1 Thermodynamic System and Processes

1.1 An insulated rigid vessel contains a mixture of fuel and air. The mixture is ignited by a minute spark. The contents of the vessel experience
(a) Increase in temperature, pressure and energy
(b) Decrease in temperature, pressure and energy
(c) Increase in temperature and pressure but no change in energy
(d) Increase in temperature and pressure but decrease in energy

[1993 : 1 Mark]

1.2 The definition of 1 K as per the internationally accepted temperature scale is
(a) 1/100th the difference between normal boiling point and normal freezing point of water
(b) 1/273.15th the normal freezing point of water
(c) 100 times the difference between the triple point of water and the normal freezing point of water
(d) 1/273.16th of the triple point of water

[1994 : 1 Mark]

1.3 The specific heats of an ideal gas depend on its
(a) Temperature
(b) Pressure
(c) Volume
(d) Molecular weight and structure

[1996 : 1 Mark]

1.4 An isolated thermodynamic system executes a process. Choose the correct statement (s) from the following
(a) No heat is transferred
(b) No work is done
(c) No mass flows across the boundary of the system
(d) No chemical reaction takes place within the system

[1999 : 2 Marks]

1.5 The following four figures have been drawn to represent a fictitious thermodynamic cycle, on the P-v and T-s planes.

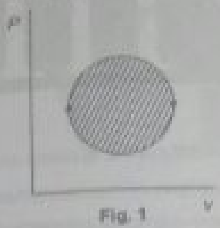


Fig. 1

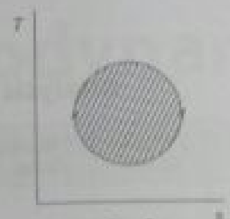


Fig. 2

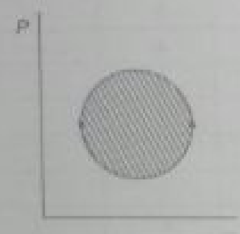


Fig. 3

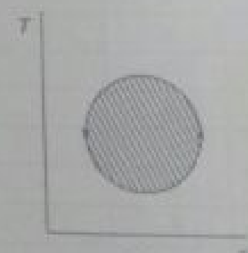


Fig. 4

According to the first law of thermodynamics, equal areas are enclosed by
(a) Figures 1 and 2
(b) Figures 1 and 3
(c) Figures 1 and 4
(d) Figures 2 and 3

[2005 : 1 Mark]

1.6 A reversible thermodynamic cycle containing only three processes and producing work is to be constructed. The constraints are (i) there must be one isothermal process, (ii) there must be one isentropic process, (iii) the maximum and minimum cycle pressures and the clearance volume are fixed, and (iv) polytropic processes are not allowed. Then the number of possible cycles are

(a) 1 (b) 2

(c) 3 (d) 4

[2005 : 2 Marks]

1.7 Match items from groups I, II, III, IV and V.

Group I	Group II When added to the system, is	Group III Differential	Group IV Function	Group V Phenomenon
E Heat	G Positive	I Exact	K Path	M Transient
F Work	H Negative	J Inexact	L Point	N Boundary

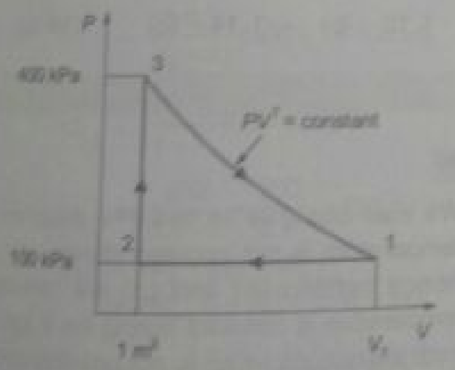
(a) F-G-J-K-M E-G-I-K-N (b) E-G-I-K-M F-H-I-K-N

(c) F-H-J-L-N E-H-I-L-M (d) E-G-J-K-N F-H-J-K-M

[2006 : 2 Marks]

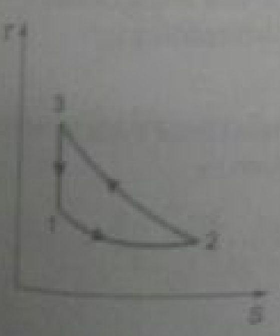
Common Data for Questions 1.8 and 1.9

A thermodynamic cycle with an ideal gas as working fluid is shown below.

