Chapter 5
First Law of Thermodynamics

What is thermodynamics? It is the field of physics that studies the properties of systems that have a temperature and involve the laws that govern the conversion of energy from one form to another, the direction in which heat will flow, and the availability of energy to do work.

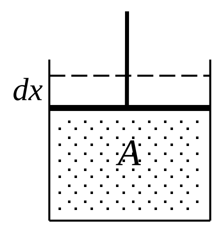
Work: (W, [W] = J) A system (e.g. gas in cylinder of a tight frictionless piston) may exchange energy with its surroundings through work. In a process, the total work done "*W*" by a system as it changes from an initial volume V_i to a final volume V_f in any process is given by:

$$W = \int_{V_i}^{V_f} P dV$$

The integration is necessary because the pressure P may be vary during the process. At constant pressure,

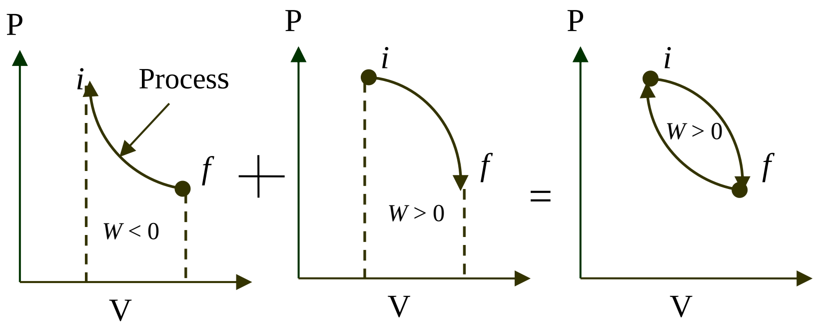
$$W = \int_{V_i}^{V_f} P dV = P\Delta V = \begin{cases} \Delta V > 0 \Rightarrow W = \text{positive} \Rightarrow \text{work done by the system} \\ \Delta V < 0 \Rightarrow W = \text{negative} \Rightarrow \text{work done on the system} \end{cases}$$

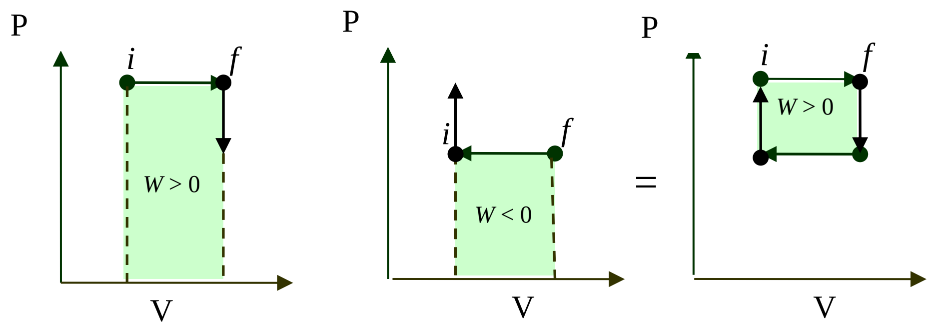
The total work done in any process and the total work is the area under the curve in *PV*-diagram]



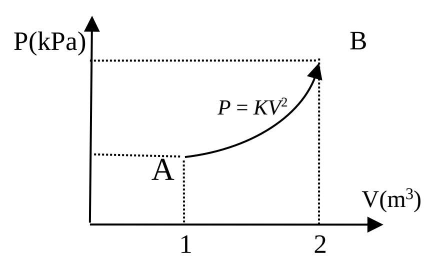
[**Proof**: Consider an ideal gas confined to a cylinder of a tight frictionless piston, see above figure. Let V = volume of the enclosed gas, P = pressure of the gas. If the gas expands moving the piston dx, so the change in volume $dV = Adx$, where A is the area of the piston. The force exerted by the gas on the piston $F = PA$ and the work done is $dW=Fdx=PAdx=PdV$.

➔





➔ A sample of an ideal gas is expanded to twice of its original volume of 1.0 m^3 in a quasi-static process for which $P = KV^2$ where K is a constant whose value is 5.0 Pa/m^6, as shown in the figure. Calculate the work done by the gas.



✓

$$W = \int_{V_i}^{V_f} PdV = K\int_1^2 V^2 dV = K\left.\frac{V^3}{3}\right|_1^2 = \frac{7}{3}K \approx 11.7 \text{ J.}$$

The Internal Energy (U) of a system is the total energy content of the system. It is the sum of the kinetic, potential, chemical, electrical, and all other forms of energy possessed by the atoms and molecules of the system. U is path independent, but Q and W are path dependent. *For an **ideal gas**, the internal energy depends only on **temperature**.*

First Law of Thermodynamics is an energy conservation statement. It states that "*if an amount of heat energy, ΔQ, flows into a system, then this energy must appear as increased internal energy, ΔU, for the system and/or work, ΔW, done by the system on its surrounding*". In symbols

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

ΔU is independent of the path over which the change from i to f is carried out. The quantities ΔQ and ΔW in general depend on the path.

Sign convention: The convention is adopted that Q indicates the heat added to the system and W the work done by it. Thus,

$dQ > 0$, heat added (entered) to system (or system absorbs (gains) heat).

$dQ < 0$, heat removed from system (or system rejects (loses) heat).

$dW > 0$, work is done by system.

$dW < 0$, work is done on the system.

$dU > 0$, internal energy of system increases.

$dU < 0$, internal energy of system decreases.

Another definition of Heat: it is the change in internal energy of a system when no work is done on (or by) the system.

Table: Summary of the most common processes.

Process	Definition	Restrictions	Work done by the gas	Consequences
Free expansion	isolated	$\Delta Q = 0$ $\Delta U = 0$ $\Delta W = 0$	$\Delta W = 0$	0
Cyclic process	closed	$\Delta U = 0$	$\Delta W = \Delta Q$	ΔQ
Adiabatic	no heat exchange	$\Delta Q = 0$	Area under the curve	$\Delta W = -\Delta U$
Isobaric $P =$ constant	no change in pressure	$\Delta P = 0$	$P\Delta V$	$\Delta W = P\Delta V$
Isochoric (Isovolumic) $V =$ constant	no change in volume	$\Delta V = 0$	Zero	$\Delta Q = \Delta U$
Isothermal $T =$ constant,	no change in temperature	$\Delta T = 0$, $\Delta U = 0$	Area under the curve	$= nRT \ln(\frac{V_f}{V_i})$ $= nRT \ln(\frac{P_i}{P_f})$

➔ Determine the change in the internal energy of a system that:

a- absorbs 500 cal of thermal energy while doing 800 J of external work.

