Quiz 4
Chemical Engineering Thermodynamics
February 11, 2016

P4.2. Twenty molecules are contained in a piston + cylinder at low pressure. The piston moves such that the volume is expanded by a factor of 4 with no work produced of any kind. Compute $\Delta S/k$ in two ways, a) using four separated initial volumes and calculating the number of states in the initial and final conditions, and b) by considering the ratio of the initial and final volumes. Why do the two answers differ and why is one larger?

4.9. Airplanes are launched from aircraft carriers by means of a steam catapult. The catapult is a well-insulated cylinder that contains steam, and is fitted with a frictionless piston. The piston is connected to the airplane by a cable. As the steam expands, the movement of the piston causes movement of the plane. A catapult design calls for 270 kg of steam at 15 MPa and 450°C to be expanded to 0.4 MPa. How much work can this catapult generate during a single stroke? Compare this to the energy required to accelerate a 30,000 kg aircraft from rest to 350 km per hour.

$R = 8.314$ J/mole-K; $N_A = 6.022 \times 10^{23}$; $N_A k_B = R$;
1 Joule = 1 N-m = 1MPa-cm^3 = 1 kg m^2/s^2 = 0.23901 cal

E.9. Properties of Water[1]

I. Saturation Temperature

T (°C)	P (MPa)	v^f m³/kg	v^g m³/kg	u^f kJ/kg	Δu^{fg} kJ/kg	u^g kJ/kg	h^f kJ/kg	Δh^{fg} kJ/kg	h^g kJ/kg	s^f kJ/kg-K	Δs^{fg} kJ/kg-K	s^g 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
205	1.72430	0.001164	0.1151	872.87	1723.53	2596.40	874.88	1919.95	2794.83	2.3777	4.0153	6.3930
210	1.90770	0.001173	0.1043	895.39	1702.92	2598.31	897.63	1899.64	2797.27	2.4245	3.9318	6.3563
215	2.10580	0.001181	0.0947	918.04	1681.90	2599.94	920.53	1878.79	2799.32	2.4712	3.8488	6.3200
220	2.31960	0.001190	0.0861	940.82	1660.43	2601.25	943.58	1857.37	2800.95	2.5177	3.7663	6.2840
225	2.54970	0.001199	0.0784	963.74	1638.50	2602.24	966.80	1835.35	2802.15	2.5640	3.6843	6.2483
230	2.79710	0.001209	0.0715	986.81	1616.09	2602.90	990.19	1812.71	2802.90	2.6101	3.6027	6.2128
235	3.06250	0.001219	0.0653	1010.04	1593.16	2603.20	1013.77	1789.40	2803.17	2.6561	3.5214	6.1775
240	3.34690	0.001229	0.0597	1033.44	1569.69	2603.13	1037.55	1765.41	2802.96	2.7020	3.4403	6.1423
245	3.65120	0.001240	0.0547	1057.02	1545.65	2602.67	1061.55	1740.67	2802.22	2.7478	3.3594	6.1072
250	3.97620	0.001252	0.0501	1080.79	1521.00	2601.79	1085.77	1715.16	2800.93	2.7935	3.2786	6.0721
255	4.32290	0.001264	0.0459	1104.77	1495.72	2600.49	1110.23	1688.84	2799.07	2.8392	3.1977	6.0369
260	4.69230	0.001276	0.0422	1128.97	1469.75	2598.72	1134.96	1661.64	2796.60	2.8849	3.1167	6.0016
265	5.08530	0.001289	0.0387	1153.41	1443.04	2596.45	1159.96	1633.53	2793.49	2.9307	3.0354	5.9661
270	5.50300	0.001303	0.0356	1178.10	1415.57	2593.67	1185.27	1604.42	2789.69	2.9765	2.9539	5.9304
275	5.94640	0.001318	0.0328	1203.07	1387.26	2590.33	1210.90	1574.27	2785.17	3.0224	2.8720	5.8944
280	6.41660	0.001333	0.0302	1228.33	1358.06	2586.39	1236.88	1542.99	2779.87	3.0685	2.7894	5.8579
285	6.91470	0.001349	0.0278	1253.92	1327.89	2581.81	1263.25	1510.48	2773.73	3.1147	2.7062	5.8209
290	7.44180	0.001366	0.0256	1279.86	1296.67	2576.53	1290.03	1476.67	2766.70	3.1612	2.6222	5.7834
295	7.99910	0.001385	0.0235	1306.19	1264.30	2570.49	1317.27	1441.43	2758.70	3.2080	2.5371	5.7451
300	8.58790	0.001404	0.0217	1332.95	1230.67	2563.62	1345.01	1404.63	2749.64	3.2552	2.4507	5.7059
305	9.20940	0.001425	0.0199	1360.18	1195.67	2555.85	1373.30	1366.13	2739.43	3.3028	2.3629	5.6657
310	9.86510	0.001448	0.0183	1387.93	1159.14	2547.07	1402.22	1325.73	2727.95	3.3510	2.2734	5.6244
315	10.55620	0.001472	0.0169	1416.28	1120.89	2537.17	1431.83	1283.22	2715.05	3.3998	2.1818	5.5816
320	11.28430	0.001499	0.0155	1445.31	1080.70	2526.01	1462.22	1238.37	2700.59	3.4494	2.0878	5.5372
325	12.05100	0.001528	0.0142	1475.11	1038.30	2513.41	1493.52	1190.81	2684.33	3.5000	1.9908	5.4908
330	12.85810	0.001561	0.0130	1505.80	993.35	2499.15	1525.87	1140.16	2666.03	3.5518	1.8904	5.4422
335	13.70730	0.001597	0.0118	1537.56	945.40	2482.96	1559.45	1085.90	2645.35	3.6050	1.7856	5.3906
340	14.60070	0.001638	0.0108	1570.62	893.82	2464.44	1594.53	1027.32	2621.85	3.6601	1.6755	5.3356
345	15.54060	0.001685	0.0098	1605.30	837.79	2443.09	1631.48	963.42	2594.90	3.7176	1.5586	5.2762
350	16.52940	0.001740	0.0088	1642.13	776.01	2418.14	1670.89	892.75	2563.64	3.7784	1.4326	5.2110
355	17.57010	0.001808	0.0079	1681.96	706.44	2388.40	1713.72	812.93	2526.65	3.8439	1.2941	5.1380
360	18.66600	0.001895	0.0069	1726.28	625.50	2351.78	1761.66	719.83	2481.49	3.9167	1.1369	5.0536
365	19.82140	0.002017	0.0060	1777.79	526.00	2303.79	1817.77	605.18	2422.95	4.0014	0.9483	4.9497
370	21.04360	0.002215	0.0050	1844.07	386.19	2230.26	1890.69	443.83	2334.52	4.1112	0.6900	4.8012
373.95	22.06400	0.003106	0.0031	2015.73	0.00	2015.73	2084.26	0.00	2084.26	4.4070	0.0000	4.4070

