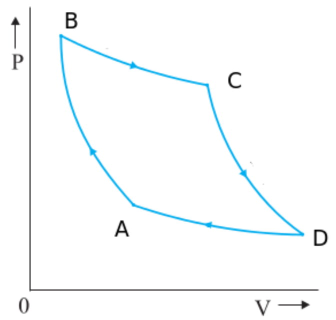
THERMODYNAMICS

Que.1. March 2014 **[Marks :(4)]**

The figure shows the pressure- volume relationship of an ideal gas that undergoes a Carnot cycle. The process B to C takes place at a constant temperature of 1000K and the process from D to A at a constant temperature of 500 K.



a) Name the processes occurring between

i) A and B

ii) B and C

b) During which of the four processes, is the work done by the gas?

c) How can you find the total work done during a cycle from the graph?

d) Calculate the efficiency of the cycle

Ans. a) i)Adiabatic compression.

ii) Isothermal expansion

b) Work is done by the ideal gas during isothermal expansion and adiabatic expansion.

c)Total work done during Carnot cycle, W= $W_{BC}+W_{CD}+W_{DA}+W_{AB}$

Since, $W_{CD}=-W_{AB}$,

Work= W= $W_{BC}+W_{DA}$

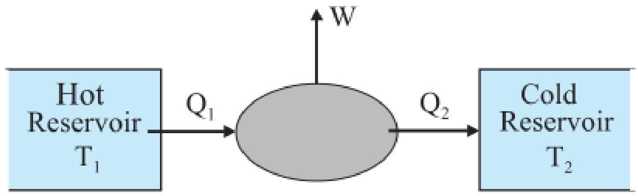
W= $nRT_1\log_e(V_2/V_1)-nRT_2\log_e(V_3/V_4)$

d) η= $1-\frac{T_2}{T_1}$ =1-(500/1000)=1/2

Efficiency=50%

Que.2. March 2013 **[Marks :(4)]**

Figure given below depicts the scematic representation of an engine.



a) Which type of engine is this, a heat engine or a refrigerator?

b) Write the 4 steps of operation in the Carnot cycle.

c) A Carnot engine is working between temperatures of 27°C and 327°C. Find its efficiency (η)

Que.3. A heat engine is a device which converts heat energy into work. [Marks :(5)]

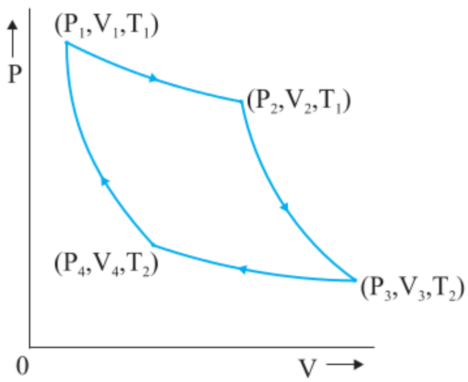
a) What is the working substance of an ideal heat engine?

b) Draw the Carnot cycle and explain its working.

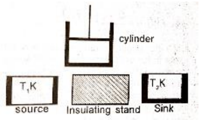
c) Calculate the efficiency of an engine working between steam point and ice point. Can you design an engine of 100% efficiency?

Ans. a)Ideal gas

b)Carnot engine is an ideal, reversible heat engine working between two reservoirs maintained at two different temperatures.



Main parts of the heat engine are the source, working substance, sink and an insulated stand. Working substance is an ideal gas kept in a cylinder with a piston. Only the bottom surface of the piston is conducting while the other surfaces are thermally insulated. Adiabatic process is performed in this insulated stand.



