UNIVERSITY OF JOHANNESBURG

PROGRAM	:	NATIONAL DIPLOMA *CHEMICAL ENGINEERING*
SUBJECT	:	**APPLIED THERMODYNAMICS III**
CODE	:	**ACT3111**
DATE	:	SUMMER EXAMINATION 29 NOVEMBER 2016
DURATION	:	(SESSION 1) 08:30 - 11:30
WEIGHT	:	40 : 60
TOTAL MARKS	:	100

EXAMINER	:	DR K MOOTHI
MODERATOR	:	DR H RUTTO
NUMBER OF PAGES	:	09 PAGES

INSTRUCTIONS	:	QUESTION PAPERS MUST BE HANDED IN.
REQUIREMENTS	:	Use of scientific (non-programmable) calculator is permitted (only one per candidate).

INSTRUCTIONS TO CANDIDATES:

- ANSWER ALL THE QUESTIONS.
- Write all your details (module name, module code, ID number, student number etc.) on your script(s).
- Number each question clearly; the order of answer/s does not matter.
- Show all units in calculations; write clearly and legibly.

Question One **[Total: 20 Marks]**

1.1 What are the air-standard assumptions? **[6]**

1.2 What four processes make up the ideal Otto cycle? **[4]**

1.3 Calculate the ideal air standard thermal efficiency based on the Otto Cycle for a petrol engine with a cylinder bore of 50 mm, a stroke of 100 mm and a clearance volume of 20 cm^3. Assume air as an ideal gas, $\gamma = 1.4$. **[10]**

Question Two **[Total: 20 Marks]**

2.1 For simple ideal Rankine cycles, list three (3) ways one can increase the efficiency? **[5]**

2.2 A steam turbine takes steam at 70 bar and 500°C and expands it to 0.1 bar with an isentropic efficiency 0.9. The process is adiabatic. The power output of the turbine is 35 MW.

2.2.1 Determine the enthalpy at exit and **[13]**
2.2.2 Calculate the flow rate of steam (in kg/s). **[2]**

Question Three **[Total: 25 Marks]**

In a gas turbine plant, air enters a compressor at atmospheric conditions of 15°C, 1.0133 bar and is compressed through a pressure ratio of 10/1. The air leaving the compressor passes through a heat exchanger before entering the combustion chamber (Figure 3.1). The hot gases leave the combustion chamber at 800°C and expand through an HP turbine which drives the compressor. On leaving the HP turbine the gases pass through a reheat combustion chamber which raises the temperature of the gases to 800°C before they expand through the power turbine and then to the heat exchanger where they flow in counter-flow to the air leaving the compressor.

Given data:
- Isentropic efficiency of the compressor is 80% while the isentropic efficiencies of the HP and power turbines are 87% for each.
- The mechanical efficiency for both the HP turbine-compressor and power turbine drive is assumed to be 92%.
- Thermal ratio of heat exchanger is 0.75.
- For air, take $C_p = 1.005$ kJ/kg-K and $\gamma = 1.4$; for the gases in the combustion chamber, in the turbines and heat exchanger take $C_p = 1.15$ kJ/kg-K and $\gamma = 1.333$.

Using the data (neglecting the mass flowrate of fuel and changes of velocity throughout) and for a net power output of 10 MW, calculate:

3.1 The temperature of the air entering the first combustion chamber. **[15]**
3.2 The overall cycle efficiency. **[4]**
3.3 The work ratio of the cycle. **[3]**
3.4 The air flowrate required. **[3]**

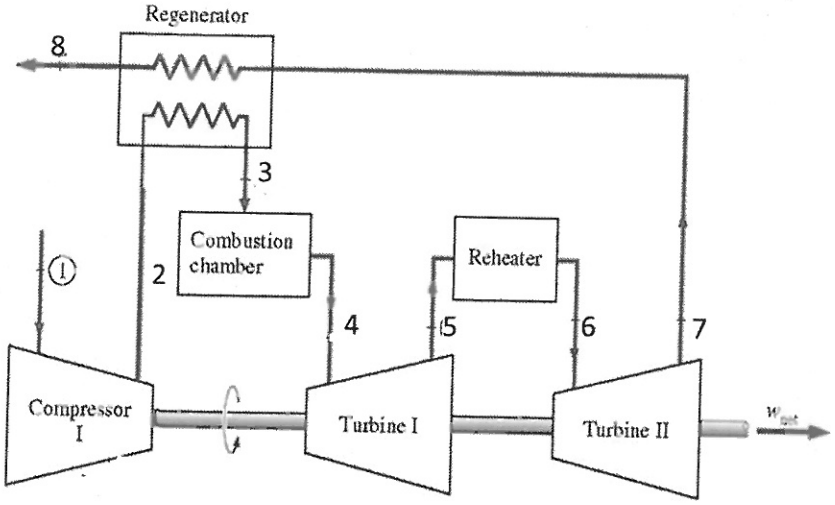


Figure 3.1: Diagram representing the process

Question Four **[Total: 25 Marks]**

A nozzle expands air at the rate of 4.5 kg/s from 8.3 bar and 327°C, into a space at 1.38 bar. Neglect the inlet velocity, assume isentropic flow and take $\gamma = 1.4$. Molar mass of air = 29 g/mol and $C_p = 1.005$ kJ/kg.K. Calculate:

4.1 The nozzle throat area, **[13]**
4.2 The nozzle exit area **[12]**

Question Five **[Total: 10 Marks]**

5. A refrigeration system requires 1.5 kW of power for a refrigeration rate of 4 kW.

5.1 What is the coefficient of performance (COP_{ref})? **[2]**
5.2 How much heat is rejected in the condenser? **[2]**
5.3 If heat rejection is at 313.15 K (40°C), what is the lowest temperature the system can possibly maintain? **[6]**

END **[Total: 100 Marks]**

USEFUL FORMULAE:

$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$; $v = \frac{V^t}{m}$; $v = \frac{V^t}{n}$; $\rho = v^{-1}$; $\gamma = \frac{C_P}{C_V}$; $\frac{T_2}{T_1} = \left(\frac{P_2}{P_1}\right)^{(\gamma-1)/\gamma}$

EB (open systems): $\frac{d(mU)_{cv}}{dt} = -\dot{m}\Delta\left[U + \frac{1}{2}u^2 + gh\right] + \dot{Q} + \dot{W}$

EB (steady-state flow processes): $\Delta\dot{m}\left(H + \frac{1}{2}u^2 + gh\right) = \dot{Q} + \dot{W}_s$

Interpolation: $M = \left(\frac{X_2 - X}{X_2 - X_1}\right)M_1 + \left(\frac{X - X_1}{X_2 - X_1}\right)M_2$

Carnot cycle: $\eta = \frac{W_{net}}{Q_1} = 1 - \frac{Q_2}{Q_1} = 1 - \frac{T_2}{T_1}$

Constant-pressure (Joule) cycle: $\eta = 1 - \frac{1}{\left(\frac{P_2}{P_1}\right)^{(\gamma-1)/\gamma}}$

Work ratio: $W = \frac{Net\ work\ output}{Gross\ work\ output} = 1 - \frac{T_1}{T_3}\left(\frac{P_2}{P_1}\right)^{(\gamma-1)/\gamma}$

Compression ratio: $\frac{swept\ volume + clearance\ volume}{clearance\ volume} = \frac{v_1}{v_2}$

Otto cycle: $\eta = 1 - \frac{1}{\left(\frac{V_1}{V_2}\right)^{\gamma-1}}$

Diesel cycle: $\eta = 1 - \left(\frac{T_4 - T_1}{\gamma(T_3 - T_2)}\right)$

Dual-combustion cycle: $\eta = 1 - \frac{C_v(T_5 - T_1)}{C_v(T_3 - T_2) + C_p(T_4 - T_3)}$

Mean effective pressure (MEP): $-W_{net} = P_m(V_1 - V_2)$

Stirling and Ericsson cycles: $\eta_{Stirling} = \eta_{Ericsson} = \eta_{Carnot} = 1 - \frac{T_2}{T_1}$

Steam rate: $\dot{m} = \frac{\dot{W}_{net}}{W_{net}} = \frac{\dot{W}_{net}}{W_{turbine} - W_{pump}}$

Rankine cycle (pump work input): $W = v_i(P_{i+1} - P_i)$

Rankine efficiency: $\eta = \frac{Net\ work\ output}{Heat\ supplied\ in\ boiler}$

Efficiency ratio: $\frac{cycle\ efficiency}{Rankine\ efficiency}$

Specific steam consumption (ssc): $ssc = \frac{1}{networkoutput}$

Condenser heat load (CHL): $CHL = ssc(\Delta H_{condenser})$

Isentropic efficiency: $\frac{ratio\ of\ work\ input\ required}{actual\ work\ required}$

Gross work output: $work\ output\ of\ HP\ turbine + work\ output\ of\ LP\ turbine$

Work ratio: $W = \frac{Net\ work\ output}{Gross\ work\ output} = 1 - \frac{T_1}{T_3}\left(\frac{P_2}{P_1}\right)^{(\gamma-1)/\gamma}$

Mass flow rate: $\dot{m} = \frac{\dot{W}_{net}}{W_{net}}$ Cycle efficiency: $\eta = \frac{W_{turbine}}{Q_1}$

For steam turbines: $\Delta C_w = C_{wi} + C_{we} = C_{re}\cos\beta_e + C_{ri}\cos\beta_i$

Velocity coefficient: $k = \frac{C_{re}}{C_{ri}}$

Diagram efficiency: $\eta_d = \frac{rate\ of\ doing\ work\ per\ unit\ mass\ of\ steam}{energy\ supplied\ per\ unit\ mass\ of\ steam} = \frac{2C_b\Delta C_w}{C_{ai}^2}$

$Energy\ supplied\ per\ unit\ mass\ of\ steam = \frac{1}{2}\dot{m}C_{ai}^2$

Driving force: $F_D = \dot{m}\Delta C_w$

Power output: $\dot{W}_{output} = \dot{m}C_b\Delta C_w$

End (Axial) thrust: $Axial\ thrust = \dot{m}\Delta C_f$ Where: $\Delta C_f = C_{fi} - C_{fe} = C_{ri}\sin\beta_i - C_{re}\sin\beta_e$

For Nozzles (EB): $H_1 + \frac{C_1^2}{2} = H_2 + \frac{C_2^2}{2}$

Critical pressure: $\frac{P_c}{P_1} = \left(\frac{2}{\gamma+1}\right)^{\gamma/(\gamma-1)}$ Critical temperature: $\frac{T_c}{T_1} = \left(\frac{P_c}{P_1}\right)^{(\gamma-1)/\gamma}$

Critical specific volume: $v_c = \frac{(R/M)T_c}{P_c}$

Critical velocity: $C_c = \sqrt{\frac{\gamma RT_c}{M}} = \sqrt{2(H_1 - H_c)} = \sqrt{2C_p(T_1 - T_c)}$

Exit specific volume: $v_2 = \frac{(R/M)T_2}{P_2}$

Exit velocity: $C_2 = \sqrt{2(H_1 - H_2)}$

Mass flowrate per unit area: $\frac{\dot{m}}{A_2} = \frac{C_2}{v_2}$

Nozzle efficiency: $\frac{H_1-H_2}{H_1-H_{2s}} = \frac{C_p(T_1-T_2)}{C_p(T_1-T_{2s})} = \frac{T_1-T_2}{T_1-T_{2s}}$

Velocity coefficient: $\frac{C_2}{C_{2s}}$ Coefficient of discharge: $\frac{\dot{m}}{\dot{m}_s}$

