NATIONAL UNIVERSITY OF SCIENCE AND TECHNOLOGY

APPLIED PHSYICS DEPARTMENT

SPH 1203 – THERMAL PHYSICS

BSc HONOURS PART I: *JANUARY 2003* *DURATION: 3 HOURS*

ANSWER **ALL** PARTS OF QUESTION 1-IN SECTION A AND ANY **THREE** QUESTIONS FROM SECTION B. SECTION A CARRIES 40 MARKS AND SECTION B 60 MARKS

Universal gas constant	R_u	=	8.314 J/mol.K
Atmospheric pressure	1atm	=	101.3 kPa
Stefan-Boltzmann's Constant	σ	=	5.67 x $10^{-8} W/m^2.K^4$
Wein's law constant	λ	=	2.898 mmK
Density of water at S. T. P.	ρ	=	0.997 x $10^3 kg/m^3$
Specific heat capacity of air	c_v	=	0.718 kJ/kg.K
Molecular mass of air		=	28.97 x 10^{-3} kg/mol

SECTION A

1. (a) Explain briefly the meaning of each of the following terms:
   (i) thermodynamic property,
   (ii) thermodynamic equilibrium,
   (iii) equation of state. [8]

(b) A steel wire of diameter 0.2mm is stretched between two rigid supports and is under tension of 36N at 25°C. if the breaking stress of wire is 1.2 x $10^9 N/m^2$, find the temperature at which the wire will snap as it cools.
   Young's modulus for steel $Y = 200x10^9 N/m^2$
   Linear expansion coefficient $\alpha = 11x10^{-6} K^{-1}$ [5]

(c) Draw a well labeled phase diagram for a substance that contracts on freezing. Define all characteristic curves and points on this diagram. [5]

(d) Distinguish between a *"reversible"* and an *"irreversible"* process. Give one example of each. [4]

(e) (i) Prove that for a thermodynamic system undergoing a reversible (Carnot) cycle there is no change in the Entropy. [4]

(ii) Show the Carnot cycle on a T-S diagram and name the processes involved in it. [4]

(f) Explain what is meant by the term *"throttling process"* [2]

(g) A refrigerator uses refrigerant – 12 as a working fluid and operates on an ideal refrigeration cycle between 0.14 Mpa and 0.8 Mpa. If the mass flow rate of the refrigerant is 0.05 kg/s determine:

(i) The rate of heat removal from the refrigerated space and the power input by the compressor. [6]

(ii) The coefficient of performance (COP) of the refrigerator. [2]

Hint Use the R-12 Tables to determine the properties of the refrigerant.

SECTION B

2. (a) (i) Write down the Van Der Waals equation of state, defining all the terms in the equation. [4]

(ii) What is the physical meaning of the constants in the above equation? [2]

(iii) Explain what conditions led to the modification of the ideal gas equation of state. [2]

(b) A cylinder with a movable piston contains 50 litres of liquid water at 25°C and 300kPa. The water is heated at constant pressure until the entire liquid is vaporised.

(i) What is the mass of the water? [1]

(ii) What are the final temperature and volume? [3]

(iii) Determine the amount of energy needed to vaporise the water. [3]

(c) Show the process on a T – V diagram with respect to the saturation lines. [5]

3. (a) Write down the differential form of the First Law of Thermodynamics and explain all terms and the sign convention used. [4]

(b) Discuss the relation above for a process occurring under:

(i) adiabatic and [3]

(ii) constant volume conditions. [3]

(c) A student living in a 4m x 6m x 5m room turns on his 200W fan before he leaves the room on a summer day, hoping that the room will be cooler when he comes back later. Assuming that all the doors and windows are tightly closed and ignoring any heat transfer through the walls and the window, determine the temperature in the room 8 hours later. Assume the room to be at 1atm and 15°C in the morning when the student leaves. [10]

4. (a) Give the Kelvin-Planck and the Claussius statements of the Second Law of Thermodynamics. [3]

(b) Show that when an ideal gas undergoes an adiabatic change of state the volume and the temperature of the gas obey the equation:

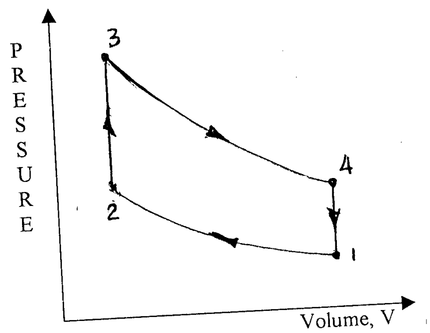
$$TV^{\gamma-1} = \textbf{const}$$

where $\gamma = c_p / c_v$ is a constant and depends on the nature of the gas. [6]

(c) On Fig 1 below you are given the P – V diagram of an air standard Otto-cycle of compression ratio 8. At the beginning of the compression stroke the pressure is 0.1 MPa and the temperature is 27°C. The heat absorbed by the system per cycle is 1200kJ/kg.