Carnot's cycle:

Carnot cycle has four stages

i) Isothermal expansion

The cylinder containing the gas is placed in thermal contact with the source kept at high temperature T1 . It absorbs Q1 amount of heat and expands. The expansion is isothermal. The initial presssure P1 and volume V1 of the gas changes to P2 and volume V2. The working substance does a work WAB.

ii) Adiabatic expansion

The cylinder is now placed on the insulating stand. No heat is transferred between the system and the surroundings. The process is adiabatic. Pressure and volume changes during the process. P2 and V2 changes to P3 and V3. The working substance does a work WBC

iii) Isothermal compression

The cylinder is then placed on the sink at temperature T2. Gas is compressed to reject some heat Q2 to the sink. Since T2 remains a constant,the compression is isothermal. Pressure and volume changes to P4 and V4. The work done by the gas is WCD

iv) Adiabatic compression

The cylinder is again placed on the insulating stand for the completion of the compression process. Since no heat transfers or leaves the system, the compresssion is adiabatic. The gas attains the original pressure P1 and volume V1 at the end of this. Work done now is WDA

c) $\eta=\frac{T_1-T_2}{T_1}$ = $\frac{373-273}{273}$ =26.8%

It is not possible to construct a heat engine with an efficiency 100% as it violates the second law of Thermodynamics.

Que.4. a)Which thermodynamic process is also called an isentropic process? [Marks :(5)]

b. The efficiency of a Carnot's engine is (1/6). If on reducing the temperature of the sink by 65°C, It's efficiency becomes (1/3), find the temperature of the sink and the source.

c. Obtain the expression for the work done during an adiabatic process.

Ans. a) Adiabatic process (Reversible)

b) $\eta=1-\frac{T_2}{T_1}$

$\frac{1}{6}=1-\frac{T_2}{T_1}$ $\frac{T_2}{T_1}=1-\frac{1}{6}=\frac{5}{6}$ -----------------(1)

$\eta^{l}=\frac{1}{3}=1-\frac{T_2^{l}}{T_1}$ (T2i is the reduced temperature of the sink.)

$$\frac{T_2^{l}}{T_1}=\frac{2}{3}$$ -----------------(2)

Dividing (1) and (2)

$$\frac{T_2}{T_2^{l}}=\frac{5}{4}$$

$$\frac{T_2}{T_2-65}=\frac{5}{4}$$ (Since the temperature of the sink is reduced by 65°C)

T2=325K and T1=6/5 x T2=390K

c) Derivation of the equation for work done during the adiabatic process.

$$W=\frac{nR}{\gamma-1}(T_1-T_2)$$

Que.5. Thermodynamics deals with the concept of heat and the exchange of heat energy.

a. Which law of thermodynamics is used to explain the working of heat engine?

b. What are the sink, source and working substance of a domestic refrigerator?

c. Explain briefly the operations of a Carnot's engine, draw the Carnot's cycle and deduce the expression for its efficiency. [Marks :(4)]

Ans. a) Second Law of Thermodynamics.

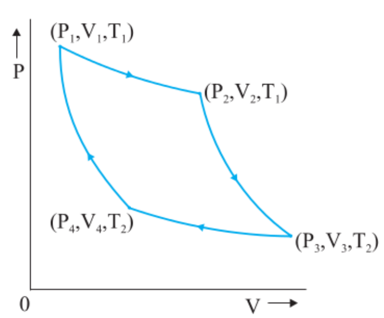
b) Sink- Parts of the refrigerator

Source- Atmosphere

Working Substance- Gas in the pipes

c) Carnot engine is an ideal, reversible heat engine working between two reservoirs maintained at two different temperatures.

Main parts of the heat engine are the source, working substance, sink and an insulated stand. Working substance is an ideal gas kept in a cylinder with a piston. Only the bottom surface of the piston is conducting while the other surfaces are thermally insulated.



Carnot Cycle.

i)Isothermal expansion (AB)

In this process, the working substance is placed on the source and the gas expands isothermally from pressure P1 and volume V1 to P2 and V2 respectively.

Work done during the process,

$W1=nRT1\log_e(V2/V1)$

Heat absorbed from source Q1=Work done W1

ii) Adiabatic expansion (BC)

Now the working substance is placed over the insulated stand and undergoes adiabatic expansion

$$W_2=\frac{nR}{\gamma-1}(T_1-T_2)$$

iii) Isothermal compression (CD)

Working substance is now placed on the sink and undergoes isothermal compression.

