Thermodynamics ENME 333
Chapter 3
Properties of pure substances

Afif Akel Hasan

Mechanical & Mechatronics Engineering Department

Outline

- What is a pure substance
- Vapor- liquid equilibrium
  - Saturation temperature and pressure
  - Compressed or sub-cooled region
  - Super heated vapor region
- Critical point
- Phase diagram
- Independent properties of a pure substance
- Equation of state,
  - ideal gas equation
  - Real gases and the generalized compressibility factor
- Thermodynamic tables

Pure Substance

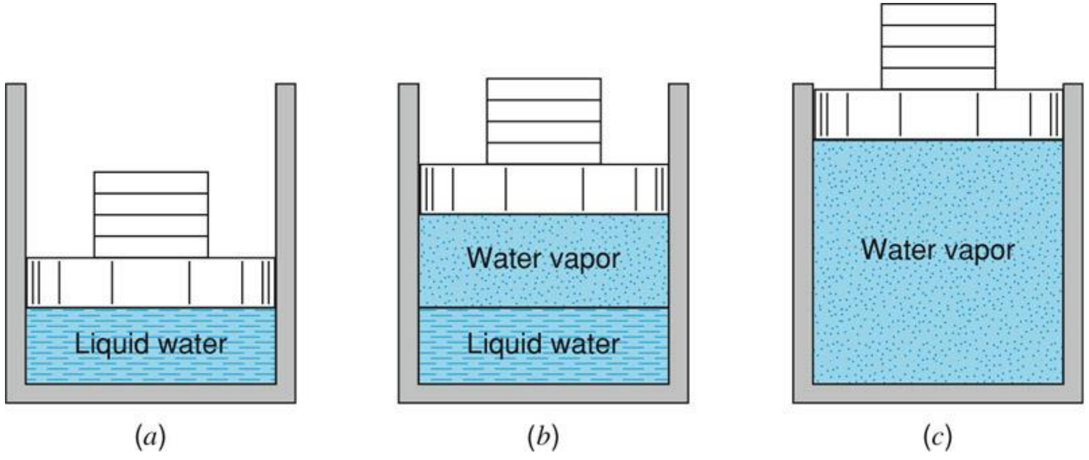
- Pure Substance: a substance that has a homogenous and invariable chemical composition.
- It may have different phases but with the same chemical composition.
- Examples: water though it might exist as ice, liquid or vapor. Other examples include ammonia, nitrogen, and helium.
- Some time a mixture of gases, such as air is considered a pure substance as long as it remains in the gaseous phase. Since liquid air has different composition than gaseous air, as oxygen condenses first.

