GA 13
THERMODYNAMICS

Question
Which of the following is a state variable?
Choices
(a) Work done
(b) Heat
(c) Internal energy
(d) None of these

Solution
Internal energy is a state variable because it depends only on the state of the system and not on the path followed.

Question
A gas expands from volume V_1 to V_2 in three different ways. The work done by the gas is W_1 in isothermal, W_2 in adiabatic and W_3 in isobaric processes. Then
Choices
(a) $W_1 > W_2 > W_3$
(b) $W_1 > W_3 > W_2$
(c) $W_2 > W_1 > W_3$
(d) $W_3 > W_1 > W_2$

Solution
$W_1 = nRT\ln\frac{V_2}{V_1}$
$W_2 = \frac{nR(T_1 - T_2)}{\gamma - 1}$
$W_3 = P(V_2 - V_1)$
$W_1 > W_3 > W_2$

Question
Which of the following is a path variable
Choices
(a) Pressure
(b) Temperature
(c) Internal energy
(d) Work done

Solution
Work done is a path variable because it depends on the path followed.

Question
Which of the following is a path variable
Choices
(a) Pressure
(b) Temperature
(c) Internal energy
(d) Heat

Solution
Heat is a path variable because it depends on the path followed.

EXERCISE

Select the correct answer of the following questions.

1) Two bodies are said to be in thermal equilibrium if they have the same

a. temperature b. amount of heat c. Specific heat d. Thermal capacities

2) In any process the maximum amount of mechanical energy that can be converted to heat

a. Depends upon the amount of friction.
b. Depends upon the initial and without temperature.
c. Depends upon whether kinetic or potential energy is involved.
d. is 100%.

3) In an isothermal change, internal energy

a. Decreases b. Increases c. Becomes zero d. Remains constant

4) A thermos bottle containing hot coffee is vigorously shaken. Consider coffee as the system, then its temperature.

a. Increases b. Decreases below than 0°C
c. Remains the same d. Decreases

5) Maximum work can be obtained in the process called

a. Cyclic b. Isothermal c. Adiabatic d. Isochoric

6) Two ideal heat engines (A) an (B) have that sources at 600K and 400K and their sinks at 300K and 200K respectively. What can you say about their efficiency?

a. A is more than B b. A is less than B
c. Both are equal efficient d. The data given is not sufficient

7) If the temperature of the heat source is increased, the efficiency of a Carnot's engine

a. Increases b. Decreases
c. Remain constant d. First increases and then becomes constant

8) Triple point of water is

a. 273.16°F b. 273.16K c. 273.16°F d. 273.16

9) A real gas can be approximated to an ideal gas at

a. Low density b. High pressure c. High density d. Low temperature

10) If the volume of the gas is to be increased by 4 times, then

a. Temperature and pressure must be doubled.
b. At constant P the temperature must be increased by four times.
c. At constant T the pressure must be increased by four times.
d. P cannot be increased.

Answers:

1.	(a)	2.	(a)	3.	(c)	4.	(a)	5.	(c)
6.	(b)	7.	(a)	8.	(c)	9.	(a)	10.	(d)

1) Why is the earth not in thermal equilibrium with the sun?

Answer

Since the temperature of the sun is almost 10⁷kelvin and that of earth is 330 K (max). Due to this large temperature difference can not be in thermal equilibrium. The two objects are in thermal equilibrium if both have same temperature. When two objects are in thermal equilibrium heat flow ceases. But we are getting heat energy continuously from the sun i.e. heat continuously flows from sun to the earth. That's why they are not in thermal equilibrium.

2) When a block with a hole in it is heated why does not the material around the hole expand into the hole and make it small?

Answer

When a block with a hole in it is heated the material as well as the hole expand because when the objects/material expands, the atoms move apart and the hole increase in size. That's why the hole be expanding the block does not become small.

3) A thermometer is placed in direct sun light. Will it read the temperature of the air, or of the sun, or of something else?

Answer

A thermometer actually measures its own temperature but when thermometer is placed in sun light then it is in thermal equilibrium with sun. So when the thermometer is in thermal equilibrium with air, the temperature must be equal. Therefore, one can say that thermometer will read the temperature of the air. Since thermometer is not in thermal equilibrium with the sun. That's why it cannot measure the temperature of the sun.

