16 Thermodynamics

BRIEF REVIEW

First law of Thermodynamics Consider an ideal gas in a cylinder fitted with a piston. Assume that the piston is fixed at its position and the walls of the cylinder are kept at a higher temperature than that of the gas. The gas molecules strike the wall and rebound. The average KE of a wall molecule is higher than the average KE of a gas molecule. On collision the gas molecule receives some energy from the wall molecule. This increasesd KE is shared by other gas molecules also. In this way total internal energy of the gas increases.

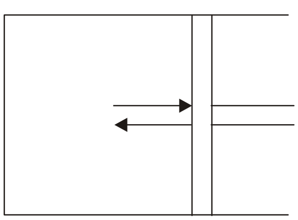

Fig. 16.1 Internal energy illustration

Now consider that the walls of the cylinder are also at the same temperature as that of the gas. As the gas molecules collide with the piston coming towards it, the speed of the molecule increases on collision (Assuming elastic collision $v_2 = v_1 + 2u$). This way internal energy of the molecules increases as the piston is pushed in. Thus we see that energy transfer and work go together. If ΔQ is the heat supplied and ΔW is the work done, then the internal energy of the gas must increase by $\Delta Q - \Delta W$.

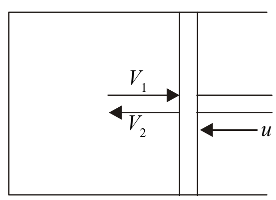

Fig. 16.2 Illustration of internal energy and work done

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

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

is called the first law of thermodynamics.

Work done by a gas $= P\Delta V$ or $W = \int_{V_1}^{V_2} PdV$

The first law denies the possibility of creating or destroying energy.

Thermal Processes In general thermal processes may be of three types: (a) reversible, (b) irreversible and (c) cyclic. A reversible process means if a process takes up the path AB (Fig. 16.3) then on reversing the conditions it comes back by BA. A thermal process however cannot be reversible. It could be reversible if the change is extremely small (infinitesimally small).

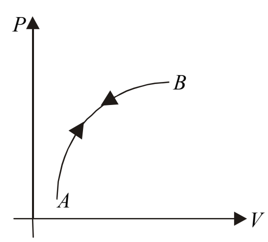

Fig. 16.3 Reversible process

In an irreversible process one will not reach back to A if the process AB has occurred.

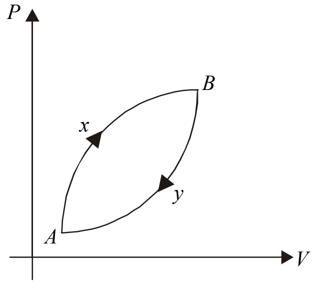

Fig. 16.4 **Cyclic process**

In a cyclic process, if the process takes the path AxB, it returns via ByA (Fig. 16.4).

Thermal processes may be cyclic or irreversible. Change in internal energy in a cyclic process is zero.

Hence $\Delta Q = \Delta W$

We can divide these processes as

(a) isobaric (b) isochoric

(c) isothermal (d) adiabatic

(e) throttling (f) polytropic

In isobaric process pressure remains constant and work done

$$W = P\Delta V = P(V_2 - V_1)$$

$$\therefore \quad dQ = dU + pdV$$

In isochoric process volume remains constant. Therefore $dV = 0$

Hence work done is zero

$$\therefore \quad \Delta Q = \Delta U$$

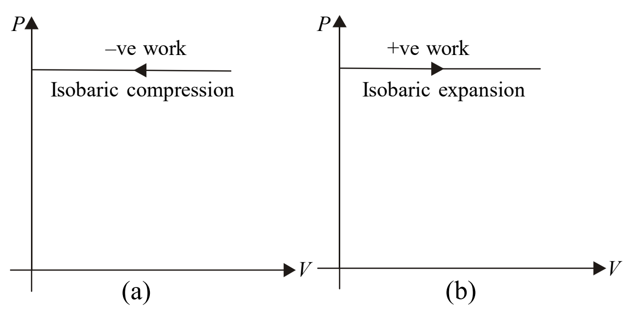

Fig. 16.5 **(a) Isobaric compression and (b) expansion**

In isothermal process the temperature remains constant. Melting and boiling are examples. Specific heat in isothermal process is ∞.

Work done,

$$W = \int pdV = n\text{RT}\int_{V_1}^{V_2}\frac{\text{dV}}{\text{V}} = nRT\log_e\frac{V_2}{V_1}$$

$$= 2.303\, nRT\log\frac{V_2}{V_1} = 2.303\, nRT\log_e\frac{P_1}{P_2}$$

Isothermal elasticity $= P$ (Bulk modulus)

In an adiabatic process heat is neither allowed to enter nor allowed to escape the system. Specific heat in an adiabatic process is zero.

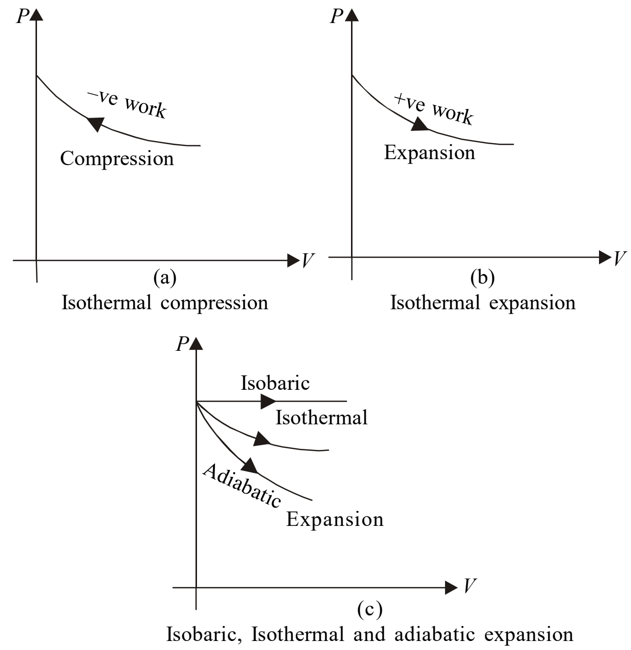

Fig. 16.6

Since $dQ = 0$

$\therefore \quad dU = -pdV$

In an adiabatic process

(i) $PV^{\gamma} =$ constant

(ii) $P^{1-\gamma}\, T^{\gamma} =$ constant

(iii) $TV^{\gamma-1} =$ constant

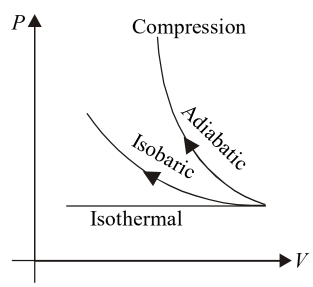

Fig. 16.7 **Work done in various cases**

Work done in an adiabatic process,

$$W = \frac{P_1V_1 - P_2V_2}{\gamma - 1} = \frac{nR(T_1 - T_2)}{\gamma - 1} \quad \text{where } \gamma = \frac{C_P}{C_V}$$

Adiabatic elasticity (Bulk modulus) $= \gamma P$

Second law of thermodynamics The second law denies the possibility of utilisation of heat out of a single body. The definitions of the second law of thermodynamics are:

(a) It is impossible to construct an engine which, operating in a cycle, will produce no effect other than the extraction of heat from a reservoir and the performance of an equivalent amout of work. (Kelvin Planck statement)

(b) Heat cannot flow itself from a colder to a hotter body.

(c) It is impossible to have a process in which the entropy of an isolated system is decreased.

Adiabatic → Thermally insulating

Diathermic → Thermally conducting

Heat Engine A heat engine takes a heat Q_1 from the furnace and rejects Q_2 to the heat sink and does a work $W = Q_1 - Q_2$

Thus efficiency of an engine $\eta = 1 - \dfrac{Q_2}{Q_1} = 1 - \dfrac{T_2}{T_1}$

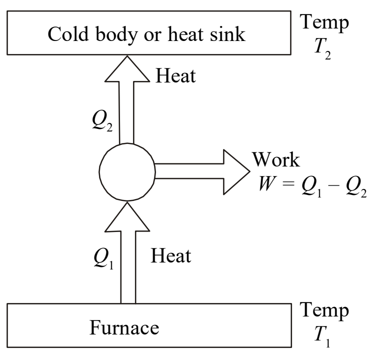

Fig. 16.8 **Carnot engine**

Entropy $dS = \dfrac{dQ}{T}$ or $S_2 - S_1 = \int \dfrac{dQ}{T}$

Note that T is not differentiable. Entropy is a measure of randomness or disorder in a system.

Clausius inequality $\oint \dfrac{dQ}{T} \leq 0$

or $\Delta S \geq \int \dfrac{dQ}{T}$ or $dQ = TdS \geq dU + pdV$

Relation between entropy and statistical weight Ω (thermodynamic property)

$S = K \log_e \Omega$

where k is Boltzmann's constant.

Amount of heat required to form a unit area of the liquid surface layer during the isothermal increase of its surface $H = -T\dfrac{d\sigma}{dT}$ where σ is surface tension.

Carnot Engine The french scientist (auto engineer) NL Sadi Carnot in 1824 suggested an idealised engine called Carnot engine. It has a cylinder piston system. The walls and the piston are completely adiabatic (insulating) and the base is diathermic (thermally conducting). It contains an ideal gas. It undergoes isothermal expansion, adiabatic expansion, isothermal compression and adiabatic compression to complete the cycle. PV and ST plots for a Carnot cycle are shown in Fig 16.9. Carnot's engine is a reversible engine.

Carnot's theorem All reversible engines operating between the same two temperatures have equal efficiency and no engine operating between the same two temperatures can have an efficiency greater than this.

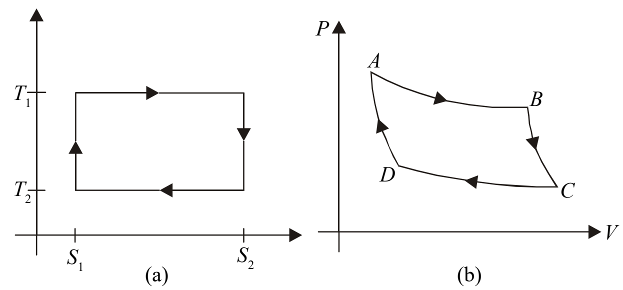

Fig. 16.9 **Carnot cycle**

According to Carnot's theorem, maximum efficiency

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

Since T_2 cannot be zero (as 0 K cannot be obtained), therefore, efficiency cannot be 1.

Refrigerator or heat pump A heat engine takes heat from a hot body, converts part of it into work and rejects to cold body. The reverse operation is done by a refrigerator (or heat pump). It takes an amount Q_2 of heat from a cold body, an amount of work W is done on it by the surrounding and a total heat $Q_1 = Q_2 + W$ is supplied to hot body as illustrated in Fig. 16.10.

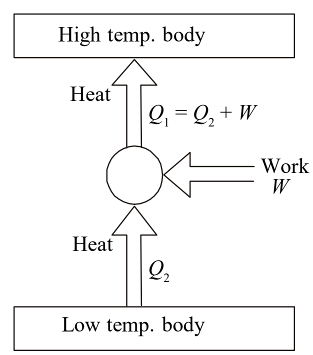

Fig. 16.10 **Refrigrator based on carnot cycle**

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

$$\frac{Q_2 + W}{Q_2} = \frac{T_1}{T_2}$$

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

This leads to another statement of second law:

It is not possible to design a refrigerator which works in a cyclic process and whose only result is to transfer heat from a colder body to a hotter body. This is the Claussius statement of the second law of thermodynamics.

