Chemical Engineering Thermodynamics
Quiz 1 January 14, 2016

1)

P1.1. Estimate the average speed (mph) of hydrogen molecules at 200 K and 3 bars.

H_2 is 2.02 g/mole
R = 8.314 J/(K mole)
Joule = kg m^2/s^2
2.24 mph/(m/s)
You can assume you know the temperature and pressure to 10% accuracy or you can make some other assumption concerning the accuracy of these values (state your assumption).

2)

1.12. The gas phase reaction A → 2R is conducted in a 0.1 m^3 spherical tank. The initial temperature and pressure in the tank are 0.05 MPa and 400 K. After species A is 50% reacted, the temperature has fallen to 350 K. What is the pressure in the vessel?

R = 8.314 cm^3 MPa/(K mole)

3)

1.17. Determine the temperature, volume, and quality for one kg water under the following conditions:

a. U = 3000 kJ/kg, P = 0.3 MPa
c. U = 2500 kJ/kg, P = 0.3 MPa

See tables below.

E.9. Properties of Water[1]

I. Saturation Temperature

T (°C)	P (MPa)	V^L m^3/kg	V^V m^3/kg	U^L kJ/kg	ΔU^{vap} kJ/kg	U^V kJ/kg	H^L kJ/kg	ΔH^{vap} kJ/kg	H^V kJ/kg	S^L kJ/kg-K	ΔS^{vap} kJ/kg-K	S^V kJ/kg-K
0.01	0.000612	0.001000	205.9912	0.00	2374.92	2374.92	0.00	2500.92	2500.92	0.0000	9.1555	9.1555
5	0.000873	0.001000	147.0113	21.02	2360.76	2381.78	21.02	2489.04	2510.06	0.0763	8.9485	9.0248
10	0.001228	0.001000	106.3032	42.02	2346.63	2388.65	42.02	2477.19	2519.21	0.1511	8.7487	8.8998
15	0.001706	0.001001	77.8755	62.98	2332.51	2395.49	62.98	2465.35	2528.33	0.2245	8.5558	8.7803
20	0.002339	0.001002	57.7567	83.91	2318.41	2402.32	83.91	2453.52	2537.43	0.2965	8.3695	8.6660
25	0.003170	0.001003	43.3373	104.83	2304.30	2409.13	104.83	2441.68	2546.51	0.3672	8.1894	8.5566
30	0.004247	0.001004	32.8783	125.73	2290.18	2415.91	125.73	2429.82	2555.55	0.4368	8.0152	8.4520
35	0.005629	0.001006	25.2053	146.63	2276.04	2422.67	146.63	2417.92	2564.55	0.5051	7.8466	8.3517
40	0.007385	0.001008	19.5151	167.53	2261.86	2429.39	167.53	2405.98	2573.51	0.5724	7.6831	8.2555
45	0.009595	0.001010	15.2521	188.43	2247.65	2436.08	188.43	2394.00	2582.43	0.6386	7.5247	8.1633
50	0.012400	0.001012	12.0269	209.33	2233.40	2442.73	209.34	2381.95	2591.29	0.7038	7.3710	8.0748
55	0.015800	0.001015	9.5643	230.24	2219.10	2449.34	230.26	2369.83	2600.09	0.7680	7.2218	7.9898
60	0.019900	0.001017	7.6672	251.16	2204.74	2455.90	251.18	2357.65	2608.83	0.8313	7.0768	7.9081
65	0.025000	0.001020	6.1935	272.09	2190.32	2462.41	272.12	2345.38	2617.50	0.8937	6.9359	7.8296
70	0.031200	0.001023	5.0395	293.03	2175.83	2468.86	293.07	2333.03	2626.10	0.9551	6.7989	7.7540