$W3=nRT2\log_e(V4/ V3)$

or ,$W3=-nRT2\log_e(V3/ V4)$

iv) Adiabatic compression (DA)

Working substance is now placed on the insulating stand and undergoes adiabatic compression

$$W_4=\frac{-nR}{\gamma-1}(T_1-T_2)$$

Total work done during Carnot cycle W= W1+W2+W3+W4

$W= nRT1\log_e(V2/V1)-nRT2\log_e(V3/ V4)$

But we can prove that (V2/V1)=(V3/ V4)

Therefore, the work, $W = nR (T1 - T2) \log_e(V2/V1)$

But the efficiency of a heat engine η=W/Q1

$= nR (T1 - T2) \log_e(V2/V1) / nRT1\log_e(V2/V1)$

$$\eta=\frac{T_1-T_2}{T_1} = 1-\frac{T_2}{T_1}$$

Efficiency of the Carnot's engine is independent of the nature of the working substance.

Also by the definition of efficiency, η=W/Q1= (Q1-Q2) / Q1

η =1- (Q2 /Q1)

Que.6. Consider a heat engine as shown in the figure. the symbols Q1,Q2,T1,T2 & W are having their respective meaning.. **[Marks :(4)]**

if W> 0 ,then possibilities are

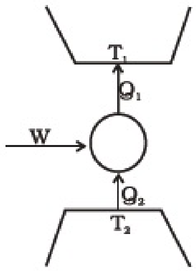


Fig .12.7

- (a) $Q_1 > Q_2 > 0$
- (b) $Q_2 > Q_1 > 0$
- (c) $Q_2 < Q_1 < 0$
- (d) $Q_1 < 0, Q_2 > 0$

Ans. (a),(c)

Que.7. An ideal gas undergoes different processes from the same initial state . The four processes are adiabatic ,isothermal,isobaric and isochoric which are represented in the graph shown below as 1,2,3, and 4. **[Marks :(1)]**

Out of 1,2,3 and 4 which one is adiabatic ?

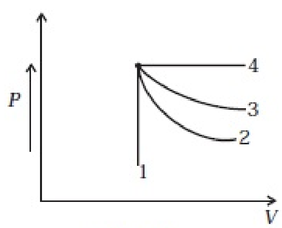


Fig. 12.1

- (a) 4
- (b) 3
- (c) 2
- (d) 1

Ans. (c)2

Que.8. Find the coefficient of performance (COP) of a refrigerator working between ice point and room temperature 27°C. **[Marks :(2)]**

Ans. Coefficient of Performance of a refrigerator is given by,

$$\alpha = \frac{T_2}{T_1 - T_2}$$

Here, T1=300K

T2=273 K

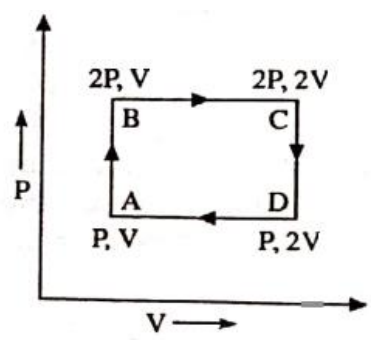
Substituting,

$$\alpha = \frac{273}{300-273} = \frac{273}{27}$$

α= 10.11

Que.9. Figure given below shows the changes of an ideal mono-atomic gas which is taken around the cycle ABCDA. What is the net work done during the process?

[Marks :(2)]



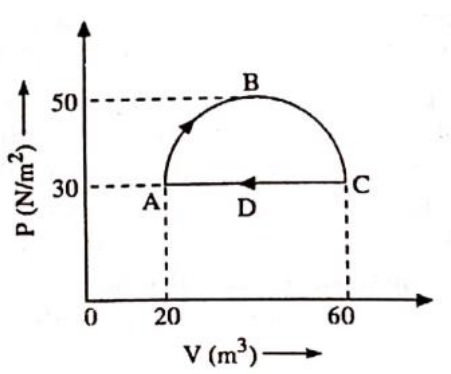
Ans. Work done during the process is given by the area of ABCDA.