Coefficient of performance,

$$K = \frac{\text{heat extracted}}{\text{work done}} \frac{Q_2}{W} = \frac{Q_2}{Q_1 - Q_2}$$

In a perfect refrigerator $K = \infty$

that is, $Q_1 = Q_2$ or $W = 0$

SHORT CUTS AND POINTS TO NOTE

1. According to the first law of thermodynamics, total energy is conserved, that is, the first law denies the possibility of creating or destroying energy. Thus

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

or $$dQ = dU + PdV$$

2. Processes may be reversible, irreversible or cyclic. Thermal processes cannot be completely reversible.

3. Thermal processes may be isochoric, isobaric, isothermal, adiabatic, polytropic and throttling.

In an isochoric process, $\Delta V = 0$

$\therefore$ $W = 0$, Specific heat $= C_V$

$$\Delta Q = \Delta U = nc_V \Delta T$$

In an isobaric process, work done

$W = P\Delta V = P(V_2 - V_1)$; specific heat $= C_P$

$$W = nR(T_2 - T_1)$$

$$dQ = dU + PdV$$

or $$nC_P \Delta T = nC_V \Delta T + nR\Delta T$$

In an isothermal process. work done

$$W = nRT \log_e \frac{V_2}{V_1} = nRT \log_e \frac{P_1}{P_2},$$

Specific heat $= \infty$

In an adiabatic process, work done

$$W = \frac{nR(T_1 - T_2)}{\gamma - 1} = \frac{P_1V_1 - P_2V_2}{\gamma - 1},$$

Specific heat $= 0$

PV^γ = constant, $P^{1-\gamma}T^\gamma$ = constant

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

4. In a throttling process a fluid, originally at high pressure, seeps through a porous wall or needle-like narrow opening into a region of constant lower pressure. Work done

$$W = P_2V_2 - P_1V_1$$

Since the process is adiabatic, therefore

$$\Delta U = U_2 - U_1 = -(P_2V_2 - P_1V_1)$$

The sum $U + PV$ is called enthalpy. Throttling process plays an important role in refrigeration.

5. The slope of an adiabatic process is higher than isothermal change.

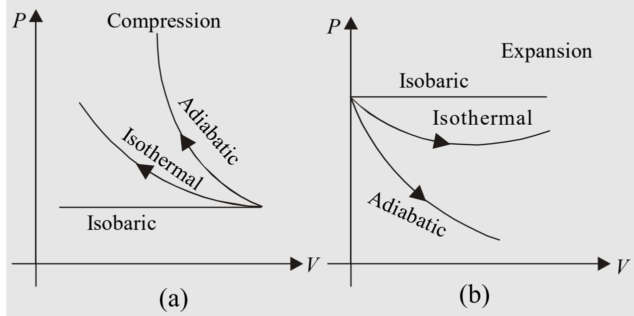

Fig. 16.11

Note- During expansion $W_{\text{isobaric}} > W_{\text{isothermal}} > W_{\text{adiabatic}}$ during compression $W_{\text{adiabatic}} > W_{\text{isothermal}} > W_{\text{isobaric}}$

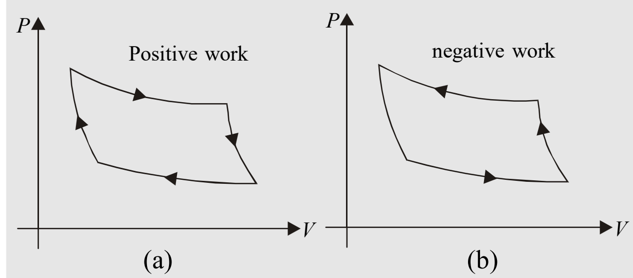

Fig. 16.12

6. Work done is positive if the arrow is clockwise and negative if the arrow is anticlockwise in a PV diagram as illusttrated in Fig 16.11 (a) and (b)

7. Second law of thermodynamics The various definitions are

(a) It is impossible to construct an engine which, operating in a cycle, will produce no effect other than the extraction of heat from a reservoir and the performance of an equivalent amount of work (Kelvin Planck Statement)

(b) Heat cannot flow by itself from a colder to a hotter body.

(c) It is impossible to have a process in which the entropy of an isolated system is decreased.

(d) It is not possible to design a refrigerator which works in a cyclic process and whose only result is to transfer heat from a colder body to a hotter body. (Claussius statement)

8. Entropy is a measure of randomness or disorder in a system.

$$dS = \frac{dQ}{T}$$

Note that T is not a differentiable quantity.

9. Thermal equilibrium If two systems have the same temperature they are said to be in thermal equilibrium.

10. Thermodynamic equilibrium is when there is the state of thermal, mechanical and chemical equilibrium.

Mechanical equilibrium means $\Sigma F = 0, \Sigma \tau = 0$ (torque)

Chemical equilibrium means the concentration of reactants and products remains constant.

11. Thermodynamic variables P, V, T, and so on which form the equation of state are called thermodynamic variables.

12. Heat engine takes up heat from a hotter body, converts it partly into work and rejects rest of the energy to a cold body (heat sink). Efficiency of a heat engine (Carnot)

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

13. Carnot suggested that even an idealied engine cannot have efficiency 1. He considered a cyclic process consisting of four processes:

(a) isothermal expansion

(b) adiabatic expansion

(3) isothermal compression

(4) adiabatic compression

Efficiency of Carnot engine

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

$T_2 \rightarrow$ temperature of heat sink (colder body)

$T_1 \rightarrow$ temperature of furnace or hot body

Since T_2 cannot be 0 K, therefore efficiency cannot be 1.

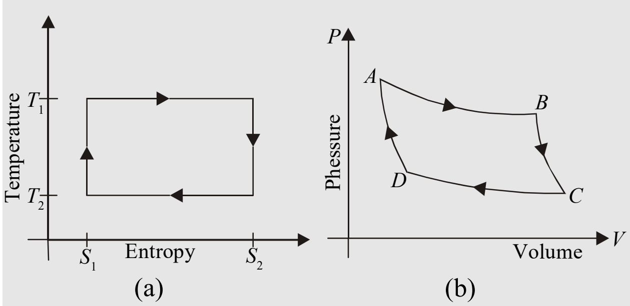

Fig. 16.13

14. Refrigerator or heat pump is reciprocal of heat engine

$$\frac{Q_1}{Q_2} = \frac{T_1}{T_2} \text{ or } \frac{Q_2 + W}{Q_2} = \frac{T_1}{T_2}$$

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

Performance coefficient $K = \frac{Q_2}{W} = \frac{Q_2}{Q_1 - Q_2}$

15. In perfect refrigerator K = ∞, that is $Q_1 = Q_2$

Area under $P - V$ graph is work done.

16. Molar heat capacity in a polytropic process PV^k = constant

$$C = \frac{R}{\gamma - 1} - \frac{R}{k - 1} = \frac{(k - \gamma)R}{(k - 1)(\gamma - 1)}$$

17. For a van der Waals gas $U = C_V T - \frac{a}{V_M}$ for one mole

CAUTION

1. Not understanding the difference between C_P and C_V.

$\Rightarrow$ Specific heat at constant volume C_V forms internal energy

$\Delta U = nC_V \Delta T$

When volume is constant, work done

$W = PdV = 0 \therefore dQ = dU$

When C_P is being used $dQ = nC_P \Delta T$ and work done

$W = PdV = nRdT$ and $dQ = dU + PdV$

2. Not understanding whether work is positive or negative.

$\Rightarrow$ When there is expansion of the gas or when the piston moves in the forward direction then work is positive. When there is compression or when the piston moves in a backward direction, work done is negative. Alternatively, if the arrow is clockwise, work done by the gas is positive (+ve). If the arrow is anticlockwise, work is done on the gas, and is negative (–ve) in a PV diagram.

3. Not remembering the three relations of adiabatic process.

$\Rightarrow$ In an adiabatic process

(a) PV^γ = constant or $P_1 V_1^\gamma = P_2 V_2^\gamma$

(b) $P^{1-\gamma} T^\gamma$ = constant or $P_1^{1-\gamma} T_1^\gamma = P_2^{1-\gamma} T_2^\gamma$

(c) $TV^{\gamma-1}$ = constant or $T_1 V_1^{\gamma-1} = T_2 V_2^{\gamma-1}$

4. Confusing when to take the process as adiabatic if not mentioned directly in the problem.

$\Rightarrow$ When the change is sudden or abrupt, the process is adiabatic.

5. Confusing between adiabatic and isothermal expansion or compression.

⇒ In isothermal expansion or compression the slope is not large while in adiabatic expansion or compression the slope is large (see Fig 16.14).

Note : during expansion $W_{\text{isobaric}} > W_{\text{isobaric}} > W_{\text{isothermal}} > W_{\text{adiabatic}}$

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

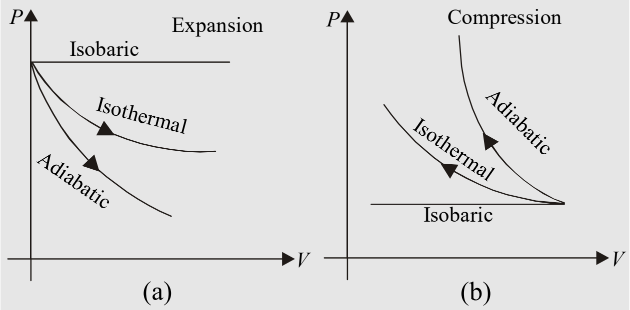

Fig. 16.14

Note: During expansion more work is done by an isothermal process and during compression more work is done on an adiabatic process.

6. Not remembering the work done in various processes.

⇒ Work done in isochoric process, $W_{\text{isochoric}} = 0$

$$W_{\text{isobaric}} = P\,\Delta V = P(V_2 - V_1) = nR(\Delta T)$$
$$= nR(T_2 - T_1)$$

$$W_{\text{isothermal}} = 2.303\, nRT \log_{10}\frac{V_2}{V_1}$$
$$= 2.303\, nRT \log_{10}\frac{P_1}{P_2}$$

$$W_{\text{adiabatic}} = \frac{P_1V_1 - P_2V_2}{\gamma - 1} = \frac{n\mathrm{R}(T_1 - T_2)}{\gamma - 1}$$

7. Considering that efficiency of an engine can be 1 (ideally or theoretically).

⇒ Efficiency of an engine cannot be 1. It is always < 1.

According to Carnot's theorem $\eta = 1 - \dfrac{T_2}{T_1}$

$\eta \to 1$ if $T_2 \to 0$. As 0 K or absolute 0 cannot be achieved, therefore, $\eta \neq 1$.

8. Considering that total heat energy can be converted into mechanical work just like mechanical work which can be completely converted to heat.

⇒ Mechanical work can be converted to heat. But the whole of the heat cannot be converted into work.

9. Considering all engines give efficiency like Carnot engine.

⇒ Carnot is a theoretical idealised engine. Practically heat engines give efficiency much less than that given by Carnot engine.

10. Confusing between first law and second law of thermodynamics.

⇒ The first law is based on conservation of energy. The second law states that no heat can flow by itself from a cold body to a hot body.

11. Not recalling a polytropic process.

⇒ In a polytropic process PV^k = constant and k is different from γ. Molar specific heat in polytropic processis $C = \dfrac{R}{\gamma - 1} - \dfrac{R}{k - 1}$

However, $C_V = \dfrac{R}{\gamma - 1}$

12. Thinking that temperature may be taken in ^{0}C.

⇒ Use temperature in Kelvin (K)

SOLVED PROBLEMS

1. Calculate the work done by the gas in the diagram shown.

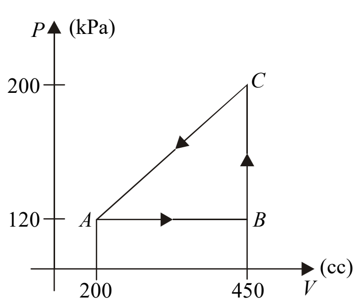

Fig. 16.15

(a) 30 J (b) 20 J

(c) –20 J (d) –10 J

Solution (d) Work done = Area under the $P - V$ curve

$$W = (80\text{ kPa})(250 \times 10^{-6}) \times \frac{1}{2} = 10\text{ J}$$

Since the arrow is anticlockwise,

∴ Work done = –10 J

2. Variation of molar specific heat of a metal with temperature is best depicted by

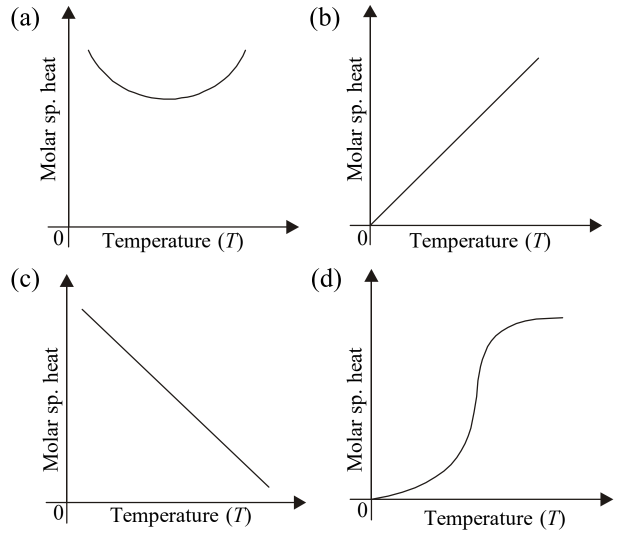

Fig. 16.16

Solution (d) For $T \to 0$, that is, at low temperature, molar specific heat $\propto T^3$ and at high temperature it becomes constant $= 3R$.

