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The Open University of Sri Lanka
Faculty of Engineering Technology

Study Programme	:	Bachelor of Technology Honours in Engineering
Name of the Examination	:	Final Examination
Course Code and Title	:	**MEX5231 Applied Thermodynamics**
Academic Year	:	2015/16
Date	:	2nd December 2016
Time	:	0930-1230h
Duration	:	**3 hours**

General instructions

1. Read all instructions carefully before answering the questions.
2. This question paper consists of 8 questions. All questions carry equal marks.
3. Answer any **5 questions.**
4. *h-s* chart and extraction of steam tables are provided.

(1) (a) What is the back work ratio? State typical back work ratio values for gas-turbine engines. (05 marks)

(b) In a regenerative gas turbine power plant, air enters the compressor at 1 bar, 300 K with a mass flow rate of 0.4 kg/s and is compressed to 4 bar. The temperature at the inlet to the high pressure turbine is 1200 K. The isentropic efficiency of the compressor is 80%, and the regenerator effectiveness is 75%. All the power developed by the high-pressure turbine is used to run the compressor. The low-pressure turbine provides the net power output. Assume isentropic turbine expansion processes.

(i) Sketch the T-S diagram to show all processes.

(ii) Determine the inlet pressure of the power turbine

(iii) Calculate net power output, in kW and the thermal efficiency of the plant.

(iv) Calculate the back work ratio and explain how do the inefficiencies of the turbine and the compressor affect the back work ratio.

(15 marks)

(2) (a) Sketch and explain how the pressure and velocity vary when a fluid passes through the fixed and moving blades of an impulse turbine and a reaction turbine. (05 marks)

(b) An impulsive stage of a steam turbine is supplied with dry saturated steam. The stage has a single row of moving blades running at 3600 rev/min. The mean diameter of the blade disc is 0.9 m. The nozzle angle is 15° and the absolute velocity of steam leaving the nozzle is 350 m/s. The nozzle efficiency is 0.9 and the blade velocity co-efficient is 0.85. The exit angle of the moving blades is 2° greater than at the inlet. Mass flow rate of steam is 100kg/s. Determine the following.

(i) Blade inlet and outlet angles.
(ii) Power developed by the stage
(iii) Stage efficiency.

(15 marks)

(3) (a) Why is excessive moisture in steam undesirable in steam turbines? What are the advantages of having reheating stages in a steam power plant ?

(05 marks)

(b) A steam power plant operates on the reheat Rankine cycle. Steam enters the high-pressure turbine at 10 MPa and 500°C at a rate of 8 kg/s and leaves at 2 MPa. Steam is then reheated at constant pressure to 500°C before it expands in the low-pressure turbine. The isentropic efficiency of the high pressure turbine and low pressure turbine are 85 percent and 100 percent respectively. Assume pump efficiency as 100%. Steam leaves the condenser as a saturated liquid.
If the dryness fraction of the steam at the exit of the turbine is 0.95 determine following.

(i) Condenser pressure,
(ii) Net power output
(iii) Thermal efficiency

(15 marks)

(4) (a) Illustrate the simple vapour absorption refrigeration cycle with the aid of a schematic diagram and compare it with a simple vapour compression refrigeration cycle.

(06 marks)

(b) Figure Q4 (b) shows a vapour compression refrigeration system with the arrangement of two stage compression with liquid inter-cooler. Draw the thermodynamic cycle on $T-S$ **or** $p-h$ diagram.

