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Chemical Thermodynamics — JEE (Main) Pattern Topic Test

FREE SAMPLE TEST · CHEMISTRY · PATTERN OF JEE (MAIN)

DURATION	MAXIMUM MARKS	QUESTIONS	NAME / ROLL NO.
60 minutes	100	25 (20 + 5)	

GENERAL INSTRUCTIONS

1. This question paper has two sections, A and B. All 25 questions are compulsory.
2. Section A has TWENTY (20) multiple-choice questions. Each has FOUR options, (1), (2), (3) and (4), of which ONLY ONE is correct.
3. Section B has FIVE (05) questions whose answer is a numerical value. Enter the value rounded off to the nearest integer.
4. Marking scheme for both sections: +4 for a correct answer, −1 for an incorrect answer, 0 if the question is not attempted.
5. Take R = 8.314 J/(K mol), log 10 = 1 and ln x = 2.303 log x. Use of a calculator, log tables or any other aid is not allowed.
6. The answer key and worked solutions are at the end of this booklet. Attempt the paper in 60 minutes before you look at them.

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Topics covered: Intensive and extensive properties · State functions · First law of thermodynamics · Heat capacity · Enthalpy · Hess's law · Standard enthalpy of formation · Bond enthalpy · Enthalpy of atomisation · Enthalpy of phase transition · Enthalpy of ionisation · Enthalpy of solution · Entropy · Second law of thermodynamics · Gibbs energy and spontaneity · Gibbs energy and equilibrium constant

SECTION A (Q1–20) · Multiple choice · +4 / 0 / −1

Each question has FOUR options. ONLY ONE of them is correct.

1. 3 mol of an ideal gas expands isothermally and reversibly at 400 K from 5 L to 50 L. The work done on the gas is about

(1) −10.0 kJ

(2) +23.0 kJ

(3) −23.0 kJ

(4) −2.3 kJ

2. 1 mol of an ideal gas expands isothermally from 10 L to 20 L against a constant external pressure of 1 bar. The values of q, w and ΔU for the gas are (1 L bar = 100 J)

(1) q = 0, w = −1000 J, ΔU = −1000 J

(2) q = +1000 J, w = −1000 J, ΔU = 0

(3) q = −1000 J, w = +1000 J, ΔU = 0

(4) q = 0, w = 0, ΔU = 0

3. For the combustion of liquid benzene at 298 K, $C_6H_6(l) + 15/2\ O_2(g) \rightarrow 6CO_2(g) + 3H_2O(l)$, ΔU = −3264.0 kJ/mol. The value of ΔH is about

(1) −3260.3 kJ/mol

(2) −3264.0 kJ/mol

(3) −3271.4 kJ/mol

(4) −3267.7 kJ/mol

4. The standard enthalpies of combustion of C(graphite), $H_2(g)$ and $C_2H_6(g)$ are −393.5, −285.8 and −1560.0 kJ/mol. The standard enthalpy of formation of ethane is

(1) −84.4 kJ/mol

(2) +84.4 kJ/mol

(3) −2204.4 kJ/mol

(4) −1560.0 kJ/mol

5. Using the bond enthalpies (kJ/mol) C=C 614, C–C 348, H–H 436 and C–H 414, the enthalpy change of $CH_2{=}CH_2(g) + H_2(g) \rightarrow CH_3{-}CH_3(g)$ is

(1) +126 kJ/mol

(2) −250 kJ/mol

(3) −126 kJ/mol

(4) −538 kJ/mol

6. Which of the following sets contains only intensive properties?

(1) temperature, molar heat capacity, density

(2) enthalpy, temperature, pressure

(3) internal energy, density, volume

(4) entropy, molar volume, heat capacity

7. Which of the following is NOT a state function?

(1) U + pV

(2) q + w

(3) H − TS

(4) q

8. For which of the following processes is the entropy change of the system negative?

(1) Melting of ice at 273 K

(2) $2SO_2(g) + O_2(g) \rightarrow 2SO_3(g)$

(3) Evaporation of water

(4) $CaCO_3(s) \rightarrow CaO(s) + CO_2(g)$

9. For the reaction $CaCO_3(s) \rightarrow CaO(s) + CO_2(g)$, $\Delta H^\circ = +178$ kJ/mol and $\Delta S^\circ = +160$ J/(K mol), both taken as independent of temperature. The reaction is spontaneous under standard conditions