Therefore, work= (2P-P) x (2V-V)= PV

Work done W= PV

Que.10. A gas undergoes a cyclic process ABCDA as shown in figure. The part ABC of the process is semicircular. Calculate the work done by the gas?

[Marks :(2)]



Ans. Area enclosed by the graph gives the work done

$W = (\pi R^2/2) = (\pi \times (20)^2/2) = 200\pi$ Joules

Que.11. The ratio of specific heat of a gas at constant pressure to that at constant volume is γ. What is the change in internal energy of one mole of a gas when the volume changes from V to 2V at constant pressure P ?

[Marks :(2)]

Ans. We have $\Delta U = nC_v\Delta T$

But $C_v = R/(\gamma - 1)$

$$\Delta U = \frac{R\Delta T}{\gamma - 1} = \frac{R(T_2 - T_1)}{\gamma - 1} = \frac{RT_2 - RT_1}{\gamma - 1} = \frac{PV_2 - PV_1}{\gamma - 1} = \frac{P(2V - V)}{\gamma - 1}$$

$$\boldsymbol{\Delta U = \frac{PV}{\gamma - 1}}$$

Que.12. "Heat cannot by itself flow from a body at lower temperature to a body at higher temperature". This statement is a consequence of:

(a) Second law of thermodynamics

(b) Conservation of momentum

(c) Conservation of mass

(d) First law of thermodynamics

[Marks :(1)]

Ans. (a) Second law of thermodynamics

Que.13. In an isobaric process of an ideal gas, what is the ratio of heat supplied and work done by the system, Q/W?

[Marks :(2)]

Ans. We have $Q = nC_p \Delta T$ and $\Delta U = nC_v\Delta T$

$$\frac{Q}{W} = \frac{nC_p\Delta T}{nC_p\Delta T - nC_v\Delta T} = \frac{nC_p\Delta T}{n\Delta T(C_p - C_v)} = \frac{C_p}{C_p - C_v}$$

Dividing Numerator and Denominator by Cv

$$\boldsymbol{\frac{Q}{W} = \frac{\gamma}{\gamma - 1}}$$

Que.14. If Q is the heat supplied and ΔU, the change internal energy of a gaseous system, undergoing an isobaric process, then find the ratio (Q/ ΔU).

[Marks :(2)]

Ans. We have $Q = nC_p \Delta T$ and $\Delta U = nC_v\Delta T$

$$\frac{Q}{\Delta U}=\frac{C_p}{C_v}=\gamma$$

Que.15. 5 moles of hydrogen (γ=7/5) initially at STP is compressed adiabatically so that its temperature becomes 400°C. Find the increase in internal energy of the gas in joules.

[Marks :(2)]

Ans. For hydrogen, $\gamma=7/5$ and $C_V=5/2R$

$nC_V\Delta T=5x(5/2)Rx400=5000R$

$=5000x8.3$ J$=41.5x10^3$ J

Que.16. For a given process in an ideal gas, dW=0 and dQ<0 then, for the gas:

(a) the temperature will decrease

(b) the volume will increase

(c) the pressure will remain a constant.

(d) the temperature will increase.

[Marks :(1)]

Ans. (a) the temperature will decrease

Hint: Since dQ<0, heat energy goes out of the system resulting in a fall of internal energy. This leads to a decrease in temperature.

Que.17. Which of the following parameters does not characterize the thermodynamic state of matter?

(a) Temperature **(b) Pressure** **(c) Work** **(d) Volume**

[Marks :(1)]

Ans. (c) Work

Que.18. For a heat engine, the temperature of the source is 127°C. At what temperature should the sink be maintained to have an efficiency 60%?

[Marks :(2)]

Ans. The efficiency of an ideal heat engine, $\eta=1-\frac{T_2}{T_1}$

We are given, η=60%

or η=0.6

T1= 127°C =400K

T2=(1- η)T1=(1-0.6) 400=160K=-113°C

Que.19. For a heat engine, the temperature of the source is 127°C. At what temperature should the sink be maintained to have an efficiency 60%?