4) The pressure in a gas cylinder containing hydrogen will leak more quickly than if it is containing oxygen. Why?

Answer

Since the molar mass of hydrogen is 16 times less than the molar mass of oxygen because the rate of leaking of a gas is inversely proportional to the square root of its density.

5) What happens to the temperature of the room in which an air conditioner is left running on the table of the room in the middle?

Answer

In ideal case when air conditioner is placed in the middle of the room absorbs as well as ejects heat in the room at the same rate then the temperature of the room remains constant and ineffective. But in practical, due to working of compressor, some heat energy during this process, as the temperature of the room may be slightly. However, this rise in temperature is negligible. Therefore, temperature of the room is almost constant when an air conditioner is left running on the table in the middle of the room.

6) When a sealed thermostat flask bottle full of hot coffee is shaken, what are the changes in (a) Temperature of the coffee (b) The internal energy of coffee?

Answer

When a sealed thermos flask bottle full of hot coffee is shaken then work is done. The system thereby increasing internal energy and hence temperature (as mandated by adiabatic compression). The rapid shaking causes increase in K.E of the molecules. That's why both temperature and internal energy will rise.

7) When an object is heated, not all the energy it absorbs goes into increasing the velocity of the molecules. Explain where does the remaining energy go?

Answer

When an object is heated, some of the energy goes to increase the velocity of the molecules. Some energy is utilized to overcome intermolecular forces. Remaining energy may be utilized in phase transition.

8) Why does the pressure of the air in automobile tyre increase of the automobile is driven for a while?

Answer

When an automobile is moving on the road, some work must be done to overcome road friction. The work done causes the temperature of the air in tyre. The temperature rise the average K.E of molecules of air in tyre than before. Molecular theory, kinetic energy is directly proportional to pressure of the air in automobile tyre increases if it is driven for a while.

9) On removing the valve, the air escaping from a cycle tube cool. Why?

Answer

On removing, the air escaping from a cycle tube expands rapidly in a nearly adiabatic process, as the temperature of the gas drops. That's why the air escaping from a cycle tube feels cool. This is sometime called adiabatic cooling. The molecules of a compressed gas in a tube are very close to each other and have sufficient intermolecular attractive forces. When the gas is allowed to expand, the molecules move apart from each other. Due to expansion, the molecules have to overcome the intermolecular forces. For this purpose, they need energy which is obtained from the gas itself. Hence expansion of a compressed air escaping from a cycle tube causes cooling.

10) Can a room be cooled by leaving the door of an electric refrigerator open?

Answer

A room cannot be cooled by leaving the door of a refrigerator open because the heat absorbed by the cold inside the refrigerator from the room is again released in the room by external coil at the back of refrigerator.

reversible. But if the following conditions are satisfied, the process may be reversible.

1) Thermal and mechanical equilibrium must be maintained throughout the process such that dissipation of energy may not occur.
2) The process must be occurred very slowly such that at an instant of time, temperature of the system remains constant.

12) Write the limitations of first law of thermodynamics.

Answer

1) This law is based on the idea that energy neither created nor destroyed in any thermodynamic system. So, it is a particular form of the law of conservation of energy which deals only with the heat energy.
2) 1st law of thermodynamics tells us that heat energy can be converted into equivalent amount of work, but it is silent about the conditions under which this conversion takes place.

13) Is it possible, according to the second law of thermodynamics, to conduct a heat engine that is free from thermal pollution?

Answer

Strictly speaking it is not possible. Because heat energy cannot be converted completely into useful work of any cost. Basically, heat engine takes heat from hot temperature reservoir, partly converted into mechanical work and remaining heat is rejected to low temperature reservoir. Thus it produces thermal

pollution. So construct a heat engine which is free from thermal pollution will be clear violation of second law of thermodynamics.

14) When two systems are in thermal equilibrium, do they have the same amount of kinetic energy?

Answer

Two systems are said to be in thermal equilibrium if both have same temperature. Since temperature is the measure of motion of molecules i.e. temperature is directly proportional to average kinetic energy, so when two systems are in thermal equilibrium both have the same amount of kinetic energy.