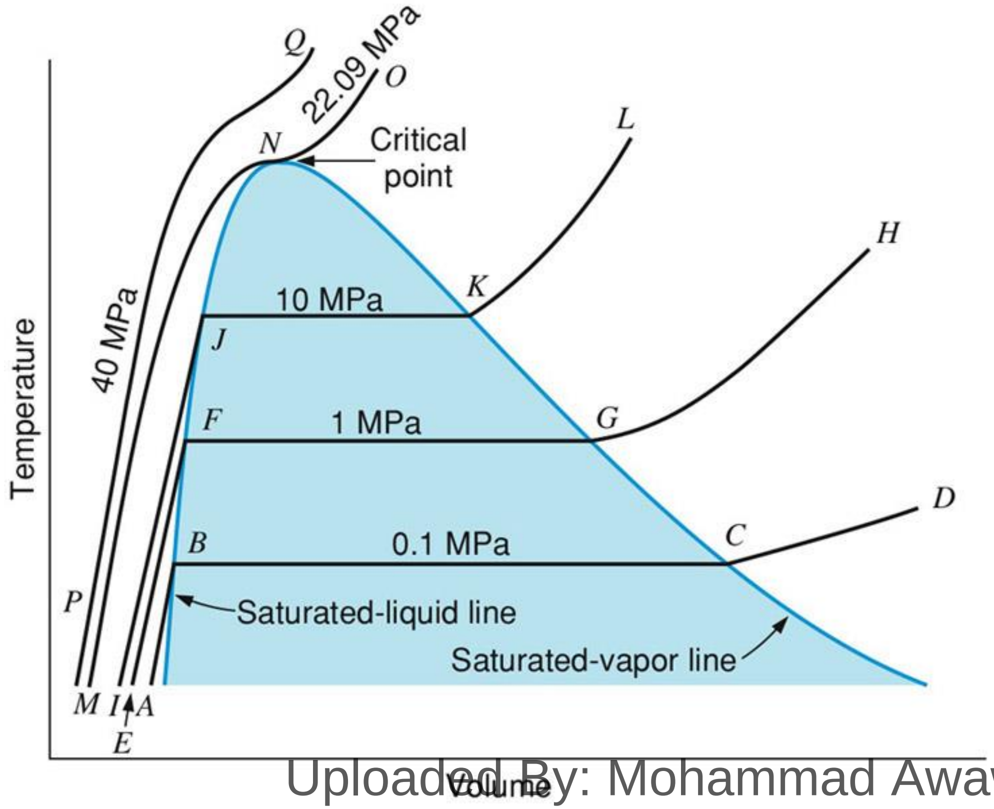
Properties of a pure substance

- In this chapter the properties of pure substances will be explained and how to determine such properties.
- It will include the properties in different phases and the equilibrium between the phases.
- Properties will include temperature, pressure, and specific -volume, more properties will be discussed in the coming chapters.
- Emphasis will be on properties of water, refrigerants and ideal gases.
- Temperature and volume diagrams and their use will be explained also in this chapter.

Vapor – liquid equilibrium

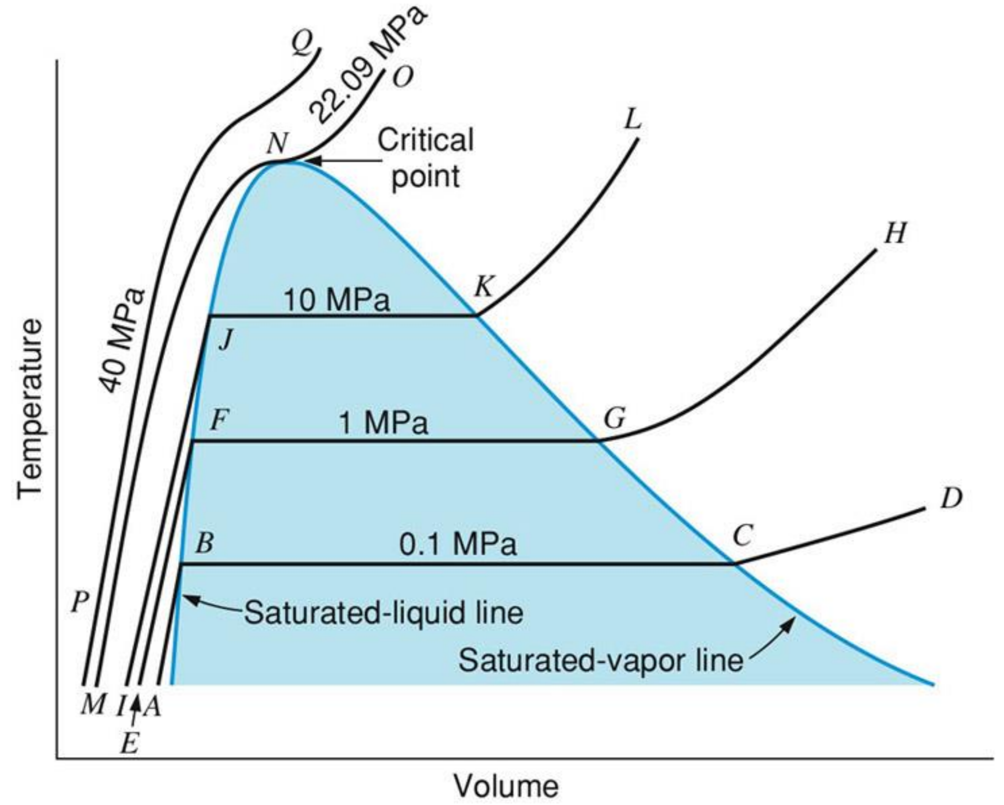
- Water contained in a frictionless piston is heated at constant pressure of 0.1 MPa, the specific volume will increase as the temperature is increased until it reaches the boiling point B in figure 3.3 p.42.





Saturation condition

- Point B is known as saturation condition, the temperature is called the saturation temperature and the pressure is called the saturation pressure.
- The water liquid is known as saturated liquid.
- The temperature remains constant at the saturation temperature and the liquid starts evaporating into vapor as long as the pressure is fixed. The vapor formed at this condition is known as the saturated vapor.
- As more heat is added the liquid evaporated at constant temperature while the specific volume increases, until point **c** where all liquid becomes vapor.



Saturation condition

- saturated temperature is the temperature at which vaporization takes place at a given pressure known as the saturation pressure.
- Saturation condition is the condition where two or more phases coexist together in equilibrium. Any phase of the substance existing under such condition is called saturated phase.
- The liquid formed at this condition is known as the saturated liquid while the formed vapor is known as saturated vapor.