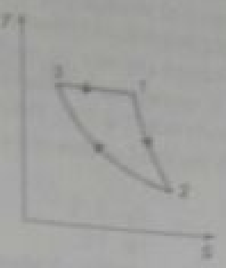


1.8 The above cycle is represented on *T-s* plane by

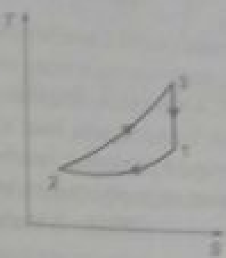
(a)



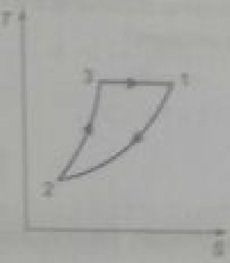
(b)



(c)



(d)



[2007 : 2 Marks]

1.9 If the specific heats of the working fluid are constant and the value of specific heat ratio γ is 1.4, the thermal efficiency (%) of the cycle is

(a) 21 (b) 40.9

(c) 42.6 (d) 59.7

[2007 : 2 Marks]

1.10 If a closed system is undergoing an irreversible process, the entropy of the system

(a) must increase

(b) always remains constant

(c) must decrease

(d) can increase, decrease or remain constant

[2009 : 1 Mark]

1.11 Heat and work are

(a) intensive properties

(b) extensive properties

(c) point functions

(d) path functions

[2011 : 1 Mark]

1.12 A certain amount of an ideal gas is initially at a pressure p_1 and temperature T_1. First, it undergoes a constant pressure process 1-2 such that $T_2 = 3T_1/4$. Then, it undergoes a constant volume process 2-3 such that $T_3 = T_1/2$. The ratio of the final volume to the initial volume of the ideal gas is

(a) 0.25 (b) 0.75
(c) 1.0 (d) 1.5

[2014 : 2 Marks, Set-3]

1.13 Two identical metal blocks L and M (specific heat = 0.4 kJ/kg K), each having a mass of 5 kg, are initially at 313 K. A reversible refrigerator extracts heat from block L and rejects heat to block M until the temperature of block L reaches 293 K. The final temperature (in K) of block M is _____

[2014 : 2 Marks, Set-4]

1.14 Which of the following statements are TRUE with respect to heat and work?

(i) The are boundary phenomena
(ii) They are exact differentials
(iii) They are path functions

(a) both (i) and (ii) (b) both (i) and (iii)
(c) both (ii) and (iii) (d) only (iii)

[2016 : 1 Mark, Set-1]

1.15 The volume and temperature of air (assumed to be an ideal gas) in a closed vessel is 2.87 m³ and 300 K, respectively. The gauge pressure indicated by a manometer fitted to the wall of the vessel is 0.5 bar. If the gas constant of air is R = 287 J/kgK and the atmospheric pressure is 1 bar, the mass of air (in kg) in the vessel is

(a) 1.67 (b) 3.33
(c) 5.00 (d) 6.66

[2017 : 2 Marks, Set-2]

■■■■

Answers Thermodynamic System and Processes

1.1	(c)	1.2	(d)	1.3	(d)	1.4	(a, b & c)	1.5	(a)	1.6	(d)	1.7	(d)
1.8	(c)	1.9	(a)	1.10	(d)	1.11	(d)	1.12	(b)	1.14	(b)	1.15	(c)

Explanations Thermodynamic System and Processes

1.5 (a)

We know that

For closed cycle change in internal energy is zero.

First law of thermodynamic for closed system

$\Sigma W_{cycle} = \Sigma Q_{cycle}$

Hence equal area are enclosed by figures 1 and 2.

1.6 (d)

1.8 (c)

We can observe in the P-v diagram that temperature is not constant during any stage hence options (b) and (d) are rejected as temperature is constant during the stage 3-1 in both the options which is not possible option (a) is rejected because clockwise process in P-v diagram

2 First Law, Heat, Work and Energy

2.1 The first law of thermodynamics takes the form $W = -\Delta H$ when applied to

(a) A closed system undergoing a reversible adiabatic process

(b) An open system undergoing an adiabatic process with negligible changes in kinetic and potential energies

(c) A closed system undergoing a reversible constant volume process

(d) A closed system undergoing a reversible constant pressure process.

[1993 : 1 Mark]

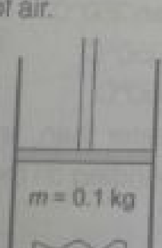
2.2 A steel ball of mass 1 kg of specific heat 0.4 kJ/kgK is at a temperature of 60°C. It is dropped into 1 kg water at 20°C. The final steady state temperature of water is

(a) 23.5°C (b) 30°C

(c) 35°C (d) 40°C

[1993 : 1 Mark]

2.3 A vertical cylinder with a freely floating piston contains 0.1 kg air at 1.2 bar and a small electrical resistor. The resistor is wired to an external 12 volt battery. When a current of 1.5 amps is passed through the resistor for 90 secs, the piston sweeps a volume of 0.01 m³. Assume (i) piston and the cylinder are insulated and (ii) air behaves as an ideal gas with $c_v = 700$ J/kgK. Find the rise in temperature of air.



[1993 : 2 Marks]

2.4 For reversible adiabatic compression in a steady flow process, the work transfer per unit mass is

(a) $\int pdv$ (b) $\int vdp$

(c) $\int Tds$ (d) $\int sdT$

[1996 : 1 Mark]

2.5 A steam turbine receives steam steadily at 10 bar with a enthalpy of 3000 kJ/kg and discharges at 1 bar with an enthalpy of 2700 kJ/kg. The work output is 250 kJ/kg. The changes in kinetic and potential energies are negligible The heat transfer from the turbine casing to the surroundings is equal to

(a) 0 kJ (b) 50 kJ

(c) 150 kJ (d) 250 kJ

[2000 : 1 Mark]

2.6 When an ideal gas with constant specific heats is throttled adiabatically, with negligible changes in kinetic and potential energies.

(a) $\Delta h = 0, \Delta T = 0$ (b) $\Delta h > 0, \Delta T = 0$

(c) $\Delta h > 0, \Delta S > 0$ (d) $\Delta h = 0, \Delta S > 0$

[2000 : 2 Marks]

2.7 A small steam whistle (perfectly insulated and doing no shaft work) causes a drop of 0.8 kJ/kg in enthalpy of steam from entry to exit. If the kinetic energy of the steam at entry is negligible, the velocity of the steam at exit is

(a) 4 m/s (b) 40 m/s

(c) 80 m/s (d) 120 m/s

[2001 : 2 Marks]

2.8 A 2 kW, 40 litres water heater is switched on for 20 minutes. The heat capacity c_p for water is 4.2 kJ/kgK. Assuming all the electrical energy has gone into heating the water, increase of the water temperature in degree centigrade is

(a) 2.7 (b) 4.0

(c) 14.3 (d) 25.25

[2003 : 1 Mark]

Common Data Questions Q.2.9 and Q.2.10

Nitrogen gas (molecular weight 28) is enclosed in a cylinder by a piston, at the initial condition of 2 bar, 298 K and 1 m³. In a particular process, the gas slowly expands under isothermal condition, until the volume becomes 2 m³. Heat exchange occurs with the atmosphere at 298 K during this process.

2.9 The work interaction for the nitrogen gas is

(a) 200 kJ (b) 138.6 kJ

(c) 2 kJ (d) –200 kJ

[2003 : 2 Marks]

2.10 The entropy changes for the universe during the process in kJ/K is
(a) 0.4652
(b) 0.0067
(c) 0
(d) −0.6711

[2003 : 2 Marks]

2.11 A gas contained in a cylinder is compressed, the work required for compression being 5000 kJ. During the process, heat interaction of 2000 kJ causes the surroundings to be heated. The changes in internal energy of the gas during the process is
(a) −7000 kJ
(b) −3000 kJ
(c) +3000 kJ
(d) +7000 kJ

[2004 : 1 Mark]

Linked Answer Questions 2.12 and 2.13

A football was inflated to a gauge pressure of 1 bar when the ambient temperature was 15°C. When the game started next day, the air temperature at the stadium was 5°C. Assume that the volume of the football remains constant at 2500 cm³.

2.12 The amount of heat lost by the air in the football and the gauge pressure of air in the football at the stadium respectively equal
(a) 30.6 J, 1.94 bar
(b) 21.8 J, 0.93 bar
(c) 61.1 J, 1.94 bar
(d) 43.7 J, 0.93 bar

[2006 : 2 Marks]

2.13 Gauge pressure of air to which the ball must have been originally inflated so that it would be equal 1 bar gauge at the stadium is
(a) 2.23 bar
(b) 1.94 bar
(c) 1.07 bar
(d) 1.00 bar

[2006 : 2 Marks]

2.14 Which of the following relationships is valid only for reversible processes undergone by a closed system of simple compressible substance (neglect changes in kinetic and potential energy)?
(a) $\delta Q = dU + \delta W$
(b) $TdS = dU + pdV$
(c) $TdS = dU + \delta W$
(d) $\delta Q = dU + pdV$

[2007 : 1 Mark]

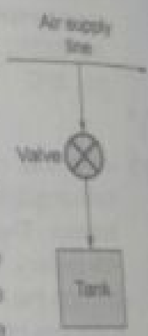
2.15 A gas expands in a frictionless piston-cylinder arrangement. The expansion process is very slow, and is resisted by an ambient pressure of 100 kPa. During the expansion process, the pressure of the system (gas) remains constant at 300 kPa. The change in volume of the gas is 0.01 m³. The maximum amount of work that could be utilized from the above process is
(a) 0 kJ
(b) 1 kJ
(c) 2 kJ
(d) 3 kJ

[2008 : 2 Marks]

2.16 A balloon containing an ideal gas is initially kept in an evacuated and insulated room. The balloon ruptures and the gas fills up the entire room. Which one of the following statements is TRUE at the end of above process?
(a) The internal energy of the gas decreases from its initial value, but the enthalpy remains constant.
(b) The internal energy of the gas increases from its initial value, but the enthalpy remains constant.
(c) Both internal energy and enthalpy of the gas remain constant.
(d) Both internal energy and enthalpy of the gas increase

[2008 : 2 Marks]

2.17 A rigid, insulated tank is initially evacuated. The tank is connected with a supply line through which air (assumed to be ideal gas with constant specific heats) passes at 1 MPa, 350°C.



A valve connected with the supply line is opened and the tank is charged with air until the final pressure inside the tank reaches 1 MPa. The final temperature inside the tank
(a) is greater than 350°C
(b) is less than 350°C
(c) is equal to 350°C
(d) may be greater than, less than, or equal to 350°C, depending on the volume of the tank

[2008 : 2 Marks]

2.18 In a steady state steady flow process taking place in a device with a single inlet and a single outlet, the work done per unit mass flow rate is given by

$$w = -\int_{\text{inlet}}^{\text{outlet}} v\,dp,$$ where v is the specific volume and p is the pressure. The expression for w given above
(a) is valid only if the process is both reversible and adiabatic

