UNIVERSITI TUN HUSSEIN ONN MALAYSIA

FINAL EXAMINATION
SEMESTER I
SESSION 2013/2014

COURSE NAME	:	CHEMICAL ENGINEERING THERMODYNAMICS
COURSE CODE	:	BNQ20103
PROGRAMME	:	BNN
EXAMINATION DATE	:	DECEMBER 2013 / JANUARY 2014
DURATION	:	3 HOURS
INSTRUCTIONS	:	ANSWER **FOUR (4)** QUESTIONS ONLY

THIS PAPER CONSISTS OF **TWELVE (12)** PAGES

Q1 (a) Briefly define the following pressures:

(i) Gauge pressure
(ii) Atmospheric pressure
(iii) Absolute pressure
(iv) Vacuum pressure

(4 marks)

(b) (i) Define "zeroth law" and "1st law" of thermodynamics.

(3 marks)

(ii) Illustrate using diagrams the differences between Open and Closed systems.

(8 marks)

(c) A stream of warm water is produced in a steady-flow mixing process by combinin 1.0 kg/s of cool water at 25°C (298.15 K) with 0.8 kg/s of hot water at 75°C (348.15 K). During mixing, heat is lost to the surroundings at the rate of 30 kJ/s.
Calculate the temperature of the warm-water stream. (Specific heat of water constant is 4.18 kJ/(kg.K).

(10 marks)

Q2 (a) Define and sketch diagrams to show the differences of the following phase change process:

(i) Compressed liquid
(ii) Saturated liquid
(iii) Saturated liquid and vapor mixture
(iv) Saturated vapor
(v) Superheated vapor

(5 marks)

(b) For each condition below, **sketch** a *P-v* diagrams for steam and **label clearly** the pressure, specific volume, temperature clearly, and **categorize** the phase of each state (on the diagram). Refer to **Table Q2 (b)**.

(i) $P = 20$ bar, $T = 250$°C,
(ii) $T = 212.4$°C, $v = 0.09957$ m3/kg,
(iii) $P = 10$ bar, $h = 2650$ kJ/kg, and
(iv) $P = 6$ bar, $h = 3166$ kJ/kg.

(15 marks)

(c) Discuss and sketch from state 1 to state 2 in either ***T-v***, or ***T-s*** diagram for the following processes:

(i) Isentropic process
(ii) Isothermal process

(iii) Isobaric process

(iv) Isochoric process

(5 marks)

Q3 (a) Determine the standard heat for the following reactions at 298.15 K. Refer to **Table Q3 (a & b)**:

(i) $H_2S\ (g) + 2H_2O\ (g) \rightarrow 3H_2\ (g) + SO_2\ (g)$

(ii) $C_2H_5OH\ (l) + O_2\ (g) \rightarrow CH_3COOH\ (l) + H_20\ (l)$

(iii) $CaC_2\ (s) + H_2O\ (l) \rightarrow C_2H_2\ (g) + CaO\ (s)$

(iv) $N_2\ (g) + O_2\ (g) \rightarrow 2NO\ (g)$

(v) $C_2H_4\ (g) + ½\ O_2\ (g) \rightarrow (CH_2)_2O\ (g)$

(5 marks)

(b) Dow Chemical is looking to expand their chemical business in South East Asia region. One of their chemical products is methanol. Methanol can be synthesized by various methods; one of them is using Methane. Below is the manufacture of Methanol from Methane as shown in the chemical reaction below:

$$CH_4\ (g) + 2H_2O\ (g) \rightarrow CO_2\ (g) + 4H_2\ (g)$$
$$CO_2\ (g) + 3H_2\ (g) \rightarrow CH_3OH\ (g) + H_2O\ (g)$$

If the reactants are supplied in the ratio, 2 mole steam to 1 mole CH_4, and if heat is supplied to the reactor so the product can reach a temperature of 1500 K. Assume that the raw material is completely converted and the product stream contains 18.7 mole % CO_2. The reactant is preheated to 600 K. Refer to **Table Q3 (a & b).**

(i) Calculate the standard heat of reaction at 298.15 K for the reactions which might involve.

(3 marks)

(ii) Determine the moles in the product stream for CO_2, H_2, CH_3OH and H_2O.

(4 marks)

(iii) Calculate the enthalpy change (ΔH) from 600 K to 1500 K.

(11 marks)

(iv) Calculate heat required in the reactor, Q. (2 marks)

Q4 (a) A Carnot engine receives 250 kJ/s of heat from a heat-source reservoir at 525°C (798.15 K) and rejects heat to a heat-sink reservoir at 50°C (323.15 K). Calculate the power developed and the heat rejected of the system.

(8 marks)

(b) A rigid vessel of 0.06 m^3 volume contains an ideal gas, $C_v = (5/2)R$, at 500 K and 1 bar.

(i) If heat in the amount of 15000 J is transferred to the gas, determine its entropy change.

(7 marks)

(ii) If the vessel is fitted with a stirrer that is rotated by a shaft so that work in the amount of 15000 J is done on the gas, calculate the entropy change of the gas if the process is adiabatic. Calculate the ΔS_{total}. Indicate the irreversible feature of the process.