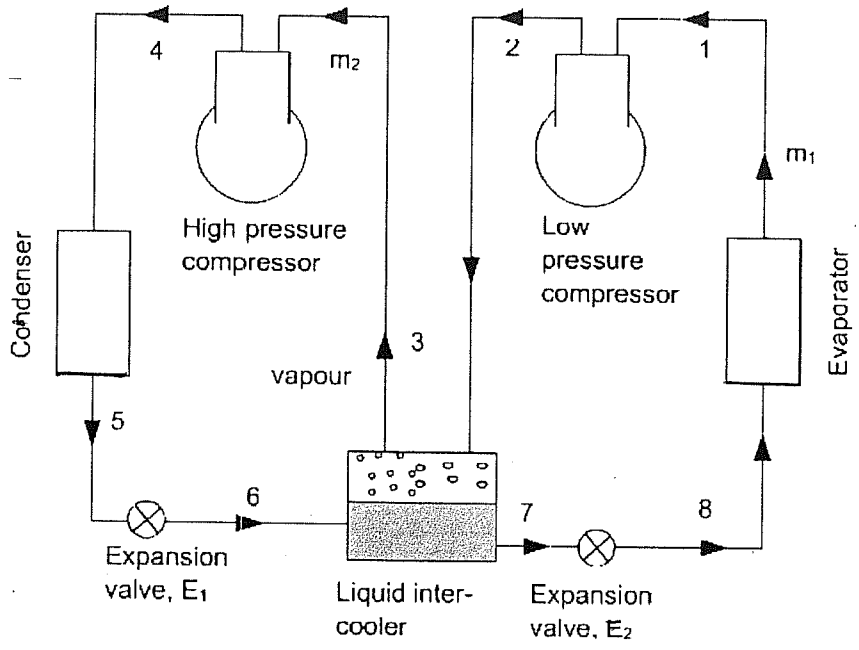


Figure Q4(b)

(04 marks)

(c) A refrigerator operating on a standard vapour compression cycle has the evaporator temperature of -10 °C and a condenser temperature of 40 °C. The vapour leaves the evaporator dry saturated. The enthalpy of the refrigerant at the end of dry compression is 220kJ/kg. The refrigerant flow rate is 1kg/min.

The refrigerant properties are given in table Q4(c).

Temperature (°C)	Specific enthalpy (kJ/kg)	
	Liquid (h_f)	Vapour (h_g)
-10	26.85	183
40	74.53	203

Table Q4(c)

(i) Show the cycle on a T-S diagram. (02 marks)

(ii) Calculate the COP of the plant, the refrigerating capacity and the compressor power for unit mass flowrate.

(08 marks)

(5) (a) What is supersaturation? Under what conditions does it occur?

(04 marks)

(b) Dry saturated steam at 12 bar expands through a convergent-divergent nozzle to atmospheric pressure of 1 bar.
Assume the following:
Inlet velocity is negligible
Expansion to be isentropic.
Expansion index for dry saturated steam is 1.135

(i) What is the throat pressure of the nozzle? (04 marks)

(ii) Calculate following properties at the throat.
- dryness fraction
- enthalpy
- velocity
- specific volume

(08 marks)

(iii) Calculate the throat area per unit mass flow rate. (04 marks)

(6) A section of a furnace wall 2m x1.5m in size, is not insulated. The temperature at the outer surface of this section is measured to be 80°C. The ambient air temperature is 30°C and the combined convection and radiation heat transfer coefficient (h) at the outer surface is 10W/m^2°C. It is proposed to insulate this section of the furnace wall with glass wool insulation (k = 0.038 W/m°C) in order to reduce the heat loss by 90 percent.

(a) Determine the rate of heat transfer from the outer surface of the furnace wall section without insulation. (05 marks)

(b) Calculate the rate of heat transfer with the insulation. (05 marks)

(c) Take the outer surface temperature to be 70°C and the same heat transfer coefficient (h) determine the thickness of the insulation needed.

(10 marks)

(7) In a steam power plant feed water is flowing through a duct of rectangular cross section of 8cm x 4cm. The inside wall temperature of the duct is 190°C throughout the length. Flow rate of feed water is 350kg/min. The inlet temperature of the feed water is 30°C and it will be heated to 170°C.
Determine

(a) Surface convection heat transfer coefficient (10 marks)

(b) Required length of the duct. (10 marks)

The following data for water is given at mean temperature of 122°C.