(i) Name the processes which form the cycle; and [2]
(ii) determine the maximum pressure and temperature that occur during the cycle. [6]

(d) Calculate the termal efficient of the heat engine. [3]



5. (a) Describe the properties of a *black-body radiator* including its nature, temperature dependence, etc.

(b) A small body of temperature T and absorptivity α is placed in a large evacuated cavity whose interior walls are at temperature T_w. When $T_w - T$ is small, show that the rate of heat transfer by radiation is

$$\dot{Q} = 4T_W^3 A\sigma\alpha(T_W - T)$$

where A is the area of the small body, and σ is Stefan – Boltsmann constant. [6]

(c) Determine the temperature of a black-body radiator whose peak intensity is at a wavelength of 1.07μm. State the appropriate law used by you for the calculations. [4]

6. (a) Define the Gibbs function (G) and the Helmholts function (A). [5]

(b) Show that for a reversible isothermal process the Gibbs function is constant. [7]

(c) Given the Maxwell's relation

$$(\delta S / \delta P)_T = -(\delta V / \delta T)_P$$

and regarding entropy as a function of temperature T and pressure P, show that:

$$TdS = c_p dT - T(\delta V / \delta T)_p dP$$

where V is the volume. [8]

- END OF EXAMINATION -

BLE A-5

aturated water–Pressure table

Press. kPa P	Sat. Temp. °C T_{sat}	Specific volume m³/kg: Sat. liquid v_f	Sat. vapor v_g	Internal energy kJ/kg: Sat. liquid u_f	Evap. u_{fg}	Sat. vapor u_g	Enthalpy kJ/kg: Sat. liquid h_f	Evap. h_{fg}	Sat. vapor h_g	Entropy kJ/(kg·K): Sat. liquid s_f	Evap. s_{fg}	Sat. vapor s_g
0.6113	0.01	0.001 000	206.14	0.00	2375.3	2375.3	0.01	2501.3	2501.4	0.0000	9.1562	9.1562
1.0	6.98	0.001 000	129.21	29.30	2355.7	2385.0	29.30	2484.9	2514.2	0.1059	8.8697	8.9756
1.5	13.03	0.001 001	87.98	54.71	2338.6	2393.3	54.71	2470.6	2525.3	0.1957	8.6322	8.8279
2.0	17.50	0.001 001	67.00	73.48	2326.0	2399.5	73.48	2460.0	2533.5	0.2607	8.4629	8.7237
2.5	21.08	0.001 002	54.25	88.48	2315.9	2404.4	88.49	2451.6	2540.0	0.3120	8.3311	8.6432
3.0	24.08	0.001 003	45.67	101.04	2307.5	2408.5	101.05	2444.5	2545.5	0.3545	8.2231	8.5776
4.0	28.96	0.001 004	34.80	121.45	2293.7	2415.2	121.46	2432.9	2554.4	0.4226	8.0520	8.4746
5.0	32.88	0.001 005	28.19	137.81	2282.7	2420.5	137.82	2423.7	2561.5	0.4764	7.9187	8.3951
7.5	40.29	0.001 008	19.24	168.78	2261.7	2430.5	168.79	2406.0	2574.8	0.5764	7.6750	8.2515
10	45.81	0.001 010	14.67	191.82	2246.1	2437.9	191.83	2392.8	2584.7	0.6493	7.5009	8.1502
15	53.97	0.001 014	10.02	225.92	2222.8	2448.7	225.94	2373.1	2599.1	0.7549	7.2536	8.0085
20	60.06	0.001 017	7.649	251.38	2205.4	2456.7	251.40	2358.3	2609.7	0.8320	7.0766	7.9085
25	64.97	0.001 020	6.204	271.90	2191.2	2463.1	271.93	2346.3	2618.2	0.8931	6.9383	7.8314
30	69.10	0.001 022	5.229	289.20	2179.2	2468.4	289.23	2336.1	2625.3	0.9439	6.8247	7.7686
