First Law of Thermodynamics

Multiple Choice Questions

1. A fixed mass of gas undergoes changes of pressure and volume as shown in Fig. 1.

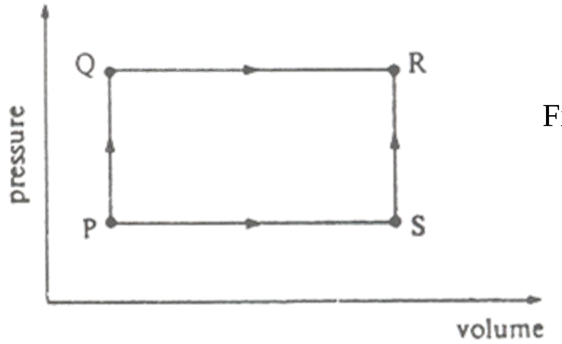


Fig.1

When the gas is taken from state P to state R by the stages PQ and QR, 8J of heat are absorbed by it and 3J of work are done by it. When the same resultant change is achieved by stages PS and SR, 1J of work is done by the gas. In this case,

A 12 J of heat are rejected.
B 10 J of heat are absorbed.
C 8 J of heat are absorbed.
D 6 J of heat are absorbed.
E 4 J of heat are rejected.

2. A sample of an ideal gas initially having internal energy U_1 is allowed to expand adiabatically performing external work W. Heat Q is then supplied to it, keeping the volume constant as its new value, until the pressure rises to its original value. The internal energy is then U_2. (See Fig. 2)

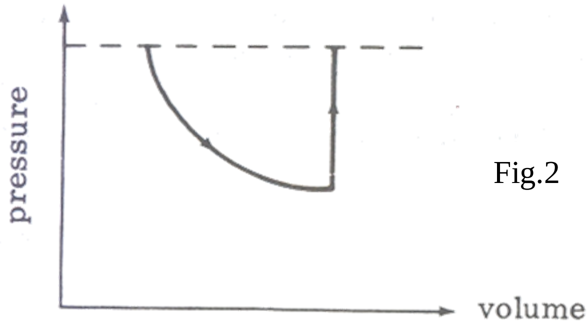


Fig.2

The increase in internal energy $U_2 - U_1$ is equal to

A zero **B** W **C** Q **D** $Q - W$ **E** $W - Q$

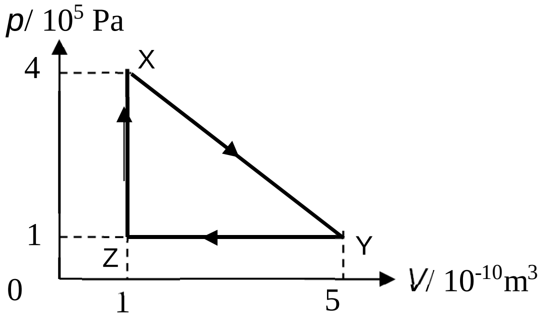
3. A fixed mass of an ideal gas slowly absorbs 1000 J of heat and as a result expands slowly, at a constant pressure of 2.0×10^4 Pa, from a volume of $0.050 m^3$ to a volume of $0.075 m^3$. What is the effect on the internal energy of the gas?

A It decreases by 1000 J.
B It decreases by 500 J.
C It is unchanged.
D It increases by 500 J.
E It increases by 1000 J.

4. A mass of an ideal gas of volume *V* at pressure *p* undergoes the cycle of changes shown in the graph.

At which points is the gas coolest and hottest?

	coolest	*hottest*
A	**X**	**Y**
B	**Y**	**X**
C	**Y**	**Z**
D	**Z**	**X**
E	**Z**	**Y**



5. An ideal gas is taken through the three processes (A → B, B → C, and C → A) shown in the drawing.

Process	ΔU	Q	W
A → B	**(b)**	+561 J	**(a)**
B → C	+4303 J	**(c)**	+2867 J
C → A	**(d)**	**(e)**	−3740 J

Δu is the increase in internal energy, *Q* is the heat supplied to the gas and *W* is the work done on the gas.