(10 marks)

Q5 Exhaust gas at 400°C and 1 bar from internal-combustion engine flows at the rate of 125 mol/s into a waste-heat boiler where saturated steam is generated at a pressure of 1200 kPa. Water enters the boiler at 20°C (T_s), and the exhaust gases are cooled to within 10°C of the of the steam temperature. The heat capacity of the exhaust gases is $C_p/R = 3.34 + 1.12 \times 10^{-3}\ T/K$. The steam flows into an adiabatic turbine and exhausts at a pressure of 25 kPa. If the turbine efficiency, η is 72%,

(a) Calculate the power output of the turbine, $\dot{W}_s$. Refer to Tables of **Q5 a(i)** and **Q5 a(ii)**.

(b) Calculate the thermodynamic efficiency of the boiler/turbine combination.

(6 marks)

(c) Calculate $\dot{S}_G$ for the boiler and the turbine.

(6 marks)

- END OF QUESTION -

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Table Q2 (b)

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
	P = 0.50 MPa (151.83°C)				*P* = 0.60 MPa (158.83°C)				*P* = 0.80 MPa (170.41°C)			
Sat.	0.37483	2560.7	2748.1	6.8207	0.31560	2566.8	2756.2	6.7593	0.24035	2576.0	2768.3	6.6616
200	0.42503	2643.3	2855.8	7.0610	0.35212	2639.4	2850.6	6.9683	0.26088	2631.1	2839.8	6.8177
250	0.47443	2723.8	2961.0	7.2725	0.39390	2721.2	2957.6	7.1833	0.29321	2715.9	2950.4	7.0402
300	0.52261	2803.3	3064.6	7.4614	0.43442	2801.4	3062.0	7.3740	0.32416	2797.5	3056.9	7.2345
350	0.57015	2883.0	3168.1	7.6346	0.47428	2881.6	3166.1	7.5481	0.35442	2878.6	3162.2	7.4107
400	0.61731	2963.7	3272.4	7.7956	0.51374	2962.5	3270.8	7.7097	0.38429	2960.2	3267.7	7.5735
500	0.71095	3129.0	3484.5	8.0893	0.59200	3128.2	3483.4	8.0041	0.44332	3126.6	3481.3	7.8692
600	0.80409	3300.4	3702.5	8.3544	0.66976	3299.8	3701.7	8.2695	0.50186	3298.7	3700.1	8.1354
700	0.89696	3478.6	3927.0	8.5978	0.74725	3478.1	3926.4	8.5132	0.56011	3477.2	3925.3	8.3794
800	0.98966	3663.6	4158.4	8.8240	0.82457	3663.2	4157.9	8.7395	0.61820	3662.5	4157.0	8.6061
900	1.08227	3855.4	4396.6	9.0362	0.90179	3855.1	4396.2	8.9518	0.67619	3854.5	4395.5	8.8185
1000	1.17480	4054.0	4641.4	9.2364	0.97893	4053.8	4641.1	9.1521	0.73411	4053.3	4640.5	9.0189
1100	1.26728	4259.0	4892.6	9.4263	1.05603	4258.8	4892.4	9.3420	0.79197	4258.3	4891.9	9.2090
1200	1.35972	4470.0	5149.8	9.6071	1.13309	4469.8	5149.6	9.5229	0.84980	4469.4	5149.3	9.3898
1300	1.45214	4686.6	5412.6	9.7797	1.21012	4686.4	5412.5	9.6955	0.90761	4686.1	5412.2	9.5625

*The temperature in parentheses is the saturation temperature at the specified pressure.

† Properties of saturated vapor at the specified pressure.

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Table Q2 (b)

Superheated water (*Continued*)