40	75.87	0.001 027	3.993	317.53	2159.5	2477.0	317.58	2319.2	2636.8	1.0259	6.6441	7.6700
50	81.33	0.001 030	3.240	340.44	2143.4	2483.9	340.49	2305.4	2645.9	1.0910	6.5029	7.5939
75	91.78	0.001 037	2.217	384.31	2112.4	2496.7	384.39	2278.6	2663.0	1.2130	6.2434	7.4564
Press. MPa P												
0.100	99.63	0.001 043	1.6940	417.36	2088.7	2506.1	417.46	2258.0	2675.5	1.3026	6.0568	7.3594
0.125	105.99	0.001 048	1.3749	444.19	2069.3	2513.5	444.32	2241.0	2685.4	1.3740	5.9104	7.2844
0.150	111.37	0.001 053	1.1593	466.94	2052.7	2519.7	467.11	2226.5	2693.6	1.4336	5.7897	7.2233
0.175	116.06	0.001 057	1.0036	486.80	2038.1	2524.9	486.99	2213.6	2700.6	1.4849	5.6868	7.1717
0.200	120.23	0.001 061	0.8857	504.49	2025.0	2529.5	504.70	2201.9	2706.7	1.5301	5.5970	7.1271
0.225	124.00	0.001 064	0.7933	520.47	2013.1	2533.6	520.72	2191.3	2712.1	1.5706	5.5173	7.0878
0.250	127.44	0.001 067	0.7187	535.10	2002.1	2537.2	535.37	2181.5	2716.9	1.6072	5.4455	7.0527
0.275	130.60	0.001 070	0.6573	548.59	1991.9	2540.5	548.89	2172.4	2721.3	1.6408	5.3801	7.0209
0.300	133.55	0.001 073	0.6058	561.15	1982.4	2543.6	561.47	2163.8	2725.3	1.6718	5.3201	6.9919
0.325	136.30	0.001 076	0.5620	572.90	1973.5	2546.4	573.25	2155.8	2729.0	1.7006	5.2646	6.9652
0.350	138.88	0.001 079	0.5243	583.95	1965.0	2548.9	584.33	2148.1	2732.4	1.7275	5.2130	6.9405
0.375	141.32	0.001 081	0.4914	594.40	1956.9	2551.3	594.81	2140.8	2735.6	1.7528	5.1647	6.9175
0.40	143.63	0.001 084	0.4625	604.31	1949.3	2553.6	604.74	2133.8	2738.6	1.7766	5.1193	6.8959
0.45	147.93	0.001 088	0.4140	622.77	1934.9	2557.6	623.25	2120.7	2743.9	1.8207	5.0359	6.8565
0.50	151.86	0.001 093	0.3749	639.68	1921.6	2561.2	640.23	2108.5	2748.7	1.8607	4.9606	6.8213
0.55	155.48	0.001 097	0.3427	655.32	1909.2	2564.5	655.93	2097.0	2753.0	1.8973	4.8920	6.7893
0.60	158.85	0.001 101	0.3157	669.90	1897.5	2567.4	670.56	2086.3	2756.8	1.9312	4.8288	6.7600
0.65	162.01	0.001 104	0.2927	683.56	1886.5	2570.1	684.28	2076.0	2760.3	1.9627	4.7703	6.7331
[illegible]	164.97	0.001 108	0.2729	696.44	1876.1	2572.5	697.22	2066.3	2763.5	1.9922	4.7158	6.7080
0.75	167.78	0.001 112	0.2556	708.64	1866.1	2574.7	709.47	2057.0	2766.4	2.0200	4.6647	6.6847
0.80	170.43	0.001 115	0.2404	720.22	1856.6	2576.8	721.11	2048.0	2769.1	2.0462	4.6166	6.6628
0.85	172.96	0.001 118	0.2270	731.27	1847.4	2578.7	732.22	2039.4	2771.6	2.0710	4.5711	6.6421
0.90	175.38	0.001 121	0.2150	741.83	1838.6	2580.5	742.83	2031.1	2773.9	2.0946	4.5280	6.6226
0.95	177.69	0.001 124	0.2042	751.95	1830.2	2582.1	753.02	2023.1	2776.1	2.1172	4.4869	6.6041
1.00	179.91	0.001 127	0.194 44	761.68	1822.0	2583.6	762.81	2015.3	2778.1	2.1387	4.4478	6.5865
1.10	184.09	0.001 133	0.177 53	780.09	1806.3	2586.4	781.34	2000.4	2781.7	2.1792	4.3744	6.5536
1.20	187.99	0.001 139	0.163 33	797.29	1791.5	2588.8	798.65	1986.2	2784.8	2.2166	4.3067	6.5233
1.30	191.64	0.001 144	0.151 25	813.44	1777.5	2591.0	814.93	1972.7	2787.6	2.2515	4.2438	6.4953

