THERMODYNAMICS

- **Thermal Equilibrium**:- Two systems are said to be in thermal equilibrium with each other if they have the same temperature.
- **Thermo dynamical system**:- An assembly of large numbers of particles having same temperature, pressure etc is called thermo dynamical system.
- **Thermodynamic variables** :- The variables which determine the thermodynamic behavior of a system are called thermodynamic variables
- **Zeroth law of Thermodynamics** :- IT states that if two system A and B are in thermal equilibrium with a third system C , then the two system A and B are also in thermal equilibrium with each other.
- **Thermodynamic Process** :- A thermodynamic process is said to be taking place , if the thermodynamic variable of the system change with time.
- **Types of thermodynamic Process**:-

  (1) *Isothermal process* – process taking place at constant temperature.

  (2) *Adiabatic process* – process where there is no exchange of heat.

  (3) *Isochoric process* – process taking place at constant volume

  (4) *Isobaric process* –Process taking place at constant Pressure.

  (5) *Cyclic process*:- Process where the system returns to its original state.
- **Equation of state** : A relation between pressure, volume and temperature for a system is called its equation of state .
- **Indicator diagram (P-V diagram**) :- The graphical representation of the state of a system with the help of two thermodynamical variables is called indicator diagram of the system.
- **Internal energy of a gas** :- It is the sum of kinetic energy and the intermolecular potential energy of the molecules of the gas. Internal energy is a function of temperature.
- **First law of Thermodynamics** :- It states that if an amount of heat dQ I added to a system , a part of heat is used in increasing its internal energy while the remaining part of heat may be used up as the external work done dW by the system.

Mathematically $dQ=dU+dW$

$dQ=dU+PdV$.

- **Work done during expansion / compression of gas**:- When the volume of gas changes from V_1 to V_2 , the work done is given by $W=\oint_{V1}^{V2} PdV$ = Area under the P -V diagram.

- **Thermodynamical operations are**

(1) **Isothermal process** : A thermodynamic process that takes place at constant temperature is called an isothermal process.

- Equation of state for isothermal process : PV = constant.
- Work done during an isothermal process

$$W_{iso} = RT \log_e \frac{V2}{V1} = 2.303\, RT \log_e \frac{V2}{V1}$$

(2) **Adiabatic process** : A thermodynamic process that takes place in such a manner that no heat enters or leaves the system is called adiabatic process

➔ Equation of state for adiabatic process

(i) PV^{γ} = constant (ii) $TV^{\gamma-1}$ =constant (iii) $\frac{P^{\gamma-1}}{T^{\gamma}}$ =constant

➔ Work done during adiabatic change

$$W_{adia} = \frac{R(T1-T2)}{(\gamma-1)}$$

- **Reversible process** :- It is a process in which the system can be retraced to its original state by reversing the condiditions.
- **Irreversible process**:- It is a process in which the system cannot be retraced to its original state by reversing the conditions.

- **Second law of thermodynamics:**

- ➔ **Kelvin's statement of second law** – It is impossible to derive a continous supply of work by cooling a body to a temperature lower than that of the coldest of its surrounding.
- ➔ **Clausius statement of second law** – It is impossible for a self –acting machine unaided by any external agency to transfer heat from a body to another body at higher temperature.

- **Heat Engine** – a heat engine is a device for converting heat energy continuously into a mechanical work.
  - ➔ Component of heat engine- (i) source of heat (ii) Sink (iii) Working substance
- **Efficiency of heat Engine** :-It is defined as the ratio of the external work obtained to the amount of heat energy absorbed from the heat source.

Mathematically

$$\eta = \frac{W}{Q1} = \frac{Q1 - Q2}{Q1} = 1 - \frac{Q2}{Q1}$$

- **Carnot's heat Engine** :- it is an ideal heat Engine which is based on carnot's reversible cycle.

Efficiency of carnot's heat Engine

$$\eta = 1 - \frac{Q2}{Q1} = 1 - \frac{T2}{T1}$$

- **Refrigerator or Heat pump**:- it is heat engine working backward.
- **Co-efficient of performance** : It is the ratio of heat absorbed from cold body to the work done by the refrigerator.