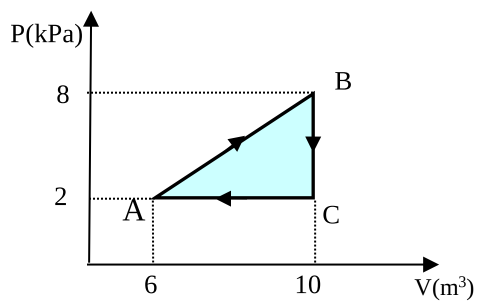
✓
$$\begin{aligned}\Delta U &= \Delta Q - \Delta W \\ &= 500 \times 4.186 - 800 = 1290 \text{ J.}\end{aligned}$$

b- absorbs 500 cal of thermal energy while doing 800 J of external work is done on the system.

✓
$$\begin{aligned}\Delta U &= \Delta Q - \Delta W \\ &= 500 \times 4.186 + 800 = 2893 \text{ J.}\end{aligned}$$

c- is maintained at a constant volume while 1000 cal is removed from the system.

✓
$$\begin{aligned}\Delta U &= \Delta Q - \Delta W \\ &= -1000 \times 4.186 + 0 = -4186 \text{ J.}\end{aligned}$$



➔ A gas is taken through the cyclic process described in the above figure.

a- Find the net heat transferred to the system during one complete cycle.

✓ For the cyclic processes

$$\Delta U = 0, \quad \Rightarrow \quad Q(\text{ABCA}) = W(\text{ABCA})$$

$$\begin{aligned}Q(\text{ABCA}) &= \text{Area of triangle} \\ &= \tfrac{1}{2}\,(10-6)\text{m}^3(8-2)\text{kPa} = 12.0 \text{ kJ}\end{aligned}$$

this means that the system (gas) gains heat.

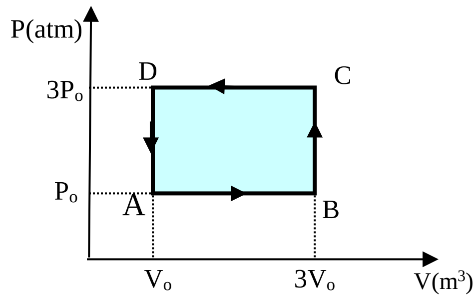
b- If the cycle is reversed, that is, the process goes along ACBA, what is the net heat transferred per cycle?

✓ In the reversible process

$$Q(\text{ACBA}) = -Q(\text{ABCA}) = -12.0 \text{ kJ.}$$

So, the system expels heat.

➔ One mole of an ideal gas is taken along the cyclic path A→B→C→D→A.



a- What is ΔU for the cycle?

✓ $\Delta U = 0$ for the cyclic process.

b- Find the net work done by the gas per cycle.

✓
$$W(AB) = P\Delta V = P(V_f - V_i) = P_o(3V_o - V_o) = 2\, P_o V_o$$
$$W(BC) = W(DA) = 0\,,$$
$$W(CD) = P\Delta V = P(V_f - V_i) = P_o(V_o - 3V_o) = -6\, P_o V_o$$

Then the net work done on the system is:

$$\Delta W = W(AB) + W(BC) + W(CD) = -4\, P_o V_o$$

c- What is ΔQ for the cycle?

✓
$$\Delta Q = \Delta W = -4 P_o V_o$$

d- Is the heat added to the gas or expelled from it? Explain your choice.

✓ The net heat is expelled from the system because ΔQ is negative.

Note that:

$$Q\,(\text{ABCDA}) = \text{Area of rectangle}$$
$$= (V_o - 3V_o) m^3 (3P_o - P_o) = -4\, V_o P_o$$

➔ Helium gas is heated at constant pressure from 32 ^oF to 212 ^oF. If the gas does 20.0 Joules of work during the process, what is the number of moles?

✓ $$W = P\Delta V = nR\Delta T$$

$$\Rightarrow \quad n = \frac{W}{R\Delta T} = \frac{20}{8.314\times\frac{5}{9}(212-32)} = 0.024 \text{ mole.}$$

Work done in Isothermal Expansion: The work done by an ideal gas during an Isothermal (constant temperature) change from initial state (P_i ,V_i) to final state (P_f ,V_f) is calculated as:

$$W = \int_{V_i}^{V_f} PdV = nRT\int_{V_i}^{V_f} \frac{dV}{V} = nRT\ln(\frac{V_f}{V_i}) = nRT\ln(\frac{P_i}{P_f})$$

Comments:

Many other relations may be used, for example by changing $nRT \rightarrow P_iV_i = P_fV_f$.

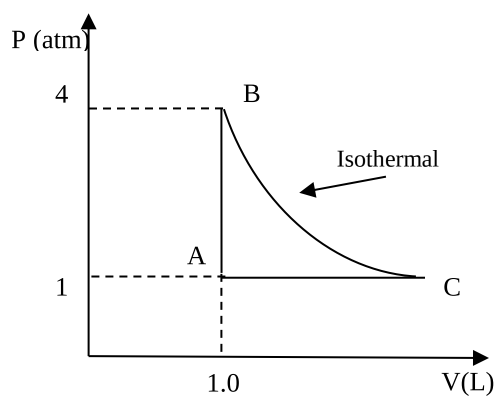
➔ One mole of an ideal gas compressed at constant temperature of 310 K from an initial volume of 19 L to a final volume of 12 L.

a) How much work is done by the compressing gas?

✓ $$W = nRT\ln(\frac{V_f}{V_i}) = (1)(8.314)(310)\ln(\frac{12}{19}) = -1180 \text{ J.}$$

The negative sign means that work is done on the system.

➔ Four moles of an ideal gas undergoes the thermodynamic process shown in the figure. If the process BC is an isothermal, how much work is done by the gas in this cyclic process?



✓ In the isothermal process BC, we can calculate V_C as:

$$\frac{V_C}{V_B} = \frac{P_B}{P_C} = 4 \quad \Rightarrow \quad V_C = 4 \text{ L.}$$

and the total work done is:

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

where

$$W_{AB} = 0 \text{ (isochoric process),}$$

$$\begin{aligned} W_{CA} &= P_A (V_A - V_C) \\ &= (1 \times 1.01 \times 10^5)(1.0 \times 10^{-3} - 4.0 \times 10^{-3}) \\ &= -3.0 \times 10^2 \text{ J,} \end{aligned}$$

$$\begin{aligned} W_{BC} &= nRT_B \ln(\frac{V_C}{V_B}) = P_B V_B \ln(\frac{V_C}{V_B}) \\ &= (4 \times 1.01 \times 10^5)(1.0 \times 10^{-3}) \ln 4 \\ &= 5.60 \times 10^2 \text{ J} \end{aligned}$$

so the total work done will be:

$$\begin{aligned} W_{total} &= W_{AB} + W_{BC} + W_{CA} \\ &= 0 - 3.0 \times 10^2 + 5.6 \times 10^2 = \underline{2.6 \times 10^2 \text{ J}}. \end{aligned}$$

The positive work done means its done by the gas.