(1) at all temperatures

(2) only below about 1113 K

(3) only above about 1113 K

(4) at no temperature

10. The equilibrium constant of a reaction at 300 K is 1.0×10^5. Its standard Gibbs energy change is about

(1) −28.7 kJ/mol

(2) +28.7 kJ/mol

(3) −12.5 kJ/mol

(4) −5.7 kJ/mol

11. The heat needed to raise the temperature of 54 g of liquid water by 10 °C is (molar heat capacity of water 75.3 J/(K mol))

(1) 4.07 kJ

(2) 0.75 kJ

(3) 2.26 kJ

(4) 40.7 kJ

12. The enthalpy of neutralisation of HCl by NaOH is −57.1 kJ/mol and that of CH_3COOH by NaOH is −55.9 kJ/mol. The enthalpy of ionisation of acetic acid is

(1) −1.2 kJ/mol

(2) +1.2 kJ/mol

(3) +57.1 kJ/mol

(4) −113.0 kJ/mol

13. The enthalpies of atomisation of $CH_4(g)$ and $C_2H_6(g)$ are 1660 and 2826 kJ/mol. Taking the C–H bond enthalpy to be the same in both, the C–C bond enthalpy is

(1) 415 kJ/mol

(2) 1166 kJ/mol

(3) 251 kJ/mol

(4) 336 kJ/mol

14. Consider the following statements.
(A) For a spontaneous process in an isolated system, $\Delta S > 0$.
(B) At constant temperature and pressure, a process is spontaneous if $\Delta G < 0$.
(C) Every exothermic reaction is spontaneous.
(D) For any spontaneous process, $\Delta S(\text{system}) + \Delta S(\text{surroundings}) > 0$.
(E) At equilibrium, $\Delta G^\circ = 0$.
Choose the correct answer from the options given below:

(1) (A), (B) and (C) only
(2) (B), (D) and (E) only
(3) (A), (B) and (D) only
(4) (A), (C) and (D) only

15. For which of the following processes of an ideal gas is $\Delta U = 0$ but $q \neq 0$?

(1) Isothermal reversible expansion
(2) Adiabatic reversible expansion
(3) Heating at constant volume
(4) Expansion into a vacuum in an insulated vessel

16. The enthalpy of vaporisation of water at its normal boiling point (373 K) is 40.8 kJ/mol. The entropy of vaporisation is about

(1) 40.8 J/(K mol)
(2) 109 J/(K mol)
(3) 0.109 J/(K mol)
(4) 9.14 J/(K mol)

17. The lattice enthalpy of NaCl (energy needed to separate it into gaseous ions) is +788 kJ/mol and the enthalpy of hydration of $Na^+(g) + Cl^-(g)$ is −784 kJ/mol. The enthalpy of solution of NaCl is

(1) −4 kJ/mol
(2) +1572 kJ/mol
(3) +4 kJ/mol
(4) −1572 kJ/mol

18. At 273 K the enthalpy of fusion of ice is 6.0 kJ/mol and the enthalpy of vaporisation of water is 45.0 kJ/mol. The enthalpy of sublimation of ice at 273 K is

(1) 39.0 kJ/mol
(2) 45.0 kJ/mol
(3) 51.0 kJ/mol
(4) 7.5 kJ/mol

19. For $N_2(g) + 3H_2(g) \rightarrow 2NH_3(g)$, $\Delta H^\circ = -92$ kJ/mol and $\Delta S^\circ = -199$ J/(K mol), both taken as independent of temperature. ΔG° at 500 K is

(1) −7.5 kJ/mol
(2) +7.5 kJ/mol
(3) −191.5 kJ/mol
(4) −82.0 kJ/mol

20. Assertion A: The standard enthalpy of formation of $O_2(g)$ is zero, but that of $O_3(g)$ is not.
Reason R: The standard enthalpy of formation of an element in its most stable form in the standard state is taken as zero.
In the light of the above statements, choose the correct answer from the options given below:

(1) A is true but R is false

(2) Both A and R are true but R is NOT the correct explanation of A

(3) A is false but R is true

(4) Both A and R are true and R is the correct explanation of A

SECTION B (Q21–25) · Numerical value · +4 / 0 / −1

The answer to each question is a NUMERICAL VALUE. Enter it rounded off to the nearest integer.