Mathematically $\beta = \frac{Q2}{W} = \frac{Q2}{Q1-Q2} = \frac{T2}{T1-T2}$

All Questions with **(mark) are HOTs Question

Q1 Which Thermodynamical variable is defined by the first law of thermodynamics? 1

Ans: Internal energy.

Q2 What is the amount of work done in the Cyclic process? 1

Ans:It is numerically equal to the area of the cyclic process.

Q3 Out of the parameters- temperature, pressure,work and volume, which parameter does not

Characterize the thermodynamics state of matter? 1

Ans: Work

Q4 What is the nature of P-V diagram for isobaric and isochoric process? 1

Ans: The P-V diagram for an isobaric process is a straight line parrel to the volume axis while that

For an isochoric process is a straight line parallel to pressure axis.

Q5 On what factors does the efficiency of Carnot engine depends? 1

Ans: Temperature of the source of heat and sink.

** Q6 Can we increase the temperature of gas without supplying heat to it? 1

Ans: Yes, the temperature of gas can be by compressing the gas under Adiabatic condition.

Q7 Why does the gas get heated on compression? 1

Ans: Because the work done in compressing the gas increases the internal energy of the gas.

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Q8 Which thermodynamic variable is defined by Zeroth law of thermodynamics? 1

Ans: Temperature

Q9 Can the whole of work be converted into heat? 1

Ans: Yes ,Through friction.

Q10 In a Carnot engine, temperature of the sink is increased. What will happen to its efficiency? 1

Ans: We know $\eta = 1 - \frac{T2}{T1}$

On increasing the temperature of the sink (T_2), the efficiency of the Carnot engine will decrease

**Q11 If hot air rises , why is it cooler at the top of mountain than near the sea level ? 2

Ans: Since atmospheric pressure decreases with height, pressure at the top of the mountain is lesser. When the hot air rises up,it suffer adiabatic expansion at the top of the mountain.For an adiabatic change,first law of thermodynamics may be express as

$$dU + dW = 0 \qquad (dQ = 0)$$

$$dW = -dU$$

Therefore work done by the air in rising up (dW =+ve) result in decrease in the internal

Energy of the air (dU = -ve) and hence a fall in the temperature.

Q12 What happen to the internal energy of a gas during (i) isothermal expansion (ii) adiabatic Expansion? 2

Ans: In isothermal expansion ,temperature remains constant.Therefore internal energy which is a function of temperature will remain constant.

(ii)for adiabatic change dQ = 0 and hence first law of thermodynamics becomes

$$0 = dU + dW$$

$$dW = - dU$$

During expansion, work is done by the gas i.e. dW is positive. Hence ,dU must be negative.

Thus ,in an adiabatic expansion , the internal energy of the system will decrease.

Q13.Air pressure in a car increases during driving. Explain Why? 2

Ans: During driving as a result of the friction between the tyre and road ,the temperature of

The tyre and the air inside it increases. Since volume of the tyre does not change, due to increase in temperature ,pressure of the increases (due to pressure law).

Q14 The efficiency of a heat engine cannot be 100%. Explain why ? 2

Ans: The efficiency of heat engine $\eta = 1 - \frac{T2}{T1}$

The efficiency will be 100% or 1, if $T_2 = 0$ K.

Since the temperature of 0 K cannot be reached, a heat engine cannot have 100% efficiency.

Q15 In an effort to cool a kitchen during summer, the refrigerator door is left open and the kitchen door and windows are closed. Will it make the room cooler ?

Ans: The refrigerator draws some heat from the air in front of it. The compressor has to do some

Mechanical work to draw heat from the air at lower temperature. The heat drawn from the air together with the work done by the compressor in drawing it, is rejected by the refrigerator with the help of the radiator provided at the back to the air. IT follows that in each cycle, the amount of heat rejected to the air at the back of the refrigerator will be greater than that is drawn from the air in front of it. Therefore temperature of the room will increase and make hotter.

Q16 Why cannot the Carnot's engine be realised in practice?

Ans: Because of the following reasons

(i) The main difficulty is that the cylinder should come in contact with the source,sink and stand again and again over a complete cycle which is very difficult to achieve in practice.

(ii) The working substance should be an ideal gas however no gas fulfils the ideal gas behaviour.