3. 1 g of H_2O changes from liquid to vapour phase at constant pressure at 1 atm. The volume increases from 1 cc to 1671 cc. The heat of vaporisation at this pressure is 540 cal/g. The increase in internal energy of water is

(a) 2099 J (b) 3000 J
(c) 992 J (d) 2122 J

Solution (a) $W = P(dV) = 1.01 \times 10^5 (1671 - 1) \times 10^{-6}$

$$= 167 \text{ J}$$

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

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

$$= mL - 167 = 540 \times 4.2 - 167 = 2099 \text{ J}$$

4. A gas mixture consists of 2 moles of oxygen and 4 moles of Ar at temperature T. Neglecting all vibrational modes, the total internal energy of the system is

(a) 4 RT (b) 15 RT
(c) 9 RT (d) 11 RT

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Solution (d) $u = n \dfrac{F}{2} RT = 2 \times \dfrac{5}{2} RT + 4 \times \dfrac{3}{2} RT = 11 \; RT$

5. A tyre pumped to a pressure 3.375 atm at 27° C suddenly bursts. What is the final temperature ($\gamma = 1.5$)?

(a) 27° C (b) –27° C
(c) 0° C (d) –73° C

Solution (d) $T_1^{\gamma} \; P_1^{1-\gamma} = T_2^{\gamma} \; P_2^{1-\gamma}$

or $$\left(\frac{T_1}{T_2}\right)^{\gamma} = \left(\frac{P_1}{P_2}\right)^{\gamma-1} = \left(\frac{300}{T_2}\right)^{3/2} = \left(\frac{3.375}{1}\right)^{3/2-1}$$

or $$T_2 = \frac{300}{(3.375)^{1/3}} = 200 \text{ K} = -73° \text{ C}$$

6. A sound wave passing through air at NTP produces a pressure of 0.001 dyne/cm^2 during a compression. The corresponding change in temperature (given $\gamma = 1.5$ and assume gas to be ideal) is

(a) 8.97×10^{-4} K (b) 8.97×10^{-6} K
(c) 8.97×10^{-8} K (d) none of these

Solution (c) $T^{\gamma} P^{1-\gamma}$ = constant. Differentiating

$$\gamma T^{\gamma-1} \, dT \, P^{1-\gamma} + T^{\gamma} (1 - \gamma) \, P^{-\gamma} \, dP = 0$$

or $$dT = \frac{(\gamma - 1)T}{\gamma P} \, dP$$

or $$dT = \left(\frac{1.5-1}{1.5}\right)\left(\frac{273}{76 \times 13.6 \times 981} \times 0.001\right)$$

$$= 8.97 \times 10^{-8} \text{ K}$$

7. When a system is taken from state 1 to 2 along the path 1a2 it absorbs 50 cal of heat and work done is 20 cal. Along the path 1b2, Q = 36 cal. What is the work done along 1b2?

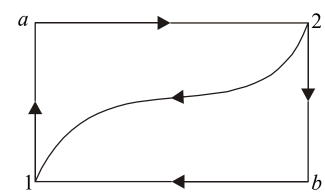


Fig. 16.17

(a) 56 cal (b) 66 cal
(c) 16 cal (d) 6 cal

Solution (d) $dQ = du + dW$ or $Q = (u_2 - u_1) + W$

$$W = Q_{1b2} - (u_2 - u_1) \text{ or } Q_{1a2} - W = u_2 - u_1$$

$$= 36 - 30 = 6 \text{ cal}$$

or $$u_2 - u_1 = 50 - 20 = 30 \text{ cal}$$

8. 1 g mole of an ideal gas at STP is subjected to a reversible adiabatic expansion to double its volume. Find the change in internal energy ($\gamma = 1.4$).

(a) 1169.5 J (b) 769.5 J
(c) 1369.5 J (d) 969.5 J

Solution (c) Use $T_1 V_1^{\gamma-1} = T_2 V_2^{\gamma-1}$

or $$T_2 = \frac{T_1 V_1^{\gamma-1}}{V_2^{\gamma-1}} = \frac{273}{(2)^{0.4}} = 207 \text{ K}$$

Change in internal energy

$$\Delta u = \frac{R}{(\gamma-1)}(T_1 - T_2)$$

$$= \frac{8.31(273-207)}{1.4-1} = 1369.5 \text{ J}$$

9. A gram mole of a gas at 127° C expands isothermally until its volume is doubled. Find the amount of work done.

(a) 238 cal (b) 548 cal

(c) 548 J (d) 238 J

Solution (b) $W = 2.303 \text{ RT} \log\left(\frac{V_2}{V_1}\right)$

$= 2.303 \times 8.311 \times 400 \times \log 2$

$= 2310.1 \text{ J} = 548 \text{ cal.}$

10. Find the work required to compress adiabatically 1 g of air initially at NTP to half its volume. Density of air at NTP = 0.001129 gcm^{-3} and $\frac{C_P}{C_V}$ = 1.4.

(a) 62.64 J (b) 32.64 J

(c) –32.64 J (d) –62.64 J

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

or $$T_2 = T_1\left(\frac{V_1}{V_2}\right)^{\gamma-1} = 273\ (2)^{0.4} = 360 \text{ K}$$

$$V = \frac{1g}{0.00129} \text{ cc}$$

We find R for 1 g of air using $PV = RT$

$$R = \frac{76\times13.6\times981}{273\times0.00129} = 2.88 \times 10^6$$

$$W = \frac{R}{\gamma-1}(T_1 - T_2) = \frac{2.88\times10^6}{0.4}\ 9273 - 360)$$

$= 62.64 \times 10^7$ erg.

$= -62.64$ J

11. A carnot engine has the same efficiency between (i) 100 K and 500 K and (ii) T and 900 K. Find T.

(a) 200 K (b) 190 K

(c) 180 K (d) none of these

Solution (c) $\eta = 1 - \frac{T_2}{T_1}$ or $\frac{T_2}{T_1} = \frac{T_2}{T_1}$ or $\frac{100}{500} = \frac{T}{900}$

12. A reversible engine takes in heat from a reservoir of heat at 527^0 C and gives heat to the sink at 127° C. How many calorie/s shall it take from the reservoir to do a work of 750 W?

(a) 257 cals^{-1} (b) 357 cals^{-1}

(c) 1500 cals^{-1} (d) none of these

Solution (b) $\eta = 1 - \frac{T_2}{T_1} = 1 - \frac{400}{800} = \frac{1}{2} = \frac{W}{Q_1}$

or $$Q_1 = 2W = \frac{2\times750}{4.2} = 357.1 \text{ cals}^{-1}.$$

13. A Carnot engine has efficiency 40% (heat sink 27° C). To increase efficiency by 10%, the temperature be increasesd by

(a) 15.7 K (b) 25.7 K

(c) 50.7 K (d) 35.7 K

Solution (d) $\eta = 40\% = \frac{2}{3}$ $\eta = 1 - \frac{T_2}{T_1}$ or $\frac{T_2}{T_1} = \frac{3}{5}$

$$\therefore \quad T_1 = 300 \times \frac{5}{3} = 500 \text{ K}$$

$$\text{new efficiency} = 40 + 40 \times \frac{10}{100} = 44\%; 0.44$$

$$= 1 - \frac{300}{T_1}$$

or $T'_1 = 535.7$ K

$\therefore$ Temperature of heat source be raised by 35.7 K

14. Two engines are working in such a way that sink of one is source of the other. Their efficiencies are equal. Find the temperature of the sink of first if its source temperature is 927° C and temperature of sink of the second is 27° C.

(a) 327 K (b) 327° C

(c) 600° C (d) none of these

Solution (b) $\eta = 1 - \frac{T_2}{T_1} = 1 - \frac{T_3}{T_2}$ or $T_2^2 = T_1 T_3$

or $$T_2 = \sqrt{1200\times300} = 600 \text{ K} = 327° \text{ C}$$

15. An ideal gas expands according to the law $PV^{3/2}$ = constant. We conclude

(a) The adiabatic exponent of the gas $K = 1.5$

(b) The molar heat capacity $C = C_V - 2R$

(c) Temperature increases during the process

(d) Such a process is not feasible

Solution (b) Molar heat capacity

$$C = C_V + \frac{R}{1-K} = C_V + \frac{R}{1-\frac{3}{2}} = C_V - 2R$$

16. The ratio of work done by an ideal diatomic gas to the heat supplied by the gas in an isobaric process is

(a) $\frac{5}{7}$ (b) $\frac{3}{5}$

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

Solution (c) $\Delta U = nC_V\Delta T = n\,\frac{5}{2}R\Delta T$

$$\Delta Q = nC_P\Delta T = n\,\frac{7}{2}R\Delta T$$

$$W = \Delta Q - \Delta U = \frac{n7}{2}R\Delta T = nR\Delta T$$

$$\frac{W}{Q} = \frac{2}{7}$$

17. A monoatomic gas is supplied heat Q very slowly keeping the pressure constant. The work done by the gas is

(a) $\frac{2}{5}Q$ (b) $\frac{3}{5}Q$

(c) $\frac{Q}{5}$ (d) $\frac{2}{3}Q$

Solution (a) For monoatomic gas

$$\frac{\Delta U}{Q} = \frac{3}{5} \text{ or } \Delta U = \frac{3}{5}Q$$

From the first law of thermodynamics

$$Q = \Delta U + W$$

$$\therefore \quad W = \frac{2}{5}Q$$

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

(a) work (b) pressure

(c) temperature (d) volume

[AIEEE 2003]

Solution (a) P, V and T are thermodynamic variables.

19. A Carnot engine takes 3×10^6 cal of heat from a reservoir at 627° C, and gives it to a sink at 27° C. The work done by the engine is

(a) 8.4×10^6 J (b) 16.8×10^6 J

(c) zero (d) 4.2×10^6 J

Solution (a) $\eta = 1 - \frac{T_2}{T_1} = 1 - \frac{300}{900} = \frac{W}{Q_1}$

or $\quad W = \frac{2}{3}Q = 2 \times 10^6 \text{ cal} = 8.4 \times 10^6 \text{ J}$

20. An ideal gas heat engine operated between 227° C to 127° C in a Carnot cycle. It absorbs 6 K cal at the higher temperature. The amount of heat (in kcal) converted to work is equal to

(a) 1.2 (b) 4.8

(c) 3.5 (d) 1.6

[CBSE 2003]

Solution (a) $\eta = 1 - \frac{T_2}{T_1} = 1 - \frac{400}{500} = \frac{W}{Q_1}$

or $\quad W = \frac{Q_1}{5} = 1.2 \text{ k cal}$

21. The efficiency of a Carnot engine operating between reservoirs maintained at 27° C and –123° C is

(a) 0.75 (b) 0.4

(c) 0.25 (d) 0.5

[DPMT 2002]

Solution (d) $\eta = 1 - \frac{T_2}{T_1} = 1 - \frac{150}{300} = \frac{1}{2}$

22. Calculate the change in entropy when 1 g of ice at 0° C is heated to form water at 40° C

(a) 0.28 cal/° C (b) 1.411 cal/° C

(c) 0.41 cal/° C (d) none of these

Solution (c) $\Delta S = \Delta S_1 + \Delta S_2$

To melt ice + to rise the temperature

$$= \frac{mL}{T} + mC\int_{T_1}^{T_2}\frac{dT}{T}$$

$$= \frac{1\times 80}{273} + 1 \times 1 \times 2.303 \log \frac{313}{273}$$

$$= 0.28 + 0.1366 = 0.42 \text{ cal °C}^{-1}$$

23. Calculate the change in entropy of n moles of a perfect gas when its temperature changes from T_1 to T_2 while its volume changes from V_1 to V_2

Solution $\quad dQ = TdS = du + PdV$

or $\quad dS = \frac{nC_V dT}{T} + \frac{PdV}{T}$

Since $PV = nRT$, therefore,

$$\frac{P}{T} = \frac{nR}{V}$$

Thus $dS = nC_V\frac{dT}{T} + n\text{R}\,\frac{dV}{V}$

Integrating $S_2 - S_1 = nC_V \log_e \frac{T_2}{T_1} + n\text{R} \log_e \frac{V_2}{V_1}$.