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21. 2 mol of an ideal gas is heated at a constant pressure from 300 K to 400 K. The magnitude of the work (in J) done by the gas is _____ (to the nearest integer; R = 8.314 J/(K mol)).

Answer: _____

22. For $N_2(g) + 3H_2(g) \rightarrow 2NH_3(g)$ at 300 K, the value of $\Delta U - \Delta H$ (in J/mol) is _____ (to the nearest integer; R = 8.314 J/(K mol)).

Answer: _____

23. For a reaction, $\Delta H = +30$ kJ/mol and $\Delta S = +105$ J/(K mol), both independent of temperature. The temperature (in K) above which the reaction becomes spontaneous is _____ (to the nearest integer).

Answer: _____

24. For a reaction at 300 K, $\Delta G^\circ = -17.232$ kJ/mol. Its equilibrium constant is _____ (take $2.303RT = 5.744$ kJ/mol at 300 K).

Answer: _____

25. The standard enthalpies of formation (kJ/mol) are $CH_4(g)$ −74.8, $CO_2(g)$ −393.5 and $H_2O(l)$ −285.8. The heat (in kJ) released when 0.5 mol of methane burns completely to $CO_2(g)$ and $H_2O(l)$ under standard conditions is _____ (to the nearest integer).

Answer: _____

END OF THE QUESTION PAPER

ANSWER KEY

Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10
(3)	(2)	(4)	(1)	(3)	(1)	(4)	(2)	(3)	(1)

Q11	Q12	Q13	Q14	Q15	Q16	Q17	Q18	Q19	Q20
(3)	(2)	(4)	(3)	(1)	(2)	(3)	(3)	(2)	(4)

Q21	Q22	Q23	Q24	Q25
1663	4988	286	1000	445

WORKED SOLUTIONS

Q1. Answer (3). $w = -nRT\ln(V_2/V_1) = -3 \times 8.314 \times 400 \times 2.303 \log 10 \approx -23.0$ kJ. The gas does work, so the work done on it is negative.

Q2. Answer (2). $w = -p_{ext}\,\Delta V = -1$ bar $\times$ 10 L $= -1000$ J. For an ideal gas at constant temperature $\Delta U = 0$, so $q = -w = +1000$ J. Work is done because the gas pushes back the constant external pressure; a free expansion into a vacuum would do none.

Q3. Answer (4). $\Delta H = \Delta U + \Delta n_g RT$, with $\Delta n_g = 6 - 7.5 = -1.5$ (liquids are not counted). $\Delta n_g RT = -1.5 \times 8.314 \times 298$ J ≈ -3.7 kJ, so $\Delta H \approx -3267.7$ kJ/mol.

Q4. Answer (1). $2C + 3H_2 \rightarrow C_2H_6$. By Hess's law, $\Delta_f H = 2(-393.5) + 3(-285.8) - (-1560.0) = -787.0 - 857.4 + 1560.0 = -84.4$ kJ/mol.

Q5. Answer (3). Bonds broken: C=C + H–H = 614 + 436 = 1050. Bonds formed: C–C + 2 C–H = 348 + 828 = 1176. $\Delta H = 1050 - 1176 = -126$ kJ/mol (the four C–H bonds of ethene are common to both sides).

Q6. Answer (1). An intensive property does not depend on the amount of matter. Temperature, pressure, density and any molar quantity are intensive; enthalpy, internal energy, volume, entropy and heat capacity are extensive.

Q7. Answer (4). $U + pV = H$, $q + w = \Delta U$ and $H - TS = G$ depend only on the state. The heat q alone depends on the path taken between two states.

Q8. Answer (2). Three moles of gas become two in the oxidation of SO_2, so the disorder falls ($\Delta S < 0$). Melting and evaporation go to less ordered phases, and the decomposition of $CaCO_3$ produces a gas: all three have $\Delta S > 0$.

Q9. Answer (3). $\Delta G^\circ = \Delta H^\circ - T\Delta S^\circ < 0$ when $T > \Delta H^\circ/\Delta S^\circ = 178\,000/160 \approx 1113$ K. With ΔH and ΔS both positive the entropy term wins only at high temperature.

Q10. Answer (1). $\Delta G^\circ = -2.303RT \log K = -2.303 \times 8.314 \times 300 \times 5$ J/mol ≈ -28.7 kJ/mol. A large K means a negative ΔG°.

Q11. Answer (3). 54 g = 3 mol. $q = nC_m\Delta T = 3 \times 75.3 \times 10 \approx 2259$ J ≈ 2.26 kJ.

Q12. Answer (2). For the strong acid only $H^+ + OH^- \rightarrow H_2O$ occurs (-57.1). For acetic acid, ionisation (ΔH_{ion}) must happen first: $\Delta H_{ion} - 57.1 = -55.9$, so $\Delta H_{ion} = +1.2$ kJ/mol. Ionisation absorbs heat.

Q13. Answer (4). CH_4 has 4 C–H bonds: C–H = 1660/4 = 415. C_2H_6 has 6 C–H and 1 C–C: C–C = $2826 - 6 \times 415 = 336$ kJ/mol.

Q14. Answer (3). (A), (B) and (D) are statements of the second law. (C) is false: an exothermic reaction with a large entropy decrease is non-spontaneous at high temperature. (E) is false: at equilibrium $\Delta G = 0$ and $\Delta G^\circ = -RT \ln K$, which is zero only if $K = 1$.

Q15. Answer (1). U of an ideal gas depends only on T. Isothermal expansion: $\Delta U = 0$ and the gas absorbs heat $q = -w = nRT\ln(V_2/V_1) > 0$. Adiabatic expansion: $q = 0$ and $\Delta U = w < 0$. Heating at constant volume: $q = \Delta U > 0$. Free expansion into a vacuum: $q = 0$, $w = 0$, $\Delta U = 0$.

Q16. Answer (2). At the boiling point the phases are in equilibrium, so $\Delta S = \Delta H/T = 40\,800/373 \approx 109$ J/(K mol).

Q17. Answer (3). Solution = break the lattice, then hydrate the ions: $\Delta_{sol}H = 788 + (-784) = +4$ kJ/mol. NaCl dissolves with a slight absorption of heat, driven by the increase in entropy.

Q18. Answer (3). Solid → liquid → vapour gives the same overall change as solid → vapour, so by Hess's law $\Delta_{sub}H = 6.0 + 45.0 = 51.0$ kJ/mol at the same temperature.

Q19. Answer (2). $\Delta G^\circ = \Delta H^\circ - T\Delta S^\circ = -92 - 500 \times (-0.199) = -92 + 99.5 = +7.5$ kJ/mol. The reaction is favourable at room temperature but not, under standard conditions, at 500 K.

Q20. Answer (4). O_2 is the stable form of oxygen, so its $\Delta_f H^\circ$ is zero by convention; O_3 is formed from O_2 with absorption of heat ($\Delta_f H^\circ \approx +142$ kJ/mol). Both are true and R explains A.

Q21. Answer 1663. $w = -p\Delta V = -nR\Delta T = -2 \times 8.314 \times 100 = -1662.8$ J, so the gas does 1663 J of work.

Q22. Answer 4988. $\Delta H = \Delta U + \Delta n_g RT$ with $\Delta n_g = 2 - 4 = -2$. $\Delta U - \Delta H = 2 \times 8.314 \times 300 = 4988.4$, i.e. 4988.

Q23. Answer 286. $\Delta G = 0$ at $T = \Delta H/\Delta S = 30\,000/105 \approx 285.7$ K; above this $\Delta G < 0$. To the nearest integer, 286.

Q24. Answer 1000. $\log K = -\Delta G^\circ/(2.303RT) = 17.232/5.744 = 3.000$, so $K = 1000$.

Q25. Answer 445. $CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$. $\Delta_c H = -393.5 + 2(-285.8) - (-74.8) = -890.3$ kJ/mol. For 0.5 mol, 445.2 kJ is released: 445.

All questions are original and © Master Testing Agency. Free to download and use for personal practice; not for resale. Every answer in this paper was checked independently by computer: reversible work by numerical integration of p dV, Δn(gas) from equations whose atom balance was checked, enthalpy sums from the data given, and spontaneity by scanning $\Delta G = \Delta H - T\Delta S$ over temperature.