Specific heat for gases: Consider the expansion of an ideal gas at constant volume (i.e. ΔV = ΔW= 0), if we define c_v as the molar specific heat at constant volume, then

$$\Delta Q = \Delta U = nc_v \Delta T$$

If we considered the expansion at constant pressure and using the first law of thermodynamics, then

$$\Delta Q = \Delta U + \Delta W = nc_v \Delta T + nR\Delta T = nc_p \Delta T, \qquad c_p = c_v + R$$

where c_p is the molar specific heat at constant pressure.

For **monatomic** ideal gases (consisting of a single atom, e.g. He, Ar), $c_v = \frac{3}{2} R$.

For **diatomic** ideal gases (consisting of two atoms, e.g. H_2, O_2, air), $c_v = \frac{5}{2} R$.

Notes:

1. The above expressions applied for ideal gas only.

2. ΔU is a function of temperature only and has the same expression in all processes.

➔ In a constant-volume process, 209 J of heat is added to 1 mole of an ideal monatomic gas initially at 300 K. Find the final temperature of the gas.

✓ Using the first law of thermodynamics:

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

with our condition at constant volume, i.e.

$$\Delta V = 0, \quad \Delta U = \Delta Q = 209 \text{ J.}$$

One can calculate

$$\Delta Q = \Delta U = nc_v \Delta T = n(\frac{3}{2}R)\Delta T = 209 \text{ J}$$

$$\Rightarrow \quad \Delta T = \frac{2\times 209}{3\times 8.314\times 1} = 16.8 \text{ K.}$$

and the final temperature will be

$$\therefore\ T_f = T_i + \Delta T = (300+16.8)\text{ K} \approx 317 \text{ K.}$$

➔ Two moles of helium (monatomic) gas are heated from 100 °C to 250 °C. How much heat is transferred to the gas if the process is isobaric?

✓ $$\Delta Q = nc_p\Delta T = 2(\frac{5}{2}8.314)(250-100) = 6.23\times 10^3 \text{ J.}$$

➔ Two moles of helium (monatomic) gas are heated from 0.0 °C to 100 °C. How much heat is transferred to the gas if the process is isochoric?

✓ $$\Delta Q = \Delta U = nc_v\Delta T = 2(\frac{3}{2}\times 8.31)(100-0.0) = 2.49\times 10^3 \text{ J.}$$

➔ Two moles of helium (monatomic) gas are initially at a temperature of 27 °C and occupy a volume of 20 liters. The helium is expanded at constant pressure until the volume is doubled. [Note thet

$$\frac{V_i}{T_i} = \frac{V_f}{T_f} \quad \Rightarrow \quad T_f = T_i\left(\frac{V_f}{T_f}\right) = 600 \text{ K.}]$$

a- Find the total heat supplied in the process,

✓ $$Q = nc_p\Delta T = nc_p(T_f - T_i) = 2(\frac{5}{2}\text{R})(300) = 1.25\times 10^4 \text{ J.}$$

b- Find the change in the internal energy,

✓ $$Q = nc_v \Delta T \; = nc_v (T_f - T_i) = 2(\frac{3}{2}\text{R})(300) = 7.48\times10^3 \text{ J.}$$

c- Find the work done by the system.

✓ $$W = Q - U = 1.25\times10^4 - 7.48\times10^3 = 5.02\times10^3 \text{ Joules.}$$

In quasi-static, **adiabatic expansion** (i.e. $\Delta Q = 0$) one gets

$$PV^\gamma = \text{ constant}, \quad \Rightarrow \quad P_i V_i^\gamma = P_f V_f^\gamma, \qquad \gamma = \frac{c_p}{c_v}$$

Using the ideal gas law, one gets

$$T_i V_i^{\gamma-1} = T_f V_f^{\gamma-1}, \qquad T_i P_i^{\frac{1-\gamma}{\gamma}} = T_f P_f^{\frac{1-\gamma}{\gamma}},$$

➔ An ideal diatomic gas ($c_v = 3/2, c_p = 5/2$), initially at a pressure P_i=1.0 atm and the initial volume V_i, is allowed to expand isothermally until its volume doubles. The gas is then compressed adiabatically until it reaches its original volume. The final pressure of the gas will be:

✓ We are giving P_i=1.0 atm, $V_f = 2V_i$ and $P_i = \frac{1}{2}$ atm, consequently:

$$P_f = P_i \left(\frac{V_f}{V_i}\right)^\gamma = (\frac{1}{2})(2)^{1.4} = 1.3 \text{ atm.}$$

➔ Two moles of an ideal gas (γ = 1.40) expand quasi-statically and adiabatically from a pressure of 5 atm and a volume of 12 liters to a final volume of 30 liters.

a-What is the final pressure of the gas?

✓ $$P_2 = P_1 \left(\frac{V_1}{V_2}\right)^\gamma = (5 \text{ atm})\left(\frac{12}{30}\right)^\gamma = 1.39 \text{ atm.}$$

b- What are the initial and final temperatures?

✓ $$T_i = \frac{P_1 V_1}{nR} = \left(\frac{(5.00)(1.01\times10^5)(12\times10^{-3})}{2(8.314)}\right) = 364.6 \text{ K},$$

$$T_f = \frac{P_2 V_2}{nR} = \left(\frac{(1.39)(1.01\times10^5)(30\times10^{-3})}{2(8.314)}\right) = 253.4 \text{ K.}$$

True-False Questions

1- For the ideal gas $C_p - C_V = R/2$. F
2- In an isothermal process, there is no change in the internal energy. T
3- In an adiabatic process, no heat enters or leaves the system. T
4- In an isochoric process, the work done by the system is positive. F
5- In an isothermal process, the work done is equal to heat energy. T
6- In any cyclic process, the work done by the gas is zero. F
7- The first law of thermodynamics represents the conservation of energy. T
8- The internal energy of a system is a state function. T
9- In an isobaric process, the change in internal energy is always zero. F

Supplementary Problems

- The work done in the expansion of a gas from an initial to a final state

(a) always equals $P(V_f - V_i)$..
(b) depends only on the end points.
(c) is the slope of a PV curve.
(d)@ is the area under the curve of a PV diagram.
(e) is negative.

- One mole of an ideal gas is taken through the cyclic process ABCA as shown in Fig. (2). What is the net heat absorbed, or lost, by the gas?

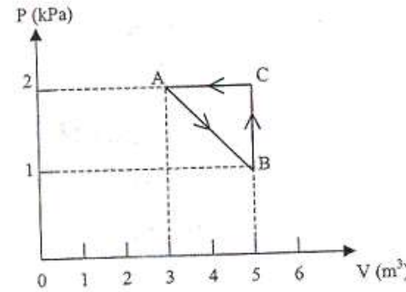


fig.(2)

(a) -2.0×10^3 J.
(b)@ -1.0×10^3 J.
(c) 1.0×10^3 J.
(d) 2.0×10^3 J.
(e) 5.0×10^3 J.