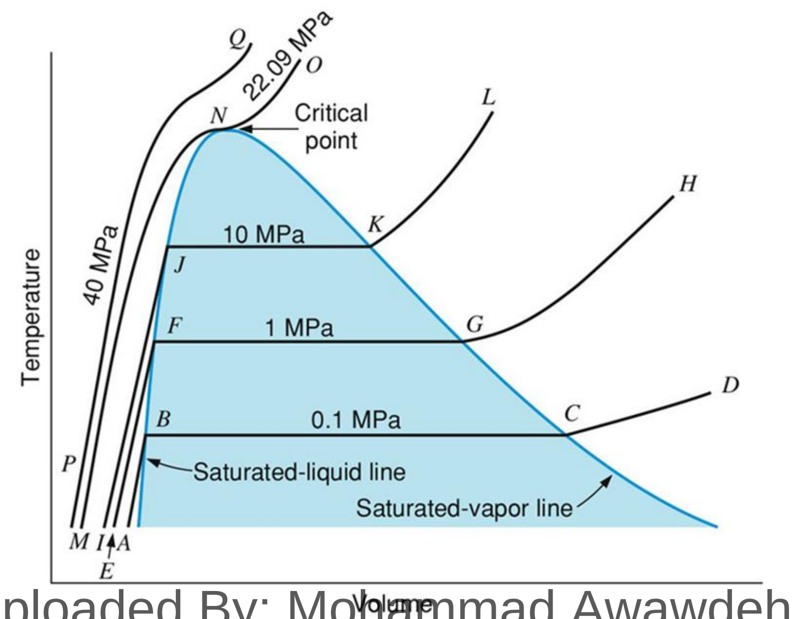
Quality

- At point B in figure 3.3 all substance exists as saturated liquid. At point **C** all substance exists as saturated vapor.
- In between point B and C there is a mixture of saturated liquid and vapor.
- In this saturation region the mixture is specified by using the term called quality.
- Quality is defined as the ratio of the vapor mass to the total mass of the mixture, and the symbol, x, is used.

x = mass of vapor/ total mass of mixture.

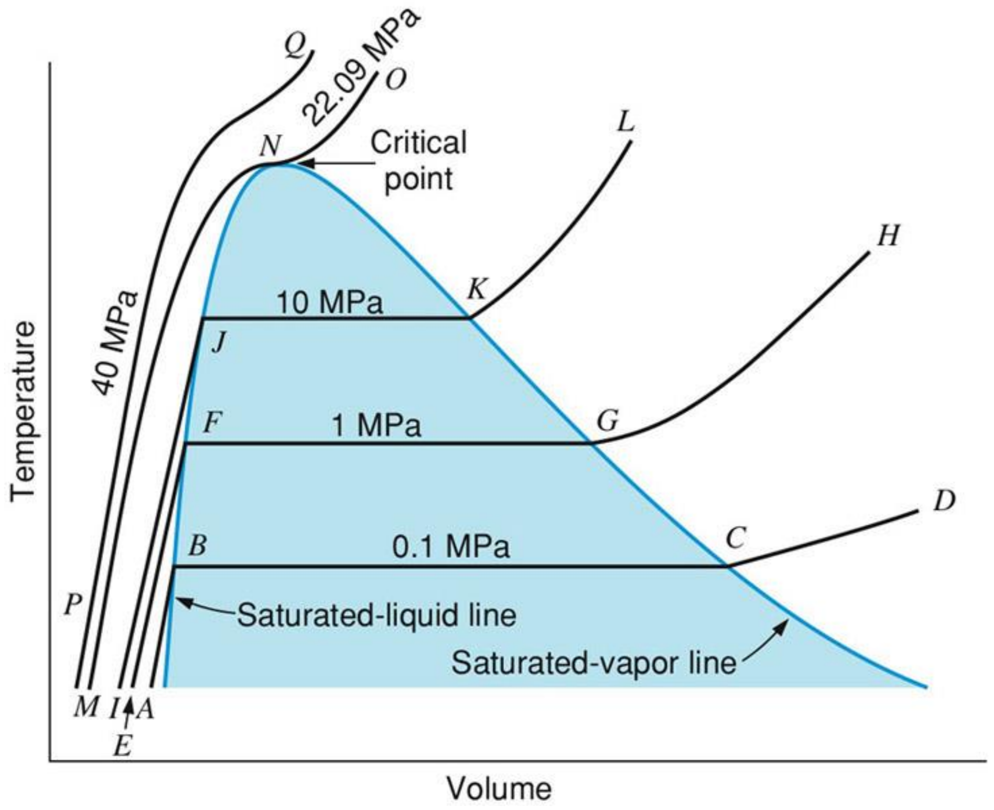
- Quality is zero at point B and equal to one at point C,