15) Work can be converted completely into heat, so can heat be converted completely into work?

Answer

Work can be converted completely into heat, but heat cannot be converted completely into work, otherwise it violates the second law of thermodynamics. Also, heat is called the most degraded form of energy which is less useful as compared to other forms of energies.

16) Entropy has often called as "time arrow". Explain?

Answer

Since entropy of the universe always increases because when any type of energy is converted into heat energy, the energy available for doing useful work decreases. When energy is continuously degrading for doing useful work.

Ultimately, the entropy of the universe should reach a maximum which is called heat death of the universe. All processes will cease due to the unavailability of useful energy. That's why entropy is called as time arrow.

17) Can specific heat of a gas be zero or infinity? Can specific heat be negative? Answer

As, $Q = cm\Delta T$, $c = \frac{Q}{m\Delta T}$ which shows that for zero specific heat, the heat supplied to the system 'Q' must be zero or mass 'm' must be infinite which is not possible. Similarly, for negative specific heat if 'Q' is given out of the system the specific heat can be negative.

18) An inventor claims to have developed a heat engine, working between 27°C and 227° C having an efficiency of 45%. Is the claim valid? Explain.

Answer

Data:

Temperature of hot reservoir = T₁=227°

$T_1 = 227°C+273 = 500\,K$

Temperature of Cold reservoir = T_2=27°

$T_2 = 27°C+273 = 300\,K$

As efficiency of the engine is given by

$$\eta = \left(1 - \frac{T_2}{T_1}\right) \times 100 \qquad \text{——— (1)}$$

$$\eta = 40\%$$

His claim is not valid because the efficiency of the engine working between 227°C and 27° C is 40% not 45%.

Numerical Problems

1. Water at 30° C fall from a height of 604 m. If the whole energy is used in increasing the temperature. Find out the final temperature. Specific heat of water is 4200 J/kg K.

Data:

Initial temperature of water $T_1 = 30°C = 303 K$

Height from which the water falls $= h = 604$ m

Final temperature of water $= T_2 = ?$

Specific heat of water $= C = 4200 J/Kg.K$

Solution

Since

$$\Delta Q = mcdT \quad \text{.....(1)}$$

But

$$mgh = \Delta Q \quad \text{.....(2)}$$

Comparing equation 1 and 2 we get

$$mcdT = mgh$$

$$dT = \frac{gh}{c}$$

$$T_2 - T_1 = \frac{gh}{c}$$

$$T_2 - \frac{gh}{c} - T_1 \quad \text{.....(3)}$$

Putting values

$$T_2 = \frac{9.8 \times 604}{4200} + 303$$

$$T_2 = 305.4$$

Ans

$$T_2 = 305 K$$

2. 20200 J of heat is supplied to the system while the system does 6000J of work. Calculate the change in internal energy of the system.

Data:

The amount of heat supplied to the system $= \Delta Q = 20200$ J

Work done by the system $= W = 6000$ J

Change in internal energy $= \Delta u = ?$

Solution

Using first law of thermodynamics

$$\Delta U = \Delta Q - \Delta W \quad \text{.....(1)}$$

Putting values, we get

$$\Delta U = 20200 J - 6000 J$$

$$\Delta U = 14200 J$$

3. A sample of gas is uniformly heated at constant pressure. If the amount of 180 J of heat is supplied to the gas. Calculate the change in internal energy of the gas and work done by the gas. take $\gamma = 1.41$.

Data:

The amount of heat given to the gas $\Delta Q = 180$ J

Change in internal energy $\Delta U = ?$

Work done by the gas $W = ?$

Solution

Since $W = P\Delta V$

$$W = nR\Delta T \quad \text{.....(1)} \quad \text{as } PV = nRT$$

Hence we are going to find ΔT

As

$$\gamma = \frac{C_p}{C_v} = 1.41$$

$$\Rightarrow \frac{C_p}{C_v} = 1.41$$

$$\Rightarrow \frac{C_p - C_v}{C_v} = 1.41 - 1$$

$$\Rightarrow \frac{R}{C_v} = 0.71 = 1$$

$$\Rightarrow \frac{R}{C_v} = 0.29 \quad \text{; } R = 8.3 J/mol\,°C$$

$$\Rightarrow \frac{R}{C_v} = 0.29 \quad \text{; } C_v = 28.6 J/mol\,°C$$

Since

$$C_v = \frac{n\Delta Q}{n\Delta T}$$

$$\Delta Q = C_v n\Delta T$$

$$dT = \frac{\Delta Q}{C_v n} = \frac{180}{28.6 \times 1}$$

$$dT = 6.29\,°C$$

Putting values in Equation (1)