- An ideal monatomic gas expands quasi-statically to twice its volume. If the process is isothermal, the work done by the gas is W_i. If the process is adiabatic, the work done by the gas is W_a. Which of the following is true?

(a) $W_i = W_a$.
(b)@ $0 < W_a < W_i$.
(c) $0 = W_a < W_i$.
(d) $0 = W_i < W_a$.
(e) $0 = W_a > W_i$.

- A system of an ideal gas undergoes the cyclic process shown in figure 5. Calculate the work done by the system along the path XY.

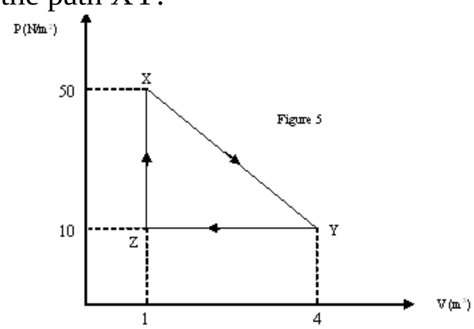


Figure 5

(a) -60 J.
(b) zero
(c) 60 J.
(d)@ 90 J.

(e) -90 J.

- In a PV diagram, a system of an ideal gas goes through the process shown in Figure 3. How much heat is absorbed after the system goes through this cycle 10 times. [Take P= 1.0 Pa and V= 1.0 m^3].

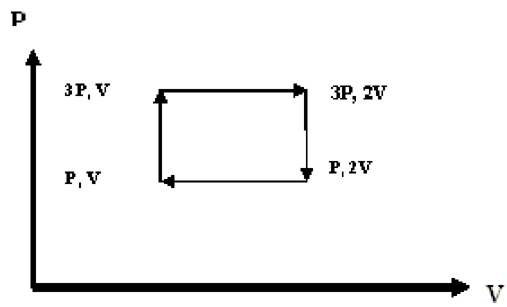


Figure 3

(a) 15 Joules.
(b)@ 20 Joules.
(c) 5 Joules.
(d) 25 Joules.
(e) 2 Joules.

- In this question use: W = work, Q = heat, S = Entropy. Which of the following are state functions, i.e. path independent?

1. W 2. Q-W 3. S 4. Q 5. Q-2W

(a) Only 2.
(b) 3 and 4.
(c) 1, 2 and 4.
(d) 2 and 5.
(e)@ 2, 3.

- Which of the following statements are CORRECT:

1. The first law of thermodynamics represents the conservation of energy.
2. Room temperature is about 20 degrees on the Kelvin scale.
3. A calorie is approximately 4.2 J.
4. Heat has the same units as work.
5. Heat is a temperature difference.

(a)@ 1, 3, and 4.
(b) 3 and 5.
(c) 1 and 5.
(d) 1, 2 and 3.
(e) 2 and 4.

- Nitrogen gas (m = 1.00 kg) is confined in a cylinder with a movable piston at a pressure of 1 atm. A quantity of heat of 25 kcal is added to the gas in an isobaric process, and its internal energy increases by 8 kcal. What is the change in the volume of the gas?

(a) 1.4 m^3
(b) 1.2 m^3
(c) 0.4 m^3
(d) 0.2 m^3
(e)@ 0.7 m^3

- Which one of the following statements is true?

(a) In an adiabatic process, the heat flow is positive
(b) In an isovolumetric process, the work done is positive
(c) The internal energy of a system is not a state function
(d)@ In a cyclic process, the change in internal energy is zero
(e) In an isobaric process, the change in internal energy is always zero

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- One gram of water is heated from 0 ^{o}C to 80 ^{o}C at a constant pressure of 1 atm. Determine the change in internal energy of the water. Neglect the change in volume of the water.

(a) 50 cal
(b)@ 80 cal
(c) 100 cal
(d) 250 cal
(e) 180 cal

- Assume an ideal gas expands adiabatically. Which one of the following statements is TRUE.

(a) the temperature of the gas increases.
(b) the pressure of the gas increases.
(c) the internal energy of the gas remains constant.
(d)@ the temperature of the gas decreases.
(e) the pressure of the gas remains constant.

- In a certain process a gas ends in its original thermodynamic state. Of the following statements, which is possible as the net result of the process?

(a) The gas absorbs 50 J of heat and 50 J of work is done on it.
(b) The gas does no work but rejects 50 J of heat.
(c) The gas does no work but absorbs 50 J of heat.
(d)@ The gas absorbs 50 J of heat and does 50 J of work.
(e) The gas rejects 50 J of heat and does 50 J of work.

- One gram of water is cooled from 100 ^{o}C to zero ^{o}C and becomes all ice. Determine the change in internal energy during this process. (Neglect any change in the volume of the water.)

(a) 752 J
(b)@ -752 J
(c) -100 J
(d) 419 J
(e) -419 J

- Two kilograms of water, at 100 ^{o}C, occupy a volume of 2.0×10^{-3} m^3. When this amount of water is boiled, at atmospheric pressure, it becomes 3.3 m^3 of steam. Find the change in the internal energy.

(a) 3.4×10^{4} J.
(b)@ 4.2×10^{6} J.
(c) -4.2×10^{6} J.
(d) 2.1×10^{6} J.
(e) -2.1×10^{6} J.

- 3.00-kg of water at 100 ^{o}C is converted to steam at 100 ^{o}C by boiling at one atmospheric pressure. For one kg of water, the volume changes from an initial value of 1.0×10^{-3} m^3 as a liquid to 1.671 m^3 as steam. The work done by the water in this process is:

(a)@ 5.07×10^{5} J.
(b) 1.23×10^{5} J.
(c) 1.69×10^{5} J.
(d) 2.45×10^{5} J.
(e) 3.01×10^{5} J.

- Which of the following statements is CORRECT for a gas undergoing an adiabatic process:

(a) The pressure of the gas remains constant.
(b) The temperature of the gas remains constant.
(c) The volume of the gas remains constant.
(d)@ There is no heat exchange between the gas and its environment.
(e) The internal energy of the gas is always zero.

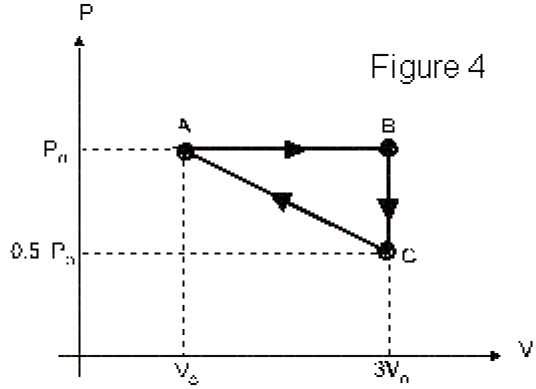
- A system undergoes an adiabatic process in which its internal energy increases by 20 J. Which of the following correctly describes changes in the system?