For dry saturated steam, $\gamma = 1.135$ For superheated steam, $\gamma = 1.3$

Refrigeration (Engine efficiency): $\eta_{carnot} = \frac{W_{net\ carnot\ engine}}{Q_1} = 1 - \frac{T_2}{T_1}$

Coefficient of Performance: $COP_{carnot} = \frac{Q_1\ refrigerator}{W_{refrigerator\ input}} = \frac{T_2}{T_1-T_2}$

Table A.1: Conversion Factors

Quantity	Conversion
Length	$1\ m = 100\ cm$ $= 3.28084(ft) = 39.3701(in)$
Mass	$1\ kg = 10^3\ g$ $= 2.20462(lb_m)$
Force	$1\ N = 1\ kg\ m\ s^{-2}$ $= 10^5(dyne)$ $= 0.224809(lb_f)$
Pressure	$1\ bar = 10^5\ kg\ m^{-1}\ s^{-2} = 10^5\ N\ m^{-2}$ $= 10^5\ Pa = 10^2\ kPa$ $= 10^6(dyne)\ cm^{-2}$ $= 0.986923(atm)$ $= 14.5038(psia)$ $= 750.061(torr)$
Volume	$1\ m^3 = 10^6\ cm^3 = 10^3$ liters $= 35.3147(ft)^3$ $= 264.172(gal)$
Density	$1\ g\ cm^{-3} = 10^3\ kg\ m^{-3}$ $= 62.4278(lb_m)(ft)^{-3}$
Energy	$1\ J = 1\ kg\ m^2\ s^{-2} = 1\ N\ m$ $= 1\ m^3\ Pa = 10^{-5}\ m^3\ bar = 10\ cm^3\ bar$ $= 9.86923\ cm^3(atm)$ $= 10^7(dyne)\ cm = 10^7(erg)$ $= 0.239006(cal)$ $= 5.12197 \times 10^{-3}(ft)^3(psia) = 0.737562(ft)(lb_f)$ $= 9.47831 \times 10^{-4}(Btu) = 2.77778 \times 10^{-7}\ kWhr$
Power	$1\ kW = 10^3\ W = 10^3\ kg\ m^2\ s^{-3} = 10^3\ J\ s^{-1}$ $= 239.006(cal)\ s^{-1}$ $= 737.562(ft)(lb_f)\ s^{-1}$ $= 0.947831(Btu)\ s^{-1}$ $= 1.34102(hp)$

Table A.2: Values of the Universal Gas Constant

$R = 8.314\ J\ mol^{-1}\ K^{-1} = 8.314\ m^3\ Pa\ mol^{-1}\ K^{-1}$
$= 83.14\ cm^3\ bar\ mol^{-1}\ K^{-1} = 8{,}314\ cm^3\ kPa\ mol^{-1}\ K^{-1}$
$= 82.06\ cm^3(atm)\ mol^{-1}\ K^{-1} = 62{,}356\ cm^3(torr)\ mol^{-1}\ K^{-1}$
$= 1.987(cal)\ mol^{-1}\ K^{-1} = 1.986(Btu)(lb\ mole)^{-1}(R)^{-1}$
$= 0.7302(ft)^3(atm)(lb\ mol)^{-1}(R)^{-1} = 10.73(ft)^3(psia)(lb\ mol)^{-1}(R)^{-1}$
$= 1{,}545(ft)(lb_f)(lb\ mol)^{-1}(R)^{-1}$

Table F.1 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 $kJ\ kg^{-1}\ K^{-1}$

	T	P	SPECIFIC VOLUME V			INTERNAL ENERGY U			ENTHALPY H			ENTROPY S		
	K	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

