

Thermodynamics

1. Consider a coal with the ultimate analysis as follows: C (66.0%), H(4.4%), N(1.5%), O(7.9%), S(1.1%), H₂O(13.5%), and ash (5.6%). (a) Determine the reaction equation for complete combustion with 20% excess air and the air-fuel ratio employed. (b) If the reactants enter a steady-flow combustor at 298 K and the product are cooled to 500 K, determine the heat transfer, in kJ/kg fuel. (20%)
2. Air is compressed from 1 bar, 300 K, to 3.5 bars, 400 K, in a steady-flow device. (a) determine the entropy change of the air, in kJ/(kg K). (b) If any heat transfer is between the air and environment at 300 K, and the actual shaft work input is 170.0 kJ/kg, determine the total entropy change for the overall process, in kJ/(kg K). (15%)
3. A piston-cylinder device which contains water substance is used to execute a Carnot cycle. From an initial state of 513 K and 20% quality, the fluid is expanded isothermally until the pressure reaches 30 bars. This process is followed by an isentropic expansion to 423 K. For the cycle determine (a) the thermal efficiency, (b) the heat supplied and the heat rejected, in kJ/kg, and (c) the net work output, in kJ/kg. (15%)
4. A gas contained within a piston-cylinder device initially at 0.020 m³ and 10 bars is expanded quasistatically at constant pressure until the volume is 0.040 m³. It is then held at constant volume and cooled until its pressure is one-half of the initial value. Then it is compressed quasistatically to the original state by following the path PV=constant. Determine the net work for the cycle, in kilojoules. (15%)
5. Water vapor enters a subsonic diffuser at a pressure of 0.7 bar, a temperature of 433 K, and a velocity of 180 m/s. The inlet to the diffuser is 100 cm². During passage through the diffuser the fluid velocity is reduced to 60 m/s, the pressure increase to 1.0 bar, and 0.6 J/g of heat is transferred to the surroundings. Determine (a) the final temperature, (b) the mass flow rate, and (c) the outlet area in cm². (15%)
6. Describe briefly the following energy systems: (a) fuel cells, (b) batteries, (c) the combined cycle, and (d) cogeneration. (20%)

Properties of water: Superheated-vapor table
 t , °C; v , cm³/kg; u , kJ/kg; h , kJ/kg; s , kJ/(kg · K)

Temp., °C	0.06 bar (0.006 MPa) ($T_{sat} = 36.16^\circ\text{C}$)					0.35 bar (0.035 MPa) ($T_{sat} = 72.69^\circ\text{C}$)					5.0 bars (0.50 MPa) ($T_{sat} = 151.86^\circ\text{C}$)					7.0 bars (0.70 MPa) ($T_{sat} = 164.97^\circ\text{C}$)					40 bars (4.0 MPa) ($T_{sat} = 250.40^\circ\text{C}$)					60 bars (6.0 MPa) ($T_{sat} = 275.64^\circ\text{C}$)					
	t	v	u	h	s	t	v	u	h	s	t	v	u	h	s	t	v	u	h	s	t	v	u	h	s	t	v	u	h	s	
Sat.	23759	2425.0	2674.4	2631.4	7.7158	4526	2473.0	2631.4	7.7158	374.9	2561.2	2748.7	6.8213	2763.5	6.7080	Sat.	280	280	280	280	280	49.78	2602.3	2801.4	6.0701	60701	32.44	2589.7	2784.3	5.8892	
80	27132	2487.3	2650.1	2645.6	7.7564	4625	2483.7	2645.6	7.7564	404.5	2609.7	2812.0	6.9656	2799.1	6.7880	280	280	280	280	280	55.46	2680.0	2901.8	6.2568	62568	33.17	2605.2	2804.2	5.9252		
120	30219	2544.7	2726.0	2723.1	7.9644	5163	2542.4	2723.1	7.9644	424.9	2642.9	2855.4	7.0592	2799.9	6.8865	320	320	320	320	320	61.99	2767.4	3015.4	6.4553	64553	38.76	2720.0	2952.6	6.1846		
160	33302	2602.7	2802.5	2800.6	8.1519	5696	2601.2	2800.6	8.1519	464.6	2707.6	2939.9	7.2307	2701.8	7.0641	360	360	360	360	360	67.88	2845.7	3117.2	6.6215	66215	43.31	2811.2	3071.1	6.3782		
200	36383	2661.4	2879.7	2878.4	8.3237	6228	2660.4	2878.4	8.3237	503.4	2771.2	3022.9	7.3865	2766.9	7.2233	400	400	400	400	400	73.41	2919.9	3213.6	6.7690	67690	47.39	2892.9	3177.2	6.5408		
240	39462	2721.0	2957.8	2956.8	8.4828	6758	2720.3	2956.8	8.4828	541.6	2834.7	3105.6	7.5308	2831.3	7.3697	440	440	440	440	440	78.72	2992.2	3307.1	6.9004	69004	51.22	2970.0	3277.3	6.6853		
280	42540	2781.5	3036.8	3036.0	8.6314	7287	2780.9	3036.0	8.6314	579.6	2898.7	3188.4	7.6660	3184.7	7.5063	500	500	500	500	500	86.43	3099.5	3445.3	7.0901	70901	56.65	3082.2	3422.2	6.8803		
320	45618	2843.0	3116.7	3116.1	8.7712	7815	2842.5	3116.1	8.7712	617.3	2963.2	3271.9	7.7938	3268.7	7.6350	540	540	540	540	540	91.45	3171.1	3536.9	7.3056	73056	60.15	3156.1	3517.0	6.9999		
360	48696	2905.5	3197.7	3197.0	8.9034	8344	2905.1	3197.0	8.9034	654.8	3028.6	3356.0	7.9152	3353.3	7.7571	600	600	600	600	600	98.85	3279.1	3674.4	7.3888	73888	65.25	3266.9	3658.4	7.1677		
400	51774	2969.0	3279.6	3279.2	9.0291	8872	2968.6	3279.2	9.0291	710.9	3128.4	3443.9	8.0873	3441.7	7.9299	640	640	640	640	640	103.7	3351.8	3766.6	7.4720	74720	68.59	3341.0	3752.6	7.2731		
440	54851	3033.5	3362.6	3362.2	9.1490	9400	3033.2	3362.2	9.1490	804.1	3209.6	3529.9	8.3522	3527.0	8.1956	700	700	700	700	700	111.0	3462.1	3905.9	7.6198	76198	73.52	3453.1	3894.1	7.4234		
500	59467	3132.3	3489.1	3488.8	9.3194	10192	3132.1	3488.8	9.3194	896.9	3299.6	3617.5	8.5952	3615.3	8.4391	740	740	740	740	740	115.7	3536.6	3999.6	7.7141	77141	76.77	3528.3	3989.2	7.5190		
0.70 bar (0.07 MPa) ($T_{sat} = 89.95^\circ\text{C}$)																															
Sat.	2365	2494.5	2660.0	2655.5	7.3594	1694	2506.1	2675.5	7.3594	194.4	2583.6	2778.1	6.5865	2792.2	6.4448	100 bars (10.0 MPa) ($T_{sat} = 311.06^\circ\text{C}$)															
100	2434	2509.7	2719.6	2716.6	7.6375	1696	2506.7	2716.6	7.6375	200	2609.7	2827.9	6.6940	2796.8	6.5456	Sat.	2352	2569.8	2758.0	5.7432	57432	18.03	2544.4	2724.7	5.6141	56141	19.25	2588.8	2781.3	5.7103	
120	2571	2539.7	2796.2	2792.7	7.6597	1793	2537.3	2796.2	7.6597	240	2679.9	2920.4	6.8817	2899.3	6.6628	320	320	320	320	320	26.82	2662.7	2877.2	5.9489	59489	23.31	2729.1	2962.1	6.0060		
160	2841	2599.4	2796.2	2792.7	7.6597	1984	2597.8	2796.2	7.6597	280	2748.6	2992.7	7.0465	2992.7	6.8381	360	360	360	360	360	34.32	2863.8	3138.3	6.3424	63424	26.41	2832.4	3096.5	6.2120		
200	3108	2659.1	2876.7	2873.3	7.8343	2172	2658.1	2873.3	7.8343	320	2678.8	2836.1	7.1962	3081.9	6.9938	400	400	400	400	400	37.42	2946.7	3246.1	6.5190	65190	29.11	2922.1	3213.2	6.3805		
240	3374	2719.3	2955.5	2954.5	7.9949	2359	2718.5	2954.5	7.9949	360	2873.3	2891.6	7.3349	3189.9	7.2690	480	480	480	480	480	40.34	3025.7	3348.4	6.6586	66586	31.60	3005.4	3321.4	6.5282		
280	3640	2780.2	3035.0	3034.2	8.1445	2546	2779.6	3034.2	8.1445	400	3066.6	2957.3	7.6660	3263.9	7.5698	520	520	520	520	520	43.13	3102.7	3447.7	6.7871	67871	33.94	3085.6	3425.1	6.6622		
320	3905	2842.0	3115.3	3114.6	8.2849	2732	2841.5	3114.6	8.2849	440	3257.7	3023.6	7.9883	3349.3	7.8940	600	600	600	600	600	48.45	3254.4	3642.0	7.0206	70206	36.19	3164.1	3526.0	6.7864		
360	4170	2904.6	3196.5	3195.9	8.4175	2917	2904.2	3195.9	8.4175	500	354.1	3124.4	8.3475	3478.5	8.1959	640	640	640	640	640	51.02	3300.1	3738.3	7.1283	71283	38.37	3241.7	3625.3	6.9039		
400	4434	2968.2	3278.6	3278.2	8.5435	3103	2967.9	3278.2	8.5435	540	372.9	3192.6	8.7820	3565.6	8.3855	700	700	700	700	700	54.81	3443.9	3882.4	7.2812	72812	40.48	3318.9	3723.7	7.0131		
440	4698	3032.9	3361.8	3361.4	8.6636	3288	3032.6	3361.4	8.6636	600	401.1	3296.8	8.9290	3697.9	8.5385	740	740	740	740	740	57.29	3520.4	3978.7	7.3782	73782	43.58	3434.7	3870.5	7.1687		
500	5095	3131.8	3488.5	3488.1	8.8342	3565	3131.6	3488.1	8.8342	640	419.8	3367.4	9.1290	3783.8	8.7931	740	740	740	740	740	57.29	3520.4	3978.7	7.3782	73782	45.60	3512.1	3968.1	7.2670		
1.5 bars (0.15 MPa) ($T_{sat} = 111.57^\circ\text{C}$)																															
Sat.	1159	2519.7	2693.6	2693.6	7.2233	606	2543.6	2725.3	6.9919	99.6	2600.3	2799.5	6.3409	2804.2	6.1869	120 bars (12.0 MPa) ($T_{sat} = 324.75^\circ\text{C}$)															
120	1188	2533.3	2711.4	2711.4	7.2693	606	2543.6	2725.3	6.9919	108.5	2659.6	2876.5	6.4952	2824.3	6.2265	Sat.	1426	2513.7	2684.9	5.4924	54924	11.49	2476.8	2637.6	5.3717	53717	14.22	2617.4	2816.5	5.602	
160	1317	2595.2	2792.8	2792.8	7.4665	651	2587.1	2782.3	7.1276	120	2736.4	2976.4	6.6828	2941.3	6.4462	360	360	360	360	360	18.11	2678.4	2895.7	5.8361	58361	17.22	2760.9	3001.9	5.9448		
200	1444	2656.2	2872.9	2872.9	7.6433	716	2650.7	2865.5	7.3115	130.8	2807.9	3069.5	6.8452	3043.4	6.6245	440	440	440	440	440	21.08	2798.3	3051.3	6.0747	60747	19.54	2868.6	3142.2	6.1474		
240	1570	2717.2	2952.7	2952.7	7.8052	781	2713.1	2947.3	7.4774	141.1	2877.0	3159.3	6.9917	3138.7	6.7801	480	480	480	480	480	23.55	2896.1	3178.7	6.2586	62586	21.57	2942.5	3264.5	6.3143		
280	1695	2778.6	3032.8	3032.8	7.9555	844	2775.4	3028.6	7.6299	151.2	2945.2	3247.6	7.1271	3183.7	6.9212	520	520	520	520	520	25.76	2984.4	3293.5	6.4154	64154	23.43	3049.8	3377.8	6.4610		
320	1819	2840.6	3113.5	3113.5	8.0964	907	2838.1	3110.1	7.7722	161.1	3013.4	3335.5	7.2540	3230.9	7.0520	560	560	560	560	560	27.81	3068.0	3401.8	6.5555	65555	25.17	3133.6	3486.0	6.5941		
360	1943	2903.5	3195.0	3195.0	8.2293	969	2901.4	3192.2	7.9061	175.7	3116.2	3416.6	7.4317	3275.0	7.2338	600	600	600	600	600	29.77	3149.0	3506.2	6.6840	66840	27.43	3049.8	3377.8	6.4610		
400	2067	2967.3	3277.4	3277.4	8.3555	1032	2965.6	3275.0	8.0330	185.3	3185.6	3496.6	7.5434	3321.5	7.3520	640	640	640	640	640	31.64	3228.7	3586.3	6.8037	68037	28.83	3215.4	3591.1	6.7172		
440	2191	3032.1	3360.7	3360.7	8.4757	1094	3030.6	3358.7	8.1538	199.6	3258.0	3566.1	7.7024	3368.3	7.5085	700	700	700	700	700	33.45	3307.5	3709.0	6.9164	69164	28.43	3296.0	3694.1	6.8326		
500	2376	3131.2	3487.6	3487.6	8.6466	1187	3130.0	3486.0	8.3251	209.1																					

Ideal-gas specific-heat data for selected gases, kJ/(kg · K)

1. Zero-pressure specific heats for six common gases, where $k = c_p/c_v$

Temp., K	Air			Carbon dioxide (CO ₂)			Carbon monoxide (CO)			Temp., K
	c_p	c_v	k	c_p	c_v	k	c_p	c_v	k	
250	1.003	0.716	1.401	0.791	0.602	1.314	1.039	0.743	1.400	250
300	1.005	0.718	1.400	0.846	0.657	1.288	1.040	0.744	1.399	300
350	1.008	0.721	1.398	0.895	0.706	1.268	1.043	0.746	1.398	350
400	1.013	0.726	1.395	0.939	0.750	1.252	1.047	0.751	1.395	400
450	1.020	0.733	1.391	0.978	0.790	1.239	1.054	0.757	1.392	450
500	1.029	0.742	1.387	1.014	0.825	1.229	1.063	0.767	1.387	500
550	1.040	0.753	1.381	1.046	0.857	1.220	1.075	0.778	1.382	550
600	1.051	0.764	1.376	1.075	0.886	1.213	1.087	0.790	1.376	600
650	1.063	0.776	1.370	1.102	0.913	1.207	1.100	0.803	1.370	650
700	1.075	0.788	1.364	1.126	0.937	1.202	1.113	0.816	1.364	700
750	1.087	0.800	1.359	1.148	0.959	1.197	1.126	0.829	1.358	750
800	1.099	0.812	1.354	1.169	0.980	1.193	1.139	0.842	1.353	800
900	1.121	0.834	1.344	1.204	1.015	1.186	1.163	0.866	1.343	900
1000	1.142	0.855	1.336	1.234	1.045	1.181	1.185	0.888	1.335	1000

Temp., K	Hydrogen (H ₂)			Nitrogen (N ₂)			Oxygen (O ₂)			Temp., K
	c_p	c_v	k	c_p	c_v	k	c_p	c_v	k	
250	14.051	9.927	1.416	1.039	0.742	1.400	0.913	0.653	1.398	250
300	14.307	10.183	1.405	1.039	0.743	1.400	0.918	0.658	1.395	300
350	14.427	10.302	1.400	1.041	0.744	1.399	0.928	0.668	1.389	350
400	14.476	10.352	1.398	1.044	0.747	1.397	0.941	0.681	1.382	400
450	14.501	10.377	1.398	1.049	0.752	1.395	0.956	0.696	1.373	450
500	14.513	10.389	1.397	1.056	0.759	1.391	0.972	0.712	1.365	500
550	14.530	10.405	1.396	1.065	0.768	1.387	0.988	0.728	1.358	550
600	14.546	10.422	1.396	1.075	0.778	1.382	1.003	0.743	1.350	600
650	14.571	10.447	1.395	1.086	0.789	1.376	1.017	0.758	1.343	650
700	14.604	10.480	1.394	1.098	0.801	1.371	1.031	0.771	1.337	700
750	14.645	10.521	1.392	1.110	0.813	1.365	1.043	0.783	1.332	750
800	14.695	10.570	1.390	1.121	0.825	1.360	1.054	0.794	1.327	800
900	14.822	10.698	1.385	1.145	0.849	1.349	1.074	0.814	1.319	900
1000	14.983	10.859	1.380	1.167	0.870	1.341	1.090	0.830	1.313	1000

Source: Data adapted from *Tables of Thermal Properties of Gases*, NBS Circular 564, 1955.

2. Specific-heat data for monatomic gases

Over a wide range of temperatures at low pressures, the specific heats c_p and c_v of all monatomic gases are essentially independent of temperature and pressure. In addition, on a molar basis all monatomic gases have the same value for either c_p or c_v in a given set of units. One set of values is

$$c_p = 12.5 \text{ kJ/(kgmol} \cdot \text{K)} \quad \text{and} \quad c_v = 20.8 \text{ kJ/(kgmol} \cdot \text{K)}$$

Source: Data adapted from *Tables of Thermal Properties of Gases*, NBS Circular 564, 1955.

3. Constant-pressure specific-heat equations for various gases at zero pressure (SI units)

$$\frac{c_p}{R_u} = a + bT + cT^2 + dT^3 + eT^4$$

where T is in kelvins, equation valid from 300 to 1000 K

Gas	a	$b \times 10^3$	$c \times 10^6$	$d \times 10^9$	$e \times 10^{12}$
CO	3.710	-1.619	3.692	-2.032	0.240
CO ₂	2.401	8.735	-6.607	2.002	
H ₂	3.057	2.677	-5.180	5.521	-1.812
H ₂ O	4.070	-1.108	4.152	-2.964	0.807
O ₂	3.626	-1.878	7.056	-6.764	2.156
N ₂	3.675	-1.208	2.324	-0.632	-0.226
Air (dry)	3.653	-1.334	3.291	-1.910	0.275
NH ₃	3.591	0.494	8.345	-8.383	2.730
NO	4.046	-3.418	7.982	-6.114	1.592
NO ₂	3.459	2.065	6.687	-9.556	3.620
SO ₂	3.267	5.324	0.684	-5.281	2.559
SO ₃	2.578	14.556	-9.176	-0.792	1.971
CH ₄	3.826	-3.979	24.558	-22.733	6.963
C ₂ H ₂	1.410	19.057	-24.501	16.391	-4.135
C ₂ H ₄	1.426	11.383	7.989	-16.254	6.749

Source: Adapted from the data in NASA SP-273, Government Printing Office, Washington, 1971.

Properties of saturated water: Pressure table

v , cm³/g; u , kJ/kg; h , kJ/kg; s , kJ/(kg · K); 1 bar = 0.1 MPa

Press., bars P	Temp., °C T	Specific volume		Internal energy		Enthalpy		Entropy		
		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
0.040	28.96	1.0040	34800	121.45	2415.2	121.46	2412.9	2354.4	4226	8.4746
0.060	36.16	1.0064	23739	151.53	2425.0	151.53	2415.9	2367.4	5210	8.3304
0.080	41.51	1.0084	18103	173.87	2432.2	173.88	2403.1	2377.0	5926	8.2287
0.10	45.81	1.0102	14674	191.82	2437.9	191.83	2392.8	2384.7	6493	8.1502
0.20	60.06	1.0172	7649	251.38	2456.7	251.40	2358.3	2609.7	8320	7.9085
0.30	69.10	1.0223	5229	289.20	2468.4	289.23	2336.1	2625.3	9439	7.7686
0.40	75.87	1.0265	3993	317.53	2477.0	317.58	2319.2	2636.8	10259	7.6700
0.50	81.33	1.0300	3240	340.44	2483.9	340.49	2305.4	2645.9	10910	7.5919
0.60	85.94	1.0331	2732	359.79	2489.6	359.86	2293.6	2653.5	11453	7.5320
0.70	89.95	1.0360	2365	376.63	2494.5	376.70	2283.3	2660.0	11919	7.4797
0.80	93.50	1.0380	2087	391.58	2498.8	391.66	2274.1	2665.8	12329	7.4346
0.90	96.71	1.0410	1869	405.06	2502.6	405.15	2265.7	2670.9	12695	7.3949
1.00	99.63	1.0432	1694	417.36	2506.1	417.46	2258.0	2675.5	13026	7.3594
1.50	111.4	1.0528	1159	466.94	2519.7	467.11	2226.5	2693.6	14336	7.2233
2.00	120.2	1.0605	885.7	504.49	2529.5	504.70	2201.9	2706.7	15301	7.1271
2.50	127.4	1.0672	718.7	535.10	2537.2	535.37	2181.5	2716.9	16072	7.0527
3.00	133.6	1.0732	605.8	561.15	2543.6	561.47	2163.8	2725.3	16718	6.9919
3.50	138.9	1.0786	524.3	583.95	2549.6	584.33	2148.1	2732.4	17275	6.9405
4.00	143.6	1.0836	462.5	604.31	2555.6	604.74	2133.8	2738.6	17766	6.8959
4.50	147.9	1.0882	414.0	622.25	2557.6	623.23	2120.7	2743.9	18207	6.8565
5.00	151.9	1.0926	374.9	639.68	2561.2	640.23	2108.5	2748.7	18607	6.8212
6.00	158.9	1.1006	315.7	669.90	2567.4	670.56	2086.3	2756.8	19312	6.7600
7.00	165.0	1.1080	272.9	696.44	2572.5	697.22	2066.3	2763.5	19922	6.7080
8.00	170.4	1.1148	240.4	720.22	2576.8	721.11	2048.0	2769.1	20462	6.6628
9.00	175.4	1.1212	215.0	741.83	2580.5	742.83	2031.1	2773.9	20946	6.6226
10.0	179.9	1.1273	194.4	761.68	2583.6	762.81	2015.3	2778.1	21387	6.5843
15.0	198.3	1.1539	131.8	843.16	2594.5	844.84	1947.3	2792.2	23150	6.4848
20.0	212.4	1.1767	99.63	906.44	2603.1	908.79	1890.7	2799.5	24474	6.3409
25.0	224.0	1.1973	79.98	959.11	2609.1	962.11	1841.0	2803.1	25547	6.2575
30.0	233.9	1.2165	66.68	1004.8	2614.1	1008.4	1795.7	2804.2	26457	6.1869
35.0	242.6	1.2347	57.07	1045.4	2618.7	1049.8	1753.7	2803.4	27253	6.1253
40.0	250.4	1.2522	49.78	1082.3	2623.3	1087.3	1714.4	2801.4	27964	6.0701
45.0	257.5	1.2692	44.06	1116.2	2627.1	1121.9	1676.4	2800.3	28610	6.0199
50.0	264.0	1.2859	39.44	1147.8	2597.1	1154.2	1640.1	2794.3	29202	5.9734
60.0	275.6	1.3187	32.44	1205.4	2589.7	1213.4	1571.0	2784.3	30267	5.8892
70.0	285.9	1.3513	27.37	1257.6	2580.5	1267.0	1505.1	2772.1	31211	5.8133
80.0	295.1	1.3842	23.52	1305.6	2569.8	1316.6	1441.3	2758.0	32068	5.7432
90.0	303.4	1.4178	20.48	1350.5	2557.8	1363.3	1378.9	2742.1	32858	5.6772
100.	311.1	1.4524	18.03	1393.0	2544.4	1407.6	1317.1	2724.7	33596	5.6141
110.	318.2	1.4886	15.99	1433.7	2529.8	1450.1	1255.5	2705.6	34295	5.5527
120.	324.8	1.5267	14.26	1473.0	2513.7	1491.3	1193.6	2684.9	34962	5.4924
130.	330.9	1.5671	12.78	1511.1	2496.1	1531.5	1130.7	2662.2	35606	5.4323
140.	336.8	1.6107	11.49	1548.6	2476.8	1571.1	1066.5	2637.6	36232	5.3717
150.	342.2	1.6581	10.34	1585.6	2455.5	1610.5	1000.0	2610.5	36848	5.3098
160.	347.4	1.7107	9.306	1622.7	2431.7	1650.1	930.6	2580.6	37461	5.2455
170.	352.4	1.7702	8.364	1660.2	2405.0	1690.3	856.9	2547.2	38079	5.1777
180.	357.1	1.8397	7.489	1698.9	2374.3	1732.0	777.1	2509.1	38715	5.1044
190.	361.5	1.9243	6.657	1739.9	2338.1	1776.5	688.4	2464.5	39388	5.0228
200.	365.8	2.016	5.834	1785.6	2293.0	1826.3	583.0	2409.7	40139	4.9269
220.9	374.1	3.155	3.155	2029.6	2029.6	2099.3	0	2099.3	44298	4.4298

Source: J. H. Keenan, F. Keyes, P. Hill, and J. Moore, "Steam Tables," Wiley, New York, 1969.

Physical constants and conversion factors

Physical constants	
Avogadro's number	$N_A = 6.023 \times 10^{26}$ atoms/kgmol
Universal gas constant	$R_u = 0.08205$ L·atm/(gmol·K)
	$= 8.314$ kJ/(kgmol·K)
	$= 0.08314$ bar·m ³ /(kgmol·K)
	$= 8.314$ kPa·m ³ /(kgmol·K)
Planck's constant	$h = 6.626 \times 10^{-34}$ J·s/molecule
Boltzmann's constant	$k = 1.380 \times 10^{-23}$ J/(K·molecule)
Speed of light	$c = 2.988 \times 10^{10}$ cm/s
Standard gravity	$g = 9.80665$ m/s ²
Conversion factors	
Length	1 cm = 0.3937 in = 10 ⁴ μm = 10 ⁸ Å
	1 km = 0.6215 mi = 3281 ft
Mass	1 kg = 2.205 lb _m
	1 N = 1 kg·m/s ² = 0.2248 lb _f
Pressure	1 bar = 10 ⁵ N/m ² = 0.9869 atm
	= 100 kPa
	1 torr = 1 mmHg at 0°C = 1.333 mbar
	= 1.933 × 10 ⁻² psi
1 mbar = 0.402 inHg	1 O ₂
Volume	1 L = 0.0353 ft ³ = 0.2642 gal = 61.025 in ³ = 10 ⁻³ m ³
	1 g/cm ³ = 1 kg/L = 62.4 lb _m /ft ³ = 10 ³ kg/m ³
Density	1 J = 1 N·m = 1 V·C
	= 0.7375 ft·lb _f = 10 bar·cm ³ = 0.624 × 10 ¹⁹ eV
Energy	1 kJ = 0.948 Btu = 737.6 ft·lb _f = 10 ⁻² bar·m ³
	1 kJ/kg = 0.431 Btu/lb
Power	1 W = 1 J/s = 3.413 Btu/h
	1 kW = 1.3405 hp = 737.3 ft·lb _f /s
Velocity	1 m/s = 2.237 mi/h = 3.60 km/h = 3.281 ft/s
	Specific heat 1 kJ/(kg·K) = 0.2389 Btu/(lb _m ·°F)
Temperature	$T(K) = \frac{5}{9}[T(^{\circ}F) + 459.67] = T(^{\circ}C) + 273.15 = T(^{\circ}R)/1.8$

