UNIT-8 HEAT AND THERMODYNAMICS

MY REVISION TIMELINE:-

SUMMARY:-

- Heat is energy in transit which flows from hot object to cold object. However it is not a quantity.
- Work is a process to transfer energy from one object to another object.
- The Ideal gas law is PV = NRT or PV = μRT. The ideal gas law holds for only at thermodynamic equilibrium. For non-thermodynamic process, it is not valid.
- Heat capacity is the amount of heat energy required to increase the object's temperature by 1°C or 1K. It is denoted by S.
- Specific heat capacity is the amount of heat energy required to increase the 1 mole of substance's temperature by 1°C or 1K. It is denoted by S.
- Molar specific heat capacity is the amount of heat energy required to increase the 1 mole of substance's temperature by 1°C or 1K. It is denoted by C.
- Water has an anomalous behaviour of expansion.
- Latent heat energy is the amount of heat energy required to change the phase of the substance.
- Stefan – Boltzmann law: E = σT^4 and Wien's law: $\lambda_{max} T$ = b
- Zeroth law of thermodynamics: If two objects are separately in thermal equilibrium with the third object, then these two are in thermal equilibrium. Temperature is the property which is the same for both the system.
- Internal energy is the sum of kinetic and potential energy of molecules in the thermodynamic system.
- First law of thermodynamic is a statement of conservation of energy. It included heat energy of the thermodynamic system.
- A quasi-static process is an infinitely slow process in which the system is always at equilibrium with the surrounding.
- Specific heat capacity at constant volume is always less than specific heat capacity at constant pressure.

FORMULAS:-

- Heat capacity S = $\frac{\Delta Q}{\Delta T}$
- Specific heat capacity S = $\frac{1}{m}\frac{\Delta Q}{\Delta T}$
- Molar specific heat capacity C = $\frac{1}{\mu}\frac{\Delta Q}{\Delta T}$
- Linear expansion $\alpha_L = \frac{\Delta L}{L_o \Delta T}$

- Area expansion $\alpha_A = \frac{\Delta A}{A_o \Delta T}$
- Volume expansion $\alpha_V = \frac{\Delta V}{V_o \Delta T}$
- Latent Heat capacity L = $\frac{Q}{m}$
- Newton's law of cooling $\frac{dQ}{dt}\ \alpha - (T - T_S)$
- Stefan – Boltzmann law: $E = \sigma T^4$
- Wien's law: $\lambda_{max} T = b$
- Internal energy $U = E_k + E_p$
- First law of thermodynamic $\Delta U = Q - W$
- Molar heat capacity $Q = \mu C_v \Delta T$
- Meyer's relation $C_p = C_v + R$ or $C_p - C_v = R$
- Work done in isothermal process $W = \mu RT \ln\left(\frac{V_f}{V_i}\right)$
- Work done in adiabatic process $W = \mu RT \ln\left(\frac{V_f}{V_i}\right)$
- Work done in isothermal process $W = \frac{\mu R}{\gamma - 1}[T_i - T_f]$
- Work done in isobaric process $W = \mu RT_f \ln\left(1 - \frac{T_i}{T_f}\right)$
- Efficiency of heat engine $\eta = \frac{W}{Q_M} = 1 - \frac{Q_L}{Q_M}$
- Coefficient of performance (COP) $\beta = \frac{Q_L}{W}$

MULTIPLE CHOICE QUESTIONS:-

1. **In hot summer after a bath, the body's**
   a) Internal energy decreases
2. **The graph between volume and temperature in Charles' law is**
   c) a straight line
3. **When a cycle tyre suddenly bursts, the air inside the tyre expands. This process is**
   b) adiabatic
4. **An ideal gas passes from one equilibrium state (P_1, V_1, T_1, N) to another equilibrium state ($2P_1$, $3V_1$, T_2, N). Then**
   b) $T_1 = \frac{T_2}{6}$
5. **When a uniform rod is heated, which of the following quantity of the rod will increase**
   d) moment of inertia
   Solution:
   Moment of inertia = MK^2
   K = Radius of gyration
   During heating K would be increased. Hence moment of inertia will increase.
6. **When food is cooked in a vessel by keeping the lid closed, after some time the steam pushes the lid outward. By considering the steam as a thermodynamic system, then in the cooking process**

a) Q>0, W>0

Solution:

-Q > 0 W > 0

$\Delta Q = \Delta U + \Delta W$

∴ ΔQ is directly proportional to ΔW

If $\Delta Q > 0$ then $\Delta W > 0$

7. When you exercise in the morning, by considering your body as thermodynamic system, which of the following is true?

b) $\Delta U < 0, W > 0$

Solution:

$\Delta Q = \Delta U + \Delta W$

When exercise is performed, internal energy is utilised ($\Delta U < 0$). So it will decrease. But as internal energy is utilised, exercise (ΔW) will be more efficient.

$\therefore\ \Delta W > 0\ \therefore \Delta U < 0, W > 0$

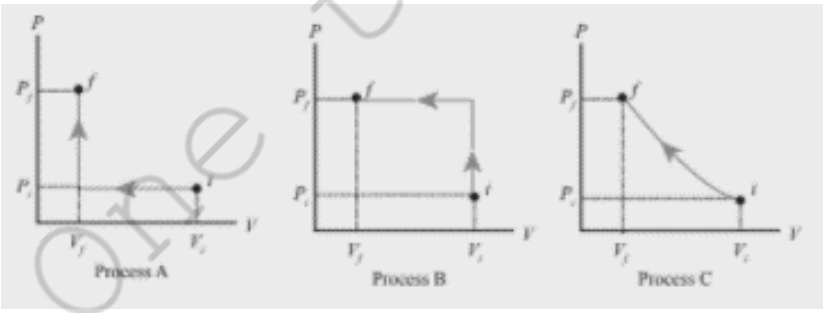
8. A hot cup of coffee is kept on the table. After some time it attains a thermal equilibrium with the surroundings. By considering the air molecules in the room as a thermodynamic system, which of the following is true?

c) $\Delta U > 0, Q > 0$

Solution:

During the thermal equilibrium with surroundings internal energy is increased and heat energy will be increased $\Delta U > 0, Q > 0$.

9. An ideal gas is taken from (P_i, V_i) to (P_f, V_f) in three different ways. Identify the process in which the work done on the gas the most.



b) Process B

Solution:

When work is done on the gas, compression takes place. P_f will be increased and remains constant.

∴Process B

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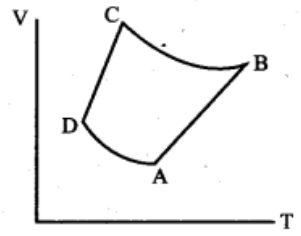
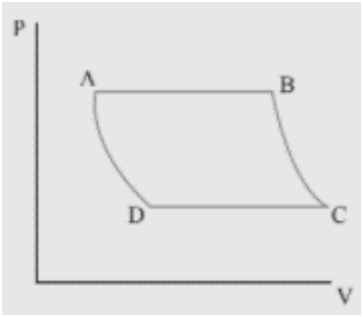
10. The V-T diagram of an ideal gas which goes through a reversible cycle A → B → C → D is shown below. (Processes D → A and B → C are adiabatic)



The corresponding PV diagram for the process is (all figures are schematic)

a)



11. A distant star emits radiation with maximum intensity at 350 nm. The temperature of the star is

a) 8280K

Solution:

$\lambda_{max} T = b$

$T = \frac{2.898 \times 10^{-3}}{350 \times 10^{-9}}$

$\boxed{T = 8280K}$

12. Identify the state variables given here?

b) P, T, U

13. In an isochoric process, we have

a) W = 0

Solution:

Work done in an isochoric process is zero.