$$\Delta U = 1 \times 8.3 \times 6.29$$

$$\Delta U = 52.2 J$$

Now

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

$$\Delta U = 180 - 52.2 J$$

$$\Delta U = 127.8 J$$

4. 5 moles of oxygen is heated at constant volume from 10°C to 20°C. What will be the specific heat of oxygen at constant pressure ≈ 8.3 Cal Mol⁻¹C⁻¹ and 8×10 J Mol⁻¹C⁻¹.

Data:

No. of moles of oxygen gas $= n = 5$

Change in temperature of oxygen at constant volume $= dT = 10°C = 10K$

Change in internal energy $= \Delta U = ?$

Specific heat of oxygen at constant pressure of oxygen $= C_p = ?$, Cal Mol⁻¹ C⁻¹

$R = 8.3 J/mol.C°$

Solution

Since the oxygen is heated at constant volume so

$$\Delta U = nC_v dT$$

$$C_p = C_v + R$$

$$C_p = 33.488 + 8.36$$

$$C_p = 25.128 J/mol\,°C$$

Put values in equation

$$\Delta U = 5 \times 25.128 \times 10$$

$$\Delta U = 1256.4 J$$

$$\Delta U = 300 Cal$$

5. Find the efficiency of a Carnot's Engine working between the steam and ice points.

Data:

Temperature of hot reservoir $= T_1 = 100°C$

$T_1 = 100°C + 273 = 373 K$

Temperature of cold reservoir $= T_2 = 0°C + 273 = 273K$

Solution

As efficiency of Carnot Engine is given by

$$\eta_{Car} = \left(1 - \frac{T_2}{T_1}\right) \times 100$$

$$\eta_{Car} = \left(1 - \frac{273}{373}\right) \times 100$$

$$\eta_{Car} = 26.8\%$$

6. A Carnot heat engine absorbs 200 J of heat from the source of heat engine at 227°C and rejects 150J of heat during each cycle to sink. Calculate efficiency of engine. temperature of sink and the amount of work done during each cycle.

Data:

i) Heat absorbs from hot temperature reservoir $= Q_1 = 200J$

ii) Heat rejects to sink $Q_2 = 150$ J

iii) Temperature of source $= T_1 = 227°C + 273 = 500$ K

iv) Temperature of the sink $T_2 = ?$

v) Efficiency of the engine $\eta = ?$

vi) The amount of work done during each cycle $= W = ?$

Solution

Since

(i)

$$\eta = \left(1 - \frac{Q_2}{Q_1}\right) \times 100$$

$$\eta = \left(1 - \frac{150J}{200J}\right) \times 100$$

$$\eta = 25\%$$

(ii) As

$$W = Q_1 - Q_2$$

$$W = 200J - 150J$$

$$W = 50J$$

(iii) Since $\eta = \left(1 - \frac{T_2}{T_1}\right)$

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

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

$$T_2 = (1 - 0.4) \times 500$$

$$T_2 = 300 K$$

$$T_2 = 27°C$$

7. In a refrigerator, heat from inside of 227 K is transformed to a room at 300 K. How many joules of heat will be delivered to the room for each Joule of electric energy consumed ideally?