TYPICAL PROBLEMS

24. 3 moles of a gas mixture having volume V and temperature T is compressed to 1/5th of the initial volume. Find the change in its adiabatic compressibility if the gas obeys $PV^{19/13}$ = constant [R = 8.3 J/mol – K]

[IIT 1995]

Solution Bulk modulus $B = \gamma P$

$$\text{Compressibility } C = \left(\frac{1}{B}\right) = \frac{1}{\gamma P}$$

and $\Delta C = C - C$

or $$\Delta C = \frac{1}{\gamma}\left[\frac{1}{P'} - \frac{1}{P}\right]$$

$$PV^{\gamma} = P'\left(\frac{V}{5}\right)^{\gamma}$$

$$\text{With } \gamma = \frac{19}{13} \text{ and } P' = 5^{\gamma}P, 11$$

$$\Delta C = \frac{1}{\gamma P}\left[\frac{1}{5^{\gamma}} - \frac{1}{1}\right] = \frac{13 \times 0.905}{19P}$$

$$\text{But } PV = n\text{RT or } P = \frac{n\text{RT}}{V}$$

$$\Delta C = \frac{13(.905)V}{19 \times 3 \times 8.317T} = \frac{-0.0248V}{T}$$

25. A refrigerator, whose coefficient of performance $K = 5$, extracts heat from the cooling compartment at the rate of 250 J/cycle. What is the work done per cycle to operate the refrigerator? How much heat is discharged per cycle to the room which acts as the high temperature reservoir?

(a) 50 J (b) 200 J

(c) 300 J (d) none

Solution (c) $W = \frac{Q_2}{K} = \frac{250}{5} = 50$ J

$$Q_1 = Q_2 + W = 300 \text{ J}$$

26. One mole of an ideal gas is contained under a weightless piston of a vertical cylinder at a temperature T. The space over the piston opens into the atmosphere. What work has to be performed in order to increase isothermally the gas volume under the piston η times by slowly raising the piston? Neglect friction.

Solution Let A be the area of the cross-section

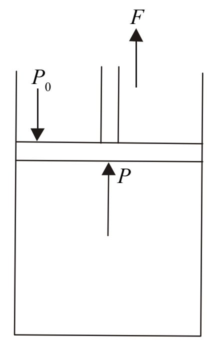


Fig. 16.18

$F + PA = P_0A$

$F = (P_0 - P)A$

Work done by the agent

$$W = \int_V^{\eta V} Fdx = \int_V^{\eta V} (P_0 - P)\, Adx$$

$$= \int_V^{\eta V} (P_0 - P)\, dV$$

$$= P_0(\eta - 1)V - \int_V^{\eta V} n\text{RT}\frac{dV}{V}$$

$$= \text{RT}\,[(\eta - 1) - n\log_e \eta]$$

27. A vertical hollow cylinder contains an ideal gas. The gas is enclosed by a 5 kg movable piston with area of cross-section 5×10^{-3} m^2. The gas is heated from 300 to 350 K and the piston rises by 0.1 m. The piston is now clamped at this position and the gas is cooled back to 300 K. Find the difference between the heat energy added during heating process and energy lost during the cooling process.

(a) 65 J (b) 55 J

(c) 75 J (d) 95 J

(e) none

[Roorkee 1996]

Solution (b) $(\Delta Q)_P = nC_P\Delta T = \Delta U + \Delta W$

When the piston is clamped, volume becomes constant

∴ Heat withdrawn,

$$(\Delta Q)_V = nC_V\Delta T = \Delta U$$

or $(\Delta Q)_P - (\Delta Q)_V = \Delta W = P\Delta V$

$$P = \left[P_0 + \frac{Mg}{A}\right]$$

$$\Delta V = A(0.1)$$

$$(\Delta Q)_P - (\Delta Q)_V = \left(P_0 + \frac{Mg}{A}\right)A(.1)$$

$= [10^5 \times 5 \times 10^{-3} + 5 \times 10]\,(0.1)$

$= 55$ J

28. 3 moles of an ideal monoatomic gas perform a cycle shown in Fig. 16.19. The gas temperatures $T_A = 400$ K, $T_B = 800$ K, $T_C = 2400$ K, $T_D = 1200$ K. Find the work done by the gas.

[Olympiad 1996]

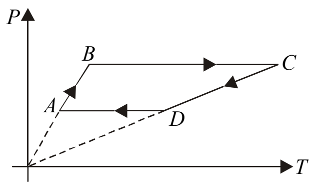


Fig. 16.19

Solution $W_{BC} = 3R\,(T_C - T_B)$

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

because the processes are isochoric

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

$\therefore$ Total work done

$W_{BC} + W_{DA} = 3R\,(T_A + T_C - T_B - T_D)$

$= 3R\,(400 + 2400 - 800 - 1200)$

$= 2400\,R = 20$ kJ

29. One mole of Argon is heated using $PV^{3/2}$ = const. Find the amount of heat obtained by the process when the temperature changes by $\Delta T = -26$ K.

[Olympiad 1998]

Solution Let p be the number of moles here $p = 1$

$$\text{then } C = \frac{R}{\gamma - 1} - \frac{R}{\eta - 1} = \frac{R}{\frac{5}{3} - 1} - \frac{R}{\frac{3}{2} - 1}$$

$$\Delta Q = pC\Delta T = 1\left(\frac{3}{2}R - 2R\right)(-26)$$

$$= +26\left(\frac{8.314}{2}\right) = 108 \text{ J}$$

30. An ideal gas with adiabatic exponent γ, is expanded according to the law

$P = \alpha V$

where α is a constant. The initial volume of the gas is V_0. As a result volume increases η times. Find the increment in internal energy and work done.

Solution Let k be number of moles

$P = \alpha V$ or $PV^{-1} = \alpha$

The process is polytropic with index $n = -1$

$\therefore \quad V_{\text{initial}} = V_0,\ V_{\text{final}} = \eta V_0$

and $\quad P_{\text{initial}} = \alpha V_0;\ P_{\text{final}} = \alpha\eta V_0$

$$\Delta U = \frac{k\text{R}}{\gamma - 1}\,(T_{\text{final}} - T_{\text{initial}}),\ P_{\text{final}} V_{\text{final}} - P_{\text{initial}}\ V_{\text{initial}}$$

Work done,

$$W = \frac{P_{\text{initial}} V_{\text{initial}} - P_{\text{final}} - V_{\text{final}}}{n - 1} = \frac{\alpha V_0^2\left[\eta_1^2 - 1\right]}{2}$$

31. One mole of oxygen is expanded from a volume 1 l to 5 l at a constant temperature $T = 280$ K. Find the change in internal energy and the amount of heat absorbed. Assume the gas to be a van der Waals gas.

Solution $\Delta U = \int_{V_1}^{V_2}\left(\frac{\partial P}{\partial T}\right)_V dV$

From second law of thermodynamics

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

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

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

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

From the first law of thermodynamics

$$Q = W + \Delta U = \text{RT}\log_e\left(\frac{V_2 - b}{V_1 - b}\right) = 3.8 \text{ kJ}$$

32. Calculate the heat absorbed by the system in going through the process shown in Fig. 16.20.

(a) 31.4 J (b) 3.14 J

(c) 3.14×10^4 J (d) none

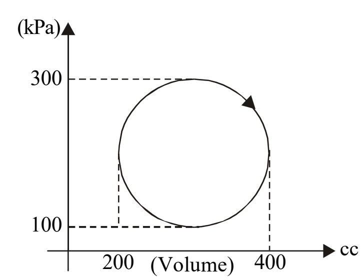


Fig. 16.20

Solution (a) Heat absorbed $= \pi r^2$

$= \pi(P_r)(V_r)$

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

$= 31.4$ J

PASSAGE 1

Read the following passage and answer the questions given at the end.

The power output of an automobile engine is directly proportional to the mass of air that can be forced into the volume of the cylinder of the engine to react chemically with gasoline. Many cars have a turbocharger which compresses the air before it enters the engine, giving a greater mass of air per unit volume. This rapid, essentially adiabatic compression, also heats the air. To compress it further the air then passes through an inter cooler in which the air exchanges heat with its surroundings at constant pressure. The air is then drawn into the cylinders. In a typical installation air is taken in turbocharger at atmospheric pressure and density 1.23 kg m^{-3} at 15^0 C. It is compressed adiabatically to 1.45×10^5 *Pa*. Volume of one of the cylinders is 575 cm^3. In intercooler the air is cooled to 15^0 C at 1.45×10^5 Pa.

1. By what percent does power output increase as compared to direct input of air at atmospheric pressure

(a) 12% (b) 16%

(c) 21% (d) 28%

2. What mass of the air exiting from inter cooler will fill the cylinder at 1.45×10^5 Pa.?

(a) 904×10^{-6} kg (b) 787.3×10^{-6} kg

(c) 7.6×10^{-6} kg (d) 834×10^{-6} kg

3. If inter cooler is not used what mass of air will fill the cylinder at 1.45×10^5 Pa?

(a) 904×10^{-6} kg (b) 787.3×10^{-6} kg

(c) 706×10^{-6} kg (d) 737.3×10^{-6} kg

Solution **1.** (d)

Solution **2.** (a)

Solution **3.** (b)

EXPLANATION

1, 2 and **3.** If no turbocharger or inter cooler is used then mass of the gas in the cylinder $m_1 = \rho V = 1.23 \times 575 \times 10^{-6}$ kg $= 697.25 \times 10^{-6}$ kg

If only turbocharger without inter cooler is used then

$$P_1 V_1^{\gamma} = p_2 V_2^{\gamma}$$

$$V_2 = \left(\frac{P_1}{P_2}\right)^{\frac{1}{\gamma}} V_1$$

$$\log V_2 = \frac{1}{\gamma}[\log P_1 - \log P_2] + \log V_1$$

$$= \frac{1}{1.4}[\log 1.01 - \log 1.45] + \log 575$$

$$= \frac{1}{1.4}[.0043 - .1614] + 2.7597$$

$$= 2.6457$$

$$P_1^{1-\gamma}\, T_1^{\gamma} = P_2^{1-\gamma}\, T_2^{\gamma}$$

or $$T_2 = \left(\frac{P_1}{P_2}\right)^{\frac{1-\gamma}{\gamma}} T_1$$

by $$T = \frac{1-\gamma}{\gamma}[\log P_1 - \log P_2]\, T \log T_1$$

$$V_2 = 442\, cm^3$$

$$\log T_2 = \frac{1-\gamma}{\gamma}[\log P_1 - \log P_2] + \log T_1$$

$$= \frac{-.4}{1.4}[.0043 - .1614] + 2.4594$$

$$\log T_2 = 2.5051$$

or $$T_2 = 320\,K = 47^0\,C$$

$$\rho_{new} = \rho_0(1 - \gamma\Delta T) = 1.23\left[1 - \frac{32}{273}\right]$$

$$= 1.0824\, kg\, m^{-3}$$

$$\text{(Without inter cooler) } M_1 = \rho_{new} \times \frac{575}{442} \times 575 \times 10^{-6}$$

$$= 787.3 \times 10^{-6}\, kg$$

$$\text{(With inter cooler) } M_2 = \frac{\rho \times 575}{442} \times 575 \times 10^{-6}$$

$$= 1.23 \times 1.3 \times 575 \times 10^{-6} = 904.25 \times 10^{-6}$$

$$\text{With inter cooler \% increse} = \frac{904 - 697}{697} \times 100 = 28\%$$

PASSAGE 2

Read the following passage and answer the questions given at the end.

A heat pump is a heat engine run in reverse. In winter it pumps heat from the cold air outside into the warmer air inside the building maintaining the building at a comfortable temperature. In summer it pumps heat from the cooler air inside the building to the warmer air outside acting as an air conditioner. The outside temperature in winter is -5° C and the inside temperature is 17° C. You have the option of using electrical resistance heating rather than a heat pump.

Consider a Carnot pump delivering heat to the inside of a house to maintain it at 68° F.

1. The efficiency of electrical heater is ____ to that of carnot pump.

(a) greater (b) lower

(c) equal (d) cannot be compared

2. How many joules of heat, does the heat pump deliver to the inside for each joule of electrical energy consumed?

(a) $\frac{1}{12.2}$ (b) 12.2

(c) 13.2 (d) $\frac{12.2}{13.2}$

(e) $\frac{13.2}{12.2}$

3. How much electrical energy would you need to deliver the same heat to the inside of a house as supplied by heat pump?

(a) 12.2 J (b) 13.2 J

(c) 11.2 J (d) none

4. What is the heat supplied by carnot pump to maintain a temperature of 68° F?

(a) 10.7 J (b) 12.7 J

(c) 11.7 J (d) none

Solution 1. (a) Because no heat engine can have efficiency 1.

Solution 2. (b) $K = \frac{T_C}{T_H - T_C} = \frac{Q_C}{W} = \frac{268}{22} = 12.2$

Solution 3. (b) $= 12.2 + 1 = 13.2$

Solution 4. (c) $k = \frac{T_C}{T_H - T_C} = \frac{Q_C}{W} = \frac{268}{25} = 10.7$

heat energy supplied $10.7 + 1 = 11.7$ J

PASSAGE 3

Read the following passage and answer the questions given at the end.