14. The efficiency of a heat engine working between the freezing point and boiling point of water is

c) 26.8%

Solution:

$T_1 = 100°C = 373K$

$T_2 = 0°C = 273K$

$\eta = \frac{T_1 - T_2}{T_1} \times 100$

$\eta = \frac{373 - 273}{373} \times 100$

$\eta = \frac{100}{373} \times 100$

$\eta = 0.26809 \times 100$

$\boldsymbol{\eta = 26.809\%}$

15. An ideal refrigerator has a freezer at temperature -12°C. The coefficient of performance of the engine is 5. The temperature of the air (to which the heat ejected) is

c) 40.2°C

Solution:

COP $(\beta) = \frac{T_L}{T_H - T_L}$

$T_L = -12 + 273 = 261K$

$5 = \frac{261}{T_H - 261}$

$5(T_H - 261) = 261$

$5T_H - 1305 = 261$

$5T_H = 1566$

$T_H = \frac{1566}{5}$

$T_H = 313.2K$

$T_H = 313.2 - 273$

$\boldsymbol{T_H = = 40.2°C}$

NUMERICAL PROBLEMS:-

1. Given:

Radius $\gamma = 10cm$

Pressure $P = 1.8 \times 10^5 Pa$

Room temperature $= 273+30 = 303K$

Formula used:

No. of moles in air $\mu = \frac{VP}{RT}$

Solution:

Volume of balloon $V = \frac{4}{3}\pi r^3$

$\mu = \frac{VP}{RT}$

$\mu = \frac{\frac{4}{3} \times 3.14 \times \left(10 \times 10^{-2}\right)^3 \times 1.8 \times 10^5}{8.314 \times 303}$

$\boldsymbol{\mu = 0.3\ moles}$

2. Given:

$T = -53°C = -53 + 273 = 220K$

$P = 0.9 \times 10^3 Pa$

$V = 1m^3$

Formula used:

$\mu = \frac{VP}{RT}$

Solution:

$\mu = \frac{VP}{RT}$

$\mu = \frac{1\times0.9\times10^3}{8.314\times220}$
$\mu = 0.49mol$
$\mu_{mars} = 0.49mol$
$\mu_{earth} = 40mol$
No, it is not greater than in Earth.

3. Solution:

$\left(\frac{P_1V_1}{RT_1} + \frac{P_2V_2}{RT_2}\right)T = \frac{P_1V_1}{R} + \frac{P_2V_2}{R}$
$U = V_1 + V_2 => \frac{3}{2}n_1RT_1 + \frac{3}{2}n_2RT_2$
$\therefore \frac{n_1T_1+n_2T_2}{n_1+n_2}$
$i.e\ (n_1 + n_2)C_vT = n_1C_vT_1 + n_2C_vT_2$
$\left(\frac{P_1V_1T_2+P_2V_2T_1}{T_1T_2}\right)T = P_1V_1 + P_2V_2$

$$\boldsymbol{T_{final} = \frac{(P_1V_1+P_2V_2)T_1T_2}{P_1V_1T_2+P_2V_2T_1}}$$

4. Formula used:

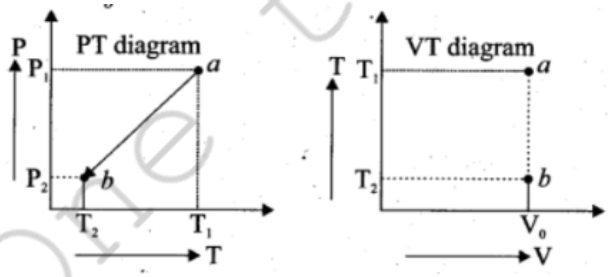
Moment of inertia (I) $= \frac{Ml^2}{12}$
$\Delta l = \alpha_L . l_o \Delta T$
Solution:

New moment of inertia $= \frac{M(l+\Delta l)^2}{12}$
$= \frac{M(l+\alpha_L . l_o \Delta T)^2}{12}$
$= \frac{Ml^2}{12}(1 + \alpha_L \Delta T)$

$$\boldsymbol{I' = I\,(1 + \alpha_L \Delta T)}$$

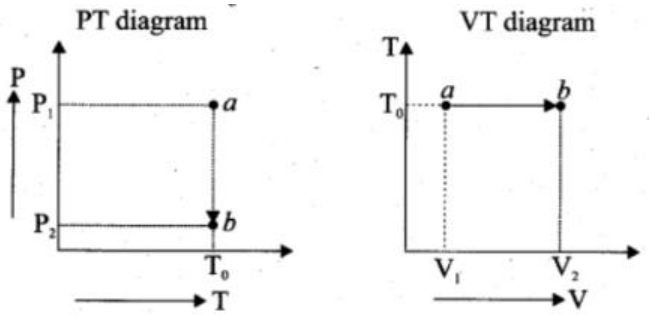
5. Solution:

a) $V = V_o$ = *constant*



$P(T) = \frac{nRT}{V_o}$ $T(V)$= *multivalued*
$b = (P_2, V_o, T_2)$ $a = (P_1, V_o, T_1)$
$PV_o = nRT$

b) $T = T_o$ = *constant*

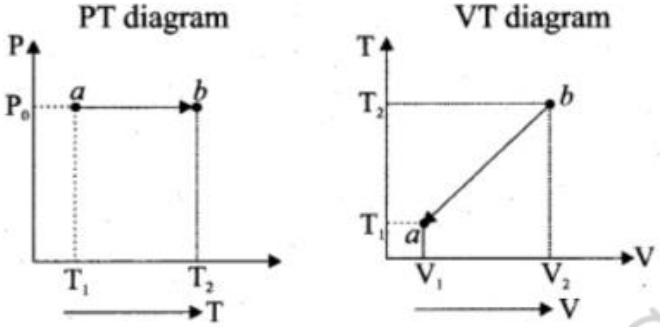


P(T) = multivalued *T(V) = T_o*

c) *P = P_o = constant*

a = (P_o, V_1, T_1) *b = (P_o, V_2, T_2)*

$P_oV = nRT$



P(T) = P_o *T(V) = $\frac{P_oV}{nR}$*

6. Given:

P_1 = 500kPa *T_1 = 298K*

P_2 = 520kPa *T_2 = ?*

Formula used:

$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$

Solution:

$P_1T_2 = P_2T_1$

$T_2 = \frac{P_2T_1}{P_1}$

$T_2 = \frac{520 \times 298}{500}$

$T_2 = \frac{154960}{500}$

T_2 = 309.92K

T_2 = 309.92 - 273

T_2 = 36.9°C

7. Solution:

a) *T = 98.6°F*

$C = \frac{(F-32)}{1.8}$ = 37°C

T = 37 + 273 = 310K

$\lambda_m = \frac{a}{T}$ (a – Wien's displacement constant)

a = 2.898 × 10^{-3}

$\lambda_m = \frac{2.898 \times 10^{-3}}{310}$

λ_m = 9348 × 10^{-9}m = 9348nm

b) *T = 104°F*

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$C = \frac{(F-32)}{1.8} = 40°C$

$T = 40 + 273 = 313K$

$\lambda = \frac{a}{T}$ *(a – Wien's displacement constant)*

$a = 2.898 \times 10^{-3}$

$\lambda = \frac{2.898\times10^{-3}}{313}$

$\lambda = 9259 \times 10^{-9} m = 9259nm$

Change in wavelength $= \lambda_m - \lambda = 9348 – 9259$

Change in wavelength = 89nm

8. Solution:

Volume increased by 4%

$\frac{\Delta V}{V} \times 100 = 4\%$

Adiabatic expression $PV^{\gamma} = constant$

$\frac{\Delta P}{P} + \gamma.\frac{\Delta V}{V} = 0$

$\frac{\Delta P}{P} = -\gamma.\frac{\Delta V}{V}$

$\frac{\Delta P}{P} = -1.4 \times 4 = 5.6\%$

Pressure is decreased by 5.6%

9. Given:

At temperature T_1

$P_1 = 1atm$

$V_1 = Vm^3$

$T_1 = 293K$

At temperature T_2

$P_2 = 1atm$

$V_1 = \frac{V}{8} m^3$

$T_2 = ?$

Formula used:

$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$

Solution:

$T_2 = \left[\frac{V_2}{V_1}\right] T_1$

$T_2 = T_1 \left[\frac{V_1}{V_2}\right]^{\gamma-1}$

$T_2 = T_1 \left[\frac{V}{\frac{V}{8}}\right]^{1.4-1}$

$T_2 = 293 \times (8)^{0.4}$

$T_2 = 673.1\ K$

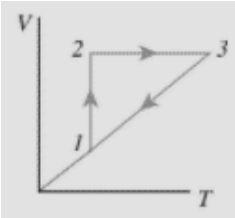
$T_2 = 673 – 273$

T_2 = 400°C

10. Solution:

Process 1 to 2 = increase in volume. So heat must be added.