SI derived units and common multipliers

1. Some SI derived units			
Physical quantity	Unit	Symbol	Definition
Force	newton	N	1 kg·m/s ²
Pressure	pascal	Pa	1 kg/m·s ² (= 1 N/m ²)
	bar	bar	10 ⁵ kg/m·s ² (= 10 ⁵ N/m ²)
Energy	joule	J	1 kg·m ² /s ² (= 1 N·m)
Power	watt	W	1 kg·m ² /s ³ (= 1 J/s)
Electric quantity	coulomb	C	1 A·s
Electric potential difference	volt	V	1 kg·m ² /(A·s ³) (= 1 A·Ω)
Electric resistance	ohm	Ω	1 kg·m ² /(A ² ·s ³) (= 1 V/A)
Electric capacitance	farad	F	1 A ² ·s ⁴ /(kg·m ²) (= 1 C/V)
2. Names and symbols for common multipliers of SI units			
Multiplier	Prefix	Symbol	
10 ⁹	giga	G	
10 ⁶	mega	M	
10 ³	kilo	k	
10 ⁻¹	deci	d	
10 ⁻²	centi	c	
10 ⁻³	milli	m	
10 ⁻⁶	micro	μ	
10 ⁻⁹	nano	n	

Properties of saturated water: Temperature table
 v_f , cm³/g; u_f , kJ/kg; h_f , kJ/kg; s_f , kJ/(kg·K); 1 bar = 0.1 MPa