II. Saturation Pressure

T (°C)	P (MPa)	V^L m³/kg	V^V m³/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
6.97	0.001	0.001000	129.1780	29.30	2355.19	2384.49	29.30	2484.37	2513.67	0.1059	8.8690	8.9749
17.50	0.002	0.001001	66.9869	73.43	2325.47	2398.90	73.43	2459.45	2532.88	0.2606	8.4620	8.7226
24.08	0.003	0.001003	45.6532	100.98	2306.90	2407.88	100.98	2443.86	2544.84	0.3543	8.2221	8.5764
28.96	0.004	0.001004	34.7911	121.38	2293.12	2414.50	121.39	2432.28	2553.67	0.4224	8.0510	8.4734
32.87	0.005	0.001005	28.1853	137.74	2282.06	2419.80	137.75	2422.98	2560.73	0.4762	7.9176	8.3938
36.16	0.006	0.001006	23.7334	151.47	2272.76	2424.23	151.48	2415.15	2566.63	0.5208	7.8082	8.3290
39.00	0.007	0.001008	20.5245	163.34	2264.71	2428.05	163.35	2408.37	2571.72	0.5590	7.7155	8.2745
41.51	0.008	0.001008	18.0989	173.83	2257.58	2431.41	173.84	2402.37	2576.21	0.5925	7.6348	8.2273
43.76	0.009	0.001009	16.1992	183.24	2251.19	2434.43	183.25	2396.97	2580.22	0.6223	7.5635	8.1858
45.81	0.01	0.001010	14.6701	191.80	2245.36	2437.16	191.81	2392.05	2583.86	0.6492	7.4996	8.1488
60.06	0.02	0.001017	7.6480	251.40	2204.58	2455.98	251.42	2357.52	2608.94	0.8320	7.0752	7.9072
69.10	0.03	0.001022	5.2284	289.24	2178.46	2467.70	289.27	2335.28	2624.55	0.9441	6.8234	7.7675
75.86	0.04	0.001026	3.9930	317.58	2158.75	2476.33	317.62	2318.43	2636.05	1.0261	6.6429	7.6690
81.32	0.05	0.001030	3.2400	340.49	2142.72	2483.21	340.54	2304.68	2645.22	1.0912	6.5018	7.5930
85.93	0.06	0.001033	2.7317	359.85	2129.10	2488.95	359.91	2292.95	2652.86	1.1455	6.3856	7.5311
89.93	0.07	0.001036	2.3648	376.68	2117.20	2493.88	376.75	2282.67	2659.42	1.1921	6.2869	7.4790
93.49	0.08	0.001039	2.0871	391.63	2106.58	2498.21	391.71	2273.47	2665.18	1.2330	6.2009	7.4339
96.69	0.09	0.001041	1.8694	405.10	2096.97	2502.07	405.20	2265.11	2670.31	1.2696	6.1247	7.3943
99.61	0.1	0.001043	1.6939	417.40	2088.15	2505.55	417.50	2257.45	2674.95	1.3028	6.0561	7.3589
120.21	0.2	0.001061	0.8857	504.49	2024.60	2529.09	504.70	2201.53	2706.23	1.5302	5.5967	7.1269
133.52	0.3	0.001073	0.6058	561.11	1982.04	2543.15	561.43	2163.45	2724.88	1.6717	5.3199	6.9916
143.61	0.4	0.001084	0.4624	604.22	1948.88	2553.10	604.66	2133.39	2738.05	1.7765	5.1190	6.8955
151.83	0.5	0.001093	0.3748	639.54	1921.17	2560.71	640.09	2108.02	2748.11	1.8604	4.9603	6.8207
158.83	0.6	0.001101	0.3156	669.72	1897.07	2566.79	670.38	2085.76	2756.14	1.9308	4.8285	6.7593