$Pr = 1.61$, $\mu = 260 \times 10^{-6}\ kg/ms$, $c_p = 4.226 kJ/kgK$, $k = 683 \times 10^{-3}\ W/mK$

The following relationship between dimensionless numbers can be used.

$$N_u = 0.023(R_e)^{0.8}(P_r)^{0.3}$$

Hydraulic diameter is given by

$$D_h = \frac{4A}{Perimeter}$$

(8) (a) Define dew point temperature. (03 marks)

(b) What is enthalpy of combustion? How does it differ from the enthalpy of reaction? (03 marks)

(c) What is enthalpy of formation? (02 marks)

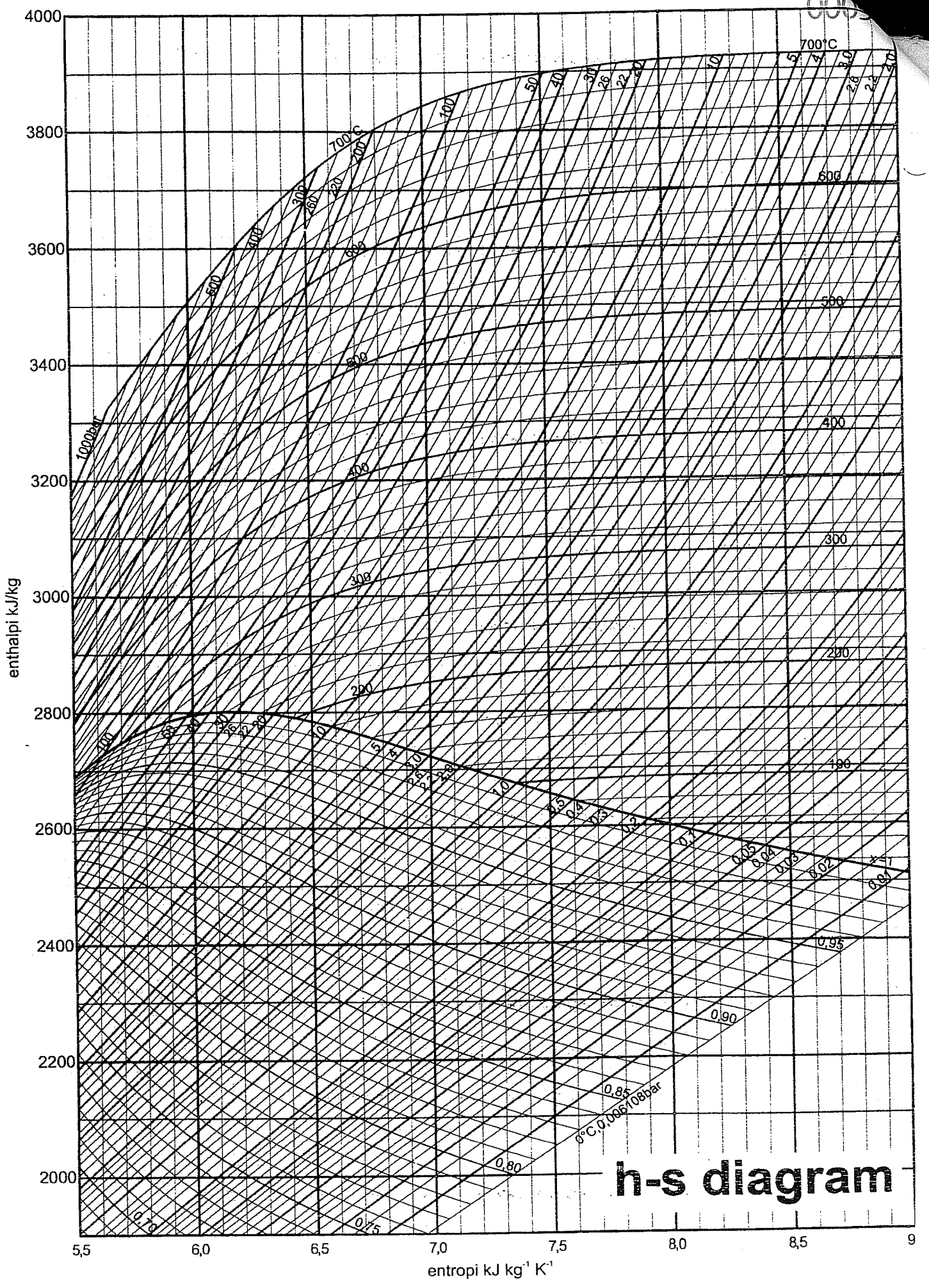
(d) What are the higher and the lower heating values of a fuel? How do they differ? (04 marks)

(e) Propylene (C_3H_6) is burned with 50 percent excess air during a combustion process. Assume complete combustion and a total pressure of products is 105 kPa.