Data:

The temperature of which heat is transformed from refrigerator $= T_1 = 277 K$

Temperature of the room $= T_2 = 300$ K

Heat energy delivered to the room $= E = ?$

Solution

As

$$\eta_{carnot} = \frac{T_2}{T_1}$$

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

$$E = \frac{277K}{300K - 277K}$$

$$E = 12.04$$

Since

$$E = \frac{Q_2}{W}$$

$$E = \frac{Q_2}{1J}$$

Putting values

$$W = \frac{Q_2}{E}$$

$$W = 40.5 J$$

$$W = 40 J$$

$$W = Q_1 - Q_2$$

$$Q_1 = 40.5 J + 20 J$$

$$Q_1 = 60.5 J$$

8. What is the least amount of work that must be performed to freeze one gram of water at 0°C by means of refrigerator? take the temperature of surrounding as 27°C. How much heat is passed on the surrounding during this process?

Data:

Mass of the water $= m = 1g = 0.001$ kg

Temperature of the surrounding $T_1 = 27°C + 273 = 300K$

Temperature of the water $T_2 = 0°C + 273 = 273 K$

Latent heat of fusion of water $L_f = 3.36 \times 10^5$ J/kg

The amount of work to freeze the water $= W = ?$

Heat passed on the surrounding $Q_1 = ?$

Solution

Since coefficient of performance of refrigerator is given as

$$E = \frac{T_2}{T_1 - T_2} \quad \text{.....(1)}$$

Putting values we get

$$E = \frac{273K}{300K - 273K}$$

$$E = 7.6 \quad \text{.....(2)}$$

As

$$Q_2 = mL_f$$

$$Q_2 = 0.001 \times 3.36 \times 10^5$$

$$Q_2 = 336 J \quad \text{.....(3)}$$

9. Calculate the change in entropy when 10 kg of water is heated from 90°C to 100°C?

Data:

Mass of water $= m = 10$ kg

Initial temperature of water $= T_1 = 90°C + 273 = 363 K$

Final temperature of water $= T_2 = 100°C = 373 + 273 K$

Change in temperature $= dT = 10°C = 10K$

Change in entropy $\Delta S = ?$

solution

Since entropy of a reversible process is given as

$$\Delta S = mc\ln\left(\frac{T_2}{T_1}\right) \quad \text{.....(1)}$$

Putting values in equation (1)

$$\Delta S = 10 \times 4190 \ln\left(\frac{373}{363}\right)$$

$$\Delta S = 110.87 J/K$$

10. A system absorbs 1176 J of heat and at the same time does 352.8 J of external work.

(i) Find change in internal energy?

ii) Find change in internal energy when it absorbs 1050 J of heat while 84 J of work is done.

(iii) What will be change in internal energy of the gas of 210 J of heat is removed at constant volume.

Data:

The heat absorbed by the system $= Q_1 = 1176$ J

Work done by the system $= W = 352.8$ J

Change in internal energy $= \Delta U = ?$

Solution

i. As law of thermodynamics

$$\Delta U = Q_1 - W$$

$$\Delta U = (1176 - 352.8) J$$

$$\Delta U = 823.2 J$$

ii. The heat absorbed by the system $Q_2 = 1050$ J

Work done by the system $= W = 84$ J

Change in internal energy $= \Delta U = ?$

Since $\Delta U = Q_2 - W$

$$\Delta U = (1050 - 84) J$$

$$\Delta U = 966 J$$

iii. The heat rejected form the gas $Q_3 = -210$ J

Change in internal energy $\Delta U = ?$

Since volume is constant so $\Delta U = 0$ and $W = 0$

Using 1st law of thermodynamics

$$\Delta U = Q_3 - W$$

$$\Delta U = 210 - 0 J$$

$$\Delta U = -210 J$$

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Objective Type Questions & Answers

Select the best answer for the following MCQs:

1) 8.1. unit of heat energy is given by.

(a) calorie (b) kilo calorie (c) Joule (d) Joule sec

2) The total sum of the energies of all the molecules (or atoms) in an object is known as.

(a) potential energy (b) kinetic energy

(c) internal energy (d) elastic PE

3) S.I. unit of pressure of a gas is.

(a) N m^2 (b) N-m (c) N2 ./m (d) N2 -m

4) A gas which strictly obeys gas laws under all conditions often temp and pressure is called.

(a) real gas (b) ideal gas (c) perfeet gas (d) inert gas

5) The ideal gas law is given in the form of.

(a) $PV\frac{nR}{T}$ (b) $PV = nRT$ (c) $PT = nRV$ (d) $TV = nRP$

6) The value of the traversal gas constant R in 8.1. units is.