(b) is valid only if the process is both reversible and isothermal

(c) is valid for any reversible process

(d) is incorrect; it must be $w = \int_{inlet}^{outlet} pdv$

[2008 : 2 Marks]

2.19 A frictionless piston-cylinder device contains a gas initially at 0.8 MPa and 0.015 m³. It expands quasistatically at constant temperature to a final volume of 0.030 m³. The work output (in kJ) during this process will be

(a) 8.32 (b) 12.00
(c) 554.67 (d) 8320.00

[2009 : 1 Mark]

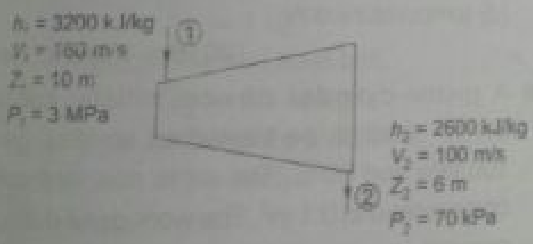
2.20 A compressor undergoes a reversible, steady flow process. The gas at inlet and outlet of the compressor is designated as state 1 and state 2 respectively. Potential and kinetic energy changes are to be ignored. The following notations are used: v = specific volume and P = pressure of the gas. The specific work required to be supplied to the compressor for this gas compression process is

(a) $\int_1^2 Pdv$ (b) $\int_1^2 vdP$
(c) $v_1(P_2 - P_1)$ (d) $-P_2(v_1 - v_2)$

[2009 : 1 Mark]

Common Data for Question 2.21 and 2.22.

The inlet and the outlet conditions of steam for an adiabatic steam turbine are as indicated in the notations are as usually followed.



2.21 If mass flow rate of steam through the turbine is 20 kg/s, the power output of the turbine (in MW) is

(a) 12.157 (b) 12.941
(c) 168.001 (d) 168.785

[2009 : 2 Marks]

2.22 Assume the above turbine to be part of a simple Rankine cycle. The density of water at the inlet to the pump is 1000 kg/m³. Ignoring kinetic and potential energy effects, the specific work (in kJ/kg) supplied to the pump is

(a) 0.293 (b) 0.351
(c) 2.930 (d) 3.510

[2009 : 2 Marks]

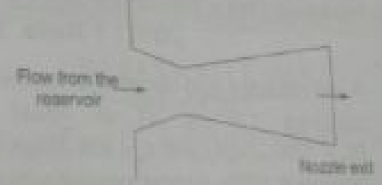
2.23 The contents of a well-insulated tank are heated by a resistor of 23 Ω in which 10 A current is flowing. Consider the tank along with its contents as a thermodynamic system. The work done by the system and the heat transfer to the system are positive. The rates of heat (Q), work (W) and change in internal energy (ΔU) during the process in kW are

(a) $Q = 0$, $W = -2.3$, $\Delta U = +2.3$
(b) $Q = +2.3$, $W = 0$, $\Delta U = +2.3$
(c) $Q = -2.3$, $W = 0$, $\Delta U = -2.3$
(d) $Q = 0$, $W = +2.3$, $\Delta U = -2.3$

[2011 : 1 Mark]

Linked Data Questions 2.24 and 2.25

The temperature and pressure of air in a large reservoir are 400 K and 3 bar respectively. A converging diverging nozzle of exit are 0.005 m² is fitted to the wall of the reservoir as shown in the figure. The static pressure of air at the exit section for isentropic flow through the nozzle is 50 kPa. The characteristic gas constant and the ratio of specific heats of air are 0.287 kJ/kgK and 1.4 respectively.