Which of following shows the correct missing entries in the above table?
A (b) 500 J (a) 0
B (c) 1436 J (e) -1124 J
C (d) -4864 J (b) -561 J
D (d) 4303 J (e) 1124 J

Self-Attempt

6. An ideal gas undergoes an expansion in volume from 1.3 x 10^{-4} m^3 to 3.6 x 10^{-4} m^3 at a constant pressure of 1.3 x 10^5 Pa. During this expansion, 24 J of heat is supplied to the gas.

What is the overall change in the internal energy of the gas?

7. A gas in a cylinder expands from a volume of 0.110 m^3 to 0.320 m^3. Heat flows into the gas just rapidly enough to keep the pressure constant at 1.80 x 10^5 Pa during the expansion. The total heat added is 1.15 x 10^5 J.

(a) Find the work done by the gas.
(b) Find the change in internal energy of the gas.

8. When water is boiled under a pressure of 2.00 atm, the heat of vaporization is 2.20 MJ kg^{-1} and the boiling point is 120 ^oC. At this pressure and temperature, 1.00 kg of water has a volume of 1.00 x 10^{-3} m^3, and 1.00 kg of steam has a volume of 0.824 m^3.

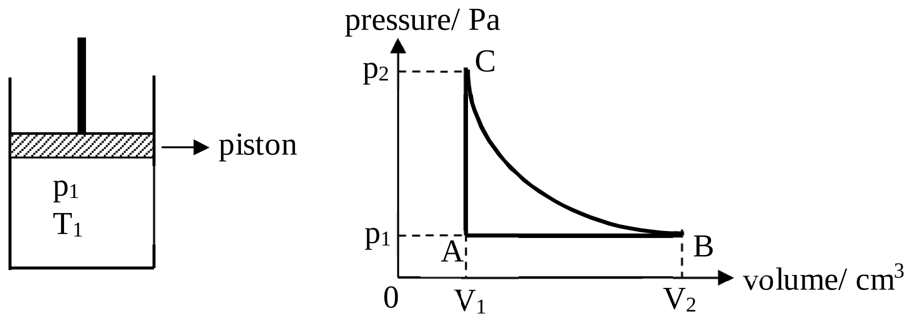
[1 atm = 1.013 x 10^5 Pa]
(a) Compute the work done when 1.00 kg of steam is formed at this temperature.
(b) Compute the increase in internal energy of the water.
(c) The work done for 1.00 kg of steam to form at 100^{o}C and 1 atm is 1.69 x 10^5 J, suggest a reason why the work done against external pressure decreases when external pressure increases.

9. During an adiabatic expansion, the temperature of 0.450 mol of argon (Ar) drops from 50.0 ^oC to 10.0 ^oC. Argon is monatomic and may be treated as an ideal gas.

(a) What is the change in internal energy of the gas?
(b) How much work does the gas do?

Discussion questions

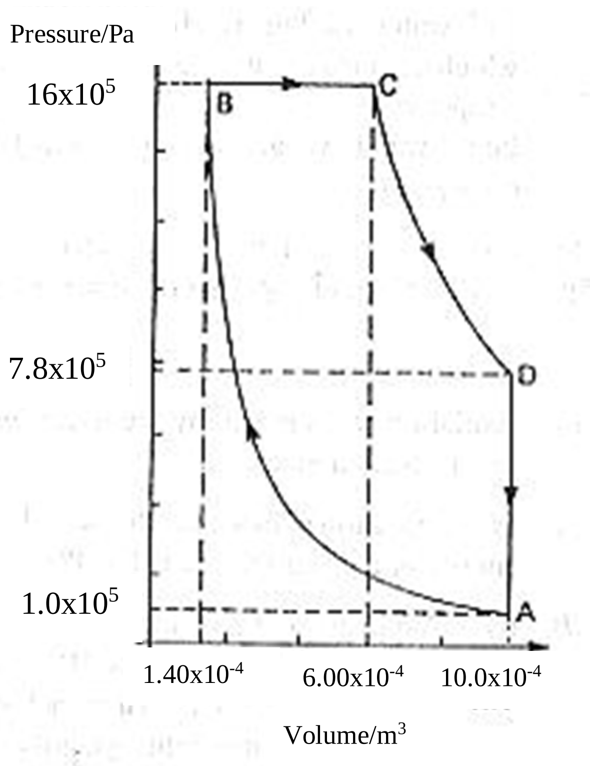
10. The cylinder in the figure shown below holds a volume V_1= 1.00 x 10^{-3} m^3 of air at an initial pressure p_1= 1.10 x 10^5 Pa and temperature T_1 = 300 K. Assume that air behaves like ideal gas. The graph below shows a sequence of changes imposed on the air in cylinder.