(a) 8.314 J more $^{-1}$ K^{-1} (b) 33.141 mole $^{-1}$ K^{-1}

(c) 8314J mole $^{-1}$ K^{-1} (d) 831.4Jmole $^{-1}$ K^{-1}

7) The Boltzmann constant k in terms of universal gas constant R and Avogadro No. NA is given

(a) $K = N_A R$ (b) $K = \frac{R}{N_A}$ (c) $K = \frac{NA}{R}$ (d) $K = nRN_A$

8) The expression for the pressure exerted by an ideal gas is given by.

(a) $\frac{1}{3}N_v < \frac{1}{2}mv^2 >$ (b) $\frac{2}{3}N_v < \frac{1}{2}mv^2 >$ (c) $\frac{1}{2}N_v < \frac{1}{2}mv^2 >$ (d) $\frac{2}{3}N_v < \frac{1}{2}mv^2 >$

9) The average translational KE per molecule of an ideal gas in terms of pressure is given by.

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

10) If the pressure is increased, the boiling point of the liquid.

(a) decreases (b) increases

(c) remains constant (d) none of these

11) Under the same condition of temperature and pressure, equal volume of all the gases contains the same No. of kilo molecules. It is the statement of.

(a) Charles' Law (b) Boyles' Law

(c) Avogadro's Law (d) Law of pressure

12) At constant temperature, the graph between V and 1 / P is a.

(a) parabola (b) hyperbola (c) straight line (d) ellipse

13) At constant pressure the graph between V and T (absolute temperature) is.

(a) ellipse (b) parabola (c) hyperbola (d) straight line

14) For a gas obeying Boyle's law, if the pressure is doubled, the volume becomes

(a) one half (b) double (c) remains constant (d) three times

15) 4180 Joules of work raises the temperature of 1 litre water through.

(a) 1 °F (b) 1 °C (c) 273 K (d) none of these

16) The first law of thermodynamics can be expressed as.

(a) Q = AU -W (b) Q = AU + W (c) AU = Q + W (d) W = Q + AU

17) In adiabatic process,

(a) Q = AU W (b) Q = AU (c) Q = W (d) Q = 0

18) Which is the process in which the temperature remains constant,

(a) adiabatic process (b) isobaric process

(c) isothermal process (d) isochoric process

19) The temperature scale which is independent of the nature of the substance used in a thermometer is called.

(a) Centigrade scale (b) Fahrenheit scale

(c) Kelvin scale (d) thermodynamic scale

20) If the temperature of the source increases, the efficiency of the Carnot engine.

(a) increases (b) decreases (c) remains constant (d) none of these

21) If the temperature of the sink is decreased the efficiency of the Carnot engine.

(a) increases (b) decreases (c) remains constant (d) none of these

22) The highest efficiency of a heat engine whose lower temperature is 17 °C and high temperature is 200 °C is,

(a) 30 % (b) 38 % (c) 40 % (d) 60

23) The change in the entropy of the system is given by.

(a) $AQ = \frac{\Delta S}{T}$ (b) $AS = \frac{T}{\Delta S}$ (c) $AS = \frac{\Delta S}{T}$ (d) $\Delta S = T \times \Delta Q$

24) When the temperature of the source and sink of the heat engine becomes equal the entropy change will be,

(a) negative (b) zero (c) maximum (d) minimum

25) Entropy is a measure of.

(a) internal energy of the system (b) order of the system

(c) disorder of the system (d) P.E. of the system

26) Temperature of -273 °C will be on Kelvin scale as

(a) 273 K (b) 373 K (c) -273 K (d) 0 K

27) The difference of the molar specific heats of a gas Cp and Cv is equal to.

(a) $\frac{C_p}{C_v} = R$ (b) $C_p + C_v = R$ (c) $C_p - C_v = R$ (d) $\frac{C_p C_v}{C_p} = R$

28) No entropy change takes place in a.

(a) isobaric process (b) isothermal process

(c) adiabatic process (d) isochoric process

29) In reversible process, the entropy,

(a) decreases (b) increases (c) remains constant (d) none of these

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