[Marks :(2)]

Ans. The efficiency of an ideal heat engine, $\eta = 1 - \frac{T_2}{T_1}$

We are given, η=60%

or η=0.6

T1= 127°C =400K

T2=(1- η)T1=(1-0.6) 400=160K=-113°C

Que.20. A friction-less heat engine can be 100% efficient only if its exhaust temperature is

(a)0°C **(b)0K**

(c)Equal to its input temperature

(d) Half of its input temperature.

[Marks :(2)]

Ans. (b) 0 K

Hint: Efficiency, $\eta = 1 - \frac{T_2}{T_1}$

if T2=0, η=1, the maximum possible efficiency of a heat engine.

Que.21. The temperature of 5 moles of gas at constant volume was changed from 100°C to 120°C. The change in internal energy was found to be 80J. Calculate the total heat capacity of the gas at constant volume.

[Marks :(2)]

Ans. Heat capacity is the amount heat required to raise the temperature of the given substance by 1°C or 1K.

Here, ΔQ=nCΔT. Since the volume is held a constant, the work done is zero. Therefore, ΔQ= ΔU

Heat Capacity, nC= ΔQ/ ΔT=80/(120-100)=4 J/K

Que.22. The temperatures of source and sink of a Carnot engine are 400K and 300K respectively. What is its efficiency?

[Marks :(2)]

Ans. Efficiency, $\eta=\frac{W}{Q_1}=1-\frac{T_2}{T_1}$

Substituting, $\eta=1-\frac{300}{400}$ = 0.25

Efficiency of the Carnot engine is 25%

Que.23. When an ideal gas is heated at constant pressure, what is the fraction of heat energy supplied which increases the internal energy of the gas?

[Marks :(2)]

Ans. Fraction of heat energy to the increase in internal energy is given by

$$f=\frac{\Delta U}{Q}=\frac{nC_v\Delta T}{nC_p\Delta T}=\frac{C_v}{C_P}$$

$$\frac{\frac{5}{2}R}{\frac{7}{2}R}=\frac{5}{7}$$

Que.24. A Carnot heat engine takes 3000 kilocalories of heat from a reservoir at 627°C and gives it to a sink at 27°C. What is the work done by the engine in joules?

[Marks :(2)]

Ans. We have the efficiency of a Carnot engine is given by

$$\eta=\frac{W}{Q_1}=1-\frac{T_2}{T_1}$$

Therefore,

$$W=\left(\frac{T_1-T_2}{T_1}\right)Q_1$$

$$W=\left(\frac{900-300}{900}\right)3000\times10^3\times4.2$$

=8.4x106 Joules

Que.25. Find the efficiency of a Carnot engine working between steam point and ice point.

[Marks :(2)]

Ans. Efficiency of Carnot heat engine is given by the equation

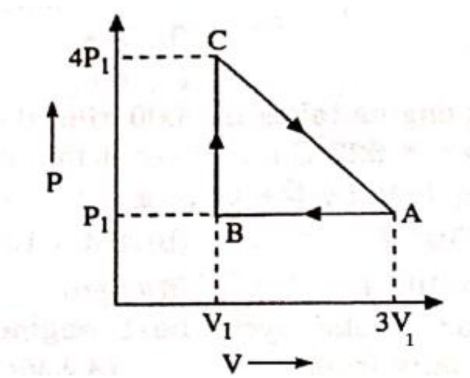
$$\eta = 1 - \frac{T_2}{T_1}$$

Substituting, $\eta = 1 - \frac{273}{373}$ =0.2681

or η=26.81%

Que.26. Figure shown below represents the series of changes of an ideal gas. Find the net work done by the gas at the end of the cycles.

[Marks :(2)]



Ans. Area of the region ABC gives the net work done.

Area is given by W= ½ $(3V_1-V_1)x(4P_1-P_1)$

= ½ $(2V_1 \text{ x } 3P_1)$

W= 3 P_1V_1

Que.27. An ideal gas heat engine operates in Carnot cycle between 227°C and 127°C. It absorbs 6.0x104 calories of energy at higher temperature. What is the amount of heat converted into mechanical work?