Process 2 to 3 = Volume remains constant. Increase in temperature. The given heat is used to increase the internal energy.
Process 3 to 1: Pressure remains constant. Volume and Temperature are reduced. Heat flows out of the system. It is an isobaric compression where the work is done on the system.



11. Solution:

a) *Work done by the gas W= Area of triangle + Area of rectangle*
W = (½ × 3 ×200) + (3 × 400)
W = 300 + 1200
W = 1500J

W = +1.3kJ

b) *Work done on the system W = Area under the curve BC*
W = Area of rectangle
W = -3 × 400
W = -1200J

W = -1.2kJ

c) *Net work done W = (1.5 – 1.2)kJ*

W = +300J

12. Given:

$Q = 6 \times 10^5 J$
$V_1 = 4m^3 \quad V_2 = 6m^3$
$\Delta V = V_2 - V_1 = 6\text{-}4 = 2m^3$
$W = ?$
$\Delta U = ?$

Solution:

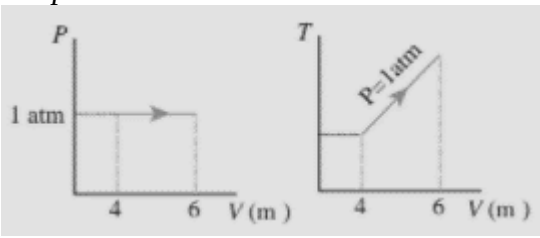
a) *Work done by the gas W = PdV*
$W = 1.013 \times 10^5 \times 2$
$W = 2.026 \times 10^5 J$

W = 202.6 kJ

b) $\Delta U = Q - W$
$\Delta U = 6 \times 10^5 - 2.026 \times 10^5 J$
$\Delta U = 3.974 \times 10^5 J$

ΔU = 397.4 kJ

c) *Graph:*



13. Given:

$T_1 = 100°C = 373K$
$T_2 = 300°C = 573K$
$\eta = ?$
For method a: $T_1 = 50°C, T_2 = 300°C, \eta_a = ?$
For method b: $T_1 = 100°C, T_2 = 350°C, \eta_b = ?$
Formula used:
$\eta = \frac{T_2 - T_1}{T_2} \times 100$
Solution:
Initial efficiency:
$\eta = \frac{T_2 - T_1}{T_2} \times 100$
$\eta = \frac{573 - 273}{573} \times 100$
$\eta = \frac{300}{573} \times 100$
$\boldsymbol{\eta = 34.9\%}$
For method a:
$\eta_a = \frac{T_2 - T_1}{T_2} \times 100$
$\eta_a = \frac{573 - 323}{573} \times 100$
$\eta_a = \frac{250}{573} \times 100$
$\boldsymbol{\eta_a = 43.6\%}$
For method b:
$\eta_b = \frac{T_2 - T_1}{T_2} \times 100$
$\eta_b = \frac{623 - 373}{573} \times 100$
$\eta_b = \frac{250}{623} \times 100$
$\boldsymbol{\eta_b = 40.1\%}$
Method (a) is more efficient.

14. Given:
$\eta_1 = 45\%$ $T_H = 327°C = 600K$
$\eta_2 = 60\%$ $T_H = ?$
Solution:
$\eta_1 = \frac{T_H - T_L}{T_H} = 1 - \frac{T_L}{T_H}$
$T_L = (1 - \eta_1)T_H$
$T_L = \left[1 - \frac{45}{100}\right] 600$
$T_L = 330K = 57°C$
$\eta_2 = \frac{T_H - T_L}{T_H} = 1 - \frac{T_L}{T_H}$
$T_H = \frac{T_L}{1 - \eta_2}$
$T_H = \frac{330}{1 - \frac{60}{100}}$
$T_H = 825K$

$\boxed{\boldsymbol{T_H = 552°C}}$

15. Given:
$T_L = 0°C$ $T_H = 27°C$

$T_L = 273K\ T_H = 300K$

Formula used:

$\beta = \frac{T_L}{T_H - T_L}$

Solution:

$\beta = \frac{T_L}{T_H - T_L}$

$\beta = \frac{273}{300-273}$

$\beta = \frac{273}{27}$

$\boxed{\boldsymbol{\beta = 10.11}}$

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