(i) Write down the balanced combustion equation for C_3H_6
(ii) Determine the air–fuel ratio
(iii) Estimate the temperature at which the water vapor in the combustion products starts condensing.

(08 marks)

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h-s diagram
enthalpi kJ/kg
entropi kJ kg⁻¹ K⁻¹
4000
3800
3600
3400
3200
3000
2800
2600
2400
2200
2000
5,5
6,0
6,5
7,0
7,5
8,0
8,5
9
700°C
1000bar
0°C,0,006108bar
x=1

Saturated Water and Steam

p [bar]	t_s [°C]	v_g [m³/kg]	u_f [kJ/kg]	u_g [kJ/kg]	h_f [kJ/kg]	h_{fg} [kJ/kg]	h_g [kJ/kg]	s_f [kJ/kg K]	s_{fg} [kJ/kg K]	s_g [kJ/kg K]
0.006112	0.01	206.1	0†	2375	0*	2501	2501	0†	9.155	9.155
0.010	7.0	129.2	29	2385	29	2485	2514	0.106	8.868	8.974
0.015	13.0	87.98	55	2393	55	2470	2525	0.196	8.631	8.827
0.020	17.5	67.01	73	2399	73	2460	2533	0.261	8.462	8.723
0.025	21.1	54.26	88	2403	88	2451	2539	0.312	8.330	8.642
0.030	24.1	45.67	101	2408	101	2444	2545	0.354	8.222	8.576
0.035	26.7	39.48	112	2412	112	2438	2550	0.391	8.130	8.521
0.040	29.0	34.80	121	2415	121	2433	2554	0.422	8.051	8.473
0.045	31.0	31.14	130	2418	130	2428	2558	0.451	7.980	8.431
0.050	32.9	28.20	138	2420	138	2423	2561	0.476	7.918	8.394
0.055	34.6	25.77	145	2422	145	2419	2564	0.500	7.860	8.360
0.060	36.2	23.74	152	2425	152	2415	2567	0.521	7.808	8.329
0.065	37.7	22.02	158	2427	158	2412	2570	0.541	7.760	8.301
0.070	39.0	20.53	163	2428	163	2409	2572	0.559	7.715	8.274
0.075	40.3	19.24	169	2430	169	2405	2574	0.576	7.674	8.250
0.080	41.5	18.10	174	2432	174	2402	2576	0.593	7.634	8.227
0.085	42.7	17.10	179	2434	179	2400	2579	0.608	7.598	8.206
0.090	43.8	16.20	183	2435	183	2397	2580	0.622	7.564	8.186
0.095	44.8	15.40	188	2436	188	2394	2582	0.636	7.531	8.167
0.100	45.8	14.67	192	2437	192	2392	2584	0.649	7.500	8.149
0.12	49.4	12.36	207	2442	207	2383	2590	0.696	7.389	8.085
0.14	52.6	10.69	220	2446	220	2376	2596	0.737	7.294	8.031
0.16	55.3	9.432	232	2450	232	2369	2601	0.772	7.213	7.985
0.18	57.8	8.444	242	2453	242	2363	2605	0.804	7.140	7.944
0.20	60.1	7.648	251	2456	251	2358	2609	0.832	7.075	7.907
0.22	62.2	6.994	260	2459	260	2353	2613	0.858	7.016	7.874
0.24	64.1	6.445	268	2461	268	2348	2616	0.882	6.962	7.844
0.26	65.9	5.979	276	2464	276	2343	2619	0.904	6.913	7.817
0.28	67.5	5.578	283	2466	283	2339	2622	0.925	6.866	7.791
0.30	69.1	5.228	289	2468	289	2336	2625	0.944	6.823	7.767
0.32	70.6	4.921	295	2470	295	2332	2627	0.962	6.783	7.745
0.34	72.0	4.649	302	2472	302	2328	2630	0.980	6.745	7.725
0.36	73.4	4.407	307	2473	307	2325	2632	0.996	6.709	7.705
0.38	74.7	4.189	312	2475	312	2322	2634	1.011	6.675	7.686
0.40	75.9	3.992	318	2476	318	2318	2636	1.026	6.643	7.669
0.42	77.1	3.814	323	2478	323	2315	2638	1.040	6.612	7.652
0.44	78.2	3.651	327	2479	327	2313	2640	1.054	6.582	7.636
0.46	79.3	3.502	332	2481	332	2310	2642	1.067	6.554	7.621
0.48	80.3	3.366	336	2482	336	2308	2644	1.079	6.528	7.607
0.50	81.3	3.239	340	2483	340	2305	2645	1.091	6.502	7.593
0.55	83.7	2.964	351	2486	351	2298	2649	1.119	6.442	7.561
0.60	86.0	2.731	360	2489	360	2293	2653	1.145	6.386	7.531
0.65	88.0	2.535	369	2492	369	2288	2657	1.169	6.335	7.504
0.70	90.0	2.364	377	2494	377	2283	2660	1.192	6.286	7.478
0.75	91.8	2.217	384	2496	384	2278	2662	1.213	6.243	7.456
0.80	93.5	2.087	392	2498	392	2273	2665	1.233	6.201	7.434
0.85	95.2	1.972	399	2500	399	2269	2668	1.252	6.162	7.414
0.90	96.7	1.869	405	2502	405	2266	2671	1.270	6.124	7.394
0.95	98.2	1.777	411	2504	411	2262	2673	1.287	6.089	7.376
1.00	99.6	1.694	417	2506	417	2258	2675	1.303	6.056	7.359