	Sat. temp. °C T_{sat}	Specific volume m³/kg Sat. liquid v_f	Sat. vapor v_g	Internal energy kJ/kg Sat. liquid u_f	Evap. u_{fg}	Sat. vapor u_g	Enthalpy kJ/kg Sat. liquid h_f	Evap. h_{fg}	Sat. vapor h_g	Entropy kJ/(kg·K) Sat. liquid s_f	Evap. s_{fg}	Sat. vapor s_g
1.40	195.07	0.001 149	0.140 84	828.70	1764.1	2592.8	830.30	1959.7	2790.0	2.2842	4.1850	6.4693
1.50	198.32	0.001 154	0.131 77	843.16	1751.3	2594.5	844.89	1947.3	2792.2	2.3150	4.1298	6.4448
1.75	205.76	0.001 166	0.113 49	876.46	1721.4	2597.8	878.50	1917.9	2796.4	2.3851	4.0044	6.3896
2.00	212.42	0.001 177	0.099 63	906.44	1693.8	2600.3	908.79	1890.7	2799.5	2.4474	3.8935	6.3409
2.25	218.45	0.001 187	0.088 75	933.83	1668.2	2602.0	936.49	1865.2	2801.7	2.5035	3.7937	6.2972
2.5	223.99	0.001 197	0.079 98	959.11	1644.0	2603.1	962.11	1841.0	2803.1	2.5547	3.7028	6.2575
3.0	233.90	0.001 217	0.066 68	1004.78	1599.3	2604.1	1008.42	1795.7	2804.2	2.6457	3.5412	6.1869
3.5	242.60	0.001 235	0.057 07	1045.43	1558.3	2603.7	1049.75	1753.7	2803.4	2.7253	3.4000	6.1253
4	250.40	0.001 252	0.049 78	1082.31	1520.0	2602.3	1087.31	1714.1	2801.4	2.7964	3.2737	6.0701
5	263.99	0.001 286	0.039 44	1147.81	1449.3	2597.1	1154.23	1640.1	2794.3	2.9202	3.0532	5.9734
6	275.64	0.001 319	0.032 44	1205.44	1384.3	2589.7	1213.35	1571.0	2784.3	3.0267	2.8625	5.8892
7	285.88	0.001 351	0.027 37	1257.55	1323.0	2580.5	1267.00	1505.1	2772.1	3.1211	2.6922	5.8133
8	295.06	0.001 384	0.023 52	1305.57	1264.2	2569.8	1316.64	1441.3	2758.0	3.2068	2.5364	5.7432
9	303.40	0.001 418	0.020 48	1350.51	1207.3	2557.8	1363.26	1378.9	2742.1	3.2858	2.3915	5.6722
10	311.06	0.001 452	0.018 026	1393.04	1151.4	2544.4	1407.56	1317.1	2724.7	3.3596	2.2544	5.6141
11	318.15	0.001 489	0.015 987	1433.7	1096.0	2529.8	1450.1	1255.5	2705.6	3.4295	2.1233	5.5527
12	324.75	0.001 527	0.014 263	1473.0	1040.7	2513.7	1491.3	1193.6	2684.9	3.4962	1.9962	5.4924
13	330.93	0.001 567	0.012 780	1511.1	985.0	2496.1	1531.5	1130.7	2662.2	3.5606	1.8718	5.4323
14	336.75	0.001 611	0.011 485	1548.6	928.2	2476.8	1571.1	1066.5	2637.6	3.6232	1.7485	5.3717
15	342.24	0.001 658	0.010 337	1585.6	869.8	2455.5	1610.5	1000.0	2610.5	3.6848	1.6249	5.3098
16	347.44	0.001 711	0.009 306	1622.7	809.0	2431.7	1650.1	930.6	2580.6	3.7461	1.4994	5.2455
17	352.37	0.001 770	0.008 364	1660.2	744.8	2405.0	1690.3	856.9	2547.2	3.8079	1.3698	5.1777
18	357.06	0.001 840	0.007 489	1698.9	675.4	2374.3	1732.0	777.1	2509.1	3.8715	1.2329	5.1044
19	361.54	0.001 924	0.006 657	1739.9	598.1	2338.1	1776.5	688.0	2464.5	3.9388	1.0839	5.0228
20	365.81	0.002 036	0.005 834	1785.6	507.5	2293.0	1826.3	583.4	2409.7	4.0139	0.9130	4.9269
21	369.89	0.002 207	0.004 952	1842.1	388.5	2230.6	1888.4	446.2	2334.6	4.1075	0.6938	4.8013
22	373.80	0.002 742	0.003 568	1961.9	125.2	2087.1	2022.2	143.4	2165.6	4.3110	0.2216	4.5327
22.09	374.14	0.003 155	0.003 155	2029.6	0	2029.6	2099.3	0	2099.3	4.4298	0	4.4298