30	303.15	4.241	1.004	32930.	32930.	125.7	2291.0	2416.7	125.7	2430.7	2556.4	0.4365	8.0180	8.4546
31	304.15	4.491	1.005	31200.	31200.	129.8	2288.2	2418.0	129.8	2428.3	2558.2	0.4503	7.9839	8.4342
32	305.15	4.753	1.005	29570.	29570.	134.0	2285.4	2419.4	134.0	2425.9	2560.0	0.4640	7.9500	8.4140
33	306.15	5.029	1.005	28040.	28040.	138.2	2282.6	2420.8	138.2	2423.6	2561.8	0.4777	7.9163	8.3939
34	307.15	5.318	1.006	26600.	26600.	142.4	2279.7	2422.1	142.4	2421.2	2563.6	0.4913	7.8828	8.3740
35	308.15	5.622	1.006	25240.	25240.	146.6	2276.9	2423.5	146.6	2418.8	2565.4	0.5049	7.8495	8.3543
36	309.15	5.940	1.006	23970.	23970.	150.7	2274.1	2424.8	150.7	2416.4	2567.2	0.5184	7.8164	8.3348
37	310.15	6.274	1.007	22760.	22760.	154.9	2271.3	2426.2	154.9	2414.1	2569.0	0.5319	7.7835	8.3154
38	311.15	6.624	1.007	21630.	21630.	159.1	2268.4	2427.5	159.1	2411.7	2570.8	0.5453	7.7509	8.2962
39	312.15	6.991	1.007	20560.	20560.	163.3	2265.6	2428.9	163.3	2409.3	2572.6	0.5588	7.7184	8.2772
40	313.15	7.375	1.008	19550.	19550.	167.4	2262.8	2430.2	167.5	2406.9	2574.4	0.5721	7.6861	8.2583
41	314.15	7.777	1.008	18590.	18590.	171.6	2259.9	2431.6	171.6	2404.5	2576.2	0.5854	7.6541	8.2395
42	315.15	8.198	1.009	17680.	17690.	175.8	2257.1	2432.9	175.8	2402.1	2577.9	0.5987	7.6222	8.2209
43	316.15	8.639	1.009	16840.	16840.	180.0	2254.3	2434.2	180.0	2399.7	2579.7	0.6120	7.5905	8.2025
44	317.15	9.100	1.009	16040.	16040.	184.2	2251.4	2435.6	184.2	2397.3	2581.5	0.6252	7.5590	8.1842
45	318.15	9.582	1.010	15280.	15280.	188.3	2248.6	2436.9	188.4	2394.9	2583.3	0.6383	7.5277	8.1661
46	319.15	10.09	1.010	14560.	14560.	192.5	2245.7	2438.3	192.5	2392.5	2585.1	0.6514	7.4966	8.1481
47	320.15	10.61	1.011	13880.	13880.	196.7	2242.9	2439.6	196.7	2390.1	2586.9	0.6645	7.4657	8.1302
48	321.15	11.16	1.011	13230.	13230.	200.9	2240.0	2440.9	200.9	2387.7	2588.6	0.6776	7.4350	8.1125
49	322.15	11.74	1.012	12620.	12620.	205.1	2237.2	2442.3	205.1	2385.3	2590.4	0.6906	7.4044	8.0950
50	323.15	12.34	1.012	12040.	12050.	209.2	2234.3	2443.6	209.3	2382.9	2592.2	0.7035	7.3741	8.0776
51	324.15	12.96	1.013	11500.	11500.	213.4	2231.5	2444.9	213.4	2380.5	2593.9	0.7164	7.3439	8.0603
52	325.15	13.61	1.013	10980.	10980.	217.6	2228.6	2446.2	217.6	2378.1	2595.7	0.7293	7.3138	8.0432
53	326.15	14.29	1.014	10490.	10490.	221.8	2225.8	2447.6	221.8	2375.7	2597.5	0.7422	7.2840	8.0262
54	327.15	15.00	1.014	10020.	10020.	226.0	2222.9	2448.9	226.0	2373.2	2599.2	0.7550	7.2543	8.0093
55	328.15	15.74	1.015	9577.9	9578.9	230.2	2220.0	2450.2	230.2	2370.8	2601.0	0.7677	7.2248	7.9925
56	329.15	16.51	1.015	9157.7	9158.7	234.3	2217.2	2451.5	234.4	2368.4	2602.7	0.7804	7.1955	7.9759
57	330.15	17.31	1.016	8758.7	8759.8	238.5	2214.3	2452.8	238.5	2365.9	2604.5	0.7931	7.1663	7.9595
58	331.15	18.15	1.016	8379.8	8380.8	242.7	2211.4	2454.1	242.7	2363.5	2606.2	0.8058	7.1373	7.9431
59	332.15	19.02	1.017	8019.7	8020.8	246.9	2208.6	2455.4	246.9	2361.1	2608.0	0.8184	7.1085	7.9269
60	333.15	19.92	1.017	7677.5	7678.5	251.1	2205.7	2456.8	251.1	2358.6	2609.7	0.8310	7.0798	7.9108
61	334.15	20.86	1.018	7352.1	7353.2	255.3	2202.8	2458.1	255.3	2356.2	2611.4	0.8435	7.0513	7.8948
62	335.15	21.84	1.018	7042.7	7043.7	259.4	2199.9	2459.4	259.5	2353.7	2613.2	0.8560	7.0230	7.8790
63	336.15	22.86	1.019	6748.2	6749.3	263.6	2197.0	2460.7	263.6	2351.3	2614.9	0.8685	6.9948	7.8633
64	337.15	23.91	1.019	6468.0	6469.0	267.8	2194.1	2462.0	267.8	2348.8	2616.6	0.8809	6.9667	7.8477
65	338.15	25.01	1.020	6201.3	6202.3	272.0	2191.2	2463.2	272.0	2346.3	2618.4	0.8933	6.9388	7.8322
66	339.15	26.15	1.020	5947.2	5948.2	276.2	2188.3	2464.5	276.2	2343.9	2620.1	0.9057	6.9111	7.8168
67	340.15	27.33	1.021	5705.2	5706.2	280.4	2185.4	2465.8	280.4	2341.4	2621.8	0.9180	6.8835	7.8015
68	341.15	28.56	1.022	5474.6	5475.6	284.6	2182.5	2467.1	284.6	2338.9	2623.5	0.9303	6.8561	7.7864
69	342.15	29.84	1.022	5254.8	5255.8	288.8	2179.6	2468.4	288.8	2336.4	2625.2	0.9426	6.8288	7.7714
70	343.15	31.16	1.023	5045.2	5046.3	292.9	2176.7	2469.7	293.0	2334.0	2626.9	0.9548	6.8017	7.7565
71	344.15	32.53	1.023	4845.4	4846.4	297.1	2173.8	2470.9	297.2	2331.5	2628.6	0.9670	6.7747	7.7417
72	345.15	33.96	1.024	4654.7	4655.7	301.3	2170.9	2472.2	301.4	2329.0	2630.3	0.9792	6.7478	7.7270
73	346.15	35.43	1.025	4472.7	4473.7	305.5	2168.0	2473.5	305.5	2326.5	2632.0	0.9913	6.7211	7.7124
74	347.15	36.96	1.025	4299.0	4300.0	309.7	2165.1	2474.8	309.7	2324.0	2633.7	1.0034	6.6945	7.6979

Table F.I Saturated Steam, SI Units (Continued)