at point C steam is called dry steam



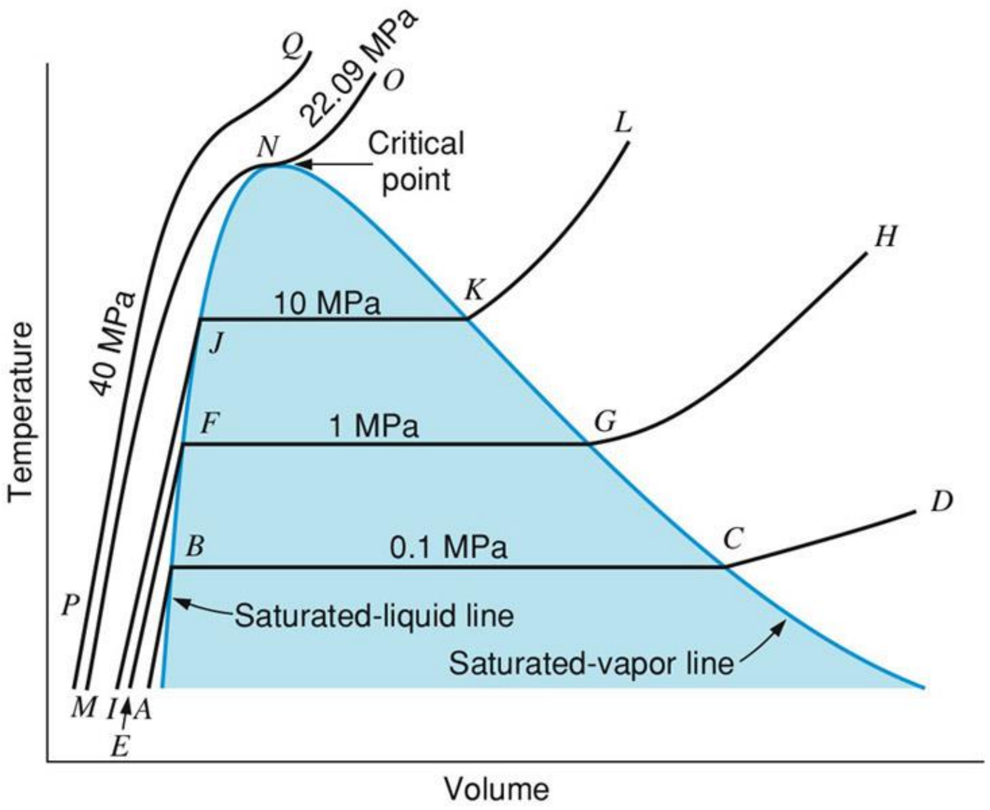
Subcooled liquid

- Sub-cooled liquid or compressed liquid: the substance existing as liquid lower than the saturation temperature at the given pressure. For example water below 99.6°C when pressure is one atmosphere.
- Water between A and B at 0.1 MPa in figure.