2.24 The density of air in kg/m³ at the nozzle exit is

(a) 0.560 (b) 0.600
(c) 0.727 (d) 0.800

[2011 : 2 Marks]

2.25 The mass flow rate of air through the nozzle in kg/s is

(a) 1.30 (b) 1.77
(c) 1.85 (d) 2.06

[2011 : 2 Marks]

Linked Data Questions Q.2.26 and Q.2.37

Air enters an adiabatic nozzle at 300 kPa, 500 K with a velocity of 10 m/s. It leaves the nozzle at 100 kPa with a velocity of 180 m/s. The inlet area is 80 cm². The specific heat of air c_p is 1008 J/kgK

2.26 The exit temperature of the air is
(a) 516 K (b) 532 K
(c) 484 K (d) 468 K
[2012 : 2 Marks]

2.27 The exit area of the nozzle in cm^2 is
(a) 90.1 (b) 56.3
(c) 4.4 (d) 12.9
[2012 : 2 Marks]

2.28 For an ideal gas with constant values of specific heats, for calculation of the specific enthalpy,
(a) it is sufficient to know only the temperature
(b) both temperature and pressure are required to be known
(c) both temperature and volume are required to be known
(d) both temperature and mass are required to be known
[2015 : 1 Mark, Set-1]

2.29 Temperature of nitrogen in a vessel of volume $2\ m^3$ is 288 K. A *U*-tube manometer connected to the vessel shows a reading of 70 cm of mercury (level higher in the end open to atmosphere). The universal gas constant is 8314 J/kmol-K, atmospheric pressure is 1.01325 bar, acceleration due to gravity is $9.81\ m/s^2$ and density of mercury is $13600\ kg/m^3$. The mass of nitrogen (in kg) in the vessel is ______.
[2015 : 2 Marks, Set-1]

2.30 A well insulated rigid container of volume $1\ m^3$ contains 1.0 kg of an ideal gas [c_p = 1000 J/(kgK) and c_v = 800 J/(kgK)] at a pressure of 10^5 Pa. A stirrer is rotated at constant rpm in the container for 1000 rotations and the applied torque is 100 Nm. The final temperature of the gas (in K) is ______.
[2015 : 2 Marks, Set-1]

2.31 Work is done on an adiabatic system due to which its velocity changes from 10 m/s to 20 m/s, elevation increases by 20 m and temperature increases by 1 K. The mass of the system is 10 kg. c_v = 100 J/(kgK) and gravitational acceleration is $10\ m/s^2$. If there is no change in any other component of the energy of the system, the magnitude of total work done (in kJ) on the system is ______.
[2015 : 2 Marks, Set-2]

2.32 Steam enters a turbine at 30 bar, 300°C (u = 2750 kJ/kg, h = 2993 kJ/kg) and exits the turbine as saturated liquid at 15 kPa (u = 225 kJ/kg, h = 226 kJ/kg). Heat loss to the surrounding is 50 kJ/kg of steam flowing through the turbine. Neglecting changes in kinetic energy and potential energy, the work output of the turbine (in kJ/kg of steam) is ______.
[2015 : 2 Marks, Set-2]

2.33 A mixture of ideal gases has the following composition by mass:

N_2	O_2	CO_2
60%	30%	10%

If the universal gas constant is 8314 J/kmol-K, the characteristic gas constant of the mixture (in J/kgK) is ______.
[2015 : 2 Marks, Set-3]

2.34 An ideal gas undergoes a reversible process in which the pressure varies linearly with volume. The conditions at the start (subscript 1) and at the end (subscript 2) of the process with usual notation are : p_1 = 100 kPa, V_1 = 0.2 m^3 and p_2 = 200 kPa, V_2 = 0.1 m^3 and the gas constant, R = 0.275 kJ/kgK. The magnitude of the work required for the process (in kJ) is ______.
[2016 : 2 Marks, Set-1]

2.35 The internal energy of an ideal gas is a function of
(a) temperature and pressure
(b) volume and pressure
(c) entropy and pressure
(d) temperature only
[2016 : 1 Mark, Set-2]