			SPECIFIC VOLUME V			INTERNAL ENERGY U			ENTHALPY H			ENTROPY S		
t °C	T K	P kPa	sat. liq.	evap.	sat. vap.	sat. liq.	evap.	sat. vap.	sat. liq.	evap.	sat. vap.	sat. liq.	evap.	sat. vap.
220	493.15	2319.8	1.190	84.85	86.04	940.9	1659.4	2600.3	943.7	1856.2	2799.9	2.5178	3.7639	6.2817
222	495.15	2409.9	1.194	81.67	82.86	950.1	1650.7	2600.8	952.9	1847.5	2800.5	2.5363	3.7311	6.2674
224	497.15	2502.7	1.197	78.62	79.82	959.2	1642.0	2601.2	962.2	1838.7	2800.9	2.5548	3.6984	6.2532
226	499.15	2598.2	1.201	75.71	76.91	968.4	1633.1	2601.5	971.5	1829.8	2801.4	2.5733	3.6657	6.2390
228	501.15	2696.5	1.205	72.92	74.12	977.6	1624.2	2601.8	980.9	1820.8	2801.7	2.5917	3.6331	6.2249
230	503.15	2797.6	1.209	70.24	71.45	986.8	1615.2	2602.1	990.3	1811.7	2802.0	2.6102	3.6006	6.2107
232	505.15	2901.6	1.213	67.66	68.89	996.2	1606.1	2602.3	999.7	1802.5	2802.2	2.6286	3.5681	6.1967
234	507.15	3008.6	1.217	65.22	66.43	1005.4	1597.0	2602.4	1009.1	1793.2	2802.3	2.6470	3.5356	6.1826
236	509.15	3118.6	1.221	62.86	64.08	1014.8	1587.7	2602.5	1018.6	1783.8	2802.3	2.6653	3.5033	6.1686
238	511.15	3231.7	1.225	60.60	61.82	1024.1	1578.4	2602.5	1028.1	1774.2	2802.3	2.6837	3.4709	6.1546
240	513.15	3347.8	1.229	58.43	59.65	1033.5	1569.0	2602.5	1037.6	1764.6	2802.2	2.7020	3.4386	6.1406
242	515.15	3467.2	1.233	56.34	57.57	1042.9	1559.5	2602.4	1047.2	1754.9	2802.0	2.7203	3.4063	6.1266
244	517.15	3589.8	1.238	54.34	55.58	1052.3	1549.9	2602.2	1056.8	1745.0	2801.8	2.7386	3.3740	6.1127
246	519.15	3715.7	1.242	52.41	53.66	1061.8	1540.2	2602.0	1066.4	1735.0	2801.4	2.7569	3.3418	6.0987
248	521.15	3844.9	1.247	50.56	51.81	1071.3	1530.5	2601.8	1076.1	1724.9	2801.0	2.7752	3.3096	6.0848
250	523.15	3977.6	1.251	48.79	50.04	1080.8	1520.6	2601.4	1085.8	1714.7	2800.4	2.7935	3.2773	6.0708
252	525.15	4113.7	1.256	47.08	48.33	1090.4	1510.6	2601.0	1095.5	1704.3	2799.8	2.8118	3.2451	6.0569
254	527.15	4253.4	1.261	45.43	46.69	1100.0	1500.5	2600.5	1105.3	1693.8	2799.1	2.8300	3.2129	6.0428
256	529.15	4396.7	1.266	43.85	45.11	1109.6	1490.4	2600.0	1115.2	1683.2	2798.3	2.8483	3.1807	6.0290
258	531.15	4543.7	1.271	42.33	43.60	1119.3	1480.1	2599.3	1125.0	1672.4	2797.4	2.8666	3.1484	6.0150
260	533.15	4694.3	1.276	40.86	42.13	1129.0	1469.7	2598.8	1134.9	1661.5	2796.4	2.8848	3.1161	6.0010
262	535.15	4848.8	1.281	39.44	40.73	1138.7	1459.2	2597.9	1144.9	1650.4	2795.3	2.9031	3.0838	5.9869
264	537.15	5007.1	1.286	38.08	39.37	1148.5	1448.5	2597.0	1154.9	1639.2	2794.1	2.9214	3.0515	5.9729
266	539.15	5169.3	1.291	36.77	38.06	1158.3	1437.8	2596.1	1165.0	1627.8	2792.8	2.9397	3.0191	5.9588
268	541.15	5335.5	1.297	35.51	36.80	1168.2	1426.9	2595.0	1175.1	1616.3	2791.4	2.9580	2.9866	5.9446
270	543.15	5505.8	1.303	34.29	35.59	1178.1	1415.9	2593.9	1185.2	1604.6	2789.9	2.9763	2.9541	5.9304
272	545.15	5680.2	1.308	33.11	34.42	1188.0	1404.7	2592.7	1195.4	1592.8	2788.2	2.9947	2.9215	5.9162
274	547.15	5858.7	1.314	31.97	33.29	1198.0	1393.4	2591.4	1205.7	1580.8	2786.5	3.0131	2.8889	5.9019
276	549.15	6041.5	1.320	30.88	32.20	1208.0	1382.0	2590.1	1216.0	1568.5	2784.6	3.0314	2.8561	5.8876
278	551.15	6228.7	1.326	29.82	31.14	1218.1	1370.4	2588.6	1226.4	1556.2	2782.6	3.0499	2.8233	5.8731
280	553.15	6420.2	1.332	28.79	30.13	1228.3	1358.7	2587.0	1236.8	1543.6	2780.4	3.0683	2.7903	5.8586
282	555.15	6616.1	1.339	27.81	29.14	1238.5	1346.8	2586.3	1247.3	1530.8	2778.1	3.0868	2.7573	5.8440
284	557.15	6816.6	1.345	26.85	28.20	1248.7	1334.8	2583.5	1257.9	1517.8	2775.7	3.1053	2.7241	5.8294
286	559.15	7021.8	1.352	25.93	27.28	1259.0	1322.6	2581.6	1268.5	1504.6	2773.2	3.1238	2.6906	5.8146
288	561.15	7231.5	1.359	25.03	26.38	1269.4	1310.2	2579.6	1279.2	1491.2	2770.5	3.1424	2.6573	5.7997
290	563.15	7446.1	1.366	24.17	25.54	1279.8	1297.7	2577.5	1290.0	1477.6	2767.6	3.1611	2.6237	5.7848
292	565.15	7665.4	1.373	23.33	24.71	1290.3	1284.9	2575.3	1300.9	1463.8	2764.6	3.1798	2.5899	5.7697
294	567.15	7889.7	1.381	22.52	23.90	1300.9	1272.0	2572.9	1311.8	1449.7	2761.5	3.1985	2.5560	5.7545
296	569.15	8118.9	1.388	21.74	23.13	1311.5	1258.9	2570.4	1322.8	1435.4	2758.2	3.2173	2.5218	5.7392
298	571.15	8353.2	1.396	20.98	22.38	1322.2	1245.6	2567.8	1333.9	1420.8	2754.7	3.2362	2.4875	5.7237