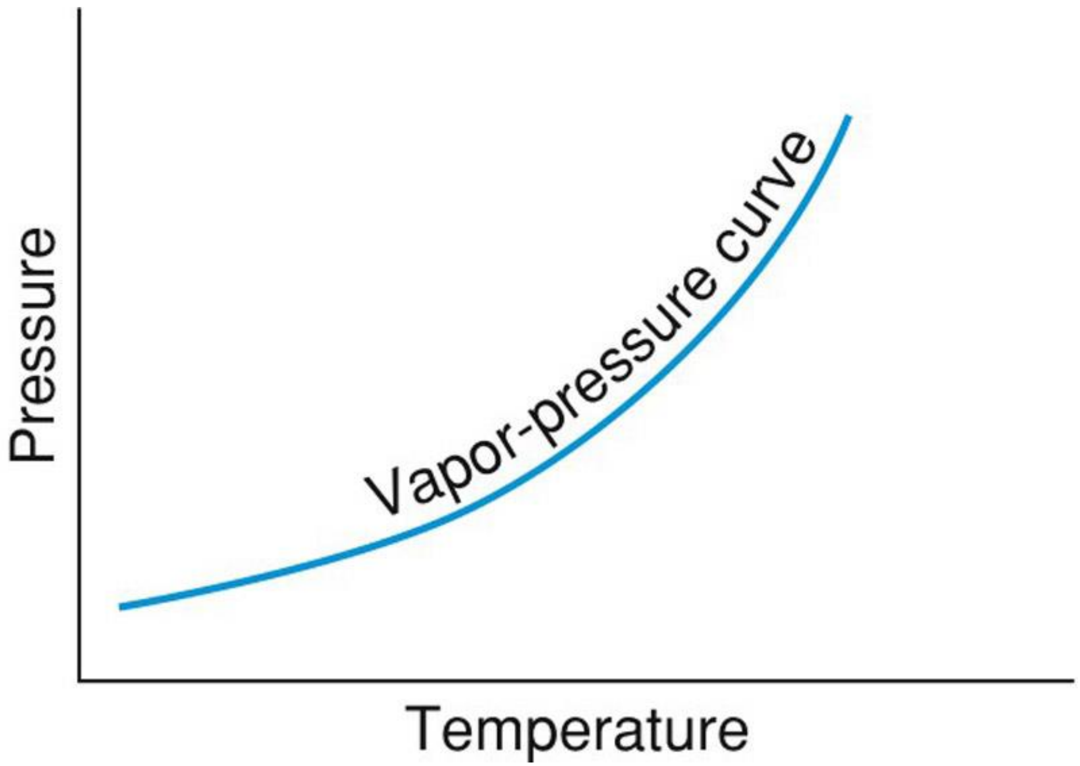
Superheated vapor

- Superheated vapor: when vapor is at a temperature above the saturation temperature at the given pressure it is called superheated vapor.
- For example water at 120 °C and 0.1 MPa , see point D in figure 3.3 .
- Pressure and temperature of superheated vapor are independent, that is to say temperature might change while pressure is held constant



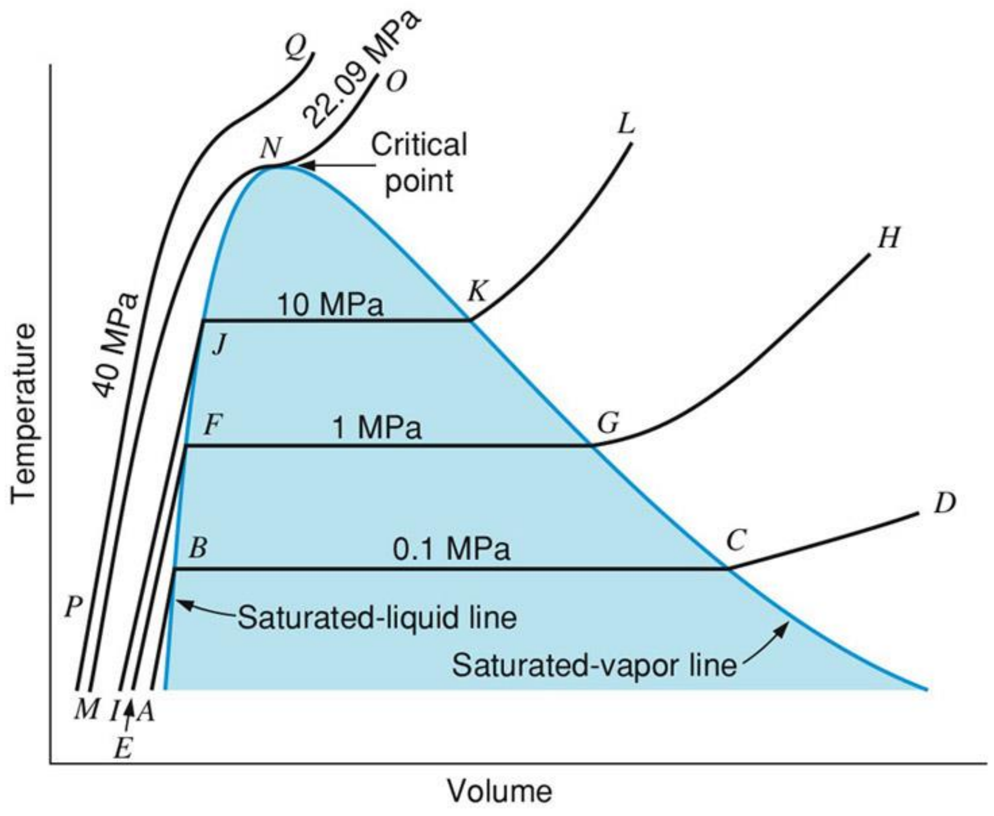
Saturation temperature and pressure

- Vