DAY FOURTEEN

Thermodynamics

Learning & Revision for the Day

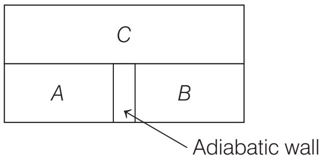
- Zeroth Law of Thermodynamics
- First Law of Thermodynamics
- Thermodynamic Processes
- Second Law of Thermodynamics
- Reversible and Irreversible Processes
- Heat Engine
- Carnot Engine and Its Efficiency
- Refrigerator

Zeroth Law of Thermodynamics

(Concept of Temperature)

When there is no exchange of heat between two systems placed in contact, then both are called in thermal equilibrium.

According to this law, if two systems A and B , separated by an adiabatic wall, are separately and independently in thermal equilibrium with a third system C, then the systems A and B are also in a state of thermal equilibrium with each other.



Basic Terms Used in Thermodynamics

Heat It is the energy, which is transferred between system and surroundings due to the temperature difference.

Internal Energy Internal energy of a system is defined as the sum of the total kinetic energy of all its constituent particles and sum of all the potential energies of interaction among these particles.

The internal energy of an ideal gas is totally kinetic and it is given by

$$U = \frac{3}{2}\mu RT$$

and change in internal energy $\Delta U = \frac{3}{2}\mu R\Delta T$.

NOTE • For non-ideal gases, internal energy depends not only on the temperature but also on the pressure.

Work

Consider a system in a cylinder with movable piston, whose volume can be changed (a gas, liquid or solid). Suppose, the cylinder has a cross-sectional area A and pressure exerted by system on the piston face is p.

The work done by the system on the surroundings for small displacement dx is $dW = pAdx$.

$$W = \int dW = \int_{V_i}^{V_f} pdV$$

i.e. work done in a finite change of volume from V_i to V_f.

NOTE
- Work done by the system depends on the initial and final states.
- If volume of the system increases, then work is done by the system and it is taken as positive work done.
- If volume of the system decreases, then work is done on the system and it is taken as negative work done.

First Law of Thermodynamics

According to this law, the heat given to a system (ΔQ) is equal to the sum of increase in its internal energy (ΔU) and the work done (ΔW) by the system against the surroundings.

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

Sign Convention

$\Delta Q = +$ ve when heat supplied $= -$ ve when heat is rejected
$\Delta U = +$ ve when temperature increases
$= -$ ve when temperature decreases
$\Delta W = +$ ve when work is done by the system (expansion)
$= -$ ve when work is done on system (compression)

First law of thermodynamics is based on the energy conservation.

Thermodynamic Processes

A thermodynamic process is the process of change of state of a system involving change of thermodynamic variables, e.g. p, V, T etc.

When a system undergo a thermodynamic change, then work done either by system on surrounding or by surroundings on system is called external work.

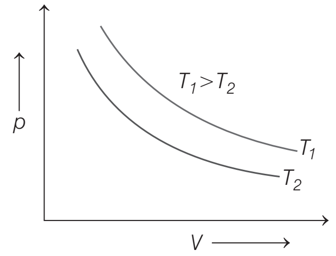
$$W_{\text{ext}} = \int_{V_1}^{V_2} p\, dV = \text{area under } p\text{-}V \text{ curve.}$$

1. Isothermal Process

It is that process in which temperature remains constant. Here, exchange of heat with the surroundings is allowed.

As temperature T remains constant in an isothermal process, hence as per Boyle's law

$$p \propto \frac{1}{V} \text{ or } pV = \text{constant}$$



p-V graph for isothermal process

Molar specific heat of a gas under isothermal condition

$$C = \frac{\Delta Q}{m\Delta T} = \frac{\Delta Q}{m(0)} = \infty$$

Slope of *p-V* curve at any point is $\frac{dp}{dV} = -\frac{p}{V}$.

Work done in an isothermal process

$$\Delta W = \int_{V_i}^{V_f} pdV = nRT \ln\left(\frac{V_f}{V_i}\right)$$

where, $n =$ number of moles, $R =$ gas constant and $T =$ temperature.

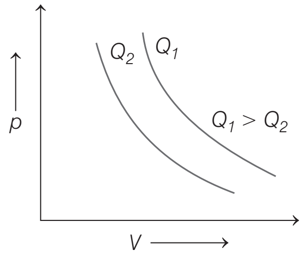
V_f and V_i are final and initial volume of the gas respectively.

As per first law of thermodynamics, since, $\Delta T = 0$, hence, $\Delta U = 0$ for an ideal gas and we have $\Delta Q = \Delta W$.

Thus, **heat supplied to the system in an isothermal process is entirely used to do work against external surroundings.**

2. Adiabatic Process

It is that process in which there is no exchange of heat of the system with its surroundings. Thus, in an adiabatic process p, V and T change but $\Delta Q = 0$ or entropy remains constant $\left(\Delta S = \frac{\Delta Q}{T} = 0\right)$.



p-V graph for adiabatic process

The equation of state for an adiabatic process is

$pV^{\gamma} =$ constant or $TV^{\gamma-1} =$ constant or $T^{\gamma}p^{1-\gamma} =$ constant

- **Molar specific heat** of a gas under adiabatic condition
$$C = \frac{\Delta Q}{m \cdot \Delta T} = \frac{0}{m \cdot \Delta T} = 0$$
- **Slope of an adiabatic** at a point is $\frac{dp}{dV} = -\gamma \frac{p}{V}$.

- **Work done in an adiabatic process**

$$\Delta W = \int_{V_i}^{V_f} p\,dV = \frac{\mu R}{(\gamma - 1)}(T_i - T_f) = -\frac{\mu R}{(\gamma - 1)}\Delta T$$

  During an adiabatic expansion $\Delta W = +$ ve, hence, temperature of gas falls, i.e. an adiabatic expansion is always accompanied with cooling.

  As per first law of thermodynamics, since, $\Delta Q = 0$ in an adiabatic process hence,

$$\Delta U = -\Delta W$$

- **Free expansion** is an adiabatic process in which $\Delta W = 0$.

  Hence, in accordance with first law of thermodynamics $\Delta U = 0$ i.e. the final and initial values of the internal energy are equal in free expansion.

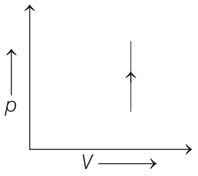
3. Isochoric Process

It is that thermodynamic process in which volume remains constant.

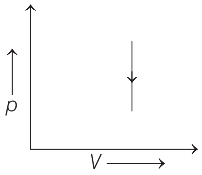
In an isochoric process for a given mass of gas

$$p \propto T \text{ or } \frac{p}{T} = \text{ constant}$$

- **Indicator diagram** for an isochoric process is a straight line parallel to p-axis.



(a)



(b)

  Graph (a) shows isometric heating graph in which pressure increases, temperature increases, ΔQ is positive and ΔU is positive.

  Similarly, Graph (b) shows isometric cooling graph in which pressure decreases, temperature decreases, ΔQ is negative and ΔU is negative.

- **Molar specific heat** of a gas under isochoric condition

  $C_V = \frac{f}{2}R$, where f is the number of degrees of freedom per molecule.

  - **Work done in an isochoric process** $\Delta W = \int p\,dV = 0$

  As $\Delta W = 0$ hence, according to first law of thermodynamics, we have

$$(\Delta Q)_V = \Delta U = \mu C_V\,\Delta T = \frac{\mu R}{(\gamma - 1)}\Delta T$$

4. Isobaric Process

It is that process in which pressure remains constant.

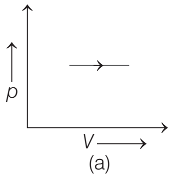
As in an isobaric process for a given mass of gas

$$V \propto T$$

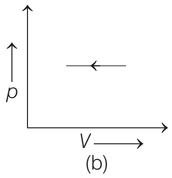
or

$$\frac{V}{T} = \text{ constant}$$

- **Indicator diagram** for an isobaric process is a straight line parallel to X-axis.



(a)



(b)

  Graph (a) represent isobaric expansion, graph (b) represent isobaric compression.

- **Work done in an isobaric process**

$$\Delta W = \int p\,dV = p\int_{V_i}^{V_f} dV = p(V_f - V_i) = p\Delta V$$

- **Molar specific heat** of a gas under isobaric condition

$$C_p = \left(\frac{f}{2} + 1\right)R = C_V + R$$

Second Law of Thermodynamics

Two most common statements of second law of thermodynamics are given below

Clausius Statement

It is impossible for a self-acting machine, working in a cyclic process to transfer heat from a colder body to a hotter body without the aid of an external agency.

Kelvin-Planck's Statement

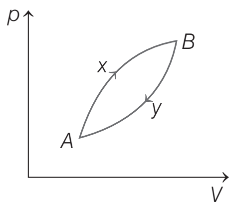
It is impossible to design an engine which extracts heat from a reservoir and fully converts it into work without producing any other effect.

Reversible and Irreversible Processes

A reversible process is one which can be reversed in such a way that all changes taking place in the direct process are exactly repeated in inverse order and in opposite sense, and no changes are left in any of the bodies taking part in the process or in the surroundings. Any process which is not reversible exactly is an irreversible process.

Cyclic Process

In cyclic process, if the process takes the path AxB, it returns *via* ByA, the initial and final points are same.



A cyclic process

Heat Engine

Any cyclic device by which heat is converted into mechanical work is called a heat engine.

There are three main parts in an engine:

(i) a hot body source
(ii) a working substance
(iii) a cold body called sink.

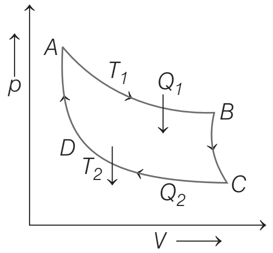
The efficiency of heat engine,

$$\eta = \frac{W}{Q_1} = \frac{Q_1 - Q_2}{Q_1} = 1 - \frac{Q_2}{Q_1}$$

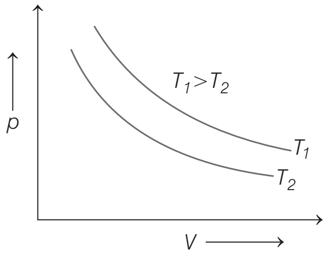
Carnot Engine and Its Efficiency

Carnot engine is a theoretical, ideal heat engine working in a reversible cyclic process operating between two temperatures T_1 (heat source) and T_2 (heat sink).

The Carnot's cycle consists of two isothermal processes connected by two adiabatic processes as shown in the figure.



Carnot's cycle



Isothermal process

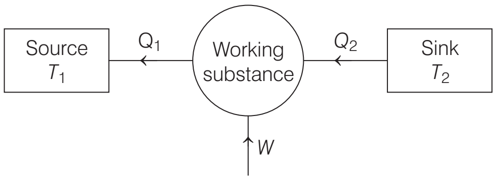
The efficiency of a Carnot's cycle is given by

$$\eta = \frac{W}{Q_1} = 1 - \frac{Q_2}{Q_1} = 1 - \frac{T_2}{T_1}$$

The efficiency does not depend on the nature or quantity of the working substance.

Refrigerator

A refrigerator or heat pump is basically a heat engine running in reverse direction. It takes heat from colder body (sink) and after doing some work gives the rest heat to the hotter body (source). An ideal refrigerator can be regarded as Carnot's ideal heat engine working in the reverse direction.



Refrigerator

Coefficient of Performance of a Refrigerator

It is defined as the ratio of quantity of heat removed per cycle (Q_2) to the work done (W) on the working substance per cycle to remove this heat.

$$\beta = \frac{Q_2}{W} = \frac{Q_2}{Q_1 - Q_2} \quad \text{or } \beta = \frac{T_2}{T_1 - T_2} = \frac{1 - \eta}{\eta}$$

DAY PRACTICE SESSION 1

FOUNDATION QUESTIONS EXERCISE

1 1 cc of water at its boiling point (100°C) absorbs 540 cal of heat to become steam with a volume of 1671 cc. If the atmospheric pressure is 1.013×10^5 Nm^{-2}, the energy spent (in cal) to overcome molecular attractive forces is nearly (mechanical equivalent of heat = 4.2 J/cal)

(a) 540 (b) 500 (c) 40 (d) zero

2 When one mole of monoatomic gas expands at constant pressure, the ratio of the heat supplied that increases the internal energy of the gas and that is used in expansion is

(a) ∞ (b) zero (c) $\frac{3}{2}$ (d) $\frac{2}{3}$

3 In a thermodynamic process with 2 moles of gas, 30 J of heat is released and 22 J of work is done on the gas. Given that initial internal energy of the sample was 20 J,what will be the final internal energy?

(a) 72 J (b) 32 J (c) 28 J (d) 12 J

4 A gas is compressed at a constant pressure of 50 Nm^{-2} from a volume of 10 m^3 to a volume of 4 m^3. Energy of 100 J is then added to the gas by heating. Its internal energy is

(a) increased by 400 J (b) increased by 200 J
(c) increased by 100 J (d) decreased by 200 J

5 The internal energy change in a system that has absorbed 2 kcal of heat and done 500 J of work is

➜ CBSE AIPMT 2009

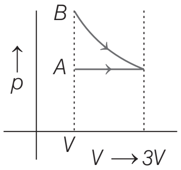
(a) 8900 J (b) 6400 J (c) 5400 J (d) 7900 J

6 Ten moles of an ideal gas at constant temperature 600 K is compressed from 100 L to 10 L. The work done in the process is

(a) 4.11×10^4 J (b) -4.11×10^4 J
(c) 11.4×10^4 J (d) -11.4×10^4 J

7 One mole of an ideal gas goes from an initial state *A* to final state *B via* two processes. It first undergoes isothermal expansion from volume *V* to 3*V* and then its volume is reduced from 3*V* to *V* at constant pressure. The correct *p*-*V* diagram representing the two processes is ➜ CBSE AIPMT 2011

(a)



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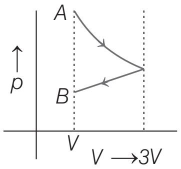
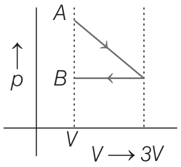
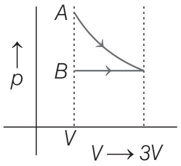


(c)



(d)



8 In thermodynamic processes, which of the following statements is not true ? ➜ CBSE AIPMT 2009

(a) In an adiabatic process the system is insulated from the surroundings
(b) In an isochoric process pressure remains constant
(c) In an isothermal process the temperature remains constant
(d) In an adiabatic process pV^{γ} = constant

9 During an isothermal expansion, a confined ideal gas does –150 J of work against its surroundings. This implies that ➜ CBSE AIPMT 2011

(a) 300 J of heat has been added to the gas
(b) no heat is transferred because the process is isothermal
(c) 150 J of heat has been added to the gas
(d) 150 J of heat has been removed from the gas

10 If ΔU and ΔW represent the increase in internal energy and work done by the system respectively in a thermodynamical process, which of the following is true? ➜ CBSE AIPMT 2010

(a) $\Delta U = -\Delta W$, in an adiabatic process
(b) $\Delta U = \Delta W$, in an isothermal process
(c) $\Delta U = \Delta W$, in an adiabatic process
(d) $\Delta U = -\Delta W$, in an isothermal process

11 A sample of perfect gas is compressed isothermally to half its volume. If it is compressed adiabatically to the same volume, the final pressure of the gas will be

(a) more (b) less (c) same
(d) more or less depending on the initial temperature of the gas

12 An ideal gas at 27°C is compressed adiabatically to 8/27 of its original volume. The rise in temperature is (take, $\gamma = 5/3$)

(a) 475°C (b) 150°C
(c) 275°C (d) 402°C

13 A monoatomic gas ($\gamma = 5/3$) at pressure *p* is suddenly compressed to $\frac{1}{64}$th of its volume adiabatically. Then, pressure of gas is

(a) 8 *p* (b) 42/3 *p*
(c) 256 *p* (d) 1024 *p*

14 A gas is compressed adiabatically till its temperature is doubled. The ratio of its final volume to initial volume will be

(a) 1/2 (b) more than 1/2
(c) less than 1/2 (d) between 1 and 2

15 One mole of an ideal gas at an initial temperature of *T* K does 6 *R* J of work adiabatically. If the ratio of specific heats of this gas at constant pressure and at constant volume is 5/3, the final temperature of gas will be

(a) (T + 2.4) K (b) (T − 2.4) K
(c) (T + 4) K (d) (T − 4) K

16 During an adiabatic process, the pressure of a gas is found to be proportional to the cube of its temperature. The ratio of $\frac{C_p}{C_V}$ for the gas is ➜ NEET 2013

(a) $\frac{4}{3}$ (b) 2 (c) $\frac{5}{3}$ (d) $\frac{3}{2}$

17 A monoatomic gas at a pressure *p*, having a volume *V* expands isothermally to a volume 2*V* and then adiabatically to a volume 16*V*. The final pressure of the gas is $\left(\text{take } \gamma = \frac{5}{3}\right)$ ➜ CBSE AIPMT 2014

(a) 64*p* (b) 32*p*
(c) $\frac{p}{64}$ (d) 16*p*

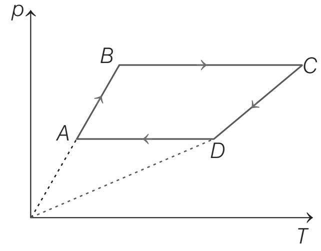
18 Which of the following statements is correct for any thermodynamic system?