(a)	Heat: 40 J added,	Work: 20 J by the system
(b)	Heat: 20 J added,	Work: none
(c)	Heat: none,	Work: 20 J by the system
(d)	Heat: 20 J removed,	Work: none
(e)@	Heat: none,	Work: 20 J on the system

- A gas is compressed at a constant pressure of 0.800 atm from a volume of 9.00 L to a volume of 2.00 L. In the process, 400 J of heat flows out of the gas. What is the change in the internal energy of the gas?

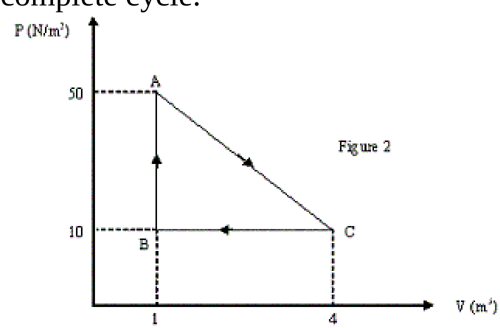
(a) - 966 J
(b) - 566 J
(c) 566 J
(d) - 166 J
(e)@ 166 J

- An ideal gas is taken through the cycle ABCA, shown in figure 4. The work done along the paths AB, BC and CA, are respectively:



(a) 2*Po*Vo, zero , +1.5*Po*Vo
(b) 2*Po*Vo, zero , -2*Po*Vo
(c)@ 2*Po*Vo, zero , -1.5*Po*Vo
(d) 2*Po*Vo, Po*Vo, -1.5*Po*Vo
(e) 2*Po*Vo, zero , -Po*Vo

- Gas within a closed chamber undergoes the cycle shown in Fig. 2. Calculate the net heat added to the system in a complete cycle.



(a) 10 J.
(b) 73 J.
(c) 14 J.
(d) 31 J.
(e)@ 60 J.

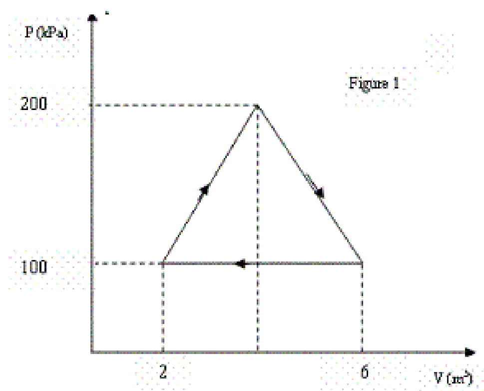
- A cylinder with a frictionless piston contains 0.2 kg of water at 100 ^{o}C. What is the change in internal energy of water when it is converted to steam at 100 ^{o}C at constant pressure of 1 atm. [Density of steam = 0.6 kg/m^3, water = 10^3 kg/m^3]

(a)@ 418 kJ.
(b) 452 kJ.
(c) 226 kJ.
(d) 113 kJ.
(e) 333 kJ.

- Air is injected from a cylinder of compressed air into a spherical balloon of initial volume V, causing its diameter to double. What is the work done at constant pressure P?

(a)@ 7.0 PV.
(b) 4.0 PV.
(c) 3.0 PV.
(d) 8.0 PV.
(e) 1.0 PV.

- An ideal gas is taken through the cyclic process shown in Figure 1. How much heat is added or removed from the gas?



(a) - 400 kJ
(b) - 800 kJ
(c) 600 kJ
(d) 100 kJ
(e)@ 200 kJ

- How much work is required to compress five moles of an ideal gas at 20 $^{\circ}C$ and 1.0 atmosphere to half of its initial volume during an isothermal process?

(a) Zero
(b) -2.1 kJ
(c) +2.1 kJ
(d) +8.4 kJ
(e)@ -8.4 kJ

- Consider an isothermal compression of 0.1 moles of an ideal gas at a temperature of 0 $^{\circ}C$. The initial pressure of the gas is 1 atm and the final volume is 1/5 the initial volume. Find the thermal energy transfer for this process.

(a) 365 J gained by the gas

(b) 0 J
(c)@ 365 J lost by the gas
(d) 124 J lost by the gas
(e) 124 J gained by the gas

➢ Air that occupies 0.14 m^3 at 2.2 atm is expanded isothermally to 1 atm. The work done by the gas, in calories, is

(a) 3500 cal
(b) 9200 cal
(c) 2100 cal
(d) 1400 cal
(e)@ 4800 cal

➢ One mole of an ideal gas has a temperature of 25 ^{o}C. If the volume is held constant and the pressure is doubled, the final temperature will be:
(a) 50 ^{o}C.
(b) 174 ^{o}C.
(c) 596 ^{o}C.
(d) 25 ^{o}C.
(e)@ 323 ^{o}C.

➢ Five moles of an ideal gas expands isothermally at 100 ^{o}C to five times its initial volume. Find the heat flow into the system.

(a) 6.7×10^4 J
(b) 7.0×10^4 J
(c) 3.1×10^4 J
(d) 1.1×10^4 J
(e)@ 2.5×10^4 J

➢ Two moles of an ideal gas, initially at 20 ^{o}C, are taken through an isothermal process in which the volume of the gas doubles. The work done by the gas during this process is:

(a) 230 J.
(b) -3375 J.
(c)@ 3375 J.
(d) Zero.
(e) -230 J.

➢ An ideal gas containing 5.00 moles expands isothermally at 127 ^{o}C to four times its initial volume. Find the heat flow during this expansion.

(a) 23.0 kJ out of the system
(b) 7.32 kJ into the system

(c) 7.32 kJ out of the system
(d)@ 23.0 kJ into the system
(e) 34.5 kJ out of the system

- Two moles of a monatomic ideal gas at a temperature of 300 K and pressure of 0.20 atm is compressed isothermally (constant temperature) to a pressure of 0.80 atm. Find the work done by the gas.

(a) -18000 J
(b) 0 J
(c) +18000 J
(d)@ -6900 J
(e) +6900 J

- An ideal gas undergoes an isothermal process starting with a pressure of 2×10^5 Pa and a volume of 6 cm^3. Which of the following might be the pressure and volume of the final state?

(a) 4×10^5 Pa and 4 cm^3
(b)@ 6×10^5 Pa and 2 cm^3
(c) 3×10^5 Pa and 6 cm^3
(d) 1×10^5 Pa and 10 cm^3
(e) 8×10^5 Pa and 2 cm^3

- Which of the following statements is CORRECT?

(a) Heat is a temperature difference.
(b) The internal energy of an ideal gas depends on the temperature and pressure only.
(c) A standing wave must be transverse.
(d) The rms speed of gas molecules decreases in an isothermal process.
(e)@ For a given medium, the frequency of a wave is inversely proportional to wavelength.

- An ideal gas, initially occupies a volume of 0.380 m^3 at a pressure of 2.04×10^5 Pa, expands isothermally to a pressure of 1.01×10^5 Pa. Calculate the work done by the gas.

