Thermodynamics

Standard difficulty · 20 questions · 40 marks · Time: 36 minutes

Name: _____ Date: _____ Score: ____ / 40

Show your working for Sections B and C. Answers are on the last page — try every question first!

Section A — Choose the correct answer 8 × 1 = 8 marks

1. A system that can exchange energy but not matter with its surroundings is:

(a) an isolated system **(b)** an adiabatic system

(c) an open system **(d)** a closed system

2. For the reaction $CaCO_3(s) \rightarrow CaO(s) + CO_2(g)$, Δn_g (the change in moles of gas) is:

(a) +1 **(b)** +2 **(c)** +3 **(d)** 0

3. A gas expands from 1 L to 20 L against a constant external pressure of 2 bar. The work done on the gas is: (1 L bar = 100 J)

(a) −38 J **(b)** 3,800 J **(c)** −38,000 J **(d)** −3,800 J

4. For a reaction, ΔH = −185 kJ/mol and ΔS = +271 J/K mol. The reaction is spontaneous:

(a) only below 682.66 K **(b)** at no temperature

(c) at all temperatures **(d)** only above 682.66 K

5. Using standard enthalpies of formation (kJ/mol): $Fe_2O_3(s)$ −824.2, $CO(g)$ −110.5, $CO_2(g)$ −393.5, find ΔH for $Fe_2O_3(s) + 3CO(g) \rightarrow 2Fe(s) + 3CO_2(g)$.

(a) −24.8 kJ **(b)** −541.2 kJ **(c)** 24.8 kJ **(d)** 541.2 kJ

6. For a reaction at 1000 K, ΔH = +112 kJ/mol and ΔS = −222 J/K mol. ΔG is:

(a) −334 kJ/mol **(b)** −221,888 kJ/mol

(c) 334 kJ/mol **(d)** −110 kJ/mol

7. Which of these is an intensive property?

(a) density **(b)** entropy **(c)** heat capacity **(d)** mass

8. Assertion (A): For $Fe_2O_3(s) + 2Al(s) \rightarrow Al_2O_3(s) + 2Fe(s)$, $\Delta H = \Delta U$.
Reason (R): $\Delta H = \Delta U + \Delta n_g RT$, so ΔH and ΔU differ only when the number of moles of gas changes.

(a) Both A and R are true, and R is the correct explanation of A.

(b) Both A and R are true, but R is not the correct explanation of A.

(c) A is true, but R is false.

(d) A is false, but R is true.

Section B — Short answer 8 × 2 = 16 marks

9. Distinguish between a state function and a path function, with one example of each.

10. For $2CO(g) + O_2(g) \rightarrow 2CO_2(g)$, $\Delta H = -566$ kJ at 400 K. Find ΔU. ($R = 8.314$ J/K mol) (2 decimal places where needed.)

11. The enthalpy of combustion of benzene, $C_6H_6(l)$, is −3,267.5 kJ/mol. Find its standard enthalpy of formation. (ΔcH: C(graphite) −393.5, $H_2(g)$ −285.8 kJ/mol)

12. Use bond enthalpies to find ΔH for $N_2(g) + 3H_2(g) \rightarrow 2NH_3(g)$. (Bond enthalpies in kJ/mol: N≡N 946, H–H 436, N–H 389)

13. A substance boils at 396 K, and its enthalpy of vaporisation is 42.1 kJ/mol. Find its entropy of vaporisation. (2 decimal places where needed.)

14. 31,350 J of heat is given to 250 g of water at 30 °C. What is its final temperature? (Specific heat capacity of water = 4.18 J/g K)

15. 4 mol of an ideal gas at 400 K is compressed reversibly and isothermally from 2 L to 1 L. Find the work done on the gas. ($R = 8.314$ J/K mol; $\log 2 = 0.3010$) (2 decimal places where needed.)

16. The equilibrium constant of a reaction at 298 K is 10^{-1}. Find $\Delta G°$. ($R = 8.314$ J/K mol) (2 decimal places where needed.)