(a) The internal energy changes in all processes
(b) Internal energy and entropy are state functions
(c) The change in entropy can never be zero
(d) The work done in an adiabatic process is always zero

19 We consider a thermodynamic system. If ΔU represents the increase in its internal energy and *W* the work done by the system, which of the following statements is true? ➜ CBSE AIPMT 2010

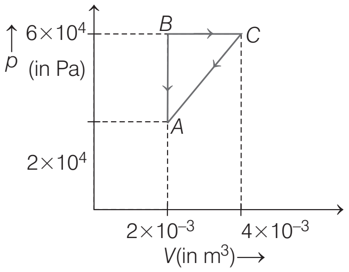
(a) $\Delta U = -W$ in an adiabatic process
(b) $\Delta U = W$ in an isothermal process
(c) $\Delta U = -W$ in an isothermal process
(d) $\Delta U = W$ in an adiabatic process

20 3 moles of an ideal monoatomic gas performs a cycle as shown in figure. The gas temperatures $T_A = 400$ K, $T_B = 800$ K, $T_C = 2400$ K, $T_D = 1200$ K, work done by the gas is



(a) 10 kJ (b) 24 kJ (c) 30 kJ (d) 40 kJ

21 Figure below shows two paths that may be taken by a gas to go from a state A to a state C.



In process AB, 400 J of heat is added to the system and in process BC, 100 J of heat is added to the system. The heat absorbed by the system in the process AC will be ➡ CBSE AIPMT 2015

(a) 380 J (b) 500 J (c) 460 J (d) 300 J

22 In an isobaric process of an ideal gas. The ratio of heat supplied and work done by the system $\left[\text{i.e.} \left(\frac{Q}{W}\right)\right]$ is

(a) $\frac{\gamma - 1}{\gamma}$ (b) γ (c) $\frac{\gamma}{\gamma - 1}$ (d) 1

23 In thermodynamic process, which of the following statements is not ture?

(a) In an adiabatic process, the system is insulated from the surroundings
(b) In an isochoric process, pressure remains constant
(c) In an isothermal process, the temperature remains constant
(d) In an adiabatic process, pv^r = constant

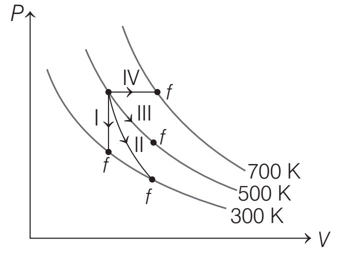
24 Two gram mole of a gas, which are kept at constant temperature of 0°C, are compressed from 4 L to 1 L. The work done will be

(a) –6500 J (b) –3000 J (c) –5800 J (d) –6359 J

25 A sample of gas expands from volume V_1 to V_2. The amount of work done by the gas is greatest when the expansion is

(a) adiabatic (b) isobaric
(c) isothermal (d) equal in all three cases

26 Thermodynamic processes are indicated in the following diagram ➡ NEET 2017



Match the following :

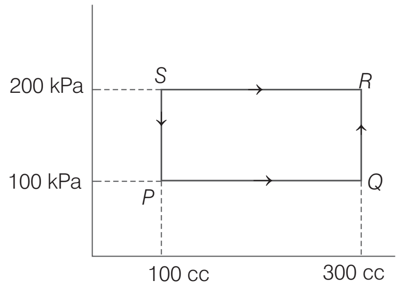
	Column-I		Column-II
P.	Process I	a.	Adiabatic
Q.	Process II	b.	Isobaric
R.	Process III	c.	Isochoric
S.	Process IV	d.	Isothermal

(a) P→ a, Q→ c, R→ d, S→ b
(b) P→ c, Q→ a, R→ d, S→ b
(c) P→ c, Q→ d, R→ b, S→ a
(d) P→ d, Q→ b, R→ a, S→ c

27 Which of the following processes is reversible?

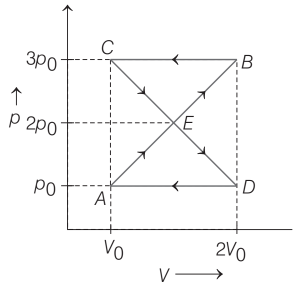
(a) Transfer of heat by radiation
(b) Electrical heating of a nichrome wire
(c) Transfer of heat by conduction
(d) Isothermal compression

28 A thermodynamic system is taken through the cycle $PQRSP$. The net work done by the system is



(a) 20 J (b) – 20 J (c) 400 J (d) – 374 J

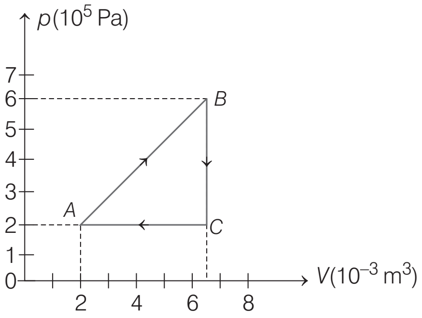
29 A thermodynamics system undergoes cyclic process $ABCDA$ as shown in figure. The work done by the system in the cycle is ➡ CBSE-AIPMT 2014



(a) p_0V_0 (b) $2p_0V_0$ c) $\frac{p_0V_0}{2}$ (d) Zero

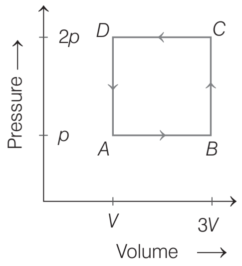
30 A gas is taken through the cycle $A \to B \to C \to A$, as shown in figure. What is the net work done by the gas?

➜ NEET 2013



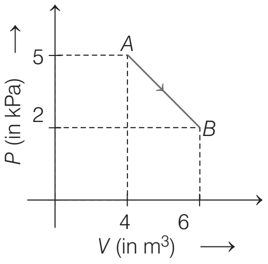
(a) 2000 J (b) 1000 J (c) Zero (d) – 2000 J

31 A thermodynamic system is taken through the cycle *ABCD* as shown in figure. Heat rejected by the gas during the cycle is ➜ CBSE AIPMT 2012



(a) 2 pV (b) 4 pV (c) $\frac{1}{2}pV$ (d) pV

32 One mole of an ideal diatomic gas undergoes a transition from *A* to *B* along a path *AB* as shown in the figure.



The change in internal energy of the gas during the transition is ➜ CBSE AIPMT 2015

(a) 20 kJ (b) –20 kJ (c) 20 J (d) –12 kJ

33 A bread gives a boy 5000 cal. How much height he can climb by using this energy, if his efficiency is 28%? (Mass of the boy = 60 kg)

(a) 2.5 m (b) 5 m (c) 10 m (d) 15 m

34 A person of mass 60 kg wants to lose 5 kg by going up and down a 10 m high stairs. Assume he burns twice as much fat while going up than coming down. If 1 kg of fat is burnt on expanding 7000 kilo calories, how many times must be go up and down to reduce his weight by 5 kg?

(a) 10.5×10^3 (b) 24.3×10^3 (c) 16.3×10^3 (d) 9×10^3

35 The efficiency of an ideal heat engine working between the freezing point and boiling point of water is

➜ NEET 2018

(a) 6.25% (b) 20% (c) 26.8% (d) 12.5 %

36 An ideal gas heat engine operates in Carnot cycle between 227°C and 127°C. It absorbs 6×10^4 cal of heat at higher temperature. Amount of heat converted to work is

(a) 2.4×10^4 cal (b) 6×10^4 cal
(c) 1.2×10^4 cal (d) 4.8×10^4 cal

37 A reversible engine takes in heat from a reservoir of heat at 527°C and gives it to the sink at 127°C. How many calorie/s it shall take from the reservoir to do a work of 750 W.