(a) **AB** – the air heated to 375 K at constant pressure. Calculate the new volume, V_2.
(b) **BC** – the air is compressed isothermally to volume V_1. Calculate the new

pressure, p_2.

11. The gas in the cylinder of a diesel engine can be considered to undergo a cycle of changes of pressure, volume and temperature. One such cycle, for an ideal gas, is shown on the graph.



(i) The temperature of the gas at A and B are 300 K and 660 K respectively. Use the ideal gas equation and data from the graph to find the temperatures at C and D.

(ii) During each of the four sections of the cycle, changes are being made to the internal energy of the gas. Some of the factors affecting these changes are given in the table below.

Explain why the work done on the gas is sometimes negative and find the work done on the gas in section D to A.

Deduce the values of the "increase in internal energy of the gas" for each section and list them.

Section of cycle	Heat supplied to gas / J	Work done on gas/J	Increase in internal energy of gas/J
A to B	0	300	
B to C	2580	-740	
C to D	0	-440	
D to A	-1700		

12 N08/III/4(b)
An ideal gas undergoes a cycle of changes A $\rightarrow$ B $\rightarrow$ C $\rightarrow$ A, as shown in Figure 4.1.

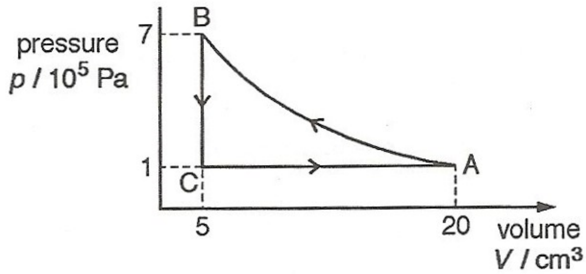


Figure 4.1

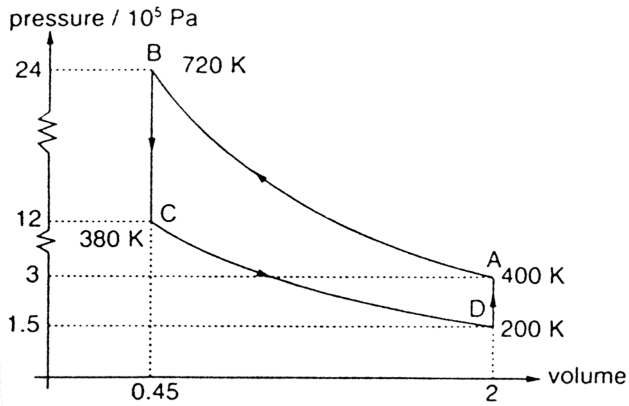
(i) Calculate the work done by the gas during the change C $\rightarrow$ A. [2]

(ii) Figure 4.2 is a table of energy changes during one cycle. Complete figure 4.2.

section of cycle	heating supplied to gas / J	work done on gas / J	increase in internal energy of gas / J
A $\rightarrow$ B	zero	4.2	
B $\rightarrow$ C	–8.5		
C $\rightarrow$ A			

Figure 4.2

13 A fixed mass of gas in a heat pump undergoes a cycle of changes of pressure, volume and temperature as shown below. The gas is assumed to be ideal.