Temp., °C T	Press., bars P	Specific volume		Internal energy		Enthalpy			Entropy	
		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	0.00611	1.0002	206278	-0.03	2375.4	-0.02	2501.4	2501.3	0.0001	9.1565
4	0.00813	1.0001	157232	16.77	2380.9	-16.78	2491.9	2508.7	0.0610	9.0514
5	0.00872	1.0001	147120	20.97	2382.3	20.98	2489.6	2510.6	0.0761	9.0257
6	0.00935	1.0001	137734	25.19	2383.6	25.20	2487.2	2512.4	0.0912	9.0003
8	0.01072	1.0002	120917	33.59	2386.4	33.60	2482.5	2516.1	0.1212	8.9501
10	0.01228	1.0004	106379	42.00	2389.2	42.01	2477.7	2519.8	0.1510	8.9008
11	0.01312	1.0004	99857	46.20	2390.5	46.20	2475.4	2521.6	0.1658	8.8765
12	0.01402	1.0005	93784	50.41	2391.9	50.41	2473.0	2523.4	0.1806	8.8524
13	0.01497	1.0007	88124	54.60	2393.3	54.60	2470.7	2525.3	0.1953	8.8285
14	0.01598	1.0008	82848	58.79	2394.7	58.80	2468.3	2527.1	0.2099	8.8048
15	0.01705	1.0009	77926	62.99	2396.1	62.99	2465.9	2528.9	0.2245	8.7814
16	0.01818	1.0011	73333	67.18	2397.4	67.19	2463.6	2530.8	0.2390	8.7582
17	0.01938	1.0012	69044	71.38	2398.8	71.38	2461.2	2532.6	0.2535	8.7351
18	0.02064	1.0014	65038	75.57	2400.2	75.58	2458.8	2534.4	0.2679	8.7123
19	0.02198	1.0016	61293	79.76	2401.6	79.77	2456.5	2536.2	0.2823	8.6897
20	0.02339	1.0018	57791	83.95	2402.9	83.96	2454.1	2538.1	0.2966	8.6672
21	0.02487	1.0020	54514	88.14	2404.3	88.14	2451.8	2539.9	0.3109	8.6450
22	0.02645	1.0022	51447	92.32	2405.7	92.33	2449.4	2541.7	0.3251	8.6229
23	0.02810	1.0024	48574	96.51	2407.0	96.52	2447.0	2543.5	0.3393	8.6011
24	0.02985	1.0027	45883	100.70	2408.4	100.70	2444.7	2545.4	0.3534	8.5794
25	0.03169	1.0029	43360	104.88	2409.8	104.89	2442.3	2547.2	0.3674	8.5580
26	0.03363	1.0032	40994	109.06	2411.1	109.07	2439.9	2549.0	0.3814	8.5367
27	0.03567	1.0035	38774	113.25	2412.5	113.25	2437.6	2550.8	0.3954	8.5156
28	0.03782	1.0037	36690	117.42	2413.9	117.43	2435.2	2552.6	0.4093	8.4946
29	0.04008	1.0040	34733	121.60	2415.2	121.61	2432.8	2554.5	0.4231	8.4739
30	0.04246	1.0043	32894	125.78	2416.6	125.79	2430.5	2556.3	0.4369	8.4533
31	0.04496	1.0046	31165	129.96	2418.0	129.97	2428.1	2558.1	0.4507	8.4329
32	0.04759	1.0050	29540	134.14	2419.3	134.15	2425.7	2559.9	0.4644	8.4127
33	0.05034	1.0053	28011	138.32	2420.7	138.33	2423.4	2561.7	0.4781	8.3927
34	0.05324	1.0056	26571	142.50	2422.0	142.50	2421.0	2563.5	0.4917	8.3728
35	0.05628	1.0060	25216	146.67	2423.4	146.68	2418.6	2565.3	0.5053	8.3531
36	0.05947	1.0063	23940	150.85	2424.7	150.86	2416.2	2567.1	0.5188	8.3336
38	0.06632	1.0071	21602	159.20	2427.4	159.21	2411.5	2570.7	0.5458	8.2950
40	0.07384	1.0078	19523	167.56	2430.1	167.57	2406.7	2574.3	0.5725	8.2570
45	0.09593	1.0099	15258	188.44	2438.8	188.45	2394.8	2583.2	0.6387	8.1648
50	.1235	1.0121	12032	209.32	2443.5	209.33	2382.7	2592.1	.7038	8.0763
55	.1576	1.0146	9568	230.21	2450.1	230.23	2370.7	2600.9	.7679	7.9913
60	.1993	1.0172	7671	251.11	2456.6	251.13	2358.5	2609.6	.8312	7.9096
65	.2504	1.0199	6197	272.02	2463.1	272.06	2346.2	2618.3	.8935	7.8310
70	.3119	1.0228	5042	292.95	2469.6	292.98	2333.8	2626.8	.9549	7.7553
75	.3858	1.0259	4131	313.90	2475.9	313.93	2321.4	2635.3	1.0155	7.6824
80	.4739	1.0291	3407	334.86	2482.2	334.91	2308.8	2643.7	1.0753	7.6122
85	.5783	1.0325	2828	355.84	2488.4	355.90	2296.0	2651.9	1.1343	7.5445
90	.7014	1.0360	2361	376.85	2494.5	376.92	2283.2	2660.1	1.1925	7.4791
95	.8455	1.0397	1982	397.88	2500.6	397.96	2270.2	2668.1	1.2500	7.4159
100	1.014	1.0435	1673.	418.94	2506.5	419.04	2257.0	2676.1	1.3069	7.3549
110	1.433	1.0516	1210.	461.14	2518.1	461.30	2230.2	2691.5	1.4185	7.2387
120	1.985	1.0603	891.9	503.50	2529.3	503.71	2202.6	2706.3	1.5276	7.1296
130	2.701	1.0697	668.5	546.02	2539.9	546.31	2174.2	2720.5	1.6344	7.0269
140	3.613	1.0797	508.9	588.74	2550.0	589.13	2144.7	2733.9	1.7391	6.9299
150	4.758	1.0905	392.8	631.68	2559.5	632.20	2114.3	2746.5	1.8418	6.8379
160	6.178	1.1020	307.1	674.86	2568.4	675.55	2082.6	2758.1	1.9427	6.7502
170	7.917	1.1143	242.8	718.33	2576.5	719.21	2049.5	2768.7	2.0419	6.6663
180	10.02	1.1274	194.1	762.09	2583.7	763.22	2015.0	2778.2	2.1396	6.5857
190	12.54	1.1414	156.5	806.19	2590.0	807.62	1978.8	2786.4	2.2359	6.5079
200	15.54	1.1565	127.4	850.65	2595.3	852.45	1940.7	2793.2	2.3309	6.4323
210	19.06	1.1726	104.4	895.53	2599.5	897.76	1900.7	2798.5	2.4248	6.3585
220	23.18	1.1900	86.19	940.87	2602.4	943.62	1858.5	2802.1	2.5178	6.2861
230	27.95	1.2088	71.58	986.74	2603.9	990.12	1813.8	2804.0	2.6099	6.2146
240	33.44	1.2291	59.76	1033.2	2604.0	1037.3	1766.5	2803.8	2.7015	6.1437
250	39.73	1.2512	50.13	1080.4	2602.4	1085.4	1716.2	2801.5	2.7927	6.0730
260	46.88	1.2755	42.21	1128.4	2599.0	1134.4	1662.5	2796.6	2.8838	6.0019
270	54.99	1.3023	35.64	1177.4	2593.7	1184.5	1605.2	2789.7	2.9751	5.9301
280	64.12	1.3321	30.17	1227.5	2586.1	1236.0	1543.6	2779.6	3.0668	5.8571
290	74.36	1.3656	25.57	1278.9	2576.0	1289.1	1477.1	2766.2	3.1594	5.7821
300	85.81	1.4036	21.67	1332.0	2563.0	1344.0	1404.9	2749.0	3.2534	5.7045
320	112.7	1.4988	15.49	1444.6	2525.5	1461.5	1238.6	2700.1	3.4480	5.5362
340	145.9	1.6379	10.80	1570.3	2464.6	1594.2	1027.9	2622.0	3.6594	5.3357
360	186.5	1.8925	6.945	1725.2	2351.5	1760.5	720.5	2481.0	3.9147	5.0526
374.14	220.9	3.155	3.155	2029.6	2029.6	2099.3	0	2099.3	4.4298	4.4298

Source: J. H. Keenan, F. G. Keyes, P. G. Hill, and J. G. Moore, "Steam Tables," Wiley, New York, 1969.