* $\dfrac{h_f}{[\mathrm{kJ/kg}]} = \dfrac{pv_f}{[\mathrm{kJ/kg}]} = \dfrac{p}{[\mathrm{bar}]} \times \dfrac{10^5[\mathrm{N}]}{[\mathrm{m^2}]} \times \dfrac{v_f}{[\mathrm{m^3/kg}]} \times \left[\dfrac{\mathrm{m^3}}{\mathrm{kg}}\right] \times \dfrac{[\mathrm{kJ}]}{10^3[\mathrm{N\,m}]} \times \dfrac{1}{[\mathrm{kJ/kg}]}$

$$= \frac{p}{[\mathrm{bar}]} \times \frac{v_f}{[\mathrm{m^3/kg}]} \times 10^2 = 0.006112 \times 0.0010002 \times 10^2 = 0.0006112$$

Saturated Water and Steam

p [bar]	t_s [°C]	v_g [m³/kg]	u_f [kJ/kg]	u_g [kJ/kg]	h_f [kJ/kg]	h_{fg} [kJ/kg]	h_g [kJ/kg]	s_f [kJ/kg K]	s_{fg} [kJ/kg K]	s_g [kJ/kg K]
1.0	99.6	1.694	417	2506	417	2258	2675	1.303	6.056	7.359
1.1	102.3	1.549	429	2510	429	2251	2680	1.333	5.994	7.327
1.2	104.8	1.428	439	2512	439	2244	2683	1.361	5.937	7.298
1.3	107.1	1.325	449	2515	449	2238	2687	1.387	5.884	7.271
1.4	109.3	1.236	458	2517	458	2232	2690	1.411	5.835	7.246
1.5	111.4	1.159	467	2519	467	2226	2693	1.434	5.789	7.223
1.6	113.3	1.091	475	2521	475	2221	2696	1.455	5.747	7.202
1.7	115.2	1.031	483	2524	483	2216	2699	1.475	5.707	7.182
1.8	116.9	0.9774	491	2526	491	2211	2702	1.494	5.669	7.163
1.9	118.6	0.9292	498	2528	498	2206	2704	1.513	5.632	7.145
2.0	120.2	0.8856	505	2530	505	2202	2707	1.530	5.597	7.127
2.1	121.8	0.8461	511	2531	511	2198	2709	1.547	5.564	7.111
2.2	123.3	0.8100	518	2533	518	2193	2711	1.563	5.533	7.096
2.3	124.7	0.7770	524	2534	524	2189	2713	1.578	5.503	7.081
2.4	126.1	0.7466	530	2536	530	2185	2715	1.593	5.474	7.067
2.5	127.4	0.7186	535	2537	535	2182	2717	1.607	5.446	7.053
2.6	128.7	0.6927	541	2539	541	2178	2719	1.621	5.419	7.040
2.7	130.0	0.6686	546	2540	546	2174	2720	1.634	5.393	7.027
2.8	131.2	0.6462	551	2541	551	2171	2722	1.647	5.368	7.015
2.9	132.4	0.6253	556	2543	556	2168	2724	1.660	5.344	7.004