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 = 1.00 MPa (179.88°C)				*P* = 1.20 MPa (187.96°C)				*P* = 1.40 MPa (195.04°C)			
Sat.	0.19437	2582.8	2777.1	6.5850	0.16326	2587.8	2783.8	6.5217	0.14078	2591.8	2788.9	6.4675
200	0.20602	2622.3	2828.3	6.6956	0.16934	2612.9	2816.1	6.5909	0.14303	2602.7	2803.0	6.4975
250	0.23275	2710.4	2943.1	6.9265	0.19241	2704.7	2935.6	6.8313	0.16356	2698.9	2927.9	6.7488
300	0.25799	2793.7	3051.6	7.1246	0.21386	2789.7	3046.3	7.0335	0.18233	2785.7	3040.9	6.9553
350	0.28250	2875.7	3158.2	7.3029	0.23455	2872.7	3154.2	7.2139	0.20029	2869.7	3150.1	7.1379
400	0.30661	2957.9	3264.5	7.4670	0.25482	2955.5	3261.3	7.3793	0.21782	2953.1	3258.1	7.3046
500	0.35411	3125.0	3479.1	7.7642	0.29464	3123.4	3477.0	7.6779	0.25216	3121.8	3474.8	7.6047
600	0.40111	3297.5	3698.6	8.0311	0.33395	3296.3	3697.0	7.9456	0.28597	3295.1	3695.5	7.8730
700	0.44783	3476.3	3924.1	8.2755	0.37297	3475.3	3922.9	8.1904	0.31951	3474.4	3921.7	8.1183
800	0.49438	3661.7	4156.1	8.5024	0.41184	3661.0	4155.2	8.4176	0.35288	3660.3	4154.3	8.3458
900	0.54083	3853.9	4394.8	8.7150	0.45059	3853.3	4394.0	8.6303	0.38614	3852.7	4393.3	8.5587
1000	0.58721	4052.7	4640.0	8.9155	0.48928	4052.2	4639.4	8.8310	0.41933	4051.7	4638.8	8.7595
1100	0.63354	4257.9	4891.4	9.1057	0.52792	4257.5	4891.0	9.0212	0.45247	4257.0	4890.5	8.9497
1200	0.67983	4469.0	5148.9	9.2866	0.56652	4468.7	5148.5	9.2022	0.48558	4468.3	5148.1	9.1308
1300	0.72610	4685.8	5411.9	9.4593	0.60509	4685.5	5411.6	9.3750	0.51866	4685.1	5411.3	9.3036
	P = 1.60 MPa (201.37°C)				*P* = 1.80 MPa (207.11°C)				*P* = 2.00 MPa (212.38°C)			
Sat.	0.12374	2594.8	2792.8	6.4200	0.11037	2597.3	2795.9	6.3775	0.09959	2599.1	2798.3	6.3390
225	0.13293	2645.1	2857.8	6.5537	0.11678	2637.0	2847.2	6.4825	0.10381	2628.5	2836.1	6.4160
250	0.14190	2692.9	2919.9	6.6753	0.12502	2686.7	2911.7	6.6088	0.11150	2680.3	2903.3	6.5475
300	0.15866	2781.6	3035.4	6.8864	0.14025	2777.4	3029.9	6.8246	0.12551	2773.2	3024.2	6.7684
350	0.17459	2866.6	3146.0	7.0713	0.15460	2863.6	3141.9	7.0120	0.13860	2860.5	3137.7	6.9583
400	0.19007	2950.8	3254.9	7.2394	0.16849	2948.3	3251.6	7.1814	0.15122	2945.9	3248.4	7.1292
500	0.22029	3120.1	3472.6	7.5410	0.19551	3118.5	3470.4	7.4845	0.17568	3116.9	3468.3	7.4337
600	0.24999	3293.9	3693.9	7.8101	0.22200	3292.7	3692.3	7.7543	0.19962	3291.5	3690.7	7.7043
700	0.27941	3473.5	3920.5	8.0558	0.24822	3472.6	3919.4	8.0005	0.22326	3471.7	3918.2	7.9509
800	0.30865	3659.5	4153.4	8.2834	0.27426	3658.8	4152.4	8.2284	0.24674	3658.0	4151.5	8.1791
900	0.33780	3852.1	4392.6	8.4965	0.30020	3851.5	4391.9	8.4417	0.27012	3850.9	4391.1	8.3925
1000	0.36687	4051.2	4638.2	8.6974	0.32606	4050.7	4637.6	8.6427	0.29342	4050.2	4637.1	8.5936
1100	0.39589	4256.6	4890.0	8.8878	0.35188	4256.2	4889.6	8.8331	0.31667	4255.7	4889.1	8.7842
1200	0.42488	4467.9	5147.7	9.0689	0.37766	4467.6	5147.3	9.0143	0.33989	4467.2	5147.0	8.9654
1300	0.45383	4684.8	5410.9	9.2418	0.40341	4684.5	5410.6	9.1872	0.36308	4684.2	5410.3	9.1384
	P = 2.50 MPa (223.95°C)				*P* = 3.00 MPa (233.85°C)				*P* = 3.50 MPa (242.56°C)			
Sat.	0.07995	2602.1	2801.9	6.2558	0.06667	2603.2	2803.2	6.1856	0.05706	2603.0	2802.7	6.1244
225	0.08026	2604.8	2805.5	6.2629								
250	0.08705	2663.3	2880.9	6.4107	0.07063	2644.7	2856.5	6.2893	0.05876	2624.0	2829.7	6.1764
300	0.09894	2762.2	3009.6	6.6459	0.08118	2750.8	2994.3	6.5412	0.06845	2738.8	2978.4	6.4484
350	0.10979	2852.5	3127.0	6.8424	0.09056	2844.4	3116.1	6.7450	0.07680	2836.0	3104.9	6.6601
400	0.12012	2939.8	3240.1	7.0170	0.09938	2933.6	3231.7	6.9235	0.08456	2927.2	3223.2	6.8428
450	0.13015	3026.2	3351.6	7.1768	0.10789	3021.2	3344.9	7.0856	0.09198	3016.1	3338.1	7.0074
500	0.13999	3112.8	3462.8	7.3254	0.11620	3108.6	3457.2	7.2359	0.09919	3104.5	3451.7	7.1593
600	0.15931	3288.5	3686.8	7.5979	0.13245	3285.5	3682.8	7.5103	0.11325	3282.5	3678.9	7.4357
700	0.17835	3469.3	3915.2	7.8455	0.14841	3467.0	3912.2	7.7590	0.12702	3464.7	3909.3	7.6855
800	0.19722	3656.2	4149.2	8.0744	0.16420	3654.3	4146.9	7.9885	0.14061	3652.5	4144.6	7.9156
900	0.21597	3849.4	4389.3	8.2882	0.17988	3847.9	4387.5	8.2028	0.15410	3846.4	4385.7	8.1304
1000	0.23466	4049.0	4635.6	8.4897	0.19549	4047.7	4634.2	8.4045	0.16751	4046.4	4632.7	8.3324
1100	0.25330	4254.7	4887.9	8.6804	0.21105	4253.6	4886.7	8.5955	0.18087	4252.5	4885.6	8.5236
1200	0.27190	4466.3	5146.0	8.8618	0.22658	4465.3	5145.1	8.7771	0.19420	4464.4	5144.1	8.7053
1300	0.29048	4683.4	5409.5	9.0349	0.24207	4682.6	5408.8	8.9502	0.20750	4681.8	5408.0	8.8786