75	0.038600	0.001026	4.1289	313.99	2161.25	2475.24	314.03	2320.57	2634.60	1.0158	6.6654	7.6812
80	0.047400	0.001029	3.4052	334.96	2146.60	2481.56	335.01	2308.01	2643.02	1.0756	6.5355	7.6111
85	0.057900	0.001032	2.8258	355.95	2131.86	2487.81	356.01	2295.32	2651.33	1.1346	6.4088	7.5434
90	0.070200	0.001036	2.3591	376.97	2117.00	2493.97	377.04	2282.49	2659.53	1.1929	6.2852	7.4781
95	0.084600	0.001040	1.9806	398.00	2102.04	2500.04	398.09	2269.52	2667.61	1.2504	6.1647	7.4151
100	0.101400	0.001043	1.6718	419.06	2086.96	2506.02	419.17	2256.40	2675.57	1.3072	6.0469	7.3541
105	0.120900	0.001047	1.4184	440.15	2071.75	2511.90	440.27	2243.12	2683.39	1.3633	5.9319	7.2952
110	0.143400	0.001052	1.2093	461.26	2056.41	2517.67	461.42	2229.64	2691.06	1.4188	5.8193	7.2381
115	0.169200	0.001056	1.0358	482.41	2040.92	2523.33	482.59	2215.99	2698.58	1.4737	5.7091	7.1828
120	0.198700	0.001060	0.8912	503.60	2025.26	2528.86	503.81	2202.12	2705.93	1.5279	5.6012	7.1291
125	0.232200	0.001065	0.7700	524.83	2009.44	2534.27	525.07	2188.03	2713.10	1.5816	5.4954	7.0770
130	0.270300	0.001070	0.6680	546.09	1993.44	2539.53	546.38	2173.70	2720.08	1.6346	5.3918	7.0264
135	0.313200	0.001075	0.5817	567.41	1977.24	2544.65	567.74	2159.13	2726.87	1.6872	5.2900	6.9772
140	0.361500	0.001080	0.5085	588.77	1960.85	2549.62	589.16	2144.28	2733.44	1.7392	5.1901	6.9293
145	0.415700	0.001085	0.4460	610.19	1944.23	2554.42	610.64	2129.16	2739.80	1.7907	5.0919	6.8826
150	0.476200	0.001091	0.3925	631.66	1927.39	2559.05	632.18	2113.75	2745.93	1.8418	4.9953	6.8371
155	0.543500	0.001096	0.3465	653.19	1910.32	2563.51	653.79	2098.02	2751.81	1.8924	4.9002	6.7926
160	0.618200	0.001102	0.3068	674.79	1892.99	2567.78	675.47	2081.97	2757.44	1.9426	4.8065	6.7491
165	0.700900	0.001108	0.2724	696.46	1875.39	2571.85	697.24	2065.57	2762.81	1.9923	4.7143	6.7066
170	0.792200	0.001114	0.2426	718.20	1857.53	2575.73	719.08	2048.82	2767.90	2.0417	4.6233	6.6650
175	0.892600	0.001121	0.2166	740.02	1839.37	2579.39	741.02	2031.69	2772.71	2.0906	4.5335	6.6241
180	1.002800	0.001127	0.1938	761.92	1820.91	2582.83	763.05	2014.16	2777.21	2.1392	4.4448	6.5840
185	1.123500	0.001134	0.1739	783.91	1802.13	2586.04	785.19	1996.22	2781.41	2.1875	4.3572	6.5447
190	1.25520	0.001141	0.1564	806.00	1783.01	2589.01	807.43	1977.85	2785.28	2.2355	4.2704	6.5059
195	1.39880	0.001149	0.1409	828.18	1763.56	2591.74	829.79	1959.03	2788.82	2.2832	4.1846	6.4678
200	1.55490	0.001157	0.1272	850.47	1743.73	2594.20	852.27	1939.74	2792.01	2.3305	4.0997	6.4302

III. Superheated Steam

$P = 0.01$MPa (45.8)

T(°C)	V(m^3/kg)	U(kJ/kg)	H(kJ/kg)	S(kJ/kg-K)
45.8	14.6701	2437.2	2583.9	8.1488
50	14.9139	2443.3	2592.4	8.1755
100	17.1964	2515.5	2687.5	8.4489
150	19.5132	2587.9	2783.0	8.6892
200	21.8256	2661.3	2879.6	8.9049
250	24.1361	2736.1	2977.4	9.1015
300	26.4456	2812.3	3076.7	9.2827
350	28.7545	2890.0	3177.5	9.4513
400	31.0631	2969.3	3279.9	9.6094
450	33.3714	3050.3	3384.0	9.7584
500	35.6796	3132.9	3489.7	9.8998
550	37.9876	3217.2	3597.1	10.0344
600	40.2956	3303.3	3706.3	10.1631
650	42.6035	3391.2	3817.2	10.2866
700	44.9113	3480.8	3929.9	10.4055
750	47.2191	3572.2	4044.4	10.5202
800	49.5269	3665.3	4160.6	10.6311
850	51.8347	3760.3	4278.6	10.7386
900	54.1424	3856.9	4398.3	10.8429
950	56.4501	3955.2	4519.7	10.9442
1000	58.7578	4055.2	4642.8	11.0428
1050	61.0655	4156.8	4767.5	11.1389
1100	63.3732	4260.0	4893.7	11.2325
1150	65.6808	4364.7	5021.5	11.3239
1200	67.9885	4470.9	5150.7	11.4132
1250	70.2961	4578.4	5281.4	11.5004
1300	72.6038	4687.4	5413.4	11.5857

$P = 0.05$MPa (81.3)

T(°C)	V(m^3/kg)	U(kJ/kg)	H(kJ/kg)	S(kJ/kg-K)
81.3	3.2400	2483.2	2645.2	7.5930
100	3.4187	2511.5	2682.4	7.6953
150	3.8897	2585.7	2780.2	7.9413
200	4.3562	2660.0	2877.8	8.1592
250	4.8206	2735.1	2976.1	8.3568
300	5.2840	2811.6	3075.8	8.5386
350	5.7469	2889.4	3176.8	8.7076
400	6.2094	2968.9	3279.3	8.8659
450	6.6717	3049.9	3383.5	9.0151
500	7.1338	3132.6	3489.3	9.1566
550	7.5957	3217.0	3596.8	9.2913
600	8.0576	3303.1	3706.0	9.4201
650	8.5195	3391.0	3816.9	9.5436
700	8.9812	3480.6	3929.7	9.6625
750	9.4430	3572.0	4044.2	9.7773
800	9.9047	3665.2	4160.4	9.8882
850	10.3663	3760.1	4278.5	9.9957
900	10.8280	3856.8	4398.2	10.1000
950	11.2896	3955.1	4519.6	10.2014
1000	11.7513	4055.1	4642.7	10.3000
1050	12.2129	4156.8	4767.4	10.3960
1100	12.6745	4259.9	4893.7	10.4897
1150	13.1361	4364.6	5021.4	10.5811
1200	13.5977	4470.8	5150.7	10.6703
1250	14.0592	4578.4	5281.3	10.7576
1300	14.5208	4687.3	5413.3	10.8428

$P = 0.10$MPa (99.6)

T(°C)	V(m^3/kg)	U(kJ/kg)	H(kJ/kg)	S(kJ/kg-K)
99.6	1.6939	2505.6	2675.0	7.3588
100	1.6959	2506.2	2675.8	7.3610
150	1.9367	2582.9	2776.6	7.6148
200	2.1724	2658.2	2875.5	7.8356
250	2.4062	2733.9	2974.5	8.0346
300	2.6388	2810.6	3074.5	8.2172
350	2.8710	2888.7	3175.8	8.3866
400	3.1027	2968.3	3278.6	8.5452
450	3.3342	3049.4	3382.8	8.6946
500	3.5655	3132.2	3488.7	8.8361
550	3.7968	3216.6	3596.3	8.9709
600	4.0279	3302.8	3705.6	9.0998
650	4.2590	3390.7	3816.6	9.2234
700	4.4900	3480.4	3929.4	9.3424
750	4.7209	3571.8	4043.9	9.4572
800	4.9519	3665.0	4160.2	9.5681
850	5.1828	3760.0	4278.2	9.6757
900	5.4137	3856.6	4398.0	9.7800
950	5.6446	3955.0	4519.5	9.8813
1000	5.8754	4055.0	4642.6	9.9800
1050	6.1063	4156.6	4767.3	10.0761
1100	6.3371	4259.8	4893.5	10.1697
1150	6.5680	4364.5	5021.3	10.2611
1200	6.7988	4470.7	5150.6	10.3504
1250	7.0296	4578.3	5281.2	10.4376
1300	7.2604	4687.2	5413.2	10.5229