(a) 257 cal s^{-1} (b) 357 cal s^{-1}
(c) 1500 cal s^{-1} (d) None of these

38 In refrigerator one removes heat from a lower temperature and deposits to the surroundings at a higher temperature. In this process, mechanical work has to be done, which is provided by an electrical motor. If the motor is of 1kW power and heat is transferred from –3°C to 27°C, find the heat taken out of the refrigerator per second assuming its efficiency is 50% of a perfect engine.

(a) 12 kJ (b) 19 kJ (c) 10 kJ (d) 7 kJ

39 A Carnot engine having an efficiency of $\frac{1}{10}$ as heat engine, is used as a refrigerator. If the work done on the system is 10 J, the amount of energy absorbed from the reservoir at lower temperature is ➜ NEET 2017

(a) 1 J (b) 90 J (c) 99 J (d) 100 J

40 If the coefficient of performance of a refrigerator is 5 and 6 operates at the room temperature (27°C), find the temperature inside the refrigerator.

(a) – 23°C (b) –20°C (c) –15°C (d) –31°C

41 A refrigerator works between 4°C and 30°C. It is required to remove 600 calories of heat every second in order to keep the temperature of the refrigerated space constant. The power required is (Take, 1 cal = 4.2 Joules)

➜ NEET 2016

(a) 23.65 W (b) 236.5 W
(c) 2365 W (d) 2.365 W

42 The temperature inside a refrigerator is $t_2\,°\mathrm{C}$ and the room temperature is $t_1\,°\mathrm{C}$. The amount of heat delivered to the room for each joule of electrical energy consumed ideally will be ➜ NEET 2016

(a) $\frac{t_1}{t_1 - t_2}$ (b) $\frac{t_1 + 273}{t_1 - t_2}$
(c) $\frac{t_2 + 273}{t_1 - t_2}$ (d) $\frac{t_1 + t_2}{t_1 + 273}$

43 The coefficient of performance of a refrigerator is 5. If the temperature inside freezer is – 20° C, the temperature of the surroundings to which it rejects heat is

➡ CBSE AIPMT 2015

(a) 31°C (b) 41°C (c) 11°C (d) 21°C

44 An ideal refrigerator has a freezer at a temperature of – 13°C. The coefficient of performance of the engine is 5. The temperature of the air (to which heat is rejected) will be

(a) 325°C (b) 325 K (c) 39°C (d) 320°C

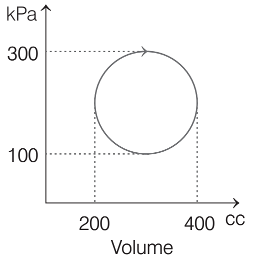
DAY PRACTICE SESSION 2

PROGRESSIVE QUESTIONS EXERCISE

1 One mole of oxygen is expanded from a volume 1 L to 5 L at a constant temperature $T = 280$ K. The change in internal energy is

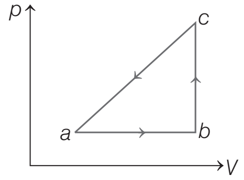
(a) 0.22 kJ (b) 22 J (c) 0.11 kJ (d) 11 J

2 The heat absorbed by the system in going through the process as shown in figure



(a) 100 J (b) 200 J (c) 31.4 J (d) 68.3 J

3 The *p-V* diagram of a system undergoing thermodynamic transformation as shown in figure. The work done by the system in going from $a \to b \to c$ is 50 J and 20 cal heat is given to the system. The change in internal energy between *a* and *c* is



(a) 34 J (b) 70 J (c) 84 J (d) 134 J

4 Consider a Carnot's cycle operating between $T_1 = 500$ K and $T_2 = 300$ K producing 1 kJ of mechanical work per cycle. Find the heat transferred to the engine by the reservoirs.

(a) 1500 J (b) 1000 J
(c) 2000 J (d) None of these

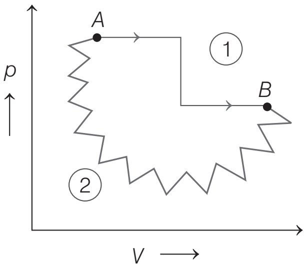
5 An engine has an efficiency of $\frac{1}{6}$. When the temperature of sink is reduced by 62°C, its efficiency is doubled. Temperature of the source is

(a) 124°C (b) 37°C (c) 62°C (d) 99°C

6 A Carnot engine whose sink is at 300K has an efficiency of 40%. By how much should the temperature of source be increased so as to increase its efficiency by 50% of original efficiency?

(a) 275 K (b) 325 K (c) 250 K (d) 380 K

7 In the given *p-V* diagram, the path (2) from *A* to *B* is *zig-zag* path, but (1) is simple path. Then,



(a) $W_1 = W_2$ (b) $\Delta U_1 = \Delta U_2$
(c) $W_1 > W_2$ (d) Both (b) and (c) are true

8 Efficiency of a Carnot engine is 50% when temperature of outlet is 500 K. In order to increase efficiency upto 60% keeping temperature of intake the same, what is temperature of outlet?

(a) 200 K (b) 400 K (c) 600 K (d) 800 K

9 A gas is compressed isothermally to half its initial volume. The same gas is compressed separately through an adiabatic process until its volume is again reduced to half. Then ➡ NEET 2016

(a) compressing the gas through adiabatic process will require more work to be done.
(b) compressing the gas isothermally or adiabatically will require the same amount of work.
(c) which of the case (whether compression through isothermal or through adiabatic process) requires more work will depend upon the atomicity of the gas.
(d) compressing the gas isothermally will require more work to be done.

10 An ideal gas is compressed to half its initial volume by means of several process. Which of the process results in the maximum work done on the gas? ➡ CBSE AIPMT 2015

(a) Adiabatic (b) Isobaric (c) Isochoric (d) Isothermal

11 A steam engine whose source is at 400 K, takes 200 cal of heat and rejects 150 cal to the sink. What is the temperature of the sink?

(a) 800 K (b) 400 K
(c) 300 K (d) None of these

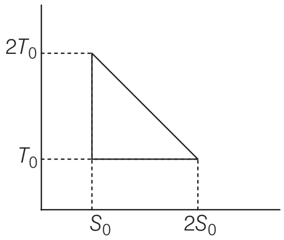
12 1 mm^3 of a gas is compressed at 1 atmosphere pressure and temperature 27°C to 627°C. What is the final pressure under adiabatic condition?
(Take, γ for the gas $= 1.5$)

(a) 27×10^5 N/m^2 (b) 80×10^5 N/m^2
(c) 36×10^5 N/m^2 (d) 56×10^5 N/m^2

13 When 1 g of water at 0°C and 1×10^5 N/m^2 pressure is converted into ice of volume 1.091 cm^3, the external work done will be

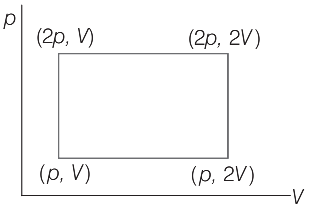
(a) 0.0091 J (b) 0.0182 J (c) – 0.0091 J (d) –0.0182 J

14 The temperature-entropy diagram of a reversible engine cycle is given in the figure. Its efficiency is



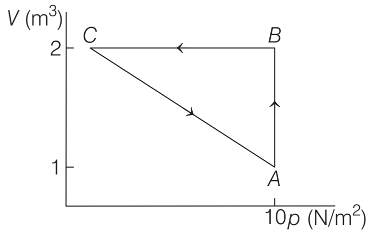
(a) $\frac{1}{3}$ (b) $\frac{2}{3}$ (c) $\frac{1}{2}$ (d) $\frac{1}{4}$

15 Work done in the given *p-V* diagram in the cyclic process is



(a) pV (b) $2pV$ (c) $\frac{pV}{2}$ (d) $3pV$

16 An ideal gas is taken through the cycle. $A \rightarrow B \rightarrow C \rightarrow A$ as shown in the figure. If the hot heat supplied to the gas in the cycle is 5J, the work done by the gas in the process $C \rightarrow A$ is