[Marks :(2)]

Ans. Efficiency of a Carnot engine is given by

$$\eta = \frac{W}{Q_1} = 1 - \frac{T_2}{T_1}$$

Therefore, $W = \left(\frac{T_1 - T_2}{T_1}\right) Q_1$

Substituting the given data in the above equation,

W=1.2x104 Calories

Que.28. A Carnot engine works between a hot reservoir at temperature T_1 and cold reservoir at temperature T_2. To increase its efficiency;

(a) T_1 and T_2 both should be increased.

(b)T_1 and T_2 both should be decreased.

(c) T_1 should be decreased and T_2 increased

(d)T_1 should be increased and T_2 decreased

[Marks :(2)]

Ans. (d)T1 should be increased and T2 decreased

Que.29. If dQ is the heat supplied, dU the change in internal energy of gas and dW the work done by the gas, then the first law of thermodynamics states that:

(a) dQ = dU-dW

(b) dU = dQ-dW

(c) dU = dW-dQ

(d) dQ+dW+dQ = 0

[Marks :(1)]

Ans. (b) dU =d Q-dW

Que.30. The maximum amount of energy that can be converted into heat in any process :

(a) is 100%

(b) depends on the temperatures of intake and exhaust.

(c) depends on the amount of friction present

(d) is the same for reversible and irreversible cycles.

[Marks :(1)]

Ans. (a) 100%

Que.31. In a cyclic process, the amount heat given to a system is equal to:

(a) the net work done by the system.

(b) net increase in internal energy.

(c) net decrease in internal energy

(d) net change in volume.

[Marks :(1)]

Ans. (a)the net work done by the system.

Que.32. An adiabatic process occurs at constant :

(a) Temperature

(b) Pressure

(c) Heat

(d)None of the above

[Marks :(1)]

Ans. (c)Heat

Que.33. What does a point on the P-V indicator diagram represent?

(a)work done in a cyclic process

(b)a thermodynamic process

(c)heat supplied to the system

(d)the state of a thermodynamic system.

[Marks :(1)]

Ans. (d)the state of a thermodynamic system.

Que.34. Two systems in thermal equilibrium is characterized by equal value of:

(a) Temperature

(b) heat

(c) Specific heat

(d) Energy

[Marks :(1)]

Ans. (a) Temperature

Que.35. The temperature inside and outside of a refrigerator are 273K and 303K respectively. Assuming that the refrigerator cycle is reversible, calculate the heat delivered to the surroundings for every joule of work done.

[Marks :(3)]

Ans. The coefficient of performance of Carnot refrigerator is

$\alpha=Q_2/W=T_2/(T_1-T_2)$

Here, T_2= 273K and T_1=303K Work done W= 1J

$Q_2/1=273/(303-273)=273/30=9.1$ J

Heat delivered to the surroundings is $Q_2+W=9.1+1=10.1$ J

Que.36. A gas under constant pressure 4.5x105 Pa when subjected to 800kJ of heat, changes the volume from 0.5m3 to 2.0 m3. What is the change in internal energy of the gas?

[Marks :(3)]

Ans. Work done by the gas is

W=PΔV=P(V2-V1)

= 4.5x105(2.0-0.5) J

=6.75x105J

From the first law of thermodynamics, ΔQ= ΔU+ΔW

or ΔU= ΔQ-ΔW

=800x103 -6.75x105 J

=8.00x105-6.75x105J

=1.25x105J

Que.37. A Carnot engine working between 300K and 600 K has a work output of 800J/cycle. What is the amount of heat energy supplied to the engine from the source per cycle?

[Marks :(3)]

Ans. Here, W=800 J,T_1=600K and T_2=300K

We have $\eta = 1 - \frac{T_2}{T_1} = \frac{W}{Q_1}$

Substituting the given values,

1-(300/600)=800/Q_1

0.5=800/Q_1

Hence, heat supplied by the source, Q_1=1600J/cycle

Que.38. The pressure of a gas during an adiabatic process is found as cube of its absolute temperature. Find the ratio Cp/Cv for the gas.