3.0	133.5	0.6057	561	2544	561	2164	2725	1.672	5.321	6.993
3.5	138.9	0.5241	584	2549	584	2148	2732	1.727	5.214	6.941
4.0	143.6	0.4623	605	2554	605	2134	2739	1.776	5.121	6.897
4.5	147.9	0.4139	623	2558	623	2121	2744	1.820	5.037	6.857
5.0	151.8	0.3748	639	2562	640	2109	2749	1.860	4.962	6.822
5.5	155.5	0.3427	655	2565	656	2097	2753	1.897	4.893	6.790
6	158.8	0.3156	669	2568	670	2087	2757	1.931	4.830	6.761
7	165.0	0.2728	696	2573	697	2067	2764	1.992	4.717	6.709
8	170.4	0.2403	720	2577	721	2048	2769	2.046	4.617	6.663
9	175.4	0.2149	742	2581	743	2031	2774	2.094	4.529	6.623
10	179.9	0.1944	762	2584	763	2015	2778	2.138	4.448	6.586
11	184.1	0.1774	780	2586	781	2000	2781	2.179	4.375	6.554
12	188.0	0.1632	797	2588	798	1986	2784	2.216	4.307	6.523
13	191.6	0.1512	813	2590	815	1972	2787	2.251	4.244	6.495
14	195.0	0.1408	828	2593	830	1960	2790	2.284	4.185	6.469
15	198.3	0.1317	843	2595	845	1947	2792	2.315	4.130	6.445
16	201.4	0.1237	857	2596	859	1935	2794	2.344	4.078	6.422
17	204.3	0.1167	870	2597	872	1923	2795	2.372	4.028	6.400
18	207.1	0.1104	883	2598	885	1912	2797	2.398	3.981	6.379
19	209.8	0.1047	895	2599	897	1901	2798	2.423	3.936	6.359
20	212.4	0.09957	907	2600	909	1890	2799	2.447	3.893	6.340
22	217.2	0.09069	928	2601	931	1870	2801	2.492	3.813	6.305
24	221.8	0.08323	949	2602	952	1850	2802	2.534	3.738	6.272
26	226.0	0.07689	969	2603	972	1831	2803	2.574	3.668	6.242
28	230.0	0.07142	988	2603	991	1812	2803	2.611	3.602	6.213
30	233.8	0.06665	1004	2603	1008	1795	2803	2.645	3.541	6.186
32	237.4	0.06246	1021	2603	1025	1778	2803	2.679	3.482	6.161
34	240.9	0.05875	1038	2603	1042	1761	2803	2.710	3.426	6.136
36	244.2	0.05544	1054	2602	1058	1744	2802	2.740	3.373	6.113
38	247.3	0.05246	1068	2602	1073	1729	2802	2.769	3.322	6.091
40	250.3	0.04977	1082	2602	1087	1714	2801	2.797	3.273	6.070