Section C — Word problems — 4 × 4 = 16 marks

17. Explain the terms system, surroundings and boundary, and the three types of system, with examples.

18. The enthalpy of combustion of propene, $C_3H_6(g)$, is −2,058 kJ/mol; those of C(graphite) and $H_2(g)$ are −393.5 and −285.8 kJ/mol. (a) Write the equation for the formation of propene. (b) Find its enthalpy of formation. (c) Find its internal energy of formation at 298 K. (R = 8.314 J/K mol) (2 decimal places where needed.)

19. For a reaction, ΔH = −181 kJ/mol and ΔS = −72 J/K mol. (a) Find ΔG at 800 K. (b) Is the reaction spontaneous at 800 K? (c) At what temperature is it at equilibrium? (d) In what temperature range is it spontaneous? (2 decimal places where needed.)

20. 2 mol of an ideal gas at 298 K expands isothermally from 2 L to 8 L. Find w, q and ΔU (a) when the expansion is reversible, (b) when it is against a constant external pressure of 1 bar. Which gives more work? (R = 8.314 J/K mol; 1 L bar = 100 J; log 4 = 0.6021) (2 decimal places where needed.)

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Answer key

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Q	Answer	Working
1	**(d) a closed system**	—
2	**(a) +1**	moles of gaseous products − moles of gaseous reactants; ignore solids and liquids
3	**(d) −3,800 J**	w = −p_ext ΔV = −2 × (20 − 1) L bar
4	**(c) at all temperatures**	ΔG = ΔH − TΔS changes sign at T = ΔH/ΔS = 682.66 K
5	**(a) −24.8 kJ**	ΔH = ΣΔfH(products) − ΣΔfH(reactants), each times its coefficient; elements are zero
6	**(c) 334 kJ/mol**	ΔG = ΔH − TΔS = 112 − 1000 × (−0.222) kJ
7	**(a) density**	it does not depend on the amount of matter
8	**(a) Both A and R are true, and R is the correct explanation of A.**	A is true: Δn_g = 0. R is true and explains A.
9	**A state function depends only on the initial and final states of the system, not on how the change happens (internal energy, enthalpy, entropy). A path function depends on the route taken (heat, work).**	—
10	**−562.67 kJ**	ΔU = ΔH − Δn_g RT = −566 − (−1 × 8.314 × 400 ÷ 1000)
11	**49.1 kJ/mol**	ΔfH = aΔcH(C) + (b/2)ΔcH(H_2) − ΔcH(compound) for $C_aH_bO_c$
12	**−80 kJ**	ΔH = bonds broken − bonds formed = 2,254 − 2,334
13	**106.31 J/K mol**	ΔS = ΔH/T = 42,100 ÷ 396
14	**60 °C**	ΔT = q/(mc) = 30 K
15	**9,221.26 J**	w = −2.303 nRT log(V_f/V_i)
16	**5.71 kJ/mol**	ΔG° = −2.303 RT log K
17	**The system is the part of the universe being studied; the surroundings are everything else; the boundary separates them. Open system: exchanges energy and matter (an open beaker of hot water). Closed system: exchanges energy but not matter (a sealed flask). Isolated system: exchanges neither (water in a perfect thermos flask).**	—
18	**(a) $3C(graphite) + 3H_2(g) \rightarrow C_3H_6(g)$; (b) 20.1 kJ/mol; (c) Δn_g = −2, ΔU = 25.06 kJ/mol**	ΔfH by Hess's law; ΔU = ΔH − Δn_g RT

Q	Answer	Working
19	**(a) −123.4 kJ/mol; (b) spontaneous; (c) 2,513.89 K; (d) below 2,513.89 K**	ΔG = ΔH − TΔS; at equilibrium ΔG = 0, so T = ΔH/ΔS
20	**(a) w = −6,870.98 J, q = 6,870.98 J, ΔU = 0; (b) w = −600 J, q = 600 J, ΔU = 0; the reversible expansion gives more work**	isothermal ideal gas: ΔU = 0, so q = −w; w_rev = −2.303 nRT log(V_2/V_1); w_irr = −p_ext ΔV