dt} = hA_s (T_s - T_f) \quad (3)$$

where

h = convection coefficient

A_s = Area of contact between the surface & the fluid

T_f = Temperature of the main body

F = fluid

T_s = Temperature of the surface

The unit of h is $J/s.m^2.co$ or W/m^2Co

6.3 RADIATION

The transfer of heat by conduction and convection requires direct physical contact between the hot and cold reservoir. The third type of heat transport including movement of heat without the action of intervening medium. This mode of heat transfer is known as RADIATION. A common example of radiation is transfer of heat from sun to the earth.

The intensity of radiant heat omitted by a surface depends on the nature as well as the temperature of the surface. For a surface of this at absolute temperature, T , the rate at which radiant heat is emitted is given by

$$Q = e AT^4 \quad (4)$$

Where is the STEFAN –BOLTZMANN CONSTANT which is equal to $5.6696 \cdot 10^{-8} \text{ Wm}^2\text{K}^4$. The parameter e , called the EMISSIVITY of the surface. The value of e lies between 0 and 1, depending on the nature of the substance. For instance, $e=0.1$. For shiny metallic surface,

6.4 WORKED EXAMPLES

(1) Compute the quantity of heat which is conducted in 30 minutes through an iron plate 2.0cm. thick and 0.10m^2 in area if temperatures of the two sides are 0°C and 20°C . The coefficient of thermal conductivity of iron is $0.12 \text{ cal/s.cm.c}^\circ$

Solution: $A = 0.1\text{m}^2$, $T = 20^\circ\text{C}$, $L = 2 \text{ exiom}^{-2}$

$$K = 0.12\text{cal/5cm.Co} = (0.12) (4.12) (100) \text{ J/s.m.c}^\circ = 50$$

$$Q = - K A \frac{\Delta T}{\Delta L} = (- 50.4) (0.1) (-20)/(2.0 \times 10^{-2})$$

$$\Delta L$$

$$= 5040\text{J/s}$$

$$\text{Heat conducted in 30s} = 5040 \times 30 \times 60\text{J}$$

$$= 9.07 \times 10^6\text{J}$$

(2) The inside surface of a wall of a home is maintained at a constant temperature of 25°C while the inside air is at 15°C . How much heat is lost by natural convection from the 8.0m by 4.0m wall in 24 hours, if the average convection coefficient is $h = 3.49\text{J/s.m}^2\text{C}^\circ$?

Solution: $A_s = 8.0 \times 4.0 = 32.0\text{m}^2$, $T = 25-15 = 10^\circ\text{C}$,

$$H = 3.49\text{J/sm}^2.\text{C}^\circ?$$

We know that

$$Q_c = dQ_c = h A^s (T_s - T_f)$$

$$= (3.49) (32.0) (10) = 1116.8\text{J/s}$$

\therefore the heat lost in 24 hours = $1116.8 \times 24 \times 36$

$$= 9.65\text{J}$$