As a budding mechanical engineer, you are called upon to design a Carnot engine that has 2.0 moles of a monoatomic ideal gas as its working substance and that operates from a high temperature reservoir at 500^0 C. The engine is to lift a load of 15 kg weight to a height of 2 m per cycle using 500 J of heat input. The gas in the engine chamber can have a minimum volume of 5L during the cycle.

1. What is the temperature of heat sink?

(a) 50° C (b) 36° C

(c) 200° C (d) none of these

2. Find the thermal efficiency of the engine.

(a) 60% (b) 70%

(c) 66% (d) 42%

3. What should be the maximum pressure that the material of the engine chamber has to withstand?

(a) 1.57×10^6 Pa (b) 1.86×10^6 Pa

(c) 2.6×10^6 Pa (d) none

4. The P.V. diagram of the processes in the engine is

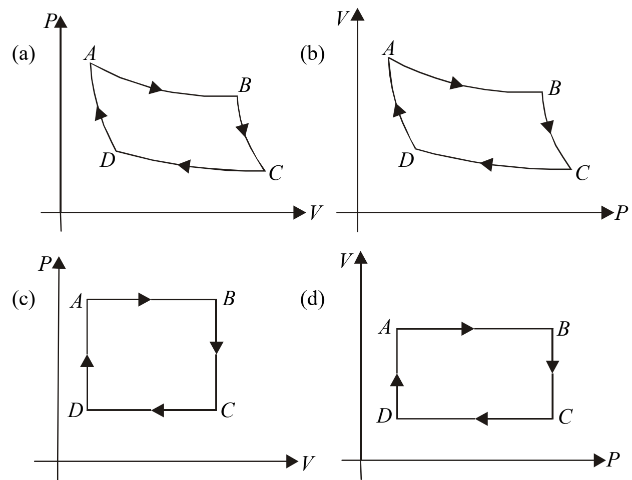


Fig. 16.21

Solution 1. (b) Efficiency $= \frac{W}{H} = \frac{15 \times g \times h}{500J} = \frac{15 \times 2 \times 10}{500} = \frac{3}{5}$

$$\frac{3}{5} = 1 - \frac{T_C}{T_H}$$

or $\frac{T_C}{773} = \frac{2}{5}$ $T_C = \frac{1546}{5} = 309.2\,K$

$309.2 - 273 = 36.2$ °C

Solution 2. (a)

Solution 3. (c)

Solution 4. (a)

QUESTIONS FOR PRACTICE

1. The amount of work done by the gas system in increasing the volume of 10 mols of an ideal gas from one litre to 20 litres at 0^0 C will be

(a) zero (b) 3.49 Joule

(c) 3.49×10^4 Joule (d) 6.79×10^4 Joule

2. The minimum number of thermodynamic parameters required to specify the state of gas system is

(a) 1 (b) 2

(c) 3 (d) ∞

3. If C_P and C_V are the molar specific heats of a gas at constant pressure and volume respectively then the ratio of adiabatic and isothermal moduliii of elasticity will be

(a) $\frac{C_P - C_V}{C_P}$ (b) $C_P\,C_V$

(c) $\frac{C_V}{C_P}$ (d) $\frac{C_P}{C_V}$

4. The internal energy of a compressed real gas, as compared to that of the normal gas at the same temperature, is

(a) less (b) more

(c) sometimes less, sometimes more

(d) none of these

5. A system is given 400 calories of heat and 1000 Joule of work is done by the system, then the change in internal energy of the system will be

(a) –860 Joule (b) 680 erg

(c) 680 Joule (d) 860 Joule

6. In a certain process 500 calories of heat is given to a system and the system does 100 Joule of work. The increase in internal energy of the system is

(a) 40 calorie (b) 82 calorie

(c) 1993 Joule (d) 2193 Joule

7. 11 g of carbondioxide is heated at constant pressure from 27^0 C to 227^0 C. The amount of heat transferred to carbondioxide will be

(a) 2200 calorie (b) 350 calorie

(c) 220 calorie (d) 110 calorie

8. The specific heat of a gas at constant pressure as compared to that at constant volume is

(a) less (b) equal

(c) more (d) constant

9. An air bubble of volume 15 cm^3 is formed at a depth of 50 m in a lake. If the temperature of the bubble while rising remains constant then the volume of bubble at the surface will be (g = 10 ms^{-2} and atmospheric pressure = 1.0×10^5 Pa)

(a) 100 cm^3 (b) 90 cm^3

(c) 80 cm^2 (d) 40 cm^2

10. The ratio of the slopes of adiabatic and isothermal curves is

(a) γ^2 (b) $1/\gamma$

(c) γ^3 (d) γ

11. Equal volumes of monoatomic and diatomic gases of same initial temperature and pressure are mixed. The ratio of the specific heats of the mixture (C_p/C_V) will be

(a) 1.53 (b) 1.52

(c) 1.5 (d) 1

12. For a thermodynamic process $\delta Q = -50$ calorie and $W = -20$ calorie. If the initial internal energy is – 30 calorie then, final internal energy will be

(a) – 100 calorie (b) – 60 calorie

(c) 100 calorie (d) 191.20 calorie

13. The change in internal energy of two mols of a gas during adiabatic expansion is found to be –100 Joule. The work done during the process is

(a) –100 Joule (b) 0

(c) 100 Joule (d) 200 Joule

14. Out of the following, the indicator diagram is

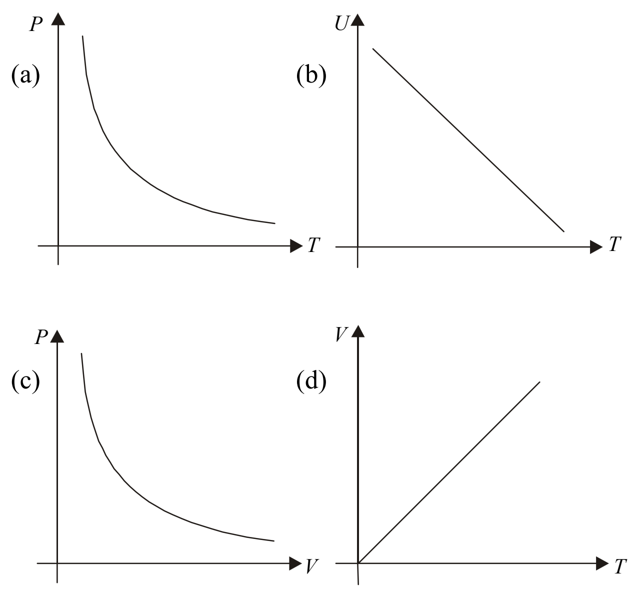


Fig. 16.22

15. The amount of heat required to raise the temperature of 100 g water from 20° C to 40° C will be

(a) zero (b) 100 calorie

(c) 2000 calorie (d) 4000 calorie

16. A liquid boils at such a temperature at which the saturated vapour pressure, as compared to atmospheric pressure, is

(a) one-third (b) equal

(c) half (d) double

17. The initial pressure of a gas is P. It is kept in an insulated container and suddenly its volume is reduced to one-third.Its final pressure will be

(a) $-3^{\gamma}P$ (b) $\dfrac{P}{(3)^{\gamma}}$

(c) $P/3$ (d) $3P$

18. The work done in Fig. 16.23 is

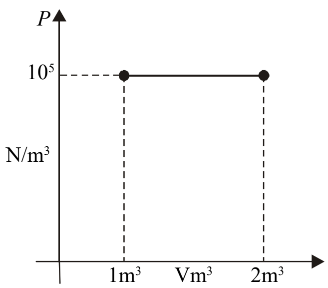


Fig. 16.23

(a) 3×10^5 J (b) 2×10^5 J

(c) 10^5 J (d) zero

19. 1 g of ice at 0° C is converted to steam at 100° C. The amount of heat required will be

(a) 12000 calorie (b) 756 calorie

(c) 716 calorie (d) 430 calorie

20. The heat capacity of a meterial depends upon

(a) density of matter

(b) specific heat of matter

(c) temperature of matter

(d) structure of matter

21. The isothermal bulk modulus of elasticity of a gas is 1.5×10^5 Nm^{-2}. Its adiabatic bulk modulus of elasticity will be (if $\gamma = 1.4$)

(a) 3×10^5 Nm^{-2} (b) 2.1×10^5 Nm^{-2}

(c) 1.5×10^5 Nm^{-2} (d) ∞

22. In changing the state of a system from state A to state B adiabatically the work done on the system is 322 Joule. If 100 calories of heat are given to the system in bringing it from state A to state B, then the work done on the system in this process will be

(a) 15.9 Joule (b) 38.2 Joule

(c) 98 Joule (d) 15.9 calorie

23. The indicator diagrams representing maximum and minimum amounts of work done are respectively

(a) a and b (b) b and c

(c) b and d (d) c and d

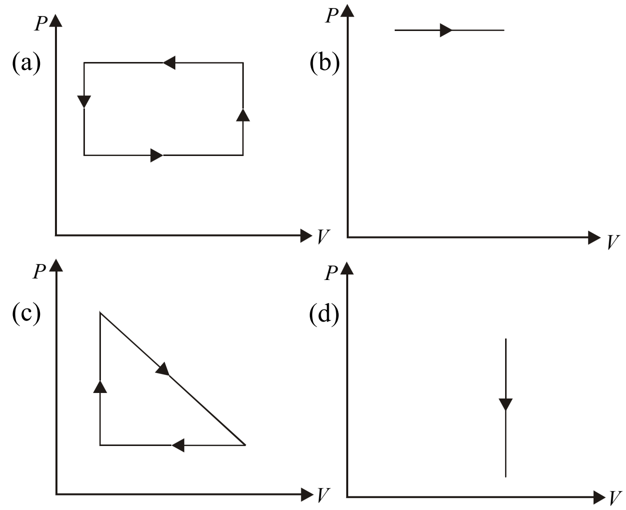


Fig. 16.24

24. Two samples of a gas A and B, initially at same temperature and pressure, are compressed to half their initial volume, A isothermally and B adiabatically. The final pressure in the two cases is related as

(a) $A = B$ (b) $A > B$

(c) $A < B$ (d) $A^2 = B$

25. A piece of ice at 0^0 C is dropped into water at 0^0 C. Then ice will

(a) melt (b) be converted to water

(c) not melt (d) partially melt

26. Four curves A, B, C and D are drawn for given mass a gas (Fig. 16.25). The curves which represent adiabatic and isothermal expansion are respectively

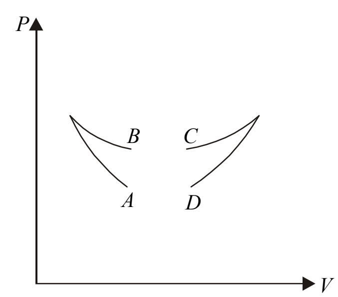


Fig. 16.25

(a) A and B (b) C and D

(c) B and A (d) D and C

27. How much work can be done by 250 calories of heat?

(a) zero (b) 1045 erg

(c) 1045 watt (d) 1050 Joule

28. In the gas equation $PV = RT$, V represents the volume of

(a) 1 mol of gas (b) 1 g of gas

(c) 1 litre of gas (d) any mass of gas

29. If, in defining the specific heat, temperature is represented in °F instead of °C then the value of specific heat will

(a) be converted to heat capacity

(b) remain unchanged

(c) decrease (d) increase

30. The specific heat of an ideal gas varies as

(a) T^3 (b) T^2

(c) T^1 (d) T^0

31. When an ideal diatomic gas is heated at constant pressure then what fraction of heat given is used to increase internal energy of gas?

(a) 2/5 (b) 3/5

(c) 3/7 (d) 5/7

32. When the temperature of a gas in a vessel is increased by 1° C then its pressure is increased by 0.5%. The initial temperature is

(a) 100 K (b) 200 K

(c) 273 K (d) 300 K

33. The internal energy of air in a room of volume 50 m^3 at atmospheric pressure will be

(a) 2.5×10^7 erg (b) 2.5×10^7 Joule

(c) 5.25×10^7 Joule (d) 1.25×10^7 Joule

34. One mol of helium is heated at 0° C and constant pressure. How much heat is required to increase its volume threefold?