(a) 27.0 kJ
(b) 32.1 kJ
(c) 539 kJ
(d) 321 kJ
(e)@ 54.5 kJ

- The volume of an oxygen container is 50.0 L. As oxygen leaks from the container, the pressure inside the container drops from 21.0 to 9.00 atm, and its temperature drops from 303 to 283 K. The number of moles that leaks from the container is:

(a)@ 22.8 mol.

(b) 11.1 mol.
(c) 19.4 mol.
(d) 65.3 mol.
(e) 42.2 mol.

- The equation of state of a certain gas is given as $PV^2 = K$, where P is the pressure, V is the volume and K is a constant. Find the work done by the gas if its volume increases from $V_i = 2.0\ m^3$ to a final volume $V_f = 4.0\ m^3$.

(a) $2K^2$.
(b) K/2.
(c) K^2.
(d)@ K/4.
(e) 4K.

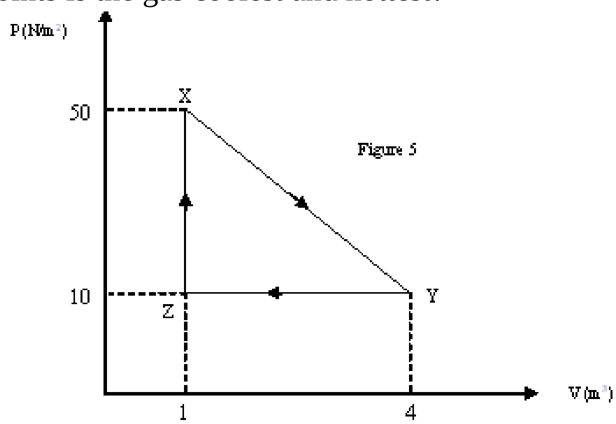
- Which one of the following statements is correct?

(a) In an isothermal process, the work done on the gas is always positive.
(b) In an adiabatic process, the work is always zero.
(c) All real gases approach the ideal gas state at low temperatures.
(d)@ Two different ideal gas molecules of different mass will have the same average translational kinetic energy if they are at the same temperature.
(e) In an isobaric process, the energy is always constant.

➢ One mole of a monatomic ideal gas at 410 K is compressed to half its original volume by an isobaric process. How much work is done in the process?

(a) 3.3 kJ done on the gas
(b)@ 1.7 kJ done on the gas
(c) 3.3 kJ done by the gas
(d) 8.3 kJ done on the gas
(e) 1.7 kJ done by the gas

➢ A mass of an ideal gas of volume V at pressure P undergoes the cyclic process shown in figure 5. At which points is the gas coolest and hottest?



(a)@ Coolest at Z and hottest at X.
(b) Coolest at Z and hottest at Y.
(c) Coolest at X and hottest at Y.
(d) Coolest at Y and hottest at X.
(e) Coolest at Y and hottest at Z.

➢ A system of monatomic ideal gas expands to twice its original volume, doing 300 J of work in the process. The heat added to the gas will be largest if the process is

(a) cyclic.
(b) done at constant volume.
(c) done adiabatically.
(d) done isothermaly.
(e)@ done at constant pressure.

➢ Five moles of an ideal gas are kept at a constant temperature of 53.0 $^{o}\mathrm{C}$ while the pressure of the gas is increased from 1.00 atm to 3.00 atm. Find the work done in the process.

(a) zero.
(b) 2.42 kJ of work done on the gas.
(c)@ 14.9 kJ of work done on the gas.
(d) 14.9 kJ of work done by the gas.
(e) 2.42 kJ of work done by the gas.

$$\boxed{\begin{aligned} W &= nRT\,\ln\left(\frac{V_f}{V_i}\right) = nRT\,\ln\left(\frac{P_i}{P_f}\right) \\ &= \underline{-14.9\text{ K}}. \end{aligned}}$$

- In a constant volume process, 209 J of heat is added to 1 mole of an ideal monatomic gas initially at 300 K. Find the final temperature of the gas.

(a) 329 K.
(b) 350 K.
(c)@ 317 K.
(d) 391 K.
(e) 373 K.

- Two moles of helium (monatomic) gas are heated from 100 ^{o}C to 250 ^{o}C. How much heat is transferred to the gas if the process is isobaric?

(a) 3.11 kJ
(b) 1.51 kJ
(c) 8.52 kJ
(d) 2.63 kJ
(e)@ 6.23 kJ

- One mole of an ideal diatomic gas (Cp = 7R/2) is cooled at constant pressure from 420 K to 300 K. Calculate the change in internal energy of the gas in calories.

(a) +596 cal
(b) +285 cal
(c) +188 cal
(d) -285 cal
(e)@ -596 cal

- Consider 100 g of helium (He) gas at 77 K. How much heat energy must be supplied to the gas to increase its temperature to 24 ^{o}C, if the process is isovolumetric? (M(He) = 4 g/mole and He is a monatomic gas.)

(a)@ 69 kJ
(b) 43 kJ
(c) 71 kJ
(d) 24 kJ
(e) 12 kJ

- A diatomic ideal gas, at a pressure of 1.0 atm, expands isobarically from a volume of 2.0 Liters to a volume of 5.0 Liters. Calculate the change in internal energy of the gas during the process.

(a) -9.0×10^{3} J.
(b) 7.6×10^{2} J.
(c)@ 1.1×10^{3} J.
(d) 1.7×10^{3} J.
(e) -3.1×10^{2} J.

- Five moles of an ideal monatomic gas are allowed to expand adiabatically to twice its volume. In the process the gas does 831 Joules of work. The temperature of the gas will:

(a) increases by 13.3 ^{o}C.
(b) decreases by 20.2 ^{o}C.
(c) increases by 20.2 ^{o}C.
(d)@ decreases by 13.3 ^{o}C.
(e) stays constant.

- Two moles of a monatomic ideal gas is compressed at a constant pressure of 1.5 atm from a volume of 70 liters to 35 liters. Calculate the change in internal energy of the gas.

(a) -1.9×10^4 J
(b) -3.5×10^4 J
(c)@ -1.3×10^4 J
(d) 2.4×10^4 J
(e) -0.87×10^4 J

- Figure (4) shows 5 paths traversed by a gas on a P-V diagram. For which of the 5 paths is the change in internal energy the greatest?

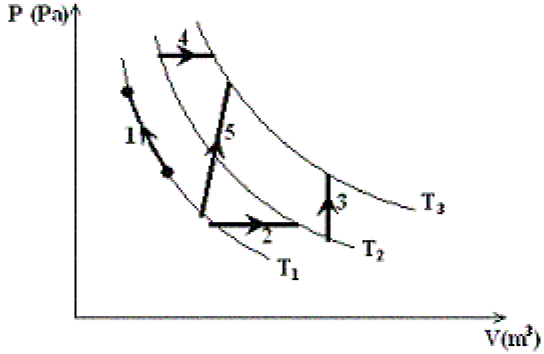


Fig. (4)

(a) 1 and 2
(b)@ 5
(c) 4
(d) 5 and 4
(e) 3

➢ One mole of an ideal monatomic gas is taken through the cyclic process shown in the figure. Calculate the net heat (lost or gained) by the gas during one complete cycle.

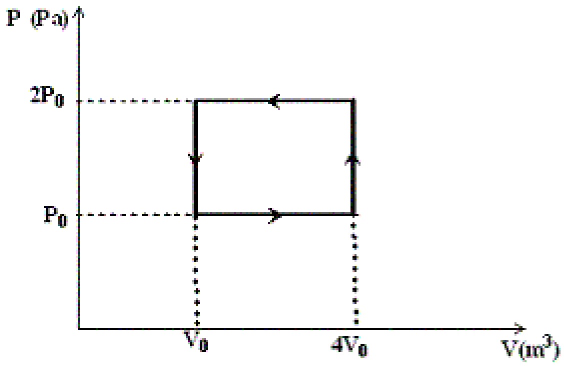
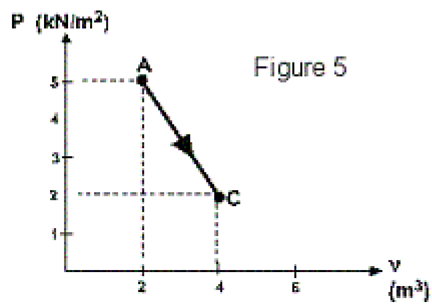


Fig. (5)

(a)@ 4*Po*Vo Joule (lost)
(b) 2*Po*Vo Joule (gained)
(c) 4*Po*Vo Joule (gained)
(d) 3*Po*Vo Joule (lost)
(e) 2*Po*Vo Joule (lost)

➢ One mole of an ideal monatomic gas is taken from A to C along the diagonal path in figure 5. What is the change in the internal energy of the gas in this process?



(a) + 5.0 kJ
(b) + 3.0 kJ
(c)@ - 3.0 kJ
(d) ZERO
(e) - 5.0 kJ

➢ An ideal monatomic gas is compressed at a constant volume of 0.500 L from a pressure of 0.500 atm to a final pressure of 0.250 atm. What is the change in the internal energy of the gas?

(a) + 0.188 J
(b)@ - 18.9 J
(c) zero
(d) + 18.9 J
(e) - 0.188 J

- An ideal gas initially occupies a volume of 2.50 L at a pressure of 1.80 atm. It expands isothermally to three times its initial volume. How much work is done by the gas?

(a)@ + 499 J
(b) - 4.94 J
(c) + 4.94 J
(d) - 499 J
(e) zero

- One mole of an ideal monatomic gas is taken through the cycle of figure 5. Calculate the work done in a complete cycle.

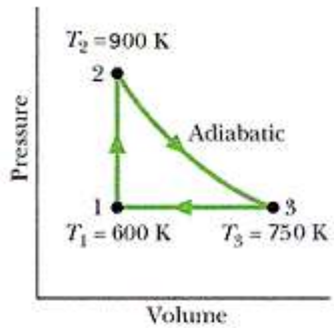


Figure 5

(a) + 895 J
(b) - 525 J
(c) + 325 J
(d)@ + 623 J
(e) zero

- For a given temperature increase, a certain amount of an ideal gas requires 80 J of heat when heated at constant volume and 150 J of heat when heated at constant pressure. How much work is done by the gas in the second situation?

(a) +80 J
(b) zero
(c) -70 J
(d)@ +70 J
(e) -80 J

- Five moles of an ideal gas expands isothermally at a temperature of 127 ^{o}C to one-fourth the initial pressure. How much heat is transferred in this process?

(a)@ 23.0 kJ into the gas
(b) 23.0 kJ out of the gas
(c) 7.32 kJ into the gas
(d) zero
(e) 7.32 kJ out of the gas

- Five moles, of an ideal monatomic gas, expand at constant pressure of 1.0×10^2 Pascal from a volume of 1.0 m^3 to a volume of 3.0 m^3. What is the change in the internal energy of the system?

(a) 100 J.
(b) 500 J.
(c) 600 J.
(d)@ 300 J.
(e) 1000 J.

- The internal energy of a fixed mass of an ideal gas depends on

(a) pressure, but not volume or temperature.
(b)@ temperature, but not volume or pressure.
(c) volume, but not temperature or pressure.
(d) temperature and pressure, but not volume.
(e) temperature and volume, but not pressure.

- Two moles of helium gas (monatomic) are initially at a temperature of 27.0 $^{\circ}C$ and occupy a volume of 20.0 liters. The helium gas is expanded at constant pressure until its volume is doubled. Find the change in the internal energy.

(a) 5.4×10^6 J.
(b) 9.2×10^3 J.
(c)@ 7.5×10^3 J.
(d) 1.9×10^5 J.
(e) 1.3×10^3 J.

- A diatomic ideal gas undergoes a constant pressure process in which its internal energy increases by 540 J. Find the heat added to the gas and the work done by the gas.

(a) Q = 0, W = 540 J.
(b) Q = 900 J, W = 360 J.
(c) Q = 230 J, W = 313 J.
(d) Q = 540 J, W = 0.
(e)@ Q = 756 J, W = 216 J.

- A system containing an ideal gas at a constant pressure of 1.22×10^5 Pa gains 2140 J of heat. During the process, the internal energy of the system increases by 2320 J. What is the change in the volume of the gas?

(a) + 3.66×10^{-3} m^3
(b) - 3.66×10^{-3} m^3
(c)@ - 1.48×10^{-3} m^3
(d) zero

(e) $+ 1.48\times10^{-3}$ m^3

- The temperature of two moles of helium gas is raised from $0\,^{o}C$ to $100\,^{o}C$ at constant pressure. Calculate the work done by the gas.

(a) 10.0 kJ.
(b) 6.00 kJ.
(c) 1.20 kJ.
(d) 1.00 kJ.
(e)@ 1.66 kJ.

- A cylinder of volume 2.5 L contains 0.25 moles of helium [M = 4.0 grams/mole] at 2.0 atm. What is the internal energy of the gas?

(a) 1.20 kJ.
(b) 0.61 kJ.
(c)@ 0.76 kJ.
(d) 0.01 kJ.
(e) 1.60 kJ.

- An ideal monatomic gas originally in state A is taken reversibly to state B along the straight line path shown in figure 4. What is the change in the internal energy of the gas for this process?

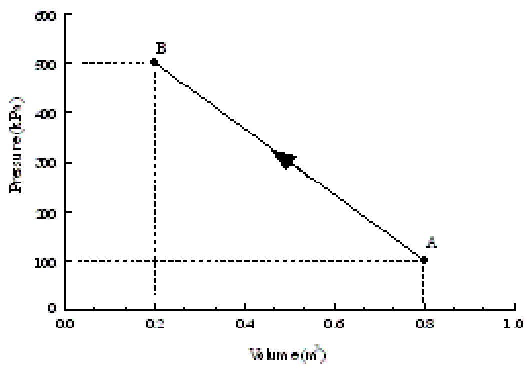


Figure 4

(a) -180 kJ.
(b) 180 kJ.
(c)@ 30 kJ.
(d) -30 kJ.
(e) -15 kJ.

