Department of Biosciences and Bioengineering
Indian Institute of Technology Guwahati
BT 202 (Biothermodynamics)
Mid-semester exam, Date: 20th Sept 2022, Time: 9-11 AM, Total Marks: 30

Section A. Select the most appropriate answer. NO marks for overwriting. **[Marks:10x0.5 =5]**

1. The properties of water are arranged in the steam tables as functions of:
(A) pressure (B) temperature (C) pressure and temperature (D) none of the mentioned

2. The internal energy of saturated water at the triple point is (A) 1 (B) 0 (C) -1 (D) ∞

3. Entropy of saturated water (steam table) is chosen to be zero at triple point. (A) true (B) false

4. How many independent variable(s) is(are) required to describe the saturated liquid or the saturated vapour?
(A) One (B) Two (C) Three (D) None of the mentioned

5. When does a vapour become superheated?
(A) When the temperature of vapour is less than the saturation temperature at a given pressure
(B) When the temperature of vapour is more than the saturation temperature at a given pressure
(C) When the temperature of vapour is equal to the saturation temperature at a given pressure
(D) None of the mentioned

6. The superheat or degree of superheat is given by
(A) the difference between the temperature of saturated liquid and the saturation temperature
(B) the sum of the temperature of superheated vapour and the saturation temperature
(C) the difference between the temperature of superheated vapour and the saturation temperature
(D) none of the mentioned

7. Which of the following statement is most appropriate for a subcooled liquid ?
(A) A subcooled liquid is cooled below its saturation temperature at a certain pressure
(B) Subcooling is the difference between the saturation temperature and the actual temperature
(C) Both "A and B"
(D) None of the mentioned

8. Sudden stretching of a rubber band decreases the entropy of the rubber band.
(A) True (B) False

9. A piece of ice falls from a height "h" so that it melts completely. Only one quarter of heat produced is absorbed by the ice and all the energy of ice gets converted into heat during its fall.
(*Given:* Latent heat of vaporization = 3.4×10^5 J/kg and g = 10 N/kg)
The value of "h" is: (A) 136 km (B) 68 km (C) 34 km (D) 544 km.

10. Adiabatic expansion of an ideal gas against vacuum satisfies:
(A) $q = 0, \Delta U = 0, w > 0, \Delta T = 0, \Delta S > 0$ (B) $q = 0, \Delta U < 0, w > 0, \Delta T = 0, \Delta S > 0$
(C) $q = 0, \Delta U = 0, w < 0, \Delta T < 0, \Delta S > 0$ (D) $q = 0, \Delta U = 0, w = 0, \Delta T = 0, \Delta S > 0$

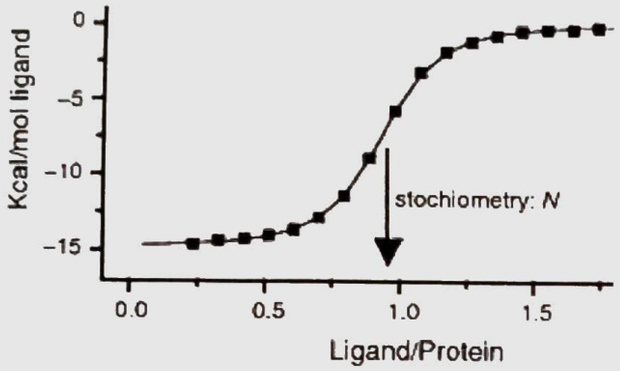
q = heat; U = internal energy; T = temperature; S = entropy

Section B. Write True or False. **NO MARKS for "T/F".** **[Marks:5x0.5= 2.5]**

1. Heat capacity at constant pressure is a state function.
2. At the critical point of water there is no demarcation between the solid and gaseous phase.
3. Isothermal Calorimetry (ITC) gives information about the binding affinity.
4. 298 K is the temperature defined for the standard state.
5. Folding of protein in the cells increases the entropy of the universe.

Section C. Answers to the numerical questions must include derivation.

1. Analyze the data (plotted below) generated by an ITC experiment (protein: ligand binding) (a) Determine if the reaction is exothermic or endothermic ? (b) What is the enthalpy change (kcal/mol) associated with the binding reaction ? (c) Draw and explain how you can obtain the dissociation equilibrium constant using ITC data ? **[Marks 0.5+1+1 = 2.5]**



2. A sample of an ideal gas in the cylinder of an engine is compressed from 400 mL to 50.0 mL during the compression stroke against a constant pressure of 8.00 atm. At the same time, 140 J of energy is transferred from the gas to the surroundings as heat. What is the total change in the internal energy (ΔU) of the gas in Joules? (1 L.atm = 101.325 J) **[Mark 2]**

3. A vessel of volume 0.04 m^3 contains a mixture of saturated water and steam at a temperature of 250°C. The mass of the liquid present is 9 kg. Find the total mass, specific volume, dryness fraction, specific enthalpy. **[Marks 1+1+1+1 = 4]**

4. Consider steam at P= 0.20 Mpa and S= 7.3 kJ/kg-K. Find specific enthalpy by interpolation. **[Mark 2]**

5. Draw and show the state (0.1 MPa and 90^0C) in the T-S diagram. Mark different regions (subcooled, superheated, saturated), isobar line and T^{Sat}. **[Mark 2]**

6. Air (Pressure = 500 KPa, Temperature = 500 K) enters into a nozzle with a velocity 100 m/s. Inlet area is 2 times of the exit area. The exit velocity of air is 200 m/s. Find the (a) exit temperature and (b) exit pressure. Assume: Ideal gas, Steady Flow and $C_{p,air}$ is constant. (*Given*, $C_{p,air}$ = 1 KJ/Kg.K, 1 KJ/Kg = 1000 m^2/S^2.)
Hint: use 1st law for open system: $\Delta \dot{U}_{CV} = \dot{q} + \dot{w}_{cv} + \dot{m}\,\Delta(\overline{H} + \frac{1}{2} v^2 + zg)$ **[Mark 2+2 = 4]**

7. A piston-cylinder device initially contains 1.4 kg of saturated liquid water at 275 KPa. Heat is transferred to the water until the liquid water is converted to a pure saturated vapor at 275 KPa and 130.58 ^{0}C. Find the internal energy change ΔU ? **[Marks 2]**

8. Define Joule-Thomson coefficient (μ_{JT}). Derive and find out the value of μ_{JT} for an ideal gas. **[Mark 1+3 = 4]**

1 MPa = 1000 kPa

Saturated water—Temperature table (*Concluded*)

Temp., T °C	Sat. press., P_{sat} kPa	Sat. liquid, v_f	Sat. vapor, v_g	Sat. liquid, u_f	Evap., u_{fg}	Sat. vapor, u_g	Sat. liquid, h_f	Evap., h_{fg}	Sat. vapor, h_g	Sat. liquid, s_f	Evap., s_{fg}	Sat. vapor, s_g
205	1724.3	0.001164	0.11508	872.86	1723.5	2596.4	874.87	1920.0	2794.8	2.3776	4.0154	6.3930
210	1907.7	0.001173	0.10429	895.38	1702.9	2598.3	897.61	1899.7	2797.3	2.4245	3.9318	6.3563
215	2105.9	0.001181	0.094680	918.02	1681.9	2599.9	920.50	1878.8	2799.3	2.4712	3.8489	6.3200
220	2319.6	0.001190	0.086094	940.79	1660.5	2601.3	943.55	1857.4	2801.0	2.5176	3.7664	6.2840
225	2549.7	0.001199	0.078405	963.70	1638.6	2602.3	966.76	1835.4	2802.2	2.5639	3.6844	6.2483
230	2797.1	0.001209	0.071505	986.76	1616.1	2602.9	990.14	1812.8	2802.9	2.6100	3.6028	6.2128
235	3062.6	0.001219	0.065300	1010.0	1593.2	2603.2	1013.7	1789.5	2803.2	2.6560	3.5216	6.1775
240	3347.0	0.001229	0.059707	1033.4	1569.8	2603.1	1037.5	1765.5	2803.0	2.7018	3.4405	6.1424
245	3651.2	0.001240	0.054656	1056.9	1545.7	2602.7	1061.5	1740.8	2802.2	2.7476	3.3596	6.1072
250	3976.2	0.001252	0.050085	1080.7	1521.1	2601.8	1085.7	1715.3	2801.0	2.7933	3.2788	6.0721
255	4322.9	0.001263	0.045941	1104.7	1495.8	2600.5	1110.1	1689.0	2799.1	2.8390	3.1979	6.0369
260	4692.3	0.001276	0.042175	1128.8	1469.9	2598.7	1134.8	1661.8	2796.6	2.8847	3.1169	6.0017
265	5085.3	0.001289	0.038748	1153.3	1443.2	2596.5	1159.8	1633.7	2793.5	2.9304	3.0358	5.9662
270	5503.0	0.001303	0.035622	1177.9	1415.7	2593.7	1185.1	1604.6	2789.7	2.9762	2.9542	5.9305
275	5946.4	0.001317	0.032767	1202.9	1387.4	2590.3	1210.7	1574.5	2785.2	3.0221	2.8723	5.8944

Superheated water

T °C	v m³/kg	u kJ/kg	h kJ/kg	s kJ/kg·K	v m³/kg	u kJ/kg	h kJ/kg	s kJ/kg·K	v m³/kg	u kJ/kg	h kJ/kg	s kJ/kg·K
	P = 0.01 MPa (45.81°C)*				P = 0.05 MPa (81.32°C)				P = 0.10 MPa (99.61°C)			
Sat.†	14.670	2437.2	2583.9	8.1488	3.2403	2483.2	2645.2	7.5931	1.6941	2505.6	2675.0	7.3589
50	14.867	2443.3	2592.0	8.1741								
100	17.196	2515.5	2687.5	8.4489	3.4187	2511.5	2682.4	7.6953	1.6959	2506.2	2675.8	7.3611
150	19.513	2587.9	2783.0	8.6893	3.8897	2585.7	2780.2	7.9413	1.9367	2582.9	2776.6	7.6148
200	21.826	2661.4	2879.6	8.9049	4.3562	2660.0	2877.8	8.1592	2.1724	2658.2	2875.5	7.8356
250	24.136	2736.1	2977.5	9.1015	4.8206	2735.1	2976.2	8.3568	2.4062	2733.9	2974.5	8.0346
300	26.446	2812.3	3076.7	9.2827	5.2841	2811.6	3075.8	8.5387	2.6389	2810.7	3074.5	8.2172
400	31.063	2969.3	3280.0	9.6094	6.2094	2968.9	3279.3	8.8659	3.1027	2968.3	3278.6	8.5452
500	35.680	3132.9	3489.7	9.8998	7.1338	3132.6	3489.3	9.1566	3.5655	3132.2	3488.7	8.8362
600	40.296	3303.3	3706.3	10.1631	8.0577	3303.1	3706.0	9.4201	4.0279	3302.8	3705.6	9.0999
700	44.911	3480.8	3929.9	10.4056	8.9813	3480.6	3929.7	9.6626	4.4900	3480.4	3929.4	9.3424
800	49.527	3665.4	4160.6	10.6312	9.9047	3665.2	4160.4	9.8883	4.9519	3665.0	4160.2	9.5682
900	54.143	3856.9	4398.3	10.8429	10.8280	3856.8	4398.2	10.1000	5.4137	3856.7	4398.0	9.7800
1000	58.758	4055.3	4642.8	11.0429	11.7513	4055.2	4642.7	10.3000	5.8755	4055.0	4642.6	9.9800
1100	63.373	4260.0	4893.8	11.2326	12.6745	4259.9	4893.7	10.4897	6.3372	4259.8	4893.6	10.1698
1200	67.989	4470.9	5150.8	11.4132	13.5977	4470.8	5150.7	10.6704	6.7988	4470.7	5150.6	10.3504
1300	72.604	4687.4	5413.4	11.5857	14.5209	4687.3	5413.3	10.8429	7.2605	4687.2	5413.3	10.5229
	P = 0.20 MPa (120.21°C)				P = 0.30 MPa (133.52°C)				P = 0.40 MPa (143.61°C)			
Sat.	0.88578	2529.1	2706.3	7.1270	0.60582	2543.2	2724.9	6.9917	0.46242	2553.1	2738.1	6.8955
150	0.95986	2577.1	2769.1	7.2810	0.63402	2571.0	2761.2	7.0792	0.47088	2564.4	2752.8	6.9306
200	1.08049	2654.6	2870.7	7.5081	0.71643	2651.0	2865.9	7.3132	0.53434	2647.2	2860.9	7.1723
250	1.19890	2731.4	2971.2	7.7100	0.79645	2728.9	2967.9	7.5180	0.59520	2726.4	2964.5	7.3804
300	1.31623	2808.8	3072.1	7.8941	0.87535	2807.0	3069.6	7.7037	0.65489	2805.1	3067.1	7.5677
400	1.54934	2967.2	3277.0	8.2236	1.03155	2966.0	3275.5	8.0347	0.77265	2964.9	3273.9	7.9003
500	1.78142	3131.4	3487.7	8.5153	1.18672	3130.6	3486.6	8.3271	0.88936	3129.8	3485.5	8.1933
600	2.01302	3302.2	3704.8	8.7793	1.34139	3301.6	3704.0	8.5915	1.00558	3301.0	3703.3	8.4580
700	2.24434	3479.9	3928.8	9.0221	1.49580	3479.5	3928.2	8.8345	1.12152	3479.0	3927.6	8.7012
800	2.47550	3664.7	4159.8	9.2479	1.65004	3664.3	4159.3	9.0605	1.23730	3663.9	4158.9	8.9274
900	2.70656	3856.3	4397.7	9.4598	1.80417	3856.0	4397.3	9.2725	1.35298	3855.7	4396.9	9.1394
1000	2.93755	4054.8	4642.3	9.6599	1.95824	4054.5	4642.0	9.4726	1.46859	4054.3	4641.7	9.3396
1100	3.16848	4259.6	4893.3	9.8497	2.11226	4259.4	4893.1	9.6624	1.58414	4259.2	4892.9	9.5295
1200	3.39938	4470.5	5150.4	10.0304	2.26624	4470.3	5150.2	9.8431	1.69966	4470.2	5150.0	9.7102
1300	3.63026	4687.1	5413.1	10.2029	2.42019	4686.9	5413.0	10.0157	1.81516	4686.7	5412.8	9.8828