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Table Q3 (a & b)

Heat Capacities of Gases in the Ideal-Gas State[†]

Constants in equation $C_P^{ig}/R = A + BT + CT^2 + DT^{-2}$ T (kelvins) from 298.15 to T_{max}

Chemical species		T_{max}	$C_{P_{298}}^{ig}/R$	A	$10^3\ B$	$10^6\ C$	$10^{-5}\ D$
Paraffins:							
Methane	CH_4	1500	4.217	1.702	9.081	−2.164	
Ethane	C_2H_6	1500	6.369	1.131	19.225	−5.561	
Propane	C_3H_8	1500	9.001	1.213	28.785	−8.824	
n-Butane	C_4H_{10}	1500	11.928	1.935	36.915	−11.402	
iso-Butane	C_4H_{10}	1500	11.901	1.677	37.853	−11.945	
n-Pentane	C_5H_{12}	1500	14.731	2.464	45.351	−14.111	
n-Hexane	C_6H_{14}	1500	17.550	3.025	53.722	−16.791	
n-Heptane	C_7H_{16}	1500	20.361	3.570	62.127	−19.486	
n-Octane	C_8H_{18}	1500	23.174	4.108	70.567	−22.208	
1-Alkenes:							
Ethylene	C_2H_4	1500	5.325	1.424	14.394	−4.392	
Propylene	C_3H_6	1500	7.792	1.637	22.706	−6.915	
1-Butene	C_4H_8	1500	10.520	1.967	31.630	−9.873	
1-Pentene	C_5H_{10}	1500	13.437	2.691	39.753	−12.447	
1-Hexene	C_6H_{12}	1500	16.240	3.220	48.189	−15.157	
1-Heptene	C_7H_{14}	1500	19.053	3.768	56.588	−17.847	
1-Octene	C_8H_{16}	1500	21.868	4.324	64.960	−20.521	
Miscellaneous organics:							
Acetaldehyde	C_2H_4O	1000	6.506	1.693	17.978	−6.158	
Acetylene	C_2H_2	1500	5.253	6.132	1.952	......	−1.299
Benzene	C_6H_6	1500	10.259	−0.206	39.064	−13.301	
1,3-Butadiene	C_4H_6	1500	10.720	2.734	26.786	−8.882	
Cyclohexane	C_6H_{12}	1500	13.121	−3.876	63.249	−20.928	
Ethanol	C_2H_6O	1500	8.948	3.518	20.001	−6.002	
Ethylbenzene	C_8H_{10}	1500	15.993	1.124	55.380	−18.476	
Ethylene oxide	C_2H_4O	1000	5.784	−0.385	23.463	−9.296	
Formaldehyde	CH_2O	1500	4.191	2.264	7.022	−1.877	
Methanol	CH_4O	1500	5.547	2.211	12.216	−3.450	
Styrene	C_8H_8	1500	15.534	2.050	50.192	−16.662	
Toluene	C_7H_8	1500	12.922	0.290	47.052	−15.716	
Miscellaneous inorganics:							
Air		2000	3.509	3.355	0.575	......	−0.016
Ammonia	NH_3	1800	4.269	3.578	3.020	......	−0.186
Bromine	Br_2	3000	4.337	4.493	0.056	......	−0.154
Carbon monoxide	CO	2500	3.507	3.376	0.557	......	−0.031
Carbon dioxide	CO_2	2000	4.467	5.457	1.045	......	−1.157
Carbon disulfide	CS_2	1800	5.532	6.311	0.805	......	−0.906
Chlorine	Cl_2	3000	4.082	4.442	0.089	......	−0.344
Hydrogen	H_2	3000	3.468	3.249	0.422	......	0.083
Hydrogen sulfide	H_2S	2300	4.114	3.931	1.490	......	−0.232
Hydrogen chloride	HCl	2000	3.512	3.156	0.623	......	0.151
Hydrogen cyanide	HCN	2500	4.326	4.736	1.359	......	−0.725
Nitrogen	N_2	2000	3.502	3.280	0.593	......	0.040
Nitrous oxide	N_2O	2000	4.646	5.328	1.214	......	−0.928
Nitric oxide	NO	2000	3.590	3.387	0.629	......	0.014
Nitrogen dioxide	NO_2	2000	4.447	4.982	1.195	......	−0.792
Dinitrogen tetroxide	N_2O_4	2000	9.198	11.660	2.257	......	−2.787
Oxygen	O_2	2000	3.535	3.639	0.506	......	−0.227
Sulfur dioxide	SO_2	2000	4.796	5.699	0.801	......	−1.015
Sulfur trioxide	SO_3	2000	6.094	8.060	1.056	......	−2.028
Water	H_2O	2000	4.038	3.470	1.450	......	0.121

[†]Selected from H. M. Spencer, *Ind. Eng. Chem.*, vol. 40, pp. 2152–2154, 1948; K. K. Kelley, *U.S. Bur. Mines Bull. 584*, 1960; L. B. Pankratz, *U.S. Bur. Mines Bull. 672*, 1982.