164.95	0.7	0.001108	0.2728	696.23	1875.58	2571.81	697.00	2065.75	2762.75	1.9918	4.7153	6.7071
170.41	0.8	0.001115	0.2403	719.97	1856.06	2576.03	720.86	2047.44	2768.30	2.0457	4.6159	6.6616
175.35	0.9	0.001121	0.2149	741.55	1838.09	2579.64	742.56	2030.47	2773.03	2.0941	4.5272	6.6213
179.88	1	0.001127	0.1944	761.39	1821.36	2582.75	762.52	2014.59	2777.11	2.1381	4.4469	6.5850
187.96	1.2	0.001139	0.1633	796.96	1790.87	2587.83	798.33	1985.41	2783.74	2.2159	4.3058	6.5217
195.04	1.4	0.001149	0.1408	828.36	1763.40	2591.76	829.97	1958.88	2788.85	2.2835	4.1840	6.4675
201.37	1.6	0.001159	0.1237	856.60	1738.23	2594.83	858.46	1934.36	2792.82	2.3435	4.0764	6.4199
207.11	1.8	0.001168	0.1104	882.37	1714.87	2597.24	884.47	1911.44	2795.91	2.3975	3.9800	6.3775
212.38	2	0.001177	0.0996	906.15	1692.97	2599.12	908.50	1889.79	2798.29	2.4468	3.8922	6.3390
223.95	2.5	0.001197	0.0799	958.91	1643.15	2602.06	961.91	1840.02	2801.93	2.5543	3.7015	6.2558
233.85	3	0.001217	0.0667	1004.69	1598.47	2603.16	1008.34	1794.81	2803.15	2.6456	3.5400	6.1856
242.56	3.5	0.001235	0.0571	1045.47	1557.47	2602.94	1049.80	1752.84	2802.64	2.7254	3.3989	6.1243
250.35	4	0.001253	0.0498	1082.48	1519.24	2601.72	1087.49	1713.33	2800.82	2.7968	3.2728	6.0696
257.44	4.5	0.001270	0.0441	1116.53	1483.15	2599.68	1122.25	1675.70	2797.95	2.8615	3.1582	6.0197
263.94	5	0.001286	0.0394	1148.21	1448.77	2596.98	1154.64	1639.57	2794.21	2.9210	3.0527	5.9737
275.59	6	0.001319	0.0324	1206.01	1383.89	2589.90	1213.92	1570.67	2784.59	3.0278	2.8623	5.8901
285.83	7	0.001352	0.0274	1258.20	1322.78	2580.98	1267.66	1504.97	2772.63	3.1224	2.6924	5.8148
295.01	8	0.001385	0.0235	1306.23	1264.25	2570.48	1317.31	1441.37	2758.68	3.2081	2.5369	5.7450
303.35	9	0.001418	0.0205	1351.11	1207.42	2558.53	1363.87	1379.07	2742.94	3.2870	2.3921	5.6791
311.00	10	0.001453	0.0180	1393.54	1151.65	2545.19	1408.06	1317.43	2725.49	3.3607	2.2553	5.6160
327.81	12.5	0.001546	0.0135	1492.26	1013.35	2505.61	1511.58	1162.73	2674.31	3.5290	1.9348	5.4638
342.16	15	0.001657	0.0103	1585.35	870.27	2455.62	1610.20	1000.50	2610.70	3.6846	1.6260	5.3106
354.67	17.5	0.001803	0.0079	1679.22	711.32	2390.54	1710.77	818.53	2529.30	3.8394	1.3037	5.1431
365.75	20	0.002040	0.0059	1786.41	508.63	2295.04	1827.21	585.14	2412.35	4.0156	0.9159	4.9315
373.95	22.06400	0.003106	0.0031	2015.73	0.00	2015.73	2084.26	0.00	2084.26	4.4070	0.0000	4.4070