- Helium gas at $27\,^{o}C$ is compressed adiabatically to 1/2 of its initial volume. Find its temperature after compression. [γ_{Helium} = 1.67]

(a) 152 ^{o}C.
(b) 075 ^{o}C.
(c) 520 ^{o}C.
(d)@ 204 ^{o}C.
(e) 307 ^{o}C.

- An ideal gas ($\gamma = 1.40$) expands slowly and adiabatically. If the final temperature is one third the initial temperature, by what factor does the volume change?

(a) 12.5
(b) 10.0
(c) 18.0
(d)@ 15.6
(e) 14.0

- A cylinder contains 4 moles of a diatomic ideal gas (Cv = 5R/2) at a temperature of 27 ^{o}C and a pressure of 1.5 atm. temperature reaches 127 ^{o}C . How much work is done by the gas in this process?

(a) 986 calories
(b) 562 calories
(c) 418 calories
(d)@ 794 calories
(e) 150 calories

- One mole of an ideal monatomic gas is initially at 300 K and 1.0 atm. The gas is compressed adiabatically to 2.0 atm. What is the final volume of the gas?

(a) 0.079 m^3
(b) 0.025 m^3
(c)@ 0.016 m^3
(d) 0.056 m^3
(e) 0.041 m^3

- The air in an automobile engine at 20 ^{o}C is compressed from an initial pressure of 1 atm and a volume of 200 cm^3 to a final volume of 20 cm^3. Find the final temperature if the air behaves like an ideal gas (γ = 1.4) and the compression is adiabatic.

(a) 50 ^{o}C
(b) 10 ^{o}C
(c)@ 463 ^{o}C
(d) 20 ^{o}C
(e) 526 ^{o}C

- An ideal gas (γ = 1.3) is initially at V = V1, T = 273 K and P = 1.0 atm. The gas is compressed adiabatically to half its original volume. It is then cooled at a constant pressure to its original temperature. The ratio of the final volume to the initial volume is:

(a)@ 0.4
(b) 2.0

(c) 0.5
(d) 0.2
(e) 1.0

➢ Which one of the following statements is TRUE? The temperature of an ideal gas decreases in an

(a) adiabatic compression.
(b) increase in pressure at constant volume.
(c) isobaric expansion.
(d) isothermal compression.
(e)@ adiabatic expansion.

➢ An ideal monatomic gas goes through the process in T-V diagram of figure (1). At Point A, the temperature is 400 K, and the volume is 2 liters. If the volume at point B is 10 liters, what is the temperature at point C be?

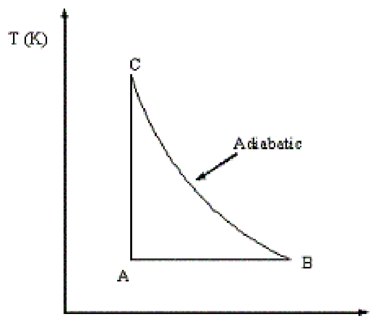


Figure 1

(a) 4.00×10^3 K
(b) 2.00×10^3 K
(c) 5.89×10^3 K
(d)@ 1.17×10^3 K
(e) 2.00×10^2 K

➢ An ideal diatomic gas, initially at a pressure Pi = 1.0 atm and volume Vi, is allowed to expand isothermally until its volume doubles. The gas is then compressed adiabatically until it reaches its original volume. The final pressure of the gas will be:

(a) 1.7 atm.
(b) 0.4 atm.
(c) 2.0 atm.
(d)@ 1.3 atm.
(e) 0.5 atm.

➢ In an adiabatic process, the temperature of one mole of an ideal monatomic gas is decreased from 500 K to 400 K. What is the work done during the process in calories?

(a)@ 300
(b) 400

(c) 500
(d) 200
(e) 100

- Initially, an ideal monatomic gas containing 10.0 moles occupies a volume of 30.0 L at a pressure of 5.00 atm. It is then compressed adiabatically to a final volume of 12.0 L. What is the final temperature of the gas?

(a) 157 K
(b) 457 K
(c) 844 K
(d) 420 K
(e)@ 336 K

- An ideal diatomic gas, initially at a pressure Pi = 1.0 atm and volume Vi, is allowed to expand isothermally until its volume doubles. The gas is then compressed adiabatically until it reaches its original volume. The final pressure of the gas will be:

(a) 0.5 atm.
(b) 1.7 atm.
(c) 2.0 atm.
(d)@ 1.3 atm.
(e) 0.4 atm.

- The air in an automobile engine at 20 ^{o}C is compressed adiabatically from an initial pressure of 1 atm and a volume of 200 cm^3 to a final volume of 20 cm^3. Find the final temperature if the air behaves like an ideal gas. [Take γ = 1.4]

(a) 50 ^{o}C
(b) 20 ^{o}C
(c) 10 ^{o}C
(d)@ 463 ^{o}C
(e) 526 ^{o}C

- Two moles of a gas, originally at atmospheric pressure, occupy a volume of 0.0500 m^3. The gas is compressed adiabatically to half its original volume. What is the final temperature of the gas? Use γ = 1.4.

(a) 128 K
(b) 573 K
(c) 295 K
(d)@ 401 K
(e) 300 K

- One mole of a monatomic ideal gas is initially at a temperature of 300 K and with a volume of 0.080 m^3. The gas is compressed adiabatically to a volume of 0.040 m^3. What is the final temperature?

(a) 100 K.
(b) 7.00 K.
(c) 522 K.
(d)@ 476 K.
(e) 999 K.

$$T_i V_i^{\gamma-1} = T_f V_f^{\gamma-1}$$

$$\Rightarrow T_f = \left(\frac{V_i}{V_f}\right)^{\gamma-1} T_i = \left(\frac{0.08}{0.04}\right)^{\gamma-1} 300 = \underline{476\ \mathrm{K}}.$$

- For an ideal gas, which of the following statements is FALSE:

(a) In an isothermal process, there is no change in the internal energy.
(b) In an adiabatic process, no heat enters or leaves the system.
(c) In an isothermal process, the work done is equal to heat energy.
(d) In a constant volume process, the work done by the gas is zero.
(e)@ In any cyclic process, the work done by the gas is zero.

- Helium gas is heated at constant pressure from 32 $^\circ\mathrm{F}$ to 212 $^\circ\mathrm{F}$. If the gas does 20.0 Joules of work during the process, what is the number of moles?

(a) 0.050 moles.
(b) 0.013 moles.
(c) 0.200 moles.
(d)@ 0.024 moles.
(e) 0.111 moles.