(iii) A cylinder with a perfectly frictionless piston cannot be realised

Q17 A slab of ice at 273K and at atmospheric pressure melt.(a) What is the nature of work done on

The ice water system by the atmosphere?(b)What happen to the internal energy of the ice- Water system?

Ans: (a) The volume of the ice decreases on melting. Hence the work done by the atmosphere on The ice – water system is positive in nature.

(b) Since heat is absorbed by the ice during melting, the internal energy of the ice-water system increases.

Q18 Why is the conversion of heat into work not possible without a sink at lower temperature? 2

Ans:For converting heat energy into work continuosly, a part of the heat energy absorbed from the source has to be rejected.The heat energy can be rejected only if there is a body whose

Temperature is less than that of the source. This body at lower temperature is called sink.

** Q19 Can water be boiled without heating ? 2

Ans:Yes, water can be boil without heating. This is done by increasing the pressure on the surface of water inside a closed insulated vessel. By doing so, the boiling point of the water decreases to the room temperature and hence starts boiling.

Q20 What are the limitations of the first law of thermodynamics ? 2

Ans: The limitations are --- (i) It does not tells us the directions of heat transfer

(ii) it does not tell us how much of the heat is converted into work.

(iii)it does not tell us under what conditions heat is converted into work.

**Q21 Calculate the fall in temperature when a gas initially at 72^0C is expanded suddenly to eight times its original volume. Given γ= 5/3. 3

Ans: Let V_1 = x cc V_2 =8x cc

T_1 =273+72 =345 K ¥ = 5/3 , T_2 = ?

Using the relation $T_1 V_1^{¥-1} = T_2 V_2^{¥-1}$

Therefore $T_2 = T_1 (V_1/V_2)^{¥-1}$

$=345x(1/8)^{2/3}$

Taking log of both sides, we get

Log T_2 = log 345 – 2/3 log 8

=2.5378 – 2/3(0.9031)

= 2.5378 -0.6020 = 1.9358

Or T_2 =86.26 K

Therefore the fall in temperature = 345 -86.26 258.74 K

Q22 A Carnot engine whose source temperature is at 400K takes 100 Kcal of heat at this temperature in each cycle and gives 70 Kcal to the sink. Calculate (i) the temperature of the sink

(ii) the efficiency of the engine.

Ans: Here T_1 =400K , Q_1 = 100 Kcal , Q_2 = 70 Kcal

T_2 = ? ,¶ = ?

(i) $Q_1/Q_2 = T_1/T_2$

Or $T_2 = (Q_2/Q_1)T_1$

Or T_2 =70/100 x400

Or T_2 = 280 K

(ii) $\eta = 1- T_2/T_1$

= 1 – 280/400

$= 1 - 0.7 = 0.3$

Or % of $\eta = 0.3 \times 100 = 30\%$

Q23 If at 50^oC and 75 cm of mercury pressure, a definite mass of gas is compressed (i)slowly

(iii) suddenly, then what will be the final pressure and temperature of the gas in each case, if the final volume is one fourth of the initial volume? Given $\gamma = 1.5$

Ans:(I) When the gas is compressed slowly, the change is isothermal.

Therefore $P_2 V_2 = P_1 V_1$

$P_2 = P_1V_1/V_2$

$= (75 \times V_1/V_1) \times 4 = 300$ cm of mercury

Temperature remains constant at 50^oC

(ii)When the gas is compressed suddenly, the change is adiabatic

As per $P_2 V_2^{\gamma} = P_1 V_1^{\gamma}$

$P_2 = P_1(V_1/V_2)^{\gamma}$

$= 75 \times (4)^{1.5} = 600$ cm of Hg

Also $T_2 V_2^{¥-1} = T_1 V_1^{¥-1}$

$T_2 = T_1 (V_1/V_2)^{¥-1} = 323x(4)^{(1.5-1)} = 646K$

$= 646 - 273 = 373\ ^oC$

Q24 Two engines A and B have their sources at 400K and 350 K and sink at350K and 300K