Source: Gordon J. Van Wylen and Richard E. Sonntag, *Fundamentals of Classical Thermodynamics*, English/SI Version, 3d ed., Wiley, New York, 1986, pp. 638–640, table A.1.2. Originally published in Joseph H. Keenan, Frederick G. Keyes, Philip G. Hill, and Joan G. Moore, *Steam Tables*, SI Units, Wiley, New York, 1978.

TABLE A-12

Saturated refrigerant-12–Pressure table

		Specific volume m^3/kg		Internal energy kJ/kg		Enthalpy kJ/kg			Entropy kJ/(kg·K)	
Press. MPa P	Sat. Temp. °C T_{sat}	Sat. liquid v_f	Sat. vapor v_g	Sat. liquid u_f	Sat. vapor u_g	Sat. liquid h_f	Evap. h_{fg}	Sat. vapor h_g	Sat. liquid s_f	Sat. vapor s_g
0.06	−41.42	0.000 657 8	0.2575	−1.29	153.49	−1.25	170.19	168.94	−0.0054	0.7290
0.10	−30.10	0.000 671 9	0.1600	8.71	158.15	8.78	165.37	174.15	0.0368	0.7171
0.12	−25.74	0.000 677 6	0.1349	12.58	159.95	12.66	163.48	176.14	0.0526	0.7133
0.14	−21.91	0.000 682 8	0.1168	15.99	161.52	16.09	161.78	177.87	0.0663	0.7102
0.16	−18.49	0.000 687 6	0.1031	19.07	162.91	19.18	160.23	179.41	0.0784	0.7076
0.18	−15.38	0.000 692 1	0.092 25	21.86	164.19	21.98	158.82	180.80	0.0893	0.7054
0.20	−12.53	0.000 696 2	0.083 54	24.43	165.36	24.57	157.50	182.07	0.0992	0.7035
0.24	−7.42	0.000 704 0	0.070 33	29.06	167.44	29.23	155.09	184.32	0.1168	0.7004
0.28	−2.93	0.000 711 1	0.060 76	33.15	169.26	33.35	152.92	186.27	0.1321	0.6980
0.32	1.11	0.000 717 7	0.053 51	36.85	170.88	37.08	150.92	188.00	0.1457	0.6960
0.40	8.15	0.000 729 9	0.043 21	43.35	173.69	43.64	147.33	190.97	0.1691	0.6928
0.50	15.60	0.000 743 8	0.034 82	50.30	176.61	50.67	143.35	194.02	0.1935	0.6899
0.60	22.00	0.000 756 6	0.029 13	56.35	179.09	56.80	139.77	196.57	0.2142	0.6878
0.70	27.65	0.000 768 6	0.025 01	61.75	181.23	62.29	136.45	198.74	0.2324	0.6860
0.80	32.74	0.000 780 2	0.021 88	66.68	183.13	67.30	133.33	200.63	0.2487	0.6845
0.90	37.37	0.000 791 4	0.019 42	71.22	184.81	71.93	130.36	202.29	0.2634	0.6832
1.0	41.64	0.000 802 3	0.017 44	75.46	186.32	76.26	127.50	203.76	0.2770	0.6820
1.2	49.31	0.000 823 7	0.014 41	83.22	188.95	84.21	122.03	206.24	0.3015	0.6799
1.4	56.09	0.000 844 8	0.012 22	90.28	191.11	91.46	116.76	208.22	0.3232	0.6778
1.6	62.19	0.000 866 0	0.010 54	96.80	192.95	98.19	111.62	209.81	0.3329	0.6758

Source: Adapted from Kenneth Wark, *Thermodynamics*, 4th ed., McGraw-Hill, New York, 1983, p. 809, table A-17M. Originally published by E. I. du Pont de Nemours & Company, Inc., 1969.