300	573.15	8592.7	1.404	20.24	21.65	1333.0	1232.0	2565.0	1345.1	1406.0	2751.0	3.2552	2.4529	5.7081
302	575.15	8837.4	1.412	19.53	20.94	1343.8	1218.3	2562.1	1356.3	1390.9	2747.2	3.2742	2.4182	5.6924
304	577.15	9087.3	1.421	18.84	20.26	1354.8	1204.3	2559.1	1367.7	1375.5	2743.2	3.2933	2.3832	5.6765
306	579.15	9342.7	1.430	18.17	19.60	1365.8	1190.1	2555.9	1379.1	1359.8	2739.0	3.3125	2.3479	5.6604
308	581.15	9603.6	1.439	17.52	18.96	1376.9	1175.6	2552.5	1390.7	1343.9	2734.6	3.3318	2.3124	5.6442
310	583.15	9870.0	1.448	16.89	18.33	1388.1	1161.0	2549.1	1402.4	1327.6	2730.0	3.3512	2.2766	5.6278
312	585.15	10142.1	1.458	16.27	17.73	1399.4	1146.0	2545.4	1414.2	1311.0	2725.2	3.3707	2.2404	5.6111
314	587.15	10420.0	1.468	15.68	17.14	1410.8	1130.8	2541.6	1426.1	1294.1	2720.2	3.3903	2.2040	5.5943
316	589.15	10703.	1.478	15.09	16.57	1422.3	1115.2	2537.5	1438.1	1276.8	2714.9	3.4101	2.1672	5.5772
318	591.15	10993.4	1.488	14.53	16.02	1433.8	1099.4	2533.3	1450.3	1259.1	2709.4	3.4300	2.1300	5.5599
320	593.15	11289.1	1.500	13.98	15.48	1445.7	1083.2	2528.9	1462.6	1241.1	2703.7	3.4500	2.0923	5.5423
322	595.15	11591.0	1.511	13.44	14.96	1457.5	1066.7	2524.3	1475.1	1222.6	2697.6	3.4702	2.0542	5.5244
324	597.15	11899.2	1.523	12.92	14.45	1469.5	1049.9	2519.4	1487.7	1203.6	2691.3	3.4906	2.0156	5.5062
326	599.15	12213.7	1.535	12.41	13.95	1481.7	1032.6	2514.3	1500.4	1184.2	2684.6	3.5111	1.9764	5.4876
328	601.15	12534.8	1.548	11.91	13.46	1494.0	1014.8	2508.8	1513.4	1164.2	2677.6	3.5319	1.9367	5.4685
330	603.15	12862.5	1.561	11.43	12.99	1506.4	996.7	2503.1	1526.5	1143.6	2670.2	3.5528	1.8962	5.4490
332	605.15	13197.0	1.575	10.95	12.53	1519.1	978.0	2497.0	1539.9	1122.5	2662.3	3.5740	1.8550	5.4290
334	607.15	13538.3	1.590	10.49	12.08	1531.9	958.7	2490.6	1553.4	1100.7	2654.1	3.5955	1.8129	5.4084
336	609.15	13886.7	1.606	10.03	11.63	1544.9	938.9	2483.7	1567.2	1078.1	2645.3	3.6172	1.7700	5.3872
338	611.15	14242.3	1.622	9.58	11.20	1558.1	918.4	2476.4	1581.2	1054.8	2636.0	3.6392	1.7261	5.3653
340	613.15	14605.2	1.639	9.14	10.78	1571.5	897.2	2468.7	1595.5	1030.7	2626.2	3.6616	1.6811	5.3427
342	615.15	14975.5	1.657	8.71	10.37	1585.2	875.2	2460.5	1610.0	1005.7	2615.7	3.6844	1.6350	5.3194
344	617.15	15353.5	1.676	8.286	9.962	1599.2	852.5	2451.7	1624.9	979.7	2604.7	3.7075	1.5877	5.2952
346	619.15	15739.3	1.696	7.870	9.566	1613.5	828.9	2442.4	1640.2	952.8	2593.0	3.7311	1.5391	5.2702
348	621.15	16133.1	1.718	7.461	9.178	1628.1	804.5	2432.6	1655.8	924.8	2580.7	3.7553	1.4891	5.2444
350	623.15	16535.1	1.741	7.058	8.799	1643.0	779.2	2422.2	1671.8	895.9	2567.7	3.7801	1.4375	5.2177
352	625.15	16945.5	1.766	6.654	8.420	1658.4	751.5	2410.8	1689.3	864.2	2553.5	3.8071	1.3822	5.1893
354	627.15	17364.4	1.794	6.252	8.045	1676.3	722.4	2398.7	1707.5	830.9	2538.4	3.8349	1.3247	5.1596
356	629.15	17792.2	1.824	5.850	7.674	1693.4	692.2	2385.6	1725.9	796.2	2522.1	3.8629	1.2654	5.1283
358	631.15	18229.0	1.858	5.448	7.306	1710.8	660.6	2371.4	1744.7	759.9	2504.6	3.8915	1.2037	5.0953
360	633.15	18675.1	1.896	5.044	6.940	1728.8	627.1	2355.8	1764.2	721.3	2485.4	3.9210	1.1390	5.0600
361	634.15	18901.7	1.917	4.840	6.757	1738.0	609.5	2347.5	1774.2	701.0	2475.2	3.9362	1.1052	5.0414
362	635.15	19130.7	1.939	4.634	6.573	1747.5	591.2	2338.7	1784.6	679.8	2464.4	3.9518	1.0702	5.0220
363	636.15	19362.1	1.963	4.425	6.388	1757.3	572.1	2329.3	1795.3	657.8	2453.0	3.9679	1.0338	5.0017
364	637.15	19596.1	1.988	4.213	6.201	1767.4	552.0	2319.4	1806.4	634.6	2440.9	3.9846	0.9958	4.9804
365	638.15	19832.6	2.016	3.996	6.012	1778.0	530.8	2308.8	1818.0	610.0	2428.0	4.0021	0.9558	4.9579
366	639.15	20071.6	2.046	3.772	5.819	1789.1	508.2	2297.3	1830.2	583.9	2414.1	4.0205	0.9134	4.9339
367	640.15	20313.2	2.080	3.540	5.621	1801.0	483.8	2284.8	1843.2	555.7	2399.0	4.0401	0.8680	4.9081
368	641.15	20557.5	2.118	3.298	5.416	1813.8	457.3	2271.1	1857.3	525.1	2382.4	4.0613	0.8189	4.8801
369	642.15	20804.4	2.162	3.039	5.201	1827.8	427.9	2255.7	1872.8	491.1	2363.9	4.0846	0.7647	4.8492
370	643.15	21054.0	2.214	2.759	4.973	1843.6	394.5	2238.1	1890.2	452.6	2342.8	4.1108	0.7036	4.8144
371	644.15	21306.4	2.278	2.446	4.723	1862.0	355.3	2217.3	1910.5	407.4	2317.9	4.1414	0.6324	4.7738
372	645.15	21561.6	2.364	2.075	4.439	1884.6	308.6	2193.2	1935.6	351.4	2287.0	4.1794	0.5446	4.7240
373	646.15	21819.7	2.496	1.588	4.084	1916.0	238.9	2154.9	1970.5	273.5	2244.0	4.2325	0.4233	4.6559
374	647.15	22080.5	2.843	0.623	3.466	1983.9	95.7	2079.7	2046.7	109.5	2156.2	4.3493	0.1692	4.5185