	Increase in Internal energy/J	Heat supplied to gas/J	Work done on gas/J
A to B	1200	0	
B to C	- 1350	-1350	
C to D	- 600	0	
D to A			

The following table shows an increase in internal energy which takes place during each of the changes A to B, B to C and C to D. It also shows that in both of sections A to B and C to D, no heat is supplied to the gas.

Using the first law of thermodynamics and other necessary data from the graph, complete the table above.

14 In the process illustrated by the *pV* diagram in Figure 2, the temperature of the ideal gas remains constant at 85.0 ^{o}C.

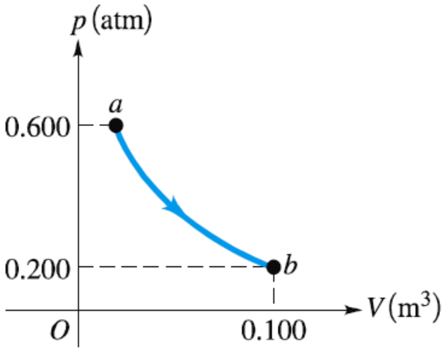


Figure 2

(a) How many moles of gas are involved?

(b) What volume does this gas occupy at *a*?

(c) How much work was done by or on the gas from *a* to *b*?

(d) By how much did the internal energy of the gas change during this process?

15 The graph in Figure 3 shows a *pV* diagram for 3.25 moles of ideal helium (He) gas. Part *ca* of this process is isothermal.

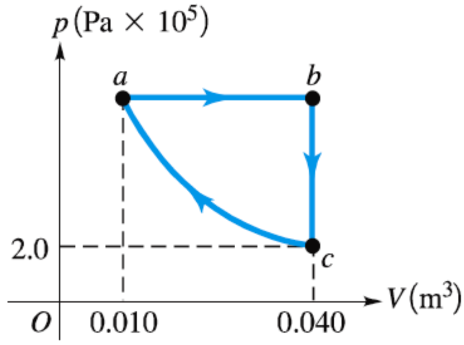


Figure 3

(a) Find the pressure of the Heat point *a*.

(b) Find the temperature of the He at points *a*, *b* and *c*.

(c) How much heat entered or left the He during segments *ab*, *bc* and *ca*? In each did heat enter or leave?

(d) By how much did the internal energy of the He change from *a* to *b*, from *b* to *c* and from *c* to *a*? Indicate whether this energy has increased or decreased.

<u>Real Life Example</u>

R1 N05/III/02

(a) The ideal gas equation is $pV = nRT$. Explain why non-SI units may be used for p and V but the temperature cannot have the unit ^{o}C. [2]

(b) Write down the exact temperature on the Kelvin scale of zero degrees Celsius. [1]

(c) In an attempt to beat the world altitude record for balloon, a helium balloon containing 15 000 m^3 of helium at a temperature of 288 K was launched from sea level, where the pressure of the gas was 101 kPa. The balloon, carrying a payload, rose to an altitude of 32.0 km before reaching equilibrium. Data concerning atmospheric conditions are given in the table.

	sea level altitude = 0	equilibrium altitude = 32.0 km
pressure of helium	101 kPa	0.890 kPa
temperature	288 K	228 K
density of air	1.23 kg m^{-3}	0.0134 kg m^{-3}

Calculate

(i) the volume of helium at 32.0 km, [2]

(ii) the weight of air displaced by the balloon at equilibrium altitude, [2]

(iii) the total weight of balloon, helium and payload [1]

(iv) the resultant force on the balloon at sea level, [2]

(v) the acceleration of the balloon at take-off. [2]

(d) (i) Using the equations $pV = \frac{1}{3}Nm\langle c^2 \rangle$ and $pV = NkT$, derive an expression for the relationship between the average translational kinetic energy of a helium atom and the temperature. [1]

(ii) Hence find the average translational kinetic energy of one of the helium atoms in the balloon in *(c)*, when the balloon is at an altitude of 32.0 km. [1]

(iii) Calculate the amount, in mol, of helium in the balloon. [2]

(iv) Assuming that the gas behaves as an ideal gas, calculate the kinetic energy of all the helium at equilibrium altitude. [2]

(e) Suggest why the change in the potential energy of the gas in the balloon as it rises does **not** change its internal energy. [2]

R2 (a) Explain what is meant by an ideal gas.

(b) (i) A car tyre has a fixed internal volume of 0.0120 m^3. On a day when the temperature is 25 °C the pressure in the tyre has to be increased from 2.62×10^5 Pa to 3.23×10^5 Pa. Assuming the air is an ideal gas, calculate the amount of air which has to be supplied at constant temperature.

(ii) A portable supply of air is used to inflate tyres has a volume of 0.0108 m^3 and is filled with air at a pressure of 8.72×10^5 Pa. Show that, at 25°C, there is more than enough air in it to supply four tyres, as in (i), without the pressure falling below 3.23×10^5 Pa.

(c) (i) Show that the internal energy of a molecule of air at a temperature of 25°C is 6.17×10^{-21} J. Assume that the air behaves as an ideal gas.

(ii) Hence, calculate the internal energy of one mole of the air at temperature of 25°C.

(iii) Calculate the increase in the internal energy of the air in the tyre in (b)(i) as a result of increasing its pressure.

Answer Key

1.	D	**10. (a)**	1.25 x 10-3 m^3	**R1(b)**	273.15 K
2.	D	**10. (b)**	1.37 x 105 Pa	**R1(c)(i)**	$1.35\text{x}10^6$ m^3
3.	D	**14.(a)**	0.681 mol	**R1(ii)**	$1.77\text{x}10^5$ N
4.	E	**14.(b)**	0.033 m^3	**R1(iii)**	$1.77\text{x}10^5$ N
5.	B	**14.(c)**	2250 J	**R1(iv)**	$3.99\text{x}10^3$ N
6.	-6 J	**14.(d)**	0	**R1(v)**	0.221 ms^{-2}
7(a)	3.78 x 10^4 J	**15.(a)**	$8.0\text{x}10^5$ Pa	**R1(d)(ii)**	$4.72\text{x}10^{-21}$J
7(b)	7.72 x 10^4 J	**15.(b)**	296 K	**R1(iii)**	$6.33\text{x}10^5$ mol
8(a)	1.66 x 10^5 J	**15.(c)**	q_{ab} =60,000J	**R1(iv)**	$1.80\text{x}10^9$ J
8(b)	2.03 x 10^6 J		q_{bc} = -36,000 J		
			q_{ca} = -11100 J	**R2(b)(i)**	0.295 mol
9(a)	-224 J	**15.(d)**	ΔU_{ab} = 36000 J	**R2(c)((ii)**	3.71 x 10^3 J
9(b)	224 J		ΔU_{bc} = 36000 J	**R2(c)((iii)**	1100 J
			ΔU_{ca} = 0		

11.

Section of cycle	Heat supplied to gas / J	Work done on gas/J	Increase in internal energy of gas/J
A to B	0	300	**300**
B to C	2580	-740	**1840**
C to D	0	-440	**-440**
D to A	-1700	**0**	**-1700**

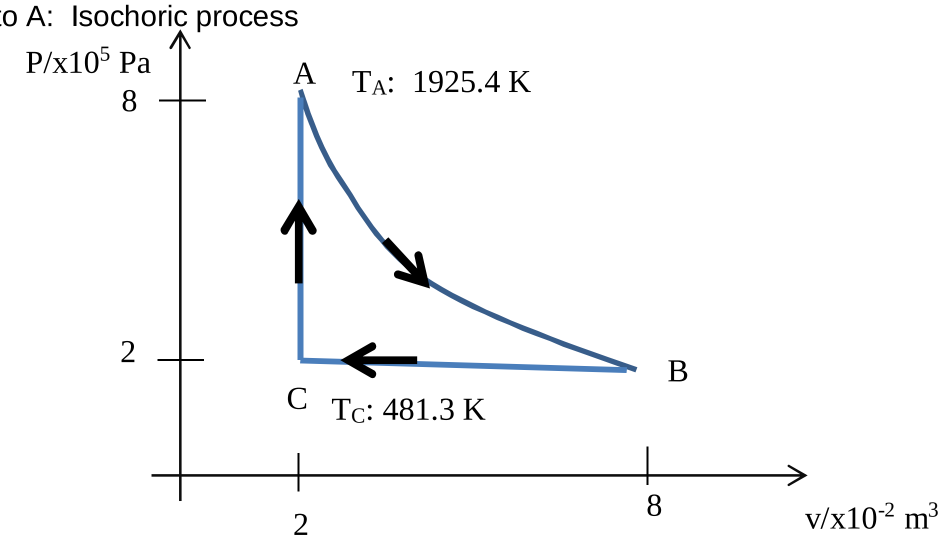
12.

Section of cycle	Heat supplied to gas / J	Work done on gas/J	Increase in internal energy of gas/J
A to B	0	4.2	**4.2**
B to C	-8.5	0	**-8.5**
C to A	5.8	1.5	**4.3**

13.

Section of cycle	Increase in Internal energy/ J	Heat supplied to gas/ J	Work done on gas/ J
A to B	1200	0	1200
B to C	- 1350	-1350	0
C to D	- 600	0	-600
D to A	750	750	0

Thermal Physics Exercise

1	An ideal gas undergoes various thermal processes as shown in the figure below. The processes are: A to B: Isothermal process B to C: Isobaric process C to A: Isochoric process  	
a	Determine the amount of gas involved in moles.	**Hint:** PV= nRT
b	i. Determine the increase in internal energy in process A to B. ii. State with reason whether heat is absorbed or given out during the process A to B?	**Process A to B**
c	i. Determine the work done by the gas in process B to C? ii. . Calculate the change in the internal energy from state B to state C. iii. State with reason whether heat is absorbed or given out during the process B to C?	**Process B to C**

d	i. Determine the work done in process C to A. ii. State with reason whether heat is absorbed or given out during the process C to A?	**Process C to A**
	iii. Calculate the increase in the internal energy from state C to state A.	

e
Complete the thermal process table below:

Process	**ΔU**	**q**	**w**
A to B			-22.18 kJ
B to C			
C to A			
Cyclic process ABCA	**0**	**Σq**	**Σw**

g. For the entire cycle, state whether

i. net work done by the gas is positive?

ii. the heat is absorbed or given out?

Hand-in Assignment

Name:___________________________ **Class:** ____________________

A1 Use the following physical data for ice, water and steam when necessary in answering this question.

	ice	**water**	**water**	**steam**
Temperature	0^oC	0^oC	100^oC	100^oC
Volume occupied by 1 kg at standard pressure /m^3	0.00109	0.00100	0.00104	1.67
Kinetic energy of all molecules in 1 kg/10^5 J	1.89	1.89	2.58	2.58
Potential energy of all the molecules in 1 kg (referred to ice at 0^oC)/10^5 J	0	3.36	3.41	24.3
Internal energy of 1 kg/10^5 J	1.89	5.25	5.99	26.9

(a) Explain what is meant by the term *internal energy of a gas.*

....

.... [1]

(b) Explain why there is no change in the kinetic energy of the molecules when ice at 0^oC changes to water at 0^oC.

....

....

....[2]

(c) Determine the specific latent heat of fusion of ice.

[1]

(d) Calculate how much work has to be done by 1 kg of water in order to change to steam at 100^oC and at atmospheric pressure of 1.01×10^5 Pa.

[2]

(e) State the first law of thermodynamic in a word equation and use it to calculate the specific latent heat of vaporisation of water.

[3]

(f) Compare the values obtained in (c) and (e) and hence suggest the reasons for the considerable difference.

[2]

(g) The work done W by an expanding gas is calculated using $W=p\Delta V$. Explain which one of the following must remain constant for this equation to be used. The options are:

- the pressure of the expanding gas or
- the pressure of the surroundings or
- the temperature of the expanding gas or
- the temperature of the surroundings.

[2]