(a) 2730 calorie (b) 273 calorie

(c) 27.30 calorie (d) 2.730 calorie

35. The pressure and volume of a gas are P and V respectively. If it is compressed suddenly to 1/32 of its initial volume then its final pressure will be

(a) $P/128$ (b) $P/32$

(c) $128P$ (d) $32P$

36. The net amount of work done in the following indicator diagram is

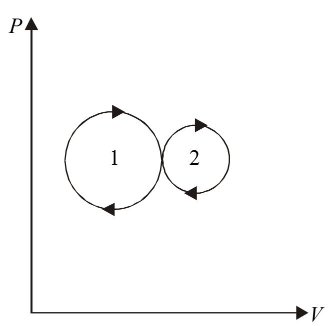


Fig. 16.26

(a) zero (b) positive

(c) negative (d) infinite

37. The volume of a gas is reduced to 1/4 of its initial volume adiabatically at 27° C. The final temperature of the gas (if $\gamma = 1.4$) will be

(a) $27 \times (4)^{0.4}$ K (b) $300 \times (1/4)^{0.4}$ K

(c) $100 \times (4)^{0.4}$ K (d) $300 \times (4)^{0.4}$ K

38. The concept of temperature is related to

(a) zeroeth law of thermodynamics

(b) first law of thermodynamics

(c) second law of thermodynamics

(d) third law of thermodynamics

39. When a liquid is heated retaining its liquid state, then its molecules gain

(a) kinetic energy (b) potential energy

(c) heat energy

(d) both kinetic and potential energy

40. A system absorbs 10^3 calories of heat and the system does 1677.3 Joule work. The internal energy of the system increases by 2515 Joule. The value of J is

(a) 4.19 Joule/cal (b) 4.18 cal/Joule

(c) 42 Joule/cal (d) 420 Joule/cal

41. The relation between P and T for monoatomic gas during adiabatic process is $P \propto T^C$. The value of c is

(a) 3/5 (b) 2/5

(c) 5/3 (d) 5/2

42. A player gets 400 kilocalories energy daily from the food. His power will be

(a) zero (b) 1.93 watt

(c) 19.3 watt (d) 193.5 watt

43. The thermodynamic scale of temperature was given by

(a) Dewar (b) Fahrenheit

(c) Kelvin (d) Carnot

44. 1 m^3 of a gas is compressed suddenly at atmospheric pressure and temperature 27° C such that its temperature becomes 627° C. The final pressure of the gas (if $\gamma = 1.5$) will be

(a) 2.7×10^5 Nm^{-2} (b) 7.2×10^5 Nm^{-2}

(c) 27×10^5 Nm–2 (d) 27×10^6 Nm^{-2}

45. The volume of 1 m^3 of gas is doubled at atmospheric pressure. The work done at constant pressure will be

(a) zero (b) 10^5 calorie

(c) 10^5 Joule (d) 10^5 erg

46. If the volume of a gas is decreased by 10% during isothermal process then its pressure will

(a) decrease by 10% (b) increase by 10%

(c) decrease by 11.11% (d) increase by 11.11%

47. At the boiling point of water the saturated vapour pressure will be (in mm of Hg)

(a) 750 (b) 760

(c) 850 (d) 860

48. The ratio of the latent heat of steam to latent heat of ice is

(a) 4/9 (b) 9/4

(c) 4/27 (d) 27/4

49. The maximum efficiency of an engine operating between the temperature 400° C and 60° C is

(a) 55% (b) 75%

(c) 95% (d) none of these

50. A Carnot engine works between ice point and steam point. Its efficiency will be

(a) 85.42% (b) 71.23%

(c) 53.36% (d) 26.81%

51. If the temperature of the sink is absolute zero, the efficiency of the heat engine should be

(a) 100% (b) 50%

(c) zero (d) none of these

52. When the temperature difference between the source and the sink increases, the efficiency of the heat engine will

(a) increase (b) decrease

(c) is not affected

(d) may increase or decrease depending upon the nature of the working substance

53. A Carnot engine can be 100% efficient if its sink is at

(a) 0 K (b) 0° C

(c) 0° F (d) 273 K

54. Which of the following is the best container for gas during adiabatic process?

(a) wood vessel (b) thermos flask

(c) copper vessel (d) glass vessel

55. In which of the following processes does the system always returns to the original thermodynamic state?

(a) isobaric (b) cyclic

(c) isothermal (d) adiabatic

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

(a) 300° C (b) 327° C

(c) 373° C (d) 273° C

57. Figure 16.27 shows four indicator diagrams. In which case is the work done maximum?

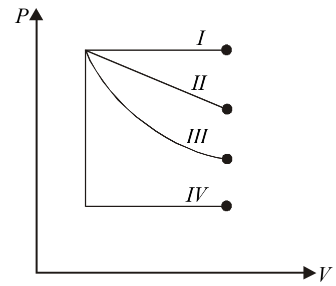


Fig. 16.27

(a) IV (b) II

(c) III (d) I

58. One mole of a monoatomic gas and one mole of a diatomic gas are mixed together. What is the molar specific heat at constant volume for the mixture?

(a) 5/2 R (b) 2 R

(c) 3/2 R (d) 3 R

59. What is the value of dp/p for adiabatic expansion of the gas?

(a) $\gamma dV/V$ (b) $-dV/V$

(c) dV/V (d) $-\gamma dV/V$

60. Which of the following has higher efficiency? An engine working between the temperatures

(a) 40 K and 20 K (b) 60 K and 40 K

(c) 80 K and 60 K (d) 100 K and 80 K

61. The temperature of the source of a Carnot heat engine is 0° C and that of sink is – 39° C. The efficiency of the heat engine is

(a) 39% (b) 14.3%

(c) zero (d) none of these

62. Work done during isothermal expansion depends on change in

(a) volume (b) pressure

(c) both (a) and (b) (d) none of these

63. For an engine operating between the temperatures t_1 °C and t_2 °C, the efficiency will be

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

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

64. For 100% efficiency of a Carnot engine the temperature of the source should be

(a) 273° C (b) 0° C

(c) –273° C (d) none of these

65. When 1 mole of a monoatomic gas expands at constant pressure the ratio of the heat supplied that increases the internal energy of the gas and that used in expansion is

(a) 2/3 (b) 3/2

(c) 0 (d) ∞

66. The efficiency of the heat engine working between 327° C and 27° C is to be increased by 10%. The temperature of the source should be increased by

(a) 52° C (b) 67° C

(c) 37° C (d) 77° C

67. A Carnot engine operates with a source at 500 K and sink at 375 K. If the engine consumes 600 K cal of heat in one cycle, the heat rejected to the sink per cycle is

(a) 550 K cal (b) 450 K cal

(c) 350 K cal (d) 250 K cal

68. The change in which of the following solely determines the work done by a gas during adiabatic process-

(a) temperature (b) pressure

(c) volume (d) none of these

69. A Carnot engine, whose source is at 400 K, takes 200 cal of heat and reflects 150 cal to the sink. What is temperature of the sink?

(a) 300 K (b) 400 K

(c) 800 K (d) none of these

70. A gas at pressure 6×10^5 Nm^{-2} and volume 1 m^3 expands to 3 m^3 and its pressure falls to 4×10^5 Nm^{-2}. Given that the indicator diagram is a straight line, the work done on the system is

(a) 12×10^5 J (b) 6×10^5 J

(c) 4×10^5 J (d) 3×10^5 J

71. During an adiabatic expansion of 5 moles of gas, the internal energy decreases by 75 J. The work done during the process is

(a) –75 J (b) zero

(c) 15 J (d) 75 J

72. A monoatomic gas expands isobarically. The percentage of heat supplied that increases the thermal energy and that involved in doing work for expansion is

(a) 40 : 60 (b) 60 : 40

(c) 50 : 50 (d) none of these

73. How many dead centres are there in one cycle of steam engine?

(a) 4 (b) 3

(c) 2 (d) 1

74. For adiabatic expansion of a monoatomic perfect gas, the volume increases by 2.4%. What is the percentage decrease in pressure?

(a) 2.4% (b) 4.0%

(c) 4.8% (d) 7.1%

75. Figure 16.28 represents two processes *a* and *b* for a given sample of gas. Let ΔQ_1 and ΔQ_2 be the heat absorbed by the systems in the two cases respectively. Which of the following relations is correct?

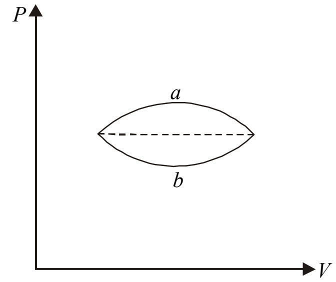


Fig. 16.28

(a) $\Delta Q_1 = \Delta Q_2$ (b) $\Delta Q_1 > \Delta Q_2$

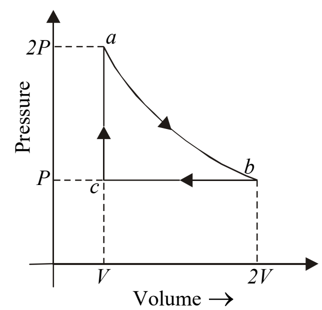
(c) $\Delta Q_1 \leq \Delta Q_2$ (d) $\Delta Q_1 < \Delta Q_2$

76. A cylinder contains helium at 2.5 atmosphere pressure. Another identical cylinder contains argon at 1.5 atmosphere pressure at the same temperature. If both the gases are filled in any one of the cylinders, the pressure of the mixture will be

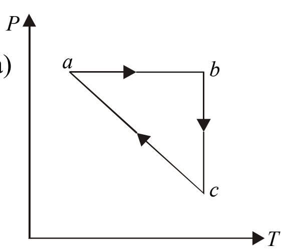
(a) 1.5 atm (b) 2.5 atm

(c) 4 atm (d) none of these

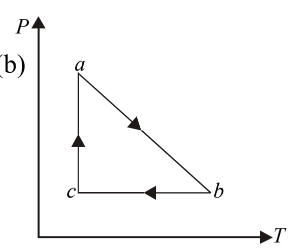
77. Figure 16.29 shows a cyclic process *abca* for one mole of an ideal gas. If *ab* is isothermal process, then which of the following is the $P - T$ diagram for the cyclic process?



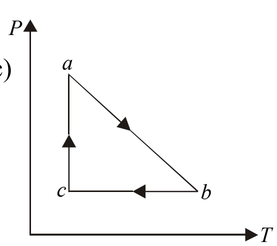
(a)



(b)



(c)



(d)

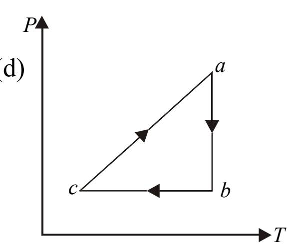


Fig. 16.29

78. A gas is enclosed in a vessel of volume 1000 cc at a pressure of 72.6 cm of Hg. It is being evacuated with the help of a piston pump, which expels 10% gas in each stroke. The pressure after the second stroke will be nearest to

(a) 60 cm (b) 55 cm
(c) 66 cm (d) 50 cm

79. An ideal gas heat engine operates in Carnot cycle between 272^0 C and 127^0 C. It absorbs 6.0×10^4 cal at the higher temperature. The amout of heat converted into work is equal to

(a) 1.2×10^4 cal (b) 1.6×10^4 cal
(c) 3.5×10^4 cal (d) 4.8×10^4 cal

80. In free expansion of a gas the internal energy of the system

(a) increases (b) decreases
(c) is unchanged (d) changes

81. A Carnot engine whose sink is at a temperature of 300 K has an efficiency of 40%. By how much should the temperature of the source be increased so as to increase the efficiency to 60%?

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

82. During an adiabatic expansion of 2 moles of a gas, the change in internal energy was found to be equal to – 200 J. The work done during the process will be equal to

(a) –100 Joule (b) zero
(c) 100 Joule (d) 200 Joule

83. Which of the following represents an isothermal expansion?

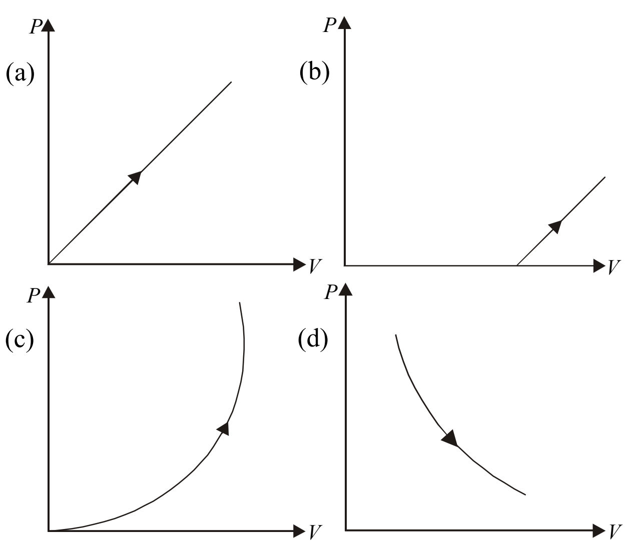


Fig. 16.30

84. Two perfect gases having masses m_1 and m_2 at temperatures T_1 and T_2 are mixed without any loss of internal kinetic energy of the molecules. The molecular weights of the gases are M_1 and M_2. What is the final temperature of the mixture?