(a) –5 J (b) –10 J (c) –15 J (d) –20 J

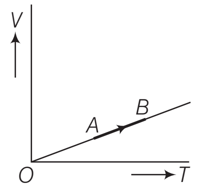
17 A Carnot engine, having an efficiency of $\eta = \frac{1}{10}$ as heat engine is used as a refrigerator. If the work done on the system is 10 J, the amount of energy absorbed from the reservoir at lower temperature is ➜ CBSE AIPMT 2015

(a) 100 J (b) 99 J (c) 90 J (d) 1 J

18 A Carnot engine has an efficiency 50% when its sink is at a temperature of 27°C. The temperature of the source is

(a) 273°C (b) 300°C (c) 327°C (d) 373°C

19 The volume (V) of a monoatomic gas varies with its temperature (T), as shown in the graph. The ratio of work done by the gas, to the heat absorbed by it, when it undergoes a change from state A to state B, is ➜ NEET 2018



(a) $\frac{1}{3}$ (b) $\frac{2}{3}$ (c) $\frac{2}{5}$ (d) $\frac{2}{7}$

20 A sample of 0.1 g of water at $100°$ C and normal pressure $(1.013 \times 10^5$ Nm$^{-2})$ requires 54 cal of heat energy to convert to steam at $100°$ C. If the volume of the steam produced is 167.1 cc, the change in internal energy of the sample, is ➜ NEET 2018

(a) 42.2 J (b) 208.7 J (c) 104.3 J (d) 84.5 J

ANSWERS

SESSION 1	**1** (b)	**2** (c)	**3** (d)	**4** (a)	**5** (d)	**6** (d)	**7** (b)	**8** (b)	**9** (c)	**10** (a)
	11 (a)	**12** (d)	**13** (d)	**14** (b)	**15** (d)	**16** (d)	**17** (c)	**18** (b)	**19** (c)	**20** (b)
	21 (c)	**22** (c)	**23** (b)	**24** (d)	**25** (d)	**26** (b)	**27** (d)	**28** (b)	**29** (d)	**30** (b)
	31 (a)	**32** (b)	**33** (c)	**34** (c)	**35** (c)	**36** (c)	**37** (b)	**38** (b)	**39** (b)	**40** (a)
	41 (b)	**42** (b)	**43** (a)	**44** (c)						
SESSION 2	**1** (c)	**2** (c)	**3** (a)	**4** (a)	**5** (d)	**6** (c)	**7** (d)	**8** (b)	**9** (c)	**10** (a)
	11 (c)	**12** (a)	**13** (a)	**14** (a)	**15** (a)	**16** (a)	**17** (c)	**18** (c)	**19** (c)	**20** (b)

Hints and Explanations

SESSION 1

1 Work done against the atmospheric pressure

$$W = p\,\Delta V$$

$$= 1.013\times 10^5\times(1671-1)\times 10^{-6}\text{J}$$

$$= 1.013\times 167\text{ J}$$

$$= \frac{1.013\times 167}{4.2}\text{ cal}\cong 40\text{ cal}$$

Water absorbs 540 cal of heat out of which 40 cal is used in doing work against the atmospheric pressure. Therefore, work done to overcome the molecular attraction

$$= 540 - 40 = 500$$

2 We know that, $\Delta Q = \Delta U + p\Delta V$

$$n\times C_p\times\Delta T = \Delta U + R\,\Delta T$$

$$1\times\frac{5}{2}R\times\Delta T = \Delta U + R\,\Delta T$$

$\Rightarrow$ $\Delta U = 1.5\,R\,\Delta T$

Therefore, $\dfrac{\Delta U}{R\,\Delta T} = 1.5 = \dfrac{3}{2}$

3 $\Delta Q = \Delta U + \Delta W$

$= U_2 - U_1 + \Delta W$

Here, $\Delta Q = -30\text{ J}, \Delta W = -22\text{ J}$

$U_1 = 20\text{ J}$

Hence,

$U_2 = \Delta Q - \Delta W + U_1$

$= -30\text{ J} - (-22\text{ J}) + 20\text{ J}$

$= 12\text{ J}$

4 Work done by the $= p\Delta V$

$$= -50(10-4) = -300\text{ J}$$

Using $dQ = dU + dW$

$\Rightarrow$ $dU = dQ - dW$

$= 300 + 100 = 400\text{ J}$

Increased by 400 J

5 According to first law of thermodynamics

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

ΔU = change in internal energy

Q = heat given to system

W = work done

$\therefore$ $\Delta U = 2\times 4.2\times 1000 - 500$

$= 8400 - 500 = 7900\text{ J}$

6 Work done in an isothermal process

$$W = 2.3026\,nRT\,\log_{10}\left(\frac{V_2}{V_1}\right)$$

$$= 2.3026\times 10\times 8.3\times 600\log_{10}\left(\frac{10}{100}\right)$$

$$= -11.4\times 10^4\text{ J}$$

7 According to question first gas goes from volume V to $3V$ and after this volume is reduced from $3V$ to V at constant pressure. In isothermal expansion p-V curve is rectangular hyperbola.

8 For an adiabatic process, there should not be any exchange of heat between the system and its surroundings. All walls of the container must be perfectly insulated. In adiabatic changes, gases obey Poisson's law, i.e., pV^γ = constant.

In an isochoric process, volume remains constant and for isobaric process, pressure remains constant.

9 According to first law of thermodynamics

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

For isothermal process, $\Delta U = 0$

So, $\Delta Q = -\Delta W$

Given, $\Delta W = -150\text{ J}$

So, $\Delta Q = +150\text{ J}$

When Q is positive, the heat is added to the gas.

10 From first law of thermodynamics

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

For adiabatic process, $\Delta Q = 0$

$\because$ $\Delta Q = 0$

So, $\Delta U = -\Delta W$

11 For isothermal compression,

$$p_2 = \frac{p_1V_1}{V_2}$$

For adiabatic compression,

$$p_2 = p_1\left(\frac{V_1}{V_2}\right)^\gamma$$

Since, $\gamma = \dfrac{C_p}{C_V} > 1$, hence p_2 will be more as compared to that of isothermal compression.

12 We know that, pV^γ = constant

$$TV^{\gamma-1} = \text{constant}$$

$$300 = \left(\frac{8}{27}\right)^{2/3}T_2$$

$\Rightarrow$ $T_2 = 675\text{ K} = 402°\text{C}$

13 $p_1V_1^\gamma = p_2V_2^\gamma$

$$pV^{5/3} = p_2\left(\frac{V}{64}\right)^{5/3} \qquad [\because p_1 = p]$$

$\Rightarrow$ $p_2 = 1024\,p$

14 In adiabatic process,

pV^γ = constant

Since, $pV = RT$

Hence, $TV^{\gamma-1} = k$

$\Rightarrow$ $T_1V_1^{\gamma-1} = T_2V_2^{\gamma-1}$

$\Rightarrow$ $\left(\dfrac{V_2}{V_1}\right)^{\gamma-1} = \left(\dfrac{T_1}{T_2}\right) = \dfrac{1}{2}$

$\Rightarrow$ $\dfrac{V_2}{V_1} = \left(\dfrac{1}{2}\right)^{\frac{1}{\gamma-1}}$

Hence, ratio will be more than $\dfrac{1}{2}$.

15 Work done in an adiabatic process

$$W = \frac{nR}{\gamma-1}(T_i - T_f) \qquad \ldots\text{(i)}$$

Here, $W = 6R$ J, $n = 1$ mol,

$R = 8.31\text{ Jmol}^{-1}\text{K}^{-1}$, $\gamma = \dfrac{5}{3}$, $T_i = T$ K

Substituting given values in Eq. (i), we get

$\therefore$ $6R = \dfrac{R}{\left(\dfrac{5}{3}-1\right)}(T - T_f)$

$\Rightarrow$ $6R = \dfrac{3R}{2}(T - T_f)$

$\Rightarrow$ $T - T_f = 4$

$\therefore$ $T_f = (T - 4)\text{K}$

16 According to question, $p \propto T^3$

$$pV = nRT \text{ and } p \propto T^3$$

Also, $p \propto (pV)^3$

$\Rightarrow$ p^2V^3 = constant

$\Rightarrow$ $pV^{3/2}$ = constant $\ldots$(i)

$\because$ pV = constant $\ldots$(ii)

Comparing eqn (i) and (ii)

$\therefore$ $\gamma = \dfrac{3}{2}$

17 In isothermal expansion

$pV = p_2 2V$

$\Rightarrow$ $p_2 = \dfrac{p}{2}$

In adiabatic expansion $p_2V_2^\gamma = p_3V_3^\gamma$

$\Rightarrow$ $\dfrac{p}{2}(2V)^{5/3} = p_3(16V)^{5/3}$

$\Rightarrow p_3 = \dfrac{p}{2}\left(\dfrac{2V}{16V}\right)^{5/3} = \dfrac{p}{2}\times\left(\dfrac{1}{8}\right)^{5/3} = \dfrac{p}{64}$

18 Internal energy does not change in isothermal process. ΔS can be zero for adiabatic process. Work done in adiabatic process may be non-zero.

19 From first law of thermodynamics,

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

For adiabatic process, $\Delta Q = 0$

$$\Delta U = -\Delta W$$

20 $W_{BC} = 3R(T_C - T_B)$

$W_{AB} = W_{CD} = 0$

Because, the processes are isochoric

$W_{DA} = 3R\,(T_A - T_D)$

$\therefore$ Total work done

$$W_{BC} + W_{DA} = 3R(T_A + T_C - T_B - T_D)$$
$$= 3R\,(400 + 2400 - 800 - 1200)$$
$$= 2400\,R = 24\text{ kJ}$$

21 As initial and final points are same, so

$\Delta U_{A \to B \to C} = \Delta U_{A \to C}$

$A \to B$ is isochoric process

$$dW_{A \to B} = 0$$
$$dQ_{A \to B} = dU_{A \to B} = 400\text{ J}$$

$B \to C$ is isobaric process

$$dQ_{B \to C} = dU_{B \to C} + dW_{B \to C}$$
$$100\text{ J} = dU_{B \to C} + 6 \times 10^4 (2 \times 10^{-3})$$
$$100\text{ J} = dU_{B \to C} + 12 \times 10$$
$$dU_{B \to C} = 100 - 120 = -20\text{ J}$$

So, $\Delta U_{A \to B \to C} = \Delta U_{A \to C}$

$$\Delta U_{A \to B} = \Delta U_{B \to C} = dQ_{A \to C} - dW_{A \to C}$$
$$400 - 20 = dQ_{A \to C} - \left(2 \times 10^{+4} \times 2 \times 10^{-3} + \frac{1}{2} \times 2 \times 10^{-3} \times 4 \times 10^{+4}\right)$$
$$380\text{ J} = dQ_{A \to C} - (40 + 40)$$
$$dQ_{A \to C} = 380 + 80 = 460\text{ J}$$

22 From ideal gas equation,

$$pV = nRT \qquad \ldots\text{(i)}$$

where, p is pressure, V is the volume, R is the gas constant, T is the absolute temperature.

For isobaric process,

$$Q = nC_p\Delta T \qquad \ldots\text{(ii)}$$
$$W = p\Delta V \qquad \ldots\text{(iii)}$$

where, C_p is specific heat at constant pressure.

From Eqs. (i), (ii) and (iii), we get

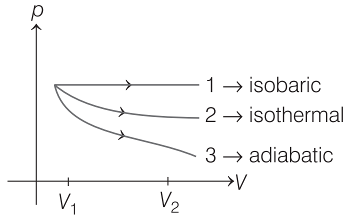
$$\frac{Q}{W} = \frac{nC_p\Delta T}{nR\Delta T} = \frac{C_p}{R} = \frac{\gamma}{\gamma - 1}$$

23 In an isochoric process, pressure remains constant.

24 We know that work done in an isothermal process is

$$W = 2.303\mu RT \log_{10}\frac{V_2}{V_1}$$
$$W = 2.303 \times 2 \times 8.4 \times 273 \log_{10}\frac{1}{4}$$
$$W = 2.303 \times 2 \times 8.4 \times 273 \times (\log_{10} 1 - \log_{10} 4)$$
$$[\because \log_{10} 4 = 0.6021]$$
$$\therefore \quad W \approx -6359\text{ J}$$

25 The p-V diagram for isobaric, isothermal and adiabatic process of an ideal gas is shown in graph below.



In thermodynamics, for same change in volume, the work done is maximum for the curve having maximum area enclosed with the volume axis.

26 In isochoric process, the curve is parallel to y-axis because volume is constant.Isobaric is parallel to x-axis because pressure is constant. Along the curve, it will be isothermal because temperature is constant.

So, P→ c ⇒ Q→ a ⇒ R→ d ⇒ S→ b

27 Isothermal compression is reversible.

28 Work done = area enclosed in indicator diagram $PQRSP$

$$= \Delta p\,\Delta V = (p_p - p_s)(V_Q - V_P)$$
$$= (1 \times 10^5 - 2 \times 10^5)(3 \times 10^{-4} - 1 \times 10^{-4})$$
$$= -20\text{ J}$$

29 Work done by the system

$$W = \text{Area of } BCE + \text{Area of } ADE$$
$$= -W_0 + W_0 = 0$$

30 Net work done area enclosed in p-V curve, i.e. ΔABC

$$= \frac{1}{2} \times 5 \times 10^{-3} \times 4 \times 10^5\text{ J}$$
$$= 10^3\text{ J} = 1000\text{ J}$$

31 For given cyclic process, $\Delta U = 0$

$$\therefore \quad \Delta Q = \Delta W$$

Also, W = area enclosed by the curve

$$= AB \times AD = (p - 2p)(3V - V)$$
$$= -p \times 2V$$

$\therefore$ Heat rejected = $2\,pV$

32 Since, $\Delta U = nC_V dT$

$$= n\left(\frac{5R}{2}\right)(T_B - T_A)$$
$$= \frac{5nR}{2}\left(\frac{p_B V_B}{nR} - \frac{p_A V_A}{nR}\right)$$
$$= \frac{5}{2}(p_B V_B - p_A V_A)$$
$$= \frac{5}{2}(2 \times 10^3 \times 6 - 5 \times 10^3 \times 4)$$
$$= \frac{5}{2}(-8 \times 10^3)$$
$$= -20\text{ kJ}$$

33

$$Mgh = \frac{28}{100} \times 5000 \times 4.2$$
$$\Rightarrow \text{height } h = \frac{28 \times 4.2 \times 50}{60 \times 9.8} \cong 10\text{ m}$$

34 $5 \times 7000 \times 10^3 \times 4.2\text{ J}$

$$= 60 \times 15 \times 10 \times N$$
$$N = \frac{21 \times 7 \times 10^6}{9000} = \frac{147}{9} \times 10^3$$
$$= 16.3 \times 10^3 \text{ times.}$$

35 Efficiency of an ideal heat engine is given as

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

where, T_1 is the temperature of the source and T_2 is the temperature of the sink.

$$T_1 = 100 + 273 = 373\text{ K}$$
$$T_2 = 0 + 273 = 273\text{ K}$$
$$\because \quad \eta = 1 - \frac{273}{373} = \frac{373 - 273}{373}$$
$$= \frac{100}{373} = 0.268$$
$$\eta\% = 0.268 \times 100 = 26.8\%$$

36 From the relation, $\dfrac{Q_2}{Q_1} = \dfrac{T_2}{T_1}$

Given, $Q_1 = 6 \times 10^4$ cal,

$$T_1 = 227 + 273 = 500\text{ K}$$
$$T_2 = 127 + 273 = 400\text{ K}$$
$$\therefore \quad \frac{Q_2}{6 \times 10^4} = \frac{400}{500}$$
$$\Rightarrow \quad Q_2 = \frac{4}{5} \times 6 \times 10^4 = 4.8 \times 10^4\text{ cal}$$

Now, heat converted to work

$$= Q_1 - Q_2 = 6.0 \times 10^4 - 4.8 \times 10^4$$
$$= 1.2 \times 10^4\text{ cal}$$

37 Efficiency of a Carnot's engine is given by

$$\eta = \frac{W}{Q} = 1 - \frac{T_2}{T_1} \Rightarrow W = \left(1 - \frac{T_2}{T_1}\right)Q$$

Substituting

$$T_2 = 127 + 273 = 400\text{ K}$$
$$T_1 = 527 + 273 = 800\text{ K}$$
$$Q = \frac{W}{\left(1 - \frac{T_2}{T_1}\right)} = \frac{2 \times 750}{4.2} = 357.1$$

Cal/s

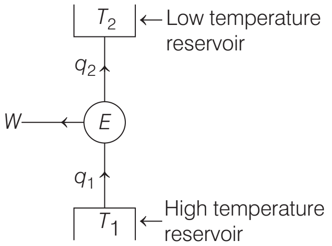
38 $\eta = 1 - \dfrac{270}{300} = \dfrac{1}{10}$. Efficiency of refrigerator $= 0.5\,\eta = \dfrac{1}{20}$

If Q is the heat/s transferred at higher temperature, then $\dfrac{W}{Q} = \dfrac{1}{20}$ or

$Q = 20\text{W} = 20\text{ kJ}$

and heat removed from lower temperature = 19 kJ.