[Marks :(3)]

Ans. During an adiabatic process, pressure P and temperature T are related as

$$\frac{T^{\gamma}}{P^{\gamma-1}} = a\,constant$$

Or, $\left(\frac{T^{\gamma}}{P^{\gamma-1}}\right)^{\gamma-1} = a\,constant$

Therefore, $\frac{T^{\gamma/\gamma-1}}{P} = a\,constant$

P is proportional to $T^{\gamma/\gamma-1}$

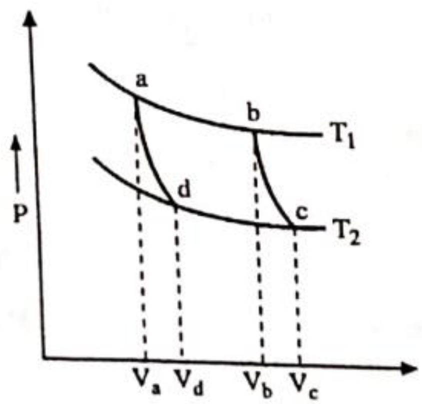
Given P is proportional to T^3.

Therefore, $\gamma/(\gamma-1) = 3$

Or $\gamma = 3/2$

Que.39. Two different adiabatic paths for the same gas intersects two isothermals at T_1 and T_2 as shown in the P-V diagram. How does V_a/V_d compare with the ratio V_b/V_c?

[Marks :(3)]



Ans. In the figure, 'ab' and 'bd' are isothermals at temperatures T_1 and T_2 respectively. Here, 'bc' and 'ad' are adiabatics. As points 'a' and 'd' lie on the same adiabatic,

$T_a V_a^{\gamma-1} = T_d V_d^{\gamma-1}$

Here, $T_a = T_1$ and $T_d = T_2$

$T_1 V_a^{\gamma-1} = T_2 V_d^{\gamma-1}$

this gives,

$(T_1/T_2) = (V_d/V_a)^{\gamma-1}$ ------------------(1)

Also the points b and c lie on the same adiabatic

$T_b V_b^{\gamma-1} = T_c V_c^{\gamma-1}$

Here, $T_b = T_1$ and $T_c = T_2$

$T_1 V_b^{\gamma-1} = T_2 V_c^{\gamma-1}$

This gives, $(T_1/T_2) = (V_c/V_b)^{\gamma-1}$ -------------------(2)

Comparing equations (1) and (2)

$(V_d/V_a)^{\gamma-1} = (V_c/V_b)^{\gamma-1}$

This gives $V_d/V_a = V_c/V_b$

Therefore, $V_a/V_d = V_b/V_c$ and their ratio is **1**.

Que.40. The volume of a gas is reduced adiabatically to (¼) of its volume at 27°C. If γ=1.4, what will be the new temperature?

[Marks :(3)]

Ans. For an adiabatic change, $TV^{\gamma-1}$ is a constant.

$T_1 V_1^{\gamma-1} = T_2 V_2^{\gamma-1}$

$T_2=T_1(V_1/V_2)^{\gamma-1}$

Here, T_1= 27° C=300K ,V_1=V and V_2=V/4

$(V_1/V_2)=V/(V/4)=4$

$T_2=(4)^{1.4-1}$x 300= 522.3 K

Que.41. A quantity of mono-atomic gas at 27°C is compressed (i)slowly (ii)suddenly to 8/27th of its volume. Find the change in temperature in each case.(Assume γ to be 5/3.)

[Marks :(3)]

Ans. (i)In a slow process, the temperature remains constant. Therefore, in first case, there is no change of temperature.

(ii)When the compression is sudden, the process is sudden so that $TV^{\gamma-1}$ is a constant.

Here, T_1= 27° C=300K ,V_1=V and γ = 5/3

V_2=(8/27)V

T_2=?

$T_1 V_1^{\gamma-1} = T_2 V_2^{\gamma-1}$

Therefore, $T_2=T_1(V_1/V_2)^{\gamma-1}$

Substituting data in the above equation, T_2=675K.

Therefore the change in temperature is 675-300=**375 K**