(a) $\dfrac{\dfrac{M_1}{m_1}T_1 + \dfrac{M_2}{m_2}T_2}{\dfrac{M_1}{m_1} + \dfrac{M_2}{m_2}}$ (b) $\dfrac{\dfrac{m_1}{M_1}T_1 + \dfrac{m_2}{M_2}T_2}{\dfrac{m_1}{M_1} + \dfrac{m_2}{M_2}}$

(c) $\dfrac{M_1T_1 + M_2T_2}{M_1 + M_2}$ (d) $\dfrac{m_1T_1 + m_2T_2}{m_1 + m_2}$

85. In the following $V - T$ diagram, what is the relation between P_1 and P_2?

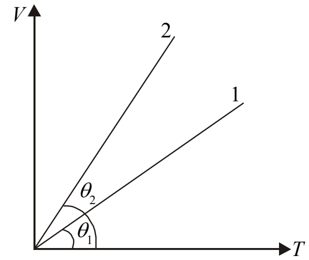


Fig. 16.31

(a) $P_2 = P_1$ (b) $P_2 > P_1$
(c) $P_2 < P_1$ (d) cannot be predicted

86. In a thermodynamic process pressure of a fixed mass of gas is changed in such a manner that the gas releases 30 Joule of heat and 18 Joule of work was done on the gas. If the initial internal energy of the gas was 60 Joule, then the final internal energy will be

(a) 96 Joule (b) 72 Joule
(c) 48 Joule (d) 32 Joule

87. A Carnot engine working between 300 K and 600 K has a work output of 800 J per cycle. The amount of heat energy supplied to the engine from the source in each cycle is

(a) 6400 J (b) 3200 J
(c) 1600 J (d) 800 J

88. Find the change in internal energy of the system when a system absorbs 2 kilocalorie of heat and at the same time does 500 Joule of work.

(a) 8200 J (b) 7900 J
(c) 6400 J (d) 5600 J

89. If 1 g of water at 40° C is converted to steam at 100° C, the change in entropy is

(a) $2.303 \log \dfrac{373}{313}$ cal °C^{-1}

(b) $\dfrac{600}{373}$ cal °C^{-1}

(c) $\dfrac{600}{313}$ cal °C^{-1}

(d) $\dfrac{540}{373} + \log \dfrac{373}{313}$ cal °C^{-1}

90. If the value of $R = 2/5\ C_V$ for a gas, then the atomicity of the gas will be

(a) monoatomic (b) diatomic
(c) polyatomic (d) any of these

91. 10 g of ice at 0° C melts. The entropy then

(a) decreases by 2.93 cal $^0C^{-1}$
(b) increases by 2.93 cal $^0C^{-1}$
(c) remains unchanged
(d) none of these

92. Which of the curve shows adiabatic compression?

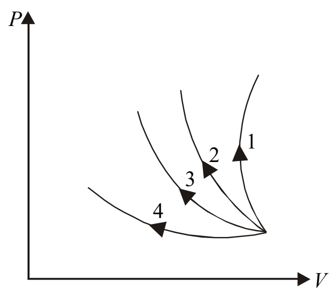


Fig. 16.32

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

93. Figure 16.33 shows a cyclic process. Which of the following is its PV conversion?

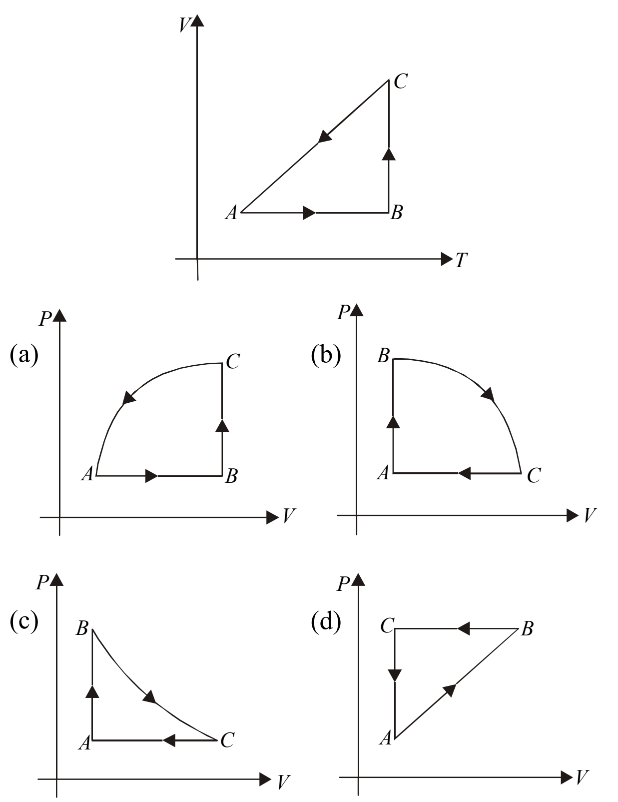


Fig. 16.33

94. The value of C_P/C_V for the mixture of 2 mols of oxygen and 5 mols of ozone is

(a) 1.34 (b) 1.41
(c) 1.51 (d) 1.67

95. When the temperature of an iron sphere of mass 1 kg falls from 30° C to 25° C, then 550 calorie of heat is released. The heat capacity of the iron sphere will be (in cal °C^{-1})

(a) 440 (b) 330
(c) 220 (d) 110

96. A hail at 0° C falls from a height of 1 km on an insulated surface and its whole kinetic energy is converted into heat. What fraction of it will melt?

(a) $1/33 \times 10^{-4}$ (b) 1/33
(c) 1/8 (d) whole of it will melt

97. A 50 g piece of iron at 100°C is dropped into 100 g water at 20° C. The temperature of the mixture is 25.5 °C. The specific heat of iron (in calg–1 °C^{-1}) is

(a) 0.148 (b) 0.082
(c) 0.267 (d) 0.341

98. If the radii of two copper spheres are in the ratio 1 : 3 and their temperatures are in the ratio 9 : 1 then the ratio of the heat contents in them will be

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

99. A reversible heat engine converts 1/6th of heat which it absorbs from source into work. When the temperature of sink is reduced by 62 °C, its efficiency is doubled. The temperature of the source is

(a) 372 K (b) 272 K
(c) 172 K (d) 72 K

100. An ideal gas is filled in a container of volume 8.3×10^3 m^3 at 300 K temperature and 2.0×10 Nm^{-2} pressure. If it is given an additional energy 2.5×10^9 J, then its final temperature will be

(a) 600 K (b) 625 K
(c) 650 K (d) 675 K

101. For which process is the relation $dQ = dU$ true?

(a) isobaric (b) isochoric
(c) isothermal (d) adiabatic

102. The molar specific heat of an ideal gas at constant pressure and volume are C_P and C_V respectively. The value of C_V is

(a) R (b) γR
(c) $\dfrac{R}{\gamma - 1}$ (d) $\dfrac{\gamma R}{\gamma - 1}$

103. Heating of a wheel on applying brakes is due to the relation

(a) $P \propto \frac{1}{V}$ (b) $P \propto T$

(c) $W \propto Q$ (d) $V \propto T$

104. A bicycle is moving at a speed of 36 kmh^{-1}. Brakes are applied. It stops in 4 m. If mass of the bicycle is 40 kg then temperature of the wheel risen is [specific heat of wheel 0.25 calg^{-1} °C^{-1}, mass of the = wheel = 5 kg]

(a) 0.19° C (b) 0.47° C

(c) 4.7° C (d) 1.9° C

105. Out of the following whose specific heat is maximum?

(a) lead (b) brass

(c) glass (d) iron

106. The correct value of temperature on Kelvin scale corresponding to 0° C is

(a) 0 K (b) 273.15 K

(c) 273.2 K (d) 273 K

107. For Boyle's law to hold good, the necessary condition is

(a) isothermal (b) adiabatic

(c) isobaric (d) isochoric

108. The mechanicl equivalent of heat (J) is a

(a) conversion factor (b) constant

(c) physical quantity (d) none of these

109. The internal energy of an isolated system

(a) keeps on changing (b) remains constant

(c) zero (d) none of these

110. The number of specific heats for a gas system is

(a) 1 (b) 2

(c) three (d) infinite

111. The internal energy of a piece of lead when beaten by a hammer will

(a) increase

(b) decrease

(c) remain constant

(d) sometimes increase and sometimes decrease

112. 20 g of water at 20° C is contained in a calorimeter of water equivalentof 10 g of water at 50° C is mixed into it. The temperature of the mixture will be

(a) 15.2° C (b) 27.5° C

(c) 35.2° C (d) 43.7° C

113. How much heat is required to heat 2 moles of a monoatomic ideal gas from 0° C to 100° C if no mechanical work is done during heating? [The specific heat of gas at constant pressure is 2.5 R, where R is the universal gas constant.]

(a) 378.6 cal (b) 417.1 cal

(c) 596.4 cal (d) 782 cal

114. Two steam engine A and B have their sources respectively at 700 K and 650 K and their sinks at 350 K and 300 K. Then

(a) A is more efficient than B

(b) B is more efficient than A

(c) both are equally efficient

(d) depends on the fuels used in A and B

115. A Carnot engine works between 600 K and 300 K. In each cycle of operations, the engine draws 1000 Joule of energy from the source at 600 K. The efficiency of the engine is

(a) 90% (b) 70%

(c) 50% (d) 20%

116. During isothermal expansion at 800 K, the working substance of a Carnot engine releases 480 calories of heat. If the sink is at 300 K then the work done by the working substance during isothermal expansion will be

(a) 480 cal (b) 300 cal

(c) 270 cal (d) 190 cal

117. A heat engine operates between 2100 K and 700 K. Its actual efficiency is 40%. What percentage of its maximum possible efficiency is this?

(a) 66.67% (b) 60%

(c) 40% (d) 33.33%

118. An ideal heat engine exhausting heat at 77° C is to have 30% efficiency. It must take heat at

(a) 673° C (b) 327° C

(c) 227° C (d) 127° C

119. The temperature, which is the same in ^{0}C and ^{0}F, is

(a) –20 (b) 20

(c) –40 (d) 40

120. Isobaric bulk modulus of elasticity is

(a) ∞ (b) zero

(c) P (d) $\frac{C_P}{C_V}$

121. A Carnot engine has same efficiency between (i) 100 K and 500 K and (ii) T_K and 900 K. The value of T is

(a) 360 K (b) 270 k

(c) 180 k (d) 90 K

122. Two systems are in thermal equilibrium. The quantity which is common for them is

(a) heat (b) momentum
(c) specific heat (d) temperature

123. The amount of heat necessary to raise the temperature of 0.2 mol of N_2 at constant pressure from 37° C to 337° C will be

(a) 764 Joule (b) 1764 erg
(c) 1764 calorie (d) 1764 Joule

124. Air is filled in a motor car tube at 27° C temperature and 2 atmosphere pressure. If the tube suddenly bursts then the final temperature will be [given $(1/2)^{2/7} = 0.82$]

(a) 642 K (b) 563 K
(c) 300 K (d) 246 K

125. A reversible engine takes heat from a reservoir at 527° C and gives out to perform useful mechanical work at the rate of 750 watt. The efficiency of the engine is

(a) 70% (b) 50%
(c) 30% (d) 10%

126. The temperature *vs* entropy diagram is shown in Fig 16.34. Its *PV* equivalent diagram is

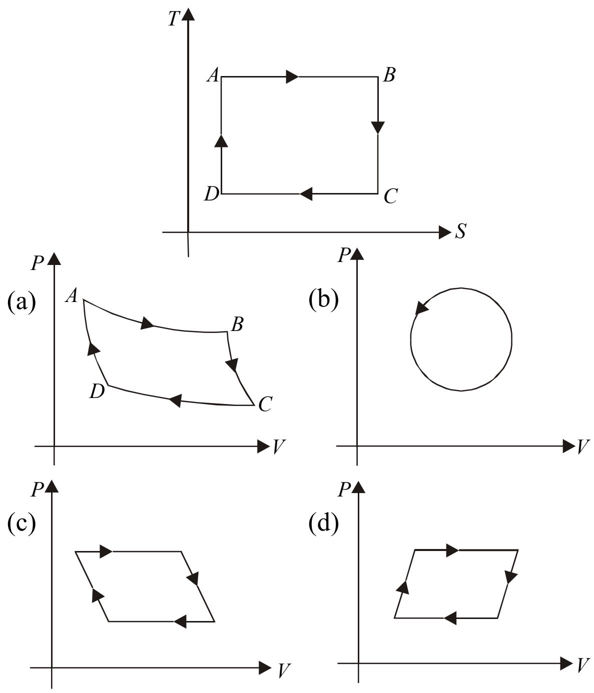


Fig. 16.34

127. Pure water, cooled to –15° C, is kept in an insulated flask. Some ice is dropped into the flask. The fraction of water frozen into ice is (specific heat of ice = 0.5 calg–1 °C^{-1})

(a) 6/29 (b) 3/35
(c) 6/35 (d) 2/35

128. A block of ice of mass 50 kg is pushed out on a horizontal plane with a velocity of 5 m/s. Dur to friction it comes to rest after covering a distance of 25 m. How much ice will melt?