$P = 0.20$MPa (120.3)

T(°C)	V(m^3/kg)	U(kJ/kg)	H(kJ/kg)	S(kJ/kg-K)
120.3	0.8857	2529.1	2706.2	7.1269
150	0.9599	2577.1	2769.1	7.2810
200	1.0805	2654.6	2870.7	7.5081
250	1.1989	2731.4	2971.2	7.7100
300	1.3162	2808.8	3072.1	7.8941
350	1.4330	2887.3	3173.9	8.0644
400	1.5493	2967.1	3277.0	8.2236
450	1.6655	3048.5	3381.6	8.3734
500	1.7814	3131.4	3487.7	8.5152
550	1.8973	3215.9	3595.4	8.6502
600	2.0130	3302.2	3704.8	8.7792
650	2.1287	3390.2	3815.9	8.9030
700	2.2443	3479.9	3928.8	9.0220
750	2.3599	3571.4	4043.4	9.1369
800	2.4755	3664.7	4159.8	9.2479
850	2.5910	3759.6	4277.8	9.3555
900	2.7066	3856.3	4397.6	9.4598
950	2.8221	3954.7	4519.1	9.5612
1000	2.9375	4054.8	4642.3	9.6599
1050	3.0530	4156.4	4767.0	9.7560
1100	3.1685	4259.6	4893.3	9.8497
1150	3.2839	4364.3	5021.1	9.9411
1200	3.3994	4470.5	5150.4	10.0304
1250	3.5148	4578.1	5281.1	10.1176
1300	3.6302	4687.0	5413.1	10.2029

$P = 0.30$MPa (133.5)

T(°C)	V(m^3/kg)	U(kJ/kg)	H(kJ/kg)	S(kJ/kg-K)
133.5	0.6058	2543.2	2724.9	6.9916
150	0.6340	2571.0	2761.2	7.0791
200	0.7164	2651.0	2865.9	7.3131
250	0.7964	2728.9	2967.9	7.5180
300	0.8753	2807.0	3069.6	7.7037
350	0.9536	2885.9	3172.0	7.8750
400	1.0315	2966.0	3275.5	8.0347
450	1.1092	3047.5	3380.3	8.1849
500	1.1867	3130.6	3486.6	8.3271
550	1.2641	3215.3	3594.5	8.4623
600	1.3414	3301.6	3704.0	8.5914
650	1.4186	3389.7	3815.3	8.7153
700	1.4958	3479.5	3928.2	8.8344
750	1.5729	3571.0	4042.9	8.9494
800	1.6500	3664.3	4159.3	9.0604
850	1.7271	3759.3	4277.4	9.1680
900	1.8042	3856.0	4397.3	9.2724
950	1.8812	3954.4	4518.8	9.3739
1000	1.9582	4054.5	4642.0	9.4726
1050	2.0352	4156.2	4766.7	9.5687
1100	2.1122	4259.4	4893.1	9.6624
1150	2.1892	4364.1	5020.9	9.7538
1200	2.2662	4470.3	5150.2	9.8431
1250	2.3432	4577.9	5280.9	9.9303
1300	2.4202	4686.9	5412.9	10.0156

$P = 0.40$MPa (143.6)