39 Consider schematic diagram for a Carnot engine as shown below.



In case of engine, engine efficiency

$$= \frac{\text{work}}{\text{heat absorbed}} = \frac{W}{q_1}$$

$$\therefore \quad \frac{W}{q_1} = \frac{1}{10} \Rightarrow \frac{10\text{ J}}{q_1} = \frac{1}{10}$$

or $q_1 = 100$ J

When this engine is reversed, it takes in work W and heat q_2 from cold reservoir and ejects 100 J of heat to hot reservoir.

$\therefore \quad W + q_2 = q_1 \Rightarrow 10 + q_2 = 100$

or $\quad q_2 = 90$ J

40 $\frac{Q_2}{W} = 5, Q_2 = 5W, Q_1 = 6W$

$\frac{T_2}{T_1} = \frac{5}{6} = \frac{T_2}{300}, T_2 = 250\text{ K} = -23°\text{C}$

41 Given, temperature of source,

$T_1 = 30°\text{C}$
$= 30 + 273$
$= 303$ K

Temperature of sink,

$T_2 = 4°\text{C} = 4 + 273 = 277$ K

As, we know that

$$\frac{Q_1}{Q_2} = \frac{T_1}{T_2}$$

$$\Rightarrow \quad \frac{Q_2 + W}{Q_2} = \frac{T_1}{T_2} \qquad [\because W = Q_1 - Q_2]$$

where Q_2 is the amount of heat drawn from the sink (at T_2), W is workdone on working substance, Q_1 is amount of heat rejected to source (at room temperature T_1).

$\Rightarrow \quad WT_2 + T_2Q_2 = T_1Q_2$

$\Rightarrow \quad WT_2 = T_1Q_2 - T_2Q_2$

$\Rightarrow \quad WT_2 = Q_2(T_1 - T_2)$

$$\Rightarrow \quad W = Q_2\left(\frac{T_1}{T_2} - 1\right)$$

$$\Rightarrow \quad W = 600 \times 4.2 \times \left(\frac{303}{277} - 1\right)$$

$$W = 600 \times 4.2 \times \left(\frac{26}{277}\right)$$

$W = 236.5$ Joules

$$\text{Power} = \frac{\text{Work done}}{\text{Time}}$$

$$= \frac{W}{t} = \frac{236.5}{1}$$

$= 236.5$ W

42 For a refrigerator, we know that

$$\frac{Q_1}{W} = \frac{Q_1}{Q_1 - Q_2} = \frac{T_1}{T_1 - T_2}$$

where,

Q_1 = amount of heat delivered to the room

W = electrical energy consumed

T_1 = room temperature $= t_1 + 273$

T_2 = temperature of sink $= t_2 + 273$

$$\therefore \quad \frac{Q_1}{1} = \frac{t_1 + 273}{t_1 + 273 - (t_2 + 273)}$$

$$\Rightarrow \quad Q_1 = \frac{t_1 + 273}{t_1 - t_2}$$

43 Given, coefficient of performance of a refrigerator, $\beta = 5$

Temperature of surface, i.e. inside freezer,

$T_2 = -20°\text{C} = -20 + 273 = 253\text{ K}$

Temperature of surrounding, i.e. heat rejected outside $T_1 = ?$

$$\text{So,} \quad \beta = \frac{T_2}{T_1 - T_2} \Rightarrow 5 = \frac{253}{T_1 - 253}$$

$\Rightarrow \quad 5T_1 - 1265 = 253$

$\Rightarrow \quad 5T_1 = 1518$

$$T_1 = \frac{1518}{5} = 303.6\text{ K}$$

$T_1 = 303.6 - 273 = 31°\text{ C}$

44 Given that, the temperature of freezer, $T_2 = -13°\text{ C} \Rightarrow T_2 = -13 + 273 = 260\text{ K}$

Coefficient of performance, $\beta = 5$

The coefficient of performance is defined as,

$$\beta = \frac{T_2}{T_1 - T_2} \quad \text{or} \quad 5 = \frac{260}{T_1 - 260}$$

$$\therefore \quad T_1 - 260 = \frac{260}{5} \text{ or } T_1 - 260 = 52$$

or $\quad T_1 = (52 + 260)\text{ K} = 312$ K

$= (312 - 273°)\text{C}$

$\Rightarrow \quad T_1 = 39°\text{C}$

SESSION 2

1 $\Delta Q = \int_{V_1}^{V_2}\left(\frac{\delta U}{\delta V}\right)dV$

From second law of thermodynamics

$$\left(\frac{\partial U}{\partial V}\right)_T = T\left(\frac{\partial S}{\partial V}\right)_T - p$$

$$= T\left(\frac{\partial p}{\partial T}\right)_V - p,$$

$$p = \frac{RT}{V - b} - \frac{a}{V^2}$$

$$T\left(\frac{\partial p}{\partial T}\right)_V = \frac{RT}{V - b} \text{ and } \left(\frac{\partial U}{\partial V}\right)_T = \frac{a}{V^2}$$

Given, $\quad V_1 = 1\text{ L}, V_2 = 5\text{ L}$

$$\Delta Q = a\left[\frac{1}{V_1} - \frac{1}{V_2}\right] = 0.11\text{ kJ}$$

2 Heat absorbed $= \pi r^2$

$= 3.14 \times (100 \times 10^3) \times (100 \times 10^{-6})$

$= 31.4$ J

3 Heat added to system is given by

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

Here, $\Delta Q = 20$ cal $= 84$ J and $\Delta W = 50$ J

$\Rightarrow \quad \Delta U = 84 - 50 = 34$ J

4 $\frac{Q_2}{Q_1} = \frac{T_2}{T_1} = \frac{3}{5}, Q_1 - Q_2 = 10^3$ J

$$Q_1\left(1 - \frac{3}{5}\right) = 10^3\text{ J}$$

$$\Rightarrow \quad Q_1 = \frac{5}{2} \times 10^3\text{ J} = 2500\text{ J},$$

$Q_2 = 1500$ J

5 Efficiency of engine is given by

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

$$\therefore \quad \frac{T_2}{T_1} = 1 - \eta = 1 - \frac{1}{6} = \frac{5}{6} \qquad \text{...(i)}$$

In other case,

$$\frac{T_2 - 62}{T_1} = 1 - \eta = 1 - \frac{2}{6} = \frac{2}{3} \qquad \text{...(ii)}$$

Using Eq. (i), we get

$$T_2 - 62 = \frac{2}{3}T_1 = \frac{2}{3} \times \frac{6}{5}T_2 \text{ or } \frac{1}{5}T_2 = 62$$

$\therefore \quad T_2 = 310$ K

$$\text{Here,} \quad T_1 = \frac{6}{5}T_2 = \frac{6}{5} \times 310$$

$= 372\text{ K} = 372 - 273 = 99°\text{C}$

6 The efficiency of Carnot engine

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

Here, T_1 is the temperature of source and T_2 is the temperature of sink.

As given, $\eta = 40\% = \frac{40}{100} = 0.4$

and $T_2 = 300$ K

$$\text{So, } 0.4 = 1 - \frac{300}{T_1} \Rightarrow T_1 = \frac{300}{1 - 0.4} = 500\text{ K}$$

Let temperature of the source be increased by x, then efficiency becomes

$\eta' = 40\% + 50\%$ of η

$$= \frac{40}{100} + \frac{50}{100} \times 0.4$$

$= 0.4 + 0.5 \times 0.4 = 0.6$

$$\text{Hence,} \quad 0.6 = 1 - \frac{300}{500 + x}$$

$$\Rightarrow \quad \frac{300}{500 + x} = 0.4$$

$\therefore \quad x = 750 - 500 = 250$ K

7 Work done depends upon the path followed by process

So, $\quad W_1 \neq W_2$

Since, change in internal energy depends upon the initial and final state, it does not depend upon the path followed by the process,

$$\Delta U_1 = \Delta U_2$$

The area under p-V diagram gives the work done by the gas. Here, path (1) is greater than path (2), so $W_1 > W_2$. Hence, option (d) is true.