Respectively. Which engine is more efficient and by how much? 3

Ans: For engine A $T_1 = 400K$, $T_2 = 350$ K

Efficiency $\eta_A = 1 - T_2/T_1$

$= 1 - 350/400 = 1/8$

% of $\eta_A = 1/8 \times 100 = 12.5\%$

For Engine B $T_1 = 350$ K , $T_2 = 300$ K

Efficiency $\eta_B = 1 - T_2/T_1$

$= 1- 300/350 =1/7$

% of η_B =1/7 x100 =14.3%

Since $\eta_B > \eta_A$ so engine A is much more efficient than engine B by (14.3% - 12.5%) = 1.8%

** Q25 Assuming a domestic refrigerator as a reversible heat engine working between melting point

Of ice and the room temperature at 27^{o}C, calculate the energy in joule that must be supplied to freeze 1Kg of water at 0^{o}C. 3

Ans: Here $T_1 = 27+273 = 300$K , $T_2 = 0 + 273 = 273$

Mass of water to be freezed , M = 1 Kg = 1000g

Amount of heat that should be removed to freeze the water

Q_2 = ML =1000X 80 cal

= 1000X80 X4.2 =3.36 x 10^5 J

Now $Q_1 = (T_1/T_2)$X Q_2 = (300/273)X3.36x10^5 = 3.692 x10^5 J

Therefore energy supplied to freeze the water

W =$Q_1 - Q_2$ = 3.693x10^5 - 3.36 x10^5

= 3.32 x10^5 J

** Q26 A refrigerator freezes 5Kg of water at 0^{o}C into ice at 0^{o}c in a time interval of 20 minutes. Assume that the room temperature is 20^{o}C, calculate the minimum power needed to accomplish it.

Ans : Amount of heat required to convert water into ice at 0^{o}C,

Q_2 =mL =(5Kg)x(80)Kcal/Kg

= 400 Kcal

Now T_1 =20^oC =273+20 = 293K

T_2 = 0^oc 0+273 =273 K

We know that $Q_2/W = T_2/(T_1 – T_2)$

Or $W = Q_2 \times (T_1 – T_2)/T_2$

= 400x(293- 273)/273

= 29.3 Kcal = $29.3 \times 4.2 \times 10^3$J

=123×10^3 J

Time t = 20 min =20x60 =1200s

Power needed P = W/t =$123 \times 10^3/1200$

=102.5 W

**Q27 The temperature T_1 and T_2 of two heat reserviour in an ideal carnot engine are 1500^oC and

500^oC. Which of this increasing the temperature T_1 by 100^oC or decreasing T_2 by 100^oC would result in greater improvement of the efficiency of the engine?

Ans: Using ¶ $=1 – T_2/T_1$ $=(T_1 - T_2)/T_1$

(1)increasing T_1 by 100^oC ¶$_1$ = (1600 -500)/(1600 + 273)

= 1100/1873 = 59 %

(ii) Decreasing T_2 by 100^0C ¶$_2$ = 1500 –(500-100)/(1500 +273)

=1100/1773 = 67%

Therefore decreasing T_2 by 100^oC results in greater improvement of efficiency.

Q28 State the first law of thermodynamics and discussed the application of this law to the boiling process. 3

Q29 What is thermodynamic system ? Prove that work done by thermodynamic system is equal to the area under P-V diagram. 3

30 Prove that $C_p - C_v = R$, for an ideal gas . 3

Q31 What is isothermal process / State two essential conditions for such a process to takes place. Show analytically that the work by one mole of an ideal gas during volume expansion from V_1 V_2 at temperature T is given by
$W = RT \log_e V_2/V_1$ 5

Q32 Define an adiabatic process. State two essential conditions for such a process to takes place.Derive an expression for adiabatic process to takes place. 5

Q33 Discuss the four steps of Carnot's cycle and show that the efficiency is given by ¶ = 1 - T_2/ T_1, Where T_1 and T_2 are the temperature of the source and sink respectively. 5

Q34 Describe the working of refrigerator as heat pump. Derive the expression of its coefficient of performance. If the door of a refrigerator is kept open for a long time ,will it make the room warm or cool ? 5

Q35 What is the need of introducing the second law of thermodynamics ? State the Kelvin –Planck and Claussius statement of second law of thermodynamics and show that both the statement are equivalent. 5

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