T(°C)	V(m^3/kg)	U(kJ/kg)	H(kJ/kg)	S(kJ/kg-K)
143.6	0.4624	2553.1	2738.1	6.8955
150	0.4709	2564.4	2752.8	6.9306
200	0.5343	2647.2	2860.9	7.1723
250	0.5952	2726.4	2964.5	7.3804
300	0.6549	2805.1	3067.1	7.5677
350	0.7140	2884.4	3170.0	7.7399
400	0.7726	2964.9	3273.9	7.9002
450	0.8311	3046.6	3379.0	8.0508
500	0.8894	3129.8	3485.5	8.1933
550	0.9475	3214.6	3593.6	8.3287
600	1.0056	3301.0	3703.2	8.4580
650	1.0636	3389.1	3814.6	8.5820
700	1.1215	3479.0	3927.6	8.7012
750	1.1794	3570.6	4042.4	8.8162
800	1.2373	3663.9	4158.8	8.9273
850	1.2951	3759.0	4277.0	9.0350
900	1.3530	3855.7	4396.9	9.1394
950	1.4108	3954.2	4518.5	9.2409
1000	1.4686	4054.3	4641.7	9.3396
1050	1.5264	4155.9	4766.5	9.4357
1100	1.5841	4259.2	4892.8	9.5295
1150	1.6419	4363.9	5020.7	9.6209
1200	1.6997	4470.1	5150.0	9.7102
1250	1.7574	4577.8	5280.7	9.7975
1300	1.8152	4686.7	5412.8	9.8828

ANSWERS: Chemical Engineering Thermodynamics
Quiz 1 January 14, 2016

1)

P1.1. Estimate the average speed (mph) of hydrogen molecules at 200 K and 3 bars.

H_2 is 2.02 g/mole
R = 8.314 J/(K mole)
Joule = kg m^2/s^2
2.24 mph/(m/s)
You can assume you know the temperature and pressure to 10% accuracy or you can make some other assumption concerning the accuracy of these values (state your assumption).

Energy = 3/2 kT = ½ mv^2

So v ~ $(3RT/M_w)^{1/2}$ = **3500 mph** if you assume 10% accuracy in the temperature and you assume an ideal gas. The ideal gas assumption is probably not very good at 3 bar. You don't need the pressure if you assume an ideal gas. The book answer seems to be wrong.

2)

1.12. The gas phase reaction A → 2R is conducted in a 0.1 m^3 spherical tank. The initial temperature and pressure in the tank are 0.05 MPa and 400 K. After species A is 50% reacted, the temperature has fallen to 350 K. What is the pressure in the vessel?

R = 8.314 cm^3 MPa/(K mole)

Initially assume you are at pure "A"
Use the ideal gas law you can get the initial moles of "A"
$n_{A,i}$ = PV/RT = 0.05 MPa 0.1 x 10^6 cm^3/(8.314 (cm^3 MPa/(K mole)) 400K)
=1.5 moles of A initially

Then 50% reacts so you have 0.75 moles of A and 1.50 moles of R so you have 2.25 moles total.
Again assume an ideal gas (doesn't matter the type of atom for an ideal gas)
P = n_{total}RT/V = 2.25 moles 8.314 (cm^3 MPa/(K mole)) 400K/0.1 x 10^6 cm^3 = **0.075 MPa** assuming 10% accuracy in the initial values. He gets 0.065 in the book answer after a bit more complicated calculation.

3)

1.17. Determine the temperature, volume, and quality for one kg water under the following conditions:

a. U = 3000 kJ/kg, P = 0.3 MPa
c. U = 2500 kJ/kg, P = 0.3 MPa

(1.17) Determine the temperature, volume, and quality under the following conditions:

a) **U=3000, P=0.3** => superheated $q = 1$, $T = 400 + (3000\text{-}2966)/(3047.5\text{-}2966.0) * 50 = 421°C$

$V = 1.0315 + 21/50 * (1.1092\text{-}1.0315) = 1.064\ m^3/kg$

Assume 10% accuracy in the P and U values so you have 1.1 m^3/kg (you can make other assumptions concerning the accuracy but need to state that.) It asks for one kg of water so the answer is **1.1 m^3 and 420°C**.

c) **U=2500,P=0.3** => two-phase, $T = 133.58°C$

$U = 2500 = 561. + q*1982.0$, $q = 0.978$

$V = 0.001073 + 0.978 * (0.6058 - 0.001073) = 0.593\ m^3/kg$

Again, assume 10% accuracy in values he specifies for U and P so,
T = 130°C, q = 0.98, and it is for 1 kg so 0.59 m^3.