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Table Q3 (a & b)

Standard Enthalpies and Gibbs Energies of Formation at 298.15 K (25°C)†

Joules per mole of the substance formed

Chemical species		State (Note 2)	$\Delta H^\circ_{f_{298}}$ (Note 1)	$\Delta G^\circ_{f_{298}}$ (Note 1)
Paraffins:				
Methane	CH_4	(g)	−74 520	−50 460
Ethane	C_2H_6	(g)	−83 820	−31 855
Propane	C_3H_8	(g)	−104 680	−24 290
n-Butane	C_4H_{10}	(g)	−125 790	−16 570
n-Pentane	C_5H_{12}	(g)	−146 760	−8 650
n-Hexane	C_6H_{14}	(g)	−166 920	150
n-Heptane	C_7H_{16}	(g)	−187 780	8 260
n-Octane	C_8H_{18}	(g)	−208 750	16 260
1-Alkenes:				
Ethylene	C_2H_4	(g)	52 510	68 460
Propylene	C_3H_6	(g)	19 710	62 205
1-Butene	C_4H_8	(g)	−540	70 340
1-Pentene	C_5H_{10}	(g)	−21 280	78 410
1-Hexene	C_6H_{12}	(g)	−41 950	86 830
1-Heptene	C_7H_{14}	(g)	−62 760	
Miscellaneous organics:				
Acetaldehyde	C_2H_4O	(g)	−166 190	−128 860
Acetic acid	$C_2H_4O_2$	(l)	−484 500	−389 900
Acetylene	C_2H_2	(g)	227 480	209 970
Benzene	C_6H_6	(g)	82 930	129 665
Benzene	C_6H_6	(l)	49 080	124 520
1,3-Butadiene	C_4H_6	(g)	109 240	149 795
Cyclohexane	C_6H_{12}	(g)	−123 140	31 920
Cyclohexane	C_6H_{12}	(l)	−156 230	26 850
1,2-Ethanediol	$C_2H_6O_2$	(l)	−454 800	−323 080
Ethanol	C_2H_6O	(g)	−235 100	−168 490
Ethanol	C_2H_6O	(l)	−277 690	−174 780
Ethylbenzene	C_8H_{10}	(g)	29 920	130 890
Ethylene oxide	C_2H_4O	(g)	−52 630	−13 010
Formaldehyde	CH_2O	(g)	−108 570	−102 530
Methanol	CH_4O	(g)	−200 660	−161 960
Methanol	CH_4O	(l)	−238 660	−166 270
Methylcyclohexane	C_7H_{14}	(g)	−154 770	27 480
Methylcyclohexane	C_7H_{14}	(l)	−190 160	20 560
Styrene	C_8H_8	(g)	147 360	213 900
Toluene	C_7H_8	(g)	50 170	122 050
Toluene	C_7H_8	(l)	12 180	113 630

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Table Q3 (a & b)

(Continued)

Chemical species		State (Note 2)	$\Delta H^\circ_{f_{298}}$ (Note 1)	$\Delta G^\circ_{f_{298}}$ (Note 1)
Miscellaneous inorganics:				
Ammonia	NH_3	(g)	−46 110	−16 450
Ammonia	NH_3	(aq)		−26 500
Calcium carbide	CaC_2	(s)	−59 800	−64 900
Calcium carbonate	$CaCO_3$	(s)	−1206 920	−1128 790
Calcium chloride	$CaCl_2$	(s)	−795 800	−748 100
Calcium chloride	$CaCl_2$	(aq)		−8101900
Calcium chloride	$CaCl_2 \cdot 6H_2O$	(s)	−2607 900	
Calcium hydroxide	$Ca(OH)_2$	(s)	−986 090	−898 490
Calcium hydroxide	$Ca(OH)_2$	(aq)		−868 070
Calcium oxide	CaO	(s)	−635 090	−604 030
Carbon dioxide	CO_2	(g)	−393 509	−394 359
Carbon monoxide	CO	(g)	−110525	−137 169
Hydrochloric acid	HCl	(g)	−92 307	−95 299
Hydrogen cyanide	HCN	(g)	135 100	124 700
Hydrogen sulfide	H_2S	(g)	−20 630	−33 560
Iron oxide	FeO	(s)	−272 000	
Iron oxide (hematite)	Fe_2O_3	(s)	−824 200	−742 200
Iron oxide (magnetite)	Fe_3O_4	(s)	−1118400	−1015 400
Iron sulfide (pyrite)	FeS_2	(s)	−178 200	−166 900
Lithium chloride	$LiCl$	(s)	−408 610	
Lithium chloride	$LiCl \cdot H_2O$	(s)	−712 580	
Lithium chloride	$LiCl \cdot 2H_2O$	(s)	−1012 650	
Lithium chloride	$LiCl \cdot 3H_2O$	(s)	−1311 300	
Nitric acid	HNO_3	(l)	−174 100	−80 710
Nitric acid	HNO_3	(aq)		−111 250
Nitrogen oxides	NO	(g)	90 250	86 550
	NO_2	(g)	33 180	51 310
	N_2O	(g)	82 050	104 200
	N_2O_4	(g)	9 160	97 540
Sodium carbonate	Na_2CO_3	(s)	−1130 680	−1044 440
Sodium carbonate	$Na_2CO_3 \cdot 10H_2O$	(s)	−4081 320	
Sodium chloride	$NaCl$	(s)	−411 153	−384 138
Sodium chloride	$NaCl$	(aq)		−393 133
Sodium hydroxide	$NaOH$	(s)	−425 609	−379 494
Sodium hydroxide	$NaOH$	(aq)		−419 150
Sulfur dioxide	SO_2	(g)	−296 830	−300 194
Sulfur trioxide	SO_3	(g)	−395 720	−371 060
Sulfur trioxide	SO_3	(l)	−441 040	
Sulfuric acid	H_2SO_4	(l)	−813 989	−690 003
Sulfuric acid	H_2SO_4	(aq)		−744 530
Water	H_2O	(g)	−241 818	−228 572
Water	H_2O	(l)	−285 830	−237 129

†From TRC Thermodynamic Tables—Hydrocarbons, Thermodynamics Research Center, Texas A & M Univ. System, College Station, TX; "The NBS Tables of Chemical Thermodynamic Properties," *J. Phys. and Chem. Reference Data*, vol. 11, supp. 2, 1982.

Notes

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Table Q5 a(i)

Saturated Steam, SI Units

V = SPECIFIC VOLUME $cm^3\ g^{-1}$
U = SPECIFIC INTERNAL ENERGY kJ kg
H = SPECIFIC ENTHALPY kJ kg
S = SPECIFIC ENTROPY $kJ\ kg^{-1}\ K^{-1}$

			SPECIFIC VOLUME V			INTERNAL ENERGY U			ENTHALPY H			ENTROPY S		
	T K	P kPa	sat. liq.	evap.	sat. vap.	sat. liq.	evap.	sat. vap.	sat. liq.	evap.	sat. vap.	sat. liq.	evap.	sat. vap.
0	273.15	0.611	1.000	206300.	206300.	−0.04	2375.7	2375.6	−0.04	2501.7	2501.6	0.0000	9.1578	9.1578
0.01	**273.16**	**0.611**	**1.000**	**206200.**	**206200.**	**0.00**	**2375.6**	**2375.6**	**0.00**	**2501.6**	**2501.6**	**0.0000**	**9.1575**	**9.1575**
1	274.15	0.657	1.000	192600.	192600.	4.17	2372.7	2376.9	4.17	2499.2	2503.4	0.0153	9.1158	9.1311
2	275.15	0.705	1.000	179900.	179900.	8.39	2369.9	2378.3	8.39	2496.8	2505.2	0.0306	9.0741	9.1047
3	276.15	0.757	1.000	168200.	168200.	12.60	2367.1	2379.7	12.60	2494.5	2507.1	0.0459	9.0326	9.0785
4	277.15	0.813	1.000	157300.	157300.	16.80	2364.3	2381.1	16.80	2492.1	2508.9	0.0611	8.9915	9.0526
5	278.15	0.872	1.000	147200.	147200.	21.01	2361.4	2382.4	21.01	2489.7	2510.7	0.0762	8.9507	9.0269
6	279.15	0.935	1.000	137800.	137800.	25.21	2358.6	2383.8	25.21	2487.4	2512.6	0.0913	8.9102	9.0014
7	280.15	1.001	1.000	129100.	129100.	29.41	2355.8	2385.2	29.41	2485.0	2514.4	0.1063	8.8699	8.9762
8	281.15	1.072	1.000	121000.	121000.	33.60	2353.0	2386.6	33.60	2482.6	2516.2	0.1213	8.8300	8.9513
9	282.15	1.147	1.000	113400.	113400.	37.80	2350.1	2387.9	37.80	2480.3	2518.1	0.1362	8.7903	8.9265
10	283.15	1.227	1.000	106400.	106400.	41.99	2347.3	2389.3	41.99	2477.9	2519.9	0.1510	8.7510	8.9020
11	284.15	1.312	1.000	99910.	99910.	46.18	2344.5	2390.7	46.19	2475.5	2521.7	0.1658	8.7119	8.8776
12	285.15	1.401	1.000	93830.	93840.	50.38	2341.7	2392.1	50.38	2473.2	2523.6	0.1805	8.6731	8.8536
13	286.15	1.497	1.001	88180.	88180.	54.56	2338.9	2393.4	54.57	2470.8	2525.4	0.1952	8.6345	8.8297
14	287.15	1.597	1.001	82900.	82900.	58.75	2336.1	2394.8	58.75	2468.5	2527.2	0.2098	8.5963	8.8060
15	288.15	1.704	1.001	77980.	77980.	62.94	2333.2	2396.2	62.94	2466.1	2529.1	0.2243	8.5582	8.7826
16	289.15	1.817	1.001	73380.	73380.	67.12	2330.4	2397.6	67.13	2463.8	2530.9	0.2388	8.5205	8.7593
17	290.15	1.936	1.001	69090.	69090.	71.31	2327.6	2398.9	71.31	2461.4	2532.7	0.2533	8.4830	8.7363
18	291.15	2.062	1.001	65090.	65090.	75.49	2324.8	2400.3	75.50	2459.0	2534.5	0.2677	8.4458	8.7135
19	292.15	2.196	1.002	61340.	61340.	79.68	2322.0	2401.7	79.68	2456.7	2536.4	0.2820	8.4088	8.6908
20	293.15	2.337	1.002	57840.	57840.	83.86	2319.2	2403.0	83.86	2454.3	2538.2	0.2963	8.3721	8.6684
21	294.15	2.485	1.002	54560.	54560.	88.04	2316.4	2404.4	88.04	2452.0	2540.0	0.3105	8.3356	8.6462
22	295.15	2.642	1.002	51490.	51490.	92.22	2313.6	2405.8	92.23	2449.6	2541.8	0.3247	8.2994	8.6241
23	296.15	2.808	1.002	48620.	48620.	96.40	2310.7	2407.1	96.41	2447.2	2543.6	0.3389	8.2634	8.6023
24	297.15	2.982	1.003	45920.	45930.	100.6	2307.9	2408.5	100.6	2444.9	2545.5	0.3530	8.2277	8.5806
25	298.15	3.166	1.003	43400.	43400.	104.8	2305.1	2409.9	104.8	2442.5	2547.3	0.3670	8.1922	8.5592
26	299.15	3.360	1.003	41030.	41030.	108.9	2302.3	2411.2	108.9	2440.2	2549.1	0.3810	8.1569	8.5379
27	300.15	3.564	1.003	38810.	38810.	113.1	2299.5	2412.6	113.1	2437.8	2550.9	0.3949	8.1218	8.5168
28	301.15	3.778	1.004	36730.	36730.	117.3	2296.7	2414.0	117.3	2435.4	2552.7	0.4088	8.0870	8.4959
29	302.15	4.004	1.004	34770.	34770.	121.5	2293.8	2415.3	121.5	2433.1	2554.5	0.4227	8.0524	8.4751