III. Superheated Steam

P = 0.01MPa	(45.8)			
T(°C)	V(m³/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 = 0.05MPa	(81.3)			
T(°C)	V(m³/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 = 0.10MPa	(99.6)			
T(°C)	V(m³/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 = 0.20MPa	(120.3)			
T(°C)	V(m³/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 = 0.30MPa	(133.5)			
T(°C)	V(m³/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 = 0.40MPa	(143.6)			
T(°C)	V(m³/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

P = 9.00MPa (303.4)				
T(°C)	V(m³/kg)	U(kJ/kg)	H(kJ/kg)	S(kJ/kg-K)
303.4	0.0205	2558.5	2742.9	5.6791
350	0.0258	2724.9	2957.3	6.0380
400	0.0300	2849.2	3118.8	6.2876
450	0.0335	2956.3	3258.0	6.4872
500	0.0368	3056.3	3387.4	6.6603
550	0.0399	3153.0	3512.0	6.8164
600	0.0429	3248.4	3634.1	6.9605
650	0.0458	3343.4	3755.2	7.0953
700	0.0486	3438.8	3876.1	7.2229
750	0.0514	3534.9	3997.3	7.3443
800	0.0541	3632.0	4119.1	7.4606
850	0.0569	3730.2	4241.9	7.5724
900	0.0596	3829.6	4365.7	7.6802
950	0.0622	3930.3	4490.6	7.7844
1000	0.0649	4032.4	4616.7	7.8855
1050	0.0676	4135.9	4744.0	7.9836
1100	0.0702	4240.6	4872.7	8.0790
1150	0.0729	4346.8	5002.5	8.1719
1200	0.0755	4454.2	5133.6	8.2625
1250	0.0781	4562.9	5266.0	8.3508
1300	0.0807	4672.9	5399.5	8.4370