2.36 A piston-cylinder device initially contains 0.4 m^3 of air (to be treated as an ideal gas) at 100 kPa and 80°C. The air is now isothermally compressed to 0.1 m^3. The work done during this process is ______ kJ.
(Take the sign convention such that work done on the system is negative)
[2016 : 2 Marks, Set-2]

2.37 Steam at an initial enthalpy of 100 kJ/kg and inlet velocity of 100 m/s, enters an insulated horizontal nozzle. It leaves the nozzle at 200 m/s. The exit enthalpy (in kJ/kg) is ______.
[2016 : 2 Marks, Set-3]

2.38 The molar specific heat at constant volume of an ideal gas is equal to 2.5 times the universal gas constant (8.314 J/mol-K). When the temperature increases by 100 K, the change in molar specific enthalpy is ________ J/mol.

[2017 : 1 Mark, Set-1]

2.39 A mass m of a perfect gas at pressure p_1 and volume V_1 undergoes an isothermal process. The final pressure is p_2 and volume is V_2. The work done on the system is considered positive. If R is the gas constant and T is the temperature, then the work done in the process is

(a) $p_1V_1\ln\dfrac{V_2}{V_1}$ (b) $-p_1V_1\ln\dfrac{p_1}{p_2}$

(c) $RT\ln\dfrac{V_2}{V_1}$ (d) $-mRT\ln\dfrac{p_2}{p_1}$

[2017 : 1 Mark, Set-2]

2.40 A calorically perfect gas (specific heat at constant pressure 1000 J/kg·K) enters and leaves a gas turbine with the same velocity. The temperatures of the gas at turbine entry and exit are 1100 K and 400 K, respectively. The power produced is 4.6 MW and heat escapes at the rate of 300 kJ/s through the turbine casing. The mass flow rate of the gas (in kg/s) through the turbine is

(a) 6.14 (b) 7.00

(c) 7.50 (d) 8.00

[2017 : 2 Marks, Set-2]

■■■■

Answers First Law, Heat, Work and Energy

2.1	(b)	2.2	(a)	2.4	(b)	2.5	(b)	2.6	(a)	2.7	(b)	2.8	(c)	2.9	(b)
2.10	(c)	2.11	(c)	2.12	(d)	2.13	(c)	2.14	(d)	2.15	(c)	2.16	(c)	2.17	(a)
2.18	(c)	2.19	(a)	2.20	(b)	2.21	(a)	2.22	(c)	2.23	(a)	2.24	(c)	2.25	(d)
2.26	(c)	2.27	(d)	2.28	(a)	2.35	(d)	2.39	(b)	2.40	(b)				

Explanations First Law, Heat, Work and Energy

2.2 (a)

Given data:

Mass of steel ball,

$$m_s = 1 \text{ kg}$$

Specific heat of steel ball,

$$c_s = 0.4 \text{ kJ/kgK}$$

Initial temperature of ball,

$$T_1 = 60°C$$

Mass of water,

$$m_w = 1 \text{ kg}$$

Initial temperature of water,

$$T_{w1} = 20°C$$

Let T_f = Final temperature of ball and water

Applying energy balance equation,

Heat lost by a steel ball

= Heat gained by the water

$$24 - 0.4\,T_f = 4.18\,T_f - 83.6$$

or $107.6 = 4.58\,T_f$

or $T_f = 23.49°C \approx 23.50°C$

2.3 Sol.

Total electrical work (which is converted to heat)

$$= (VI)t = 12 \times 1.5 \times 90 = 1620 \text{ J}$$

$\therefore$ $Q = 1620$ J

Work done by air

$$= \int p\,dv = 1.2 \times 10^5 (0.01)$$

$$= 1200 \text{ J}$$

Now from 1st law of thermodynamic

$$Q = \Delta U + W$$

$$1620 = \Delta U + 1200$$

$$\Delta U = 420 \text{ J}$$

$$mc_v dT = 420$$

$$0.1 \times 700 \times dT = 420$$

$$dT = 6°C$$

or