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Table Q5 a(ii)

Superheated Steam, SI Units

TEMPERATURE: T kelvins
(TEMPERATURE: t °C)

P/kPa T^{sat}/K (t^{sat}/°C)		sat. liq.	sat. vap.	448.15 (175)	473.15 (200)	493.15 (220)	513.15 (240)	533.15 (260)	553.15 (280)	573.15 (300)	598.15 (325)
750	V	1.112	255.43	260.88	279.05	293.03	306.65	320.01	333.17	346.19	362.32
440.91(167.76)	U	708.467	2573.3	2586.9	2632.1	2666.8	2700.6	2733.7	2766.4	2798.9	2839.3
	H	709.301	2764.8	2782.5	2841.4	2886.6	2930.6	2973.7	3016.3	3058.5	3111.0
	S	2.0195	6.6817	6.7215	6.8494	6.9429	7.0303	7.1128	7.1912	7.2662	7.3558
775	V	1.113	247.61	251.93	269.63	283.22	296.45	309.41	322.19	334.81	350.44
442.25(169.10)	U	714.326	2574.3	2585.4	2631.0	2665.9	2699.8	2733.1	2765.9	2798.4	2838.9
	H	715.189	2766.2	2780.7	2840.0	2885.4	2929.6	2972.9	3015.6	3057.9	3110.5
	S	2.0328	6.6705	6.7031	6.8319	6.9259	7.0137	7.0965	7.1751	7.2502	7.3400
800	V	1.115	240.26	243.53	260.79	274.02	286.88	299.48	311.89	324.14	339.31
443.56(170.41)	U	720.043	2575.3	2584.0	2629.9	2665.0	2699.1	2732.5	2765.4	2797.9	2838.5
	H	720.935	2767.5	2778.8	2838.6	2884.2	2928.6	2972.1	3014.9	3057.3	3109.9
	S	2.0457	6.6596	6.6851	6.8148	6.9094	6.9976	7.0807	7.1595	7.2348	7.3247
825	V	1.117	233.34	235.64	252.48	265.37	277.90	290.15	302.21	314.12	328.85
444.84(171.69)	U	725.625	2576.2	2582.5	2628.8	2664.1	2698.4	2731.8	2764.8	2797.5	2838.1
	H	726.547	2768.7	2776.9	2837.1	2883.1	2927.6	2971.2	3014.1	3056.6	3109.4
	S	2.0583	6.6491	6.6675	6.7982	6.8933	6.9819	7.0653	7.1443	7.2197	7.3098
850	V	1.118	226.81	228.21	244.66	257.24	269.44	281.37	293.10	304.68	319.00
446.09(172.94)	U	731.080	2577.1	2581.1	2627.7	2663.2	2697.6	2731.2	2764.3	2797.0	2837.7
	H	732.031	2769.9	2775.1	2835.7	2881.9	2926.6	2970.4	3013.4	3056.0	3108.8
	S	2.0705	6.6388	6.6504	6.7820	6.8777	6.9666	7.0503	7.1295	7.2051	7.2954
875	V	1.120	220.65	221.20	237.29	249.56	261.46	273.09	284.51	295.79	309.72
447.31(174.16)	U	736.415	2578.0	2579.6	2626.6	2662.3	2696.8	2730.6	2763.7	2796.5	2837.3
	H	737.394	2771.0	2773.1	2834.2	2880.7	2925.6	2969.5	3012.7	3055.3	3108.3
	S	2.0825	6.6289	6.6336	6.7662	6.8624	6.9518	7.0357	7.1152	7.1909	7.2813
900	V	1.121	214.81	....	230.32	242.31	253.93	265.27	276.40	287.39	300.96
448.51(175.36)	U	741.635	2578.8	....	2625.5	2661.4	2696.1	2729.9	2763.2	2796.1	2836.9
	H	742.644	2772.1	....	2832.7	2879.5	2924.6	2968.7	3012.0	3054.7	3107.7
	S	2.0941	6.6192	....	6.7508	6.8475	6.9373	7.0215	7.1012	7.1771	7.2676
925	V	1.123	209.28	....	223.73	235.46	246.80	257.87	268.73	279.44	292.66
449.68(176.53)	U	746.746	2579.6	....	2624.3	2660.5	2695.3	2729.3	2762.6	2795.6	2836.5
	H	747.784	2773.2	....	2831.3	2878.3	2923.6	2967.8	3011.2	3054.1	3107.2
	S	2.1055	6.6097	....	6.7357	6.8329	6.9231	7.0076	7.0875	7.1636	7.2543