8 $$\eta = 1 - \frac{T_2}{T_1} \Rightarrow \frac{1}{2} = 1 - \frac{500}{T_1}$$

$$\frac{500}{T_1} = \frac{1}{2} \quad \ldots\text{(i)}$$

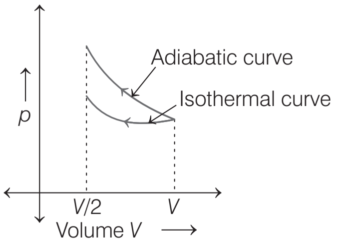
$$\Rightarrow \frac{60}{100} = 1 - \frac{T_2'}{T_1} \Rightarrow \frac{T_2'}{T_1} = \frac{2}{5} \quad \ldots\text{(ii)}$$

On dividing Eq. (i) by Eq. (ii), we get

$$\frac{500}{T_2'} = \frac{5}{4}$$

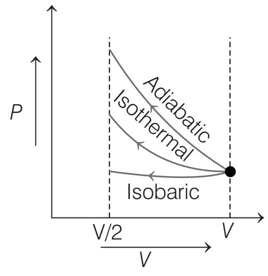
$$\therefore \quad T_2' = 400\,\text{K}$$

9 The solution of this question can be understood by plotting a p-V graph for the compression of a gas isothermally and adiabatically simultaneously to half of its initial volume. *i.e.*



Since, the isothermal curve is less steeper than the adiabatic curve. So, area under the p-V curve for adiabatic process has more magnitude than isothermal curve. Hence, work done in adiabatic process will be more than in isothermal process.

10 Given, ideal gas is compressed to half its initial volume i.e. $V_0 = \frac{V}{2}$



The isochoric process is one in which volume is kept constant, meaning that work done by the system will be zero. i.e. $W_{\text{isochoric}} = 0$

As we know, work done on the gas = Area under curve, i.e.

$$W_{\text{adiabatic}} > W_{\text{isothermal}} > W_{\text{isobaric}}$$

11 $$\eta = \frac{Q_1 - Q_2}{Q_1} = \frac{200 - 150}{200} = \frac{1}{4}$$

$$\eta = \frac{1}{4} = 1 - \frac{T_2}{T_1}$$

This gives

$$T_2 = \frac{3}{4}T_1 = \frac{3}{4} \times 400\text{ K} = 300\text{ K}$$

12 Given, $p_1 = 10^5\ \text{N/m}^2$,

$T_1 = 27 + 273 = 300\,\text{K}$,

$T_2 = 627 + 273 = 900\,\text{K}$, $\gamma = 1.5$

For adiabatic change $= \dfrac{T^{\gamma}}{p^{\gamma-1}} =$ constant

$$\left(\frac{p_2}{p_1}\right)^{1/2} = \left(\frac{T_2}{T_1}\right)^{3/2} \Rightarrow \left(\frac{p_2}{10^5}\right)^{1/2} = \left(\frac{900}{300}\right)^{3/2}$$

$$\therefore \quad p_2 = 27 \times 10^5\ \text{N/m}$$

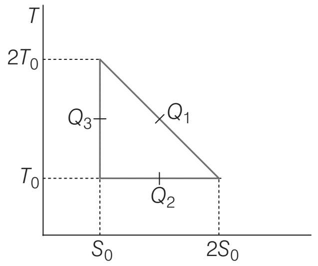
13 It is an isothermal process. Hence, work done

$$= p(V_2 - V_1) = 1 \times 10^5 (1.091 - 1) \times 10^{-6}$$

$$= 0.0091\ \text{J}$$

14 $$Q_1 = T_0S_0 + \frac{1}{2}T_0S_0 = \frac{3}{2}T_0S_0$$

$$Q_2 = T_0S_0 \text{ and } Q_3 = 0$$



$$\eta = \frac{W}{Q_1} = \frac{Q_1 - Q_2}{Q_1} = 1 - \frac{Q_2}{Q_1} = 1 - \frac{2}{3} = \frac{1}{3}$$

15 Work done = Area of closed pV diagram

$$= (2V - V) \times (2p - p) = pV$$

16 For cyclic process, total work done

$$= W_{AB} + W_{BC} + W_{CA}$$

$$\Delta W_{AB} = p\Delta V$$

$$= 10(2 - 1) = 10\ \text{J}$$

and $\Delta W_{AB} = 0$ (as = constant)

From First law of thermodynamics,

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

$$\Delta U = 0$$

(process $ABCA$ is cyclic)

$$\Delta Q = \Delta W_{AB} + \Delta W_{BC} + \Delta W_{CA}$$

$$5 = 10 + 0 + \Delta W_{CA}$$

$$\Delta W_{CA} = -5\ \text{J}$$

17 $$\frac{Q_2}{Q_1} = \frac{T_2}{T_1} \Rightarrow \frac{\Theta_1 + \Omega}{\Theta_1} = \frac{\mathrm{T}_2}{\mathrm{T}_1}$$

$$\Rightarrow \frac{Q_1 + 10}{Q_1} = \frac{10}{9}$$

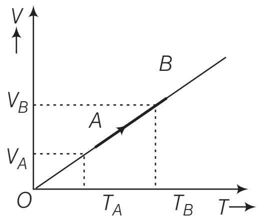
$$\Rightarrow 9Q_1 + 90 = 10Q_1$$

$$\Rightarrow Q_1 = 90\ \text{J}$$

18 $$\eta = \frac{T_1 - T_2}{T_1} = 1 - \frac{T_2}{T_1}$$

$$\Rightarrow T_1 = \frac{T_2}{1 - \eta} = \frac{300}{1/2} = 600\ \text{K} = 327°\text{C}$$

19 According to the given graph,



Volume $(V) \propto$ Temperature (T)

or $\dfrac{V}{T} =$ constant

Thus, the process is isobaric.

$\therefore$ Work done, $\Delta W = p\Delta V$

$$= nR\Delta T = nR(T_B - T_A) \quad \ldots\text{(i)}$$

Heat absorbed, $\Delta Q = nC_p\Delta T$

$$= nC_p(T_B - T_A) \quad \ldots\text{(ii)}$$

As, $C_p = \dfrac{\gamma R}{\gamma - 1}$, $\left(\text{where, } \gamma = 1 + \dfrac{2}{f}\right)$

For a monoatomic gas, $f = 3$

$$\Rightarrow \quad C_p = \left(R + \frac{3}{2}R\right) = \frac{5}{2}R$$

Substituting the value of C_p in Eq. (ii), we get

$$\Delta Q = n\left(\frac{5}{2}R\right)(T_B - T_A)$$

Hence, $$\frac{\Delta W}{\Delta Q} = \frac{nR(T_B - T_A)}{n\left(\frac{5}{2}R\right)(T_B - T_A)} = \frac{2}{5}$$

20 According to the question,

Heat spent during the conversion of sample of water at 100°C to steam is,

$$\Delta Q = 54\ \text{cal} = 54 \times 4.18\ \text{J}$$

$$= 225.72\ \text{J}$$

Normal pressure, $p = 1.013 \times 10^5\ \text{Nm}^{-2}$

Net work done during the conversion would be given as

$$\Delta W = p\Delta V = p[V_{\text{steam}} - V_{\text{water}}]$$

Here, $V_{\text{steam}} = 167.1\ \text{cc} = 167.1 \times 10^{-6}\ \text{m}^3$

$V_{\text{water}} = 0.1\ \text{g} = 0.1\text{cc} = 0.1 \times 10^{-6}\ \text{m}^3$

$$\therefore \Delta W = 1.013 \times 10^5\ [(167.1 - 0.1) \times 10^{-6}]$$

$$= 1.013 \times 167 \times 10^{-1} = 16.917\ \text{J}$$

Now, by the first law of thermodynamics, $\Delta Q = \Delta U + \Delta W$

where, ΔU is the change in internal energy of the sample. $\Rightarrow \Delta U = \Delta Q - \Delta W$

Substituting the values in the above equation, we get

$$\Delta U = 225.72 - 16.917 = 208.7\ \text{J}$$