P = 10.00MPa (311.0)				
T(°C)	V(m³/kg)	U(kJ/kg)	H(kJ/kg)	S(kJ/kg-K)
311.0	0.0180	2545.2	2725.5	5.6160
350	0.0224	2699.6	2924.0	5.9459
400	0.0264	2833.1	3097.4	6.2141
450	0.0298	2944.5	3242.3	6.4219
500	0.0328	3047.0	3375.1	6.5995
550	0.0357	3145.4	3502.0	6.7585
600	0.0384	3242.0	3625.8	6.9045
650	0.0410	3337.9	3748.1	7.0408
700	0.0436	3434.0	3870.0	7.1693
750	0.0461	3530.7	3992.0	7.2916
800	0.0486	3628.2	4114.5	7.4085
850	0.0511	3726.8	4237.8	7.5207
900	0.0535	3826.5	4362.0	7.6290
950	0.0560	3927.5	4487.3	7.7335
1000	0.0584	4029.9	4613.8	7.8349
1050	0.0608	4133.5	4741.4	7.9332
1100	0.0632	4238.5	4870.3	8.0288
1150	0.0656	4344.8	5000.4	8.1219
1200	0.0679	4452.3	5131.7	8.2126
1250	0.0703	4561.2	5264.2	8.3010
1300	0.0727	4671.3	5397.9	8.3874

P = 12.50MPa (327.8)				
T(°C)	V(m³/kg)	U(kJ/kg)	H(kJ/kg)	S(kJ/kg-K)
327.8	0.0135	2505.61	2674.31	5.4638
350	0.0161	2624.8	2826.6	5.7130
400	0.0200	2789.6	3040.0	6.0433
450	0.0230	2913.7	3201.4	6.2749
500	0.0256	3023.2	3343.6	6.4650
550	0.0280	3126.1	3476.5	6.6317
600	0.0303	3225.8	3604.6	6.7828
650	0.0325	3324.1	3730.2	6.9227
700	0.0346	3422.0	3854.6	7.0539
750	0.0367	3520.1	3978.6	7.1782
800	0.0387	3618.7	4102.8	7.2967
850	0.0407	3718.3	4227.5	7.4102
900	0.0427	3818.9	4352.9	7.5194
950	0.0447	3920.6	4479.2	7.6249
1000	0.0466	4023.5	4606.5	7.7269
1050	0.0486	4127.7	4734.9	7.8258
1100	0.0505	4233.1	4864.5	7.9219
1150	0.0524	4339.8	4995.1	8.0154
1200	0.0543	4447.7	5127.0	8.1065
1250	0.0562	4556.9	5260.0	8.1952
1300	0.0581	4667.3	5394.1	8.2819

P = 15.00MPa (342.2)				
T(°C)	V(m³/kg)	U(kJ/kg)	H(kJ/kg)	S(kJ/kg-K)
342.2	0.0103	2455.6	2610.7	5.3106
350	0.0115	2520.9	2693.1	5.4437
400	0.0157	2740.6	2975.7	5.8819
450	0.0185	2880.7	3157.9	6.1434
500	0.0208	2998.4	3310.8	6.3480
550	0.0229	3106.2	3450.4	6.5230
600	0.0249	3209.3	3583.1	6.6796
650	0.0268	3310.1	3712.1	6.8233
700	0.0286	3409.8	3839.1	6.9572
750	0.0304	3509.4	3965.2	7.0836
800	0.0321	3609.2	4091.1	7.2037
850	0.0338	3709.8	4217.1	7.3185
900	0.0355	3811.2	4343.7	7.4288
950	0.0372	3913.6	4471.0	7.5350
1000	0.0388	4017.1	4599.2	7.6378
1050	0.0404	4121.8	4728.4	7.7373
1100	0.0421	4227.7	4858.6	7.8339
1150	0.0437	4334.8	4989.9	7.9278
1200	0.0453	4443.1	5122.3	8.0192
1250	0.0469	4552.6	5255.7	8.1083
1300	0.0485	4663.2	5390.3	8.1952