Table F.2 Superheated Steam, SI Units (Continued)

P/kPa T^{sat}/K (t^{sat}/°C)		sat. liq.	sat. vap.	TEMPERATURE: T kelvins (TEMPERATURE: t °C) 723.15 (450)	748.15 (475)	773.15 (500)	798.15 (525)	823.15 (550)	848.15 (575)	873.15 (600)	923.15 (650)
5800	V	1.312	33.651	54.026	56.357	58.644	60.896	63.120	65.320	67.500	71.807
546.50(273.35)	U	1194.7	2591.9	2992.9	3038.8	3084.4	3129.8	3175.2	3220.7	3266.4	3358.5
	H	1202.3	2787.0	3306.3	3365.7	3424.5	3483.0	3541.2	3599.5	3657.9	3775.0
	S	3.0071	5.9066	6.7416	6.8223	6.8996	6.9740	7.0460	7.1157	7.1835	7.3139
5900	V	1.315	33.034	53.048	55.346	57.600	59.819	62.010	64.176	66.322	70.563
547.61(274.46)	U	1200.3	2591.1	2991.9	3037.9	3083.5	3129.0	3174.4	3220.0	3265.7	3357.9
	H	1208.0	2786.0	3304.9	3364.4	3423.3	3481.9	3540.3	3598.6	3657.0	3774.3
	S	3.0172	5.8986	6.7322	6.8132	6.8906	6.9652	7.0372	7.1070	7.1749	7.3054
6000	V	1.319	32.438	52.103	54.369	56.592	58.778	60.937	63.071	65.184	69.359
548.70(275.55)	U	1205.8	2590.4	2990.8	3036.9	3082.6	3128.2	3173.7	3219.3	3265.1	3357.4
	H	1213.7	2785.0	3303.5	3363.2	3422.2	3480.8	3539.3	3597.7	3656.2	3773.5
	S	3.0273	5.8908	6.7230	6.8041	6.8818	6.9564	7.0285	7.0985	7.1664	7.2971
6100	V	1.322	31.860	51.189	53.424	55.616	57.771	59.898	62.001	64.083	68.196
549.78(276.63)	U	1211.2	2589.8	2989.8	3036.0	3081.8	3127.4	3173.0	3218.6	3264.5	3356.8
	H	1219.3	2783.9	3302.0	3361.9	3421.0	3479.8	3538.3	3596.8	3655.4	3772.8
	S	3.0372	5.8830	6.7139	6.7952	6.8730	6.9478	7.0200	7.0900	7.1581	7.2889
6200	V	1.325	31.300	50.304	52.510	54.671	56.797	58.894	60.966	63.018	67.089
550.85(277.70)	U	1216.6	2588.8	2988.7	3035.0	3080.9	3126.6	3172.2	3218.0	3263.8	3356.3
	H	1224.8	2782.9	3300.6	3360.6	3419.9	3478.7	3537.4	3595.9	3654.5	3772.1
	S	3.0471	5.8753	6.7049	6.7864	6.8644	6.9393	7.0116	7.0817	7.1498	7.2808
6300	V	1.328	30.757	49.447	51.624	53.757	55.853	57.921	59.964	61.986	65.979
551.90(278.75)	U	1221.9	2588.0	2987.7	3034.1	3080.1	3125.8	3171.5	3217.3	3263.2	3355.7
	H	1230.3	2781.8	3299.2	3359.3	3418.7	3477.7	3536.4	3595.0	3653.7	3771.4
	S	3.0568	5.8677	6.6960	6.7778	6.8559	6.9309	7.0034	7.0735	7.1417	7.2728
6400	V	1.332	30.230	48.617	50.767	52.871	54.939	56.978	58.993	60.987	64.922
552.94(279.79)	U	1227.2	2587.2	2986.6	3033.1	3079.2	3125.0	3170.8	3216.6	3262.6	3355.2
	H	1235.7	2780.6	3297.7	3358.0	3417.6	3476.6	3535.4	3594.1	3652.9	3770.7
	S	3.0664	5.8601	6.6872	6.7692	6.8475	6.9226	6.9952	7.0655	7.1337	7.2649
6500	V	1.335	29.719	47.812	49.935	52.012	54.053	56.065	58.052	60.018	63.898
553.97(280.82)	U	1232.5	2586.3	2985.5	3032.2	3078.3	3124.2	3170.0	3215.9	3261.9	3354.6
	H	1241.1	2779.5	3296.3	3356.8	3416.4	3475.6	3534.4	3593.2	3652.1	3770.0
	S	3.0759	5.8527	6.6786	6.7608	6.8392	6.9145	6.9871	7.0575	7.1258	7.2572