(a) 100 g (b) 100 g
(c) 1.86 g (d) 0.86 g

129. The height of a water spring is 50 m. The difference of temperature at the top and bottom of the spring will be

(a) 0.117° C (b) 1.17° C
(c) 0.437° C (d) 11.7° C

130. The radiator of a car contains 20 litre water. If the motor supplies 2×10^5 calorie heat to it, then rise in its temperature will be

(a) 1000° C (b) 100° C
(c) 20° C (d) 10° C

PASSAGE 1

Read the following passage and answer the questions given at the end.

The maximum power that can be extracted by a wind turbine from an air stream is approximately $P = kd^2v^3$ where d is the blade diameter, v is the wind speed and constant $k = 0.5\ W\text{–}s^3\ m^{-5}$. The cylinder shown in Fig. 16.35 has length $L = vt$, diameter d and density ρ. The Mod – 5*B* wind turbine at Kahaku on the Hawaian island of Oahu has blade diameter of 97 m, slightly longer than a football field, and sits atop a 58 m tower. It can produce 3.2 MW of electric power. Assume 25% efficiency.

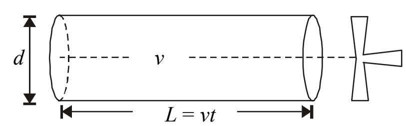


Fig. 16.35

1. What wind speed is required to produce amount of power mentioed in the passage?

(a) 10 ms^{-1} (b) 12 ms^{-1}
(c) 14 ms^{-1} (d) 16 ms^{-1}

2. Commercial wind turbines are commonly located in or down wind of mountain passes because

(a) wind speed is very high
(b) wind is directional
(c) wind is abundantly available
(d) wind blows the whole year

Solution **1.** (d) $3.2 \times 10^6 = .5 \times (97)^2 \times \frac{1}{4} \times v^2$

$v = 16.2\ \text{ms}^{-1}$

Solution **2.** (b)

PASSAGE 2

Read the following passage and answer the questions given at the end.

An automobile has a six cylinder otto cycle engine with compression ratio 10.6. The diameter of each cylinder, called the bore of the engines, is 82.5 mm. The distance that the piston moves during each compression, called the stroke, is 86.4 mm. The initial pressure of the fuel air mixture is 8.5×10^4 Pa and initial temperature is 300 K, the same as the outside air. Assume 200 J is added by burning gasoline in each cylinder. $C_V = 20.5$ J/mole/K

1. The work done in one complete cycle in each cylinder is

(a) 732 J (b) 510 J

(c) 340 J (d) 122 J

2. The difference in efficiency of the engine as compared to Carnot engine

(a) 5.1% (b) 9.9%

(c) 13.5% (d) 16.9%

Solution **1.** (d) $\eta = 1 - \dfrac{1}{r^{\gamma-1}} = 1 - \dfrac{1}{(10.6)1.4-1}$

$$= 1 - \frac{1}{0.2578} = 61.1\%$$

$$\eta = \frac{W}{H} = .61 \times 200 = 122 \text{ J}$$

Solution **2.** (d) $T_1 V_1^{\gamma-1} = T_2 V_2^{\gamma-1}$

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

$$V_1 = \frac{82.5^2 \pi \times 86.4 \times 10.6}{4}$$

$$= 300\,(10.6)^{0.4} = 300\,(0.2578) = 773.4 \text{ K}$$

$$nC_V\Delta T = 200$$

$$P_1 V_1^{\gamma} = p_2 V_2^{\gamma} = p_2 = 8.5 \times 10^4 (10.6)^{1.4}$$

$$= 2.3 \times 10^6 \text{ Pa}$$

$$PV = nRT$$

$$n = \frac{PV}{RT} = \frac{8.5 \times 10^4 \times 5.1 \times 10^{-4}}{8.3 \times 300}$$

$$= \frac{5.2}{300}$$

$$nC_V\Delta T = 200$$

$$\Delta T = 200 \times n\,C_V$$

$$= \frac{200 \times 5.2 \times 20.5}{300} = 670$$

$$670 + 773.4 = 1443.4$$

$$\eta_{\text{carnot}} = \left(1 - \frac{300}{1443}\right) \times 100 = 78\%$$

$$78 - 61.1 = 16.9\%$$

PASSAGE 3

Read the following passage and answer the questions given at the end.

To heat one cup of coffee you place 250 cm^3 of water on an electric heater in a cup. As the water temperature rises from 20° C to 65° C, the temperature of (element of the heater) remains constant at 120° C. Assume specific heat of water remains constant and ignore the heat that flows into the ceramic cup itself.

1. The change in entropy of water is

(a) 150 J k^{-1} (b) 120 J k^{-1}

(c) 30 J k^{-1} (d) none of these

2. The change in entropy of element (heater) is

(a) –150 J k^{-1} (b) –120 J k^{-1}

(c) –30 J k^{-1} (d) –180 J k^{-1}

3. The change in entropy of the system is

(a) 120 J k^{-1} (b) –30 J k^{-1}

(c) 30 J k^{-1} (d) –180 J k^{-1}

4. The process is

(a) reversible (b) irreversible

(c) cyclic (d) none of these

Solution **1.** (a) $\Delta S = mc \log_e \dfrac{T_2}{T_1}$

$$= \frac{1}{4} \times 4200 \times 2.303 \log \frac{338}{293}$$

$$= 150 \text{ J k}^{-1}$$

Solution **2.** (b) $\Delta S = \dfrac{-mc\Delta T}{T}$

$$= \frac{\frac{-1}{4} \times 4200 \times 45}{393}$$

$$= -120 \text{ J k}^{-1}$$

Solution **3.** (c) $150 - 120 = 30$ J k^{-1}

Solution **4.** (b) $\because$ $\Delta S \neq 0$ over whole cycle

Answers to Questions for Practice

1.	(d)	**2.**	(b)	**3.**	(d)	**4.**	(a)	**5.**	(c)	**6.**	(c)	**7.**	(b)
8.	(c)	**9.**	(b)	**10.**	(d)	**11.**	(c)	**12.**	(b)	**13.**	(c)	**14.**	(c)
15.	(c)	**16.**	(b)	**17.**	(a)	**18.**	(c)	**19.**	(c)	**20.**	(b)	**21.**	(b)
22.	(c)	**23.**	(c)	**24.**	(c)	**25.**	(c)	**26.**	(a)	**27.**	(d)	**28.**	(a)
29.	(c)	**30.**	(d)	**31.**	(d)	**32.**	(b)	**33.**	(d)	**34.**	(a)	**35.**	(c)
36.	(a)	**37.**	(d)	**38.**	(a)	**39.**	(a)	**40.**	(a)	**41.**	(d)	**42.**	(c)
43.	(c)	**44.**	(c)	**45.**	(c)	**46.**	(b)	**47.**	(b)	**48.**	(d)	**49.**	(d)
50.	(d)	**51.**	(a)	**52.**	(a)	**53.**	(a)	**54.**	(b)	**55.**	(b)	**56.**	(b)
57.	(d)	**58.**	(b)	**59.**	(d)	**60.**	(a)	**61.**	(b)	**62.**	(c)	**63.**	(b)
64.	(c)	**65.**	(b)	**66.**	(b)	**67.**	(b)	**68.**	(a)	**69.**	(a)	**70.**	(c)
71.	(d)	**72.**	(b)	**73.**	(c)	**74.**	(b)	**75.**	(b)	**76.**	(c)	**77.**	(d)
78.	(a)	**79.**	(b)	**80.**	(c)	**81.**	(a)	**82.**	(d)	**83.**	(d)	**84.**	(b)
85.	(c)	**86.**	(c)	**87.**	(c)	**88.**	(b)	**89.**	(d)	**90.**	(b)	**91.**	(b)
92.	(b)	**93.**	(c)	**94.**	(a)	**95.**	(d)	**96.**	(b)	**97.**	(a)	**98.**	(a)
99.	(a)	**100.**	(d)	**101.**	(b)	**102.**	(c)	**103.**	(c)	**104.**	(a)	**105.**	(a)
106.	(b)	**107.**	(a)	**108.**	(a)	**109.**	(b)	**110.**	(b)	**111.**	(a)	**112.**	(b)
113.	(c)	**114.**	(b)	**115.**	(c)	**116.**	(b)	**117.**	(b)	**118.**	(c)	**119.**	(c)
120.	(b)	**121.**	(c)	**122.**	(d)	**123.**	(d)	**124.**	(d)	**125.**	(b)	**126.**	(a)
127.	(c)	**128.**	(c)	**129.**	(a)	**130.**	(d)						

EXPLANATION

7. $n = \frac{1}{44} = \frac{1}{4}$

$\Delta Q = nc_p \Delta T = \frac{1}{4} \times \frac{7}{2} R \times 200 = 350$ cal.

12. $\Delta Q = \Delta U + W$ or $\Delta U = -50 + 20 = -30$ cal

$U_f = u_i + \Delta u = -30 - 30 = -60$ cal.

21. $P_{\text{adiabatic}} = \gamma P_{\text{iso}} = 1.4\ (1.5 \times 10^5) = 2.1 \times 10^5\ \text{Nm}^{-2}$.

32. $\frac{\Delta P}{P} = \frac{\Delta T}{T} = \frac{0.5}{100}$ or $\frac{1}{T} = \frac{0.5}{100}$ or $T = 200$ K.

33. $U = \frac{5}{2} nRT = \frac{5}{2} \times \frac{50}{22.4 \times 10^{-3}} \times 8.3 \times 273$

$= 1.25 \times 10^7$ J.

37. $T_1 V_1^{\gamma-1} = T_2 V_2^{\gamma-1}$ or $T_2 = 300\ (4)^{0.4}$ K.

44. $P_1^{1-\gamma} T_1^{\gamma} = P_2^{1-\gamma} T_2^{\gamma}$

or $P_2 = P_1 \left(\frac{T_1}{T_2}\right)^{\frac{\gamma}{1-\gamma}} = 10^5(3)^3$.

66. $\eta = 1 - \frac{300}{600}$. $\eta_{\text{new}} = 0.55 = 1 - \frac{300}{T}$ or $T = \frac{300}{0.45}$.

69. $\frac{Q_1 - Q_2}{Q_1} = 1 - \frac{T_2}{T_1}\ \frac{50}{200} = 1 - \frac{T_2}{400}$

or $T_2 = 300$ K.

70. $W = (P_1 - P_2)\ (V_2 - V_1) = 2 \times 10^5 \times 2 = 4 \times 10^5$J

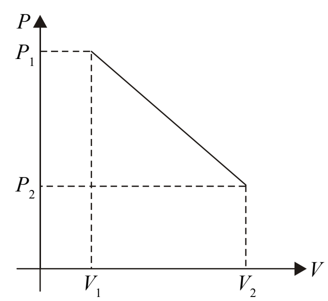


Fig. 16.36

78. $P_1 V_1 = P_2 V_2\ P_2 = 72.6\ (.81)$ as volume after two strokes will be 810 cc.

85. Conclude using $\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2}$.

89. $S = \frac{dQ}{T}\ \Delta S = mc \int \frac{dT}{T} + \frac{mL}{T}$

$= 1 \times 1 \int_{313}^{373} \frac{dT}{T} + \frac{540}{373}$.

90. $C_V = \frac{5}{2} R\ \therefore$ the gas is diatomic.

96. $\frac{m'}{m} = \frac{gh}{JL} = \frac{980 \times 10^5}{4.2 \times 10^7 \times 80} = \frac{1}{33}$.

127. $M \times 1 \times 15 = m\ 80 + m(0.5)\ (15)$

$\frac{m}{M} = \frac{15}{87.5} = \frac{6}{35}$.