P = 17.50MPa (354.7)				
T(°C)	V(m³/kg)	U(kJ/kg)	H(kJ/kg)	S(kJ/kg-K)
354.7	0.0079	2390.5	2529.3	5.1431
400	0.0125	2684.3	2902.4	5.7211
450	0.0152	2845.4	3111.4	6.0212
500	0.0174	2972.4	3276.7	6.2424
550	0.0193	3085.8	3423.6	6.4266
600	0.0211	3192.5	3561.3	6.5890
650	0.0227	3295.8	3693.8	6.7366
700	0.0243	3397.5	3823.5	6.8734
750	0.0259	3498.6	3951.7	7.0019
800	0.0274	3599.7	4079.3	7.1236
850	0.0289	3701.2	4206.8	7.2398
900	0.0303	3803.4	4334.5	7.3511
950	0.0318	3906.6	4462.9	7.4582
1000	0.0332	4010.7	4592.0	7.5616
1050	0.0346	4115.9	4721.9	7.6617
1100	0.0360	4222.3	4852.8	7.7588
1150	0.0374	4329.8	4984.6	7.8531
1200	0.0388	4438.4	5117.5	7.9449
1250	0.0402	4548.3	5251.5	8.0343
1300	0.0416	4659.2	5386.4	8.1215

P = 20.00MPa (365.8)				
T(°C)	V(m³/kg)	U(kJ/kg)	H(kJ/kg)	S(kJ/kg-K)
365.8	0.0059	2295.0	2412.4	4.9315
400	0.0100	2617.9	2816.9	5.5525
450	0.0127	2807.2	3061.7	5.9043
500	0.0148	2945.3	3241.2	6.1446
550	0.0166	3064.7	3396.1	6.3389
600	0.0182	3175.3	3539.0	6.5075
650	0.0197	3281.4	3675.3	6.6593
700	0.0211	3385.1	3807.8	6.7990
750	0.0225	3487.7	3938.1	6.9297
800	0.0239	3590.1	4067.5	7.0531
850	0.0252	3692.6	4196.4	7.1705
900	0.0265	3795.7	4325.4	7.2829
950	0.0278	3899.5	4454.7	7.3909
1000	0.0290	4004.3	4584.7	7.4950
1050	0.0303	4110.0	4715.4	7.5957
1100	0.0315	4216.9	4846.9	7.6933
1150	0.0327	4324.8	4979.4	7.7880
1200	0.0340	4433.8	5112.8	7.8802
1250	0.0352	4544.0	5247.2	7.9699
1300	0.0364	4655.2	5382.6	8.0574

Properties of Selected Compounds

*Heat capacities are values for **ideal gas at 298 K** and should be used for **order of magnitude calculations** only. See appendices for temperature-dependent formulas and constants.*

ID	Compound	T_c (K)	P_c (MPa)	ω	ρ g/cm³	MW	C_P^{ig}/R	δ (J/cm³)^½	α (J/cm³)^½	β (J/cm³)^½
902	HYDROGEN	33.3	1.297	−0.215	*0.20*	2	3.507	*2.0*	0	0
905	NITROGEN	126.1	3.394	0.040	*0.88*	28	3.500	5.3	0	0
908	CARBON MONOXIDE	132.9	3.499	0.066	*0.88*	28	3.505	6.3	0	0
909	CARBON DIOXIDE	304.2	7.382	0.228	*1.18*	44	4.456	14.6	1.87	0
Nasty gases										
1922	HYDROGEN SULFIDE	373.5	8.937	0.081	*0.95*	34	4.115	18.0	3.19	3.19
1938	CARBON DISULFIDE	552	7.800	0.115	*1.26*	76	4.109	20.4	0.59	0.33
1904	HYDROGEN CHLORIDE	324.6	8.200	0.120	*1.19*	36.5	3.551	22.0	22.0*	0
1771	HYDROGEN CYANIDE	456.8	5.320	0.407	*0.68*	27	4.330	24.8	3.00	3.00
Miscellaneous compounds										
1051	ACETONE	508.2	4.701	0.306	0.79	58	8.96	19.6	0.00	11.14
1772	ACETONITRILE	545.5	4.833	0.353	0.78	44	6.28	24.1	3.49	8.98
1252	ACETIC ACID	592.7	5.786	0.462	1.04	60	15.01	19.0	24.03	7.50
1911	AMMONIA	406.6	11.270	0.252	0.68	17	4.29	29.2	2.11	8.44
1921	WATER	647.3	22.120	0.344	1.00	18	4.04	47.9	50.13	15.06

ANSWERS Quiz 4
Chemical Engineering Thermodynamics
February 11, 2016

(P4.2) Initial (each x represents 5 molecule)

xxxx	

Final

x	x
x	x

Create a space with a three empty boxes for the initial state. The number of molecules is too small to use Stirling's approximation.
p1 = 20!/(20!0!0!0!) = 1
p2 = 20!/(5!5!5!5!) = 20*19*18*17*16*15*14*13*12*11*10*9*8*7*6/(5*4*3*2)^3 = 11732745024
ΔS/k = ln(p2/p1) = ln(11732745024) = 23.18

This can also be calculated from the volume ratio,
$\Delta S/k = 20 \ln(V_2/V_1) = 20\ (1.39) = 27.7$
The increase of 4.53k in ΔS is due to release of the constraint of confinement of the groups of five atoms in the four boxes.

(4.09) Airplanes are launched from aircraft carriers by means of a steam catapult.

Solution : It cannot generate more than the adiabatic reversible result. But in principle it could generate at most the adiabatic reversible result.

Energy Balance : d(mU)= Q + W = W
Entropy balance : Δ S = 0

State 1 : $U_1 = 2880.7$
$S_1 = 6.1434$
$V_1 = 18.5\ cm^3/g$

State 2 : Sat liq U =604.22 S= 1.7765
Sat Vap U =2553.1 S = 6.8955
$V^{satL} = 1.08\ cm^3/g$, $V^{satV} = 462\ cm^3/g$

Therefore, work done by gas
q = (6.1434 – 1.7765)/(6.8955 – 1.7765) = 0.853
$U_2 = 0.853 * 2553.1 + 0.147*604.2 = 2266.6$
$W_{gas} = 2266.6 – 2880.7 = -614.1$ kJ/kg
$\underline{W}_{gas} = 270 *(-614.1) = -165{,}800$ kJ

Some of the work is done on the atmosphere, need $P_{atm}\Delta\underline{V}$
$V^f = 1.085 + 0.853(461) = 394\ cm^3/g$
$\underline{W}_{EC,\ atm} = -P_{atm}(\underline{V}^f - \underline{V}^i) = -0.1MPa*(270E3g)(394-185) = 10{,}139$ kJ

Net work (ignoring acceleration of piston -- mass not given) = -165,800 + 10,139
= -156,000 J

For the Airplane, calculate the KE necessary at 350 km/h
$W_S = \int d(\ m(v^2/2))$
$= m(v^f)^2/2 = 30000kg*(\ 350000m\text{-}hr/3600hr\text{-}s)^2/2$
= 141,782 kJ

156,000 > 142,000 Therefore the catapult can generate enough work to launch the plane.
Or, one could calculate the final plane velocity for 156,000 kJ.
Sqrt((1.56E8 J)*2/30E3kg) = 102 m/s = 367 km/hr, plenty of speed.