Saturated water—Pressure table

Press., P kPa	Sat. temp., T_{sat} °C	Sat. liquid, v_f	Sat. vapor, v_g	Sat. liquid, u_f	Evap., u_{fg}	Sat. vapor, u_g	Sat. liquid, h_f	Evap., h_{fg}	Sat. vapor, h_g	Sat. liquid, s_f	Evap., s_{fg}	Sat. vapor, s_g
175	116.04	0.001057	1.0037	486.82	2037.7	2524.5	487.01	2213.1	2700.2	1.4850	5.6865	7.1716
200	120.21	0.001061	0.88578	504.50	2024.6	2529.1	504.71	2201.6	2706.3	1.5302	5.5968	7.1270
225	123.97	0.001064	0.79329	520.47	2012.7	2533.2	520.71	2191.0	2711.7	1.5706	5.5171	7.0877
250	127.41	0.001067	0.71873	535.08	2001.8	2536.8	535.35	2181.2	2716.5	1.6072	5.4453	7.0525
275	130.58	0.001070	0.65732	548.57	1991.6	2540.1	548.86	2172.0	2720.9	1.6408	5.3800	7.0207
300	133.52	0.001073	0.60582	561.11	1982.1	2543.2	561.43	2163.5	2724.9	1.6717	5.3200	6.9917
325	136.27	0.001076	0.56199	572.84	1973.1	2545.9	573.19	2155.4	2728.6	1.7005	5.2645	6.9650