6600	V	1.338	29.223	47.031	49.129	51.180	53.194	55.179	57.139	59.079	62.905
554.99(281.84)	U	1237.8	2585.5	2984.5	3031.2	3077.4	3123.4	3169.3	3215.2	3261.3	3354.1
	H	1246.5	2778.3	3294.9	3355.5	3415.2	3474.5	3533.5	3592.3	3651.2	3769.2
	S	3.0853	5.8452	6.6700	6.7524	6.8310	6.9064	6.9792	7.0497	7.1181	7.2495
6700	V	1.342	28.741	46.274	48.346	50.372	52.361	54.320	56.254	58.168	61.942
555.99(282.84)	U	1242.8	2584.6	2983.4	3030.3	3076.6	3122.6	3168.6	3214.5	3260.7	3353.5
	H	1251.8	2777.1	3293.4	3354.2	3414.1	3473.4	3532.5	3591.4	3650.4	3768.5
	S	3.0946	5.8379	6.6618	6.7442	6.8229	6.8985	6.9714	7.0419	7.1104	7.2420
6800	V	1.345	28.272	45.539	47.587	49.588	51.552	53.486	55.395	57.283	61.007
556.99(283.84)	U	1247.9	2583.7	2982.3	3029.3	3075.7	3121.8	3167.8	3213.9	3260.0	3353.0
	H	1257.0	2775.9	3292.0	3352.9	3412.9	3472.4	3531.5	3590.5	3649.6	3767.8
	S	3.1038	5.8306	6.6532	6.7361	6.8150	6.8907	6.9636	7.0343	7.1028	7.2345
7000	V	1.351	27.373	44.131	46.133	48.086	50.003	51.889	53.750	55.590	59.217
558.94(285.79)	U	1258.0	2581.8	2980.1	3027.4	3074.0	3120.2	3166.3	3212.5	3258.8	3351.9
	H	1267.4	2773.5	3289.1	3350.3	3410.6	3470.2	3529.6	3588.7	3647.9	3766.4
	S	3.1219	5.8162	6.6368	6.7201	6.7993	6.8753	6.9485	7.0193	7.0880	7.2200
7200	V	1.358	26.522	42.802	44.759	46.668	48.540	50.381	52.197	53.991	57.527
560.85(287.70)	U	1267.9	2579.9	2978.0	3025.4	3072.2	3118.6	3164.9	3211.1	3257.5	3350.7
	H	1277.6	2770.9	3286.1	3347.7	3408.2	3468.1	3527.6	3586.9	3646.2	3764.9
	S	3.1397	5.8020	6.6208	6.7044	6.7840	6.8602	6.9337	7.0047	7.0735	7.2058
7400	V	1.364	25.715	41.544	43.460	45.327	47.156	48.954	50.727	52.478	55.928
562.72(289.57)	U	1277.6	2578.0	2975.8	3023.5	3070.4	3117.0	3163.4	3209.8	3256.2	3349.8
	H	1287.7	2768.3	3283.2	3345.1	3405.9	3466.0	3525.7	3585.1	3644.5	3763.5
	S	3.1571	5.7880	6.6050	6.6892	6.7691	6.8456	6.9192	6.9904	7.0594	7.1919
7600	V	1.371	24.949	40.351	42.228	44.058	45.845	47.603	49.335	51.045	54.413
564.56(291.41)	U	1287.2	2575.9	2973.6	3021.5	3068.7	3115.4	3161.9	3208.4	3254.9	3348.5
	H	1297.6	2765.5	3280.3	3342.5	3403.5	3463.8	3523.7	3583.3	3642.9	3762.1
	S	3.1742	5.7742	6.5896	6.6742	6.7545	6.8312	6.9051	6.9765	7.0457	7.1784
7800	V	1.378	24.220	39.220	41.060	42.850	44.601	46.320	48.014	49.686	52.976
566.36(293.21)	U	1296.7	2573.8	2971.4	3019.6	3066.9	3113.8	3160.4	3207.0	3253.7	3347.4
	H	1307.4	2762.8	3277.3	3339.8	3401.1	3461.7	3521.7	3581.5	3641.2	3760.6
	S	3.1911	5.7605	6.5745	6.6596	6.7402	6.8172	6.8913	6.9629	7.0322	7.1652
8000	V	1.384	23.525	38.145	39.950	41.704	43.419	45.102	46.759	48.394	51.611
568.12(294.97)	U	1306.0	2571.7	2969.2	3017.6	3065.1	3112.2	3158.9	3205.6	3252.4	3346.3
	H	1317.1	2759.9	3274.3	3337.2	3398.8	3459.5	3519.7	3579.7	3639.5	3759.2
	S	3.2076	5.7471	6.5597	6.6452	6.7262	6.8035	6.8778	6.9496	7.0191	7.1523