FINAL EXAMINATION

SEMESTER / SESSION : SEM I/ SESSI 2013/2014
COURSE NAME : CHEMICAL ENGINEERING THERMODYNAMICS
PROGRAMME : 2 BNN
COURSE CODE : BNQ 20103

Table Q5 a(ii)

	V	1.124	204.03	....	217.48	228.96	240.05	250.86	261.46	271.91	284.81
950	U	751.754	2580.4	....	2623.2	2659.5	2694.6	2728.7	2762.1	2795.1	2836.0
450.82(177.67)	H	752.822	2774.2	....	2829.8	2877.0	2922.6	2967.0	3010.5	3053.4	3106.6
	S	2.1166	6.6005	....	6.7209	6.8187	6.9093	6.9941	7.0742	7.1505	7.2413
	V	1.126	199.04	....	211.55	222.79	233.64	244.20	254.56	264.76	277.35
975	U	756.663	2581.1	....	2622.0	2658.6	2693.8	2728.0	2761.5	2794.6	2835.6
451.94(178.79)	H	757.761	2775.2	....	2828.3	2875.8	2921.6	2966.1	3009.7	3052.8	3106.1
	S	2.1275	6.5916	....	6.7064	6.8048	6.8958	6.9809	7.0612	7.1377	7.2286
	V	1.127	194.29	....	205.92	216.93	227.55	237.89	248.01	257.98	270.27
1000	U	761.478	2581.9	....	2620.9	2657.7	2693.0	2727.4	2761.0	2794.2	2835.2
453.03(179.88)	H	762.605	2776.2	....	2826.8	2874.6	2920.6	2965.2	3009.0	3052.1	3105.5
	S	2.1382	6.5828	....	6.6922	6.7911	6.8825	6.9680	7.0485	7.1251	7.2163
	V	1.130	185.45	....	195.45	206.04	216.24	226.15	235.84	245.37	257.12
1050	U	770.843	2583.3	....	2618.5	2655.8	2691.5	2726.1	2759.9	2793.2	2834.4
455.17(182.02)	H	772.029	2778.0	....	2823.8	2872.1	2918.5	2963.5	3007.5	3050.8	3104.4
	S	2.1588	6.5659	....	6.6645	6.7647	6.8569	6.9430	7.0240	7.1009	7.1924
	V	1.133	177.38	....	185.92	196.14	205.96	215.47	224.77	233.91	245.16
1100	U	779.878	2584.5	....	2616.2	2653.9	2689.9	2724.7	2758.8	2792.2	2833.6
457.22(184.07)	H	781.124	2779.7	....	2820.7	2869.6	2916.4	2961.8	3006.0	3049.6	3103.3
	S	2.1786	6.5497	....	6.6379	6.7392	6.8323	6.9190	7.0005	7.0778	7.1695
	V	1.136	169.99	....	177.22	187.10	196.56	205.73	214.67	223.44	234.25
1150	U	788.611	2585.8	....	2613.8	2651.9	2688.3	2723.4	2757.7	2791.3	2832.8
459.20(186.05)	H	789.917	2781.3	....	2817.6	2867.1	2914.4	2960.0	3004.5	3048.2	3102.2
	S	2.1977	6.5342	....	6.6122	6.7147	6.8086	6.8959	6.9779	7.0556	7.1476
	V	1.139	163.20	....	169.23	178.80	187.95	196.79	205.40	213.85	224.24
1200	U	797.064	2586.9	....	2611.3	2650.0	2686.7	2722.1	2756.5	2790.3	2832.0
461.11(187.96)	H	798.430	2782.7	....	2814.4	2864.5	2912.2	2958.2	3003.0	3046.9	3101.0
	S	2.2161	6.5194	....	6.5872	6.6909	6.7858	6.8738	6.9562	7.0342	7.1266
	V	1.141	156.93	....	161.88	171.17	180.02	188.56	196.88	205.02	215.03
1250	U	805.259	2588.0	....	2608.9	2648.0	2685.1	2720.8	2755.4	2789.3	2831.1
462.96(189.81)	H	806.685	2784.1	....	2811.2	2861.9	2910.1	2956.5	3001.5	3045.6	3099.9
	S	2.2338	6.5050	....	6.5630	6.6680	6.7637	6.8523	6.9353	7.0136	7.1064
	V	1.144	151.13	....	155.09	164.11	172.70	180.97	189.01	196.87	206.53
1300	U	813.213	2589.0	....	2606.4	2646.0	2683.5	2719.4	2754.3	2788.4	2830.3
464.76(191.61)	H	814.700	2785.4	....	2808.0	2859.3	2908.0	2954.7	3000.0	3044.3	3098.8
	S	2.2510	6.4913	....	6.5394	6.6457	6.7424	6.8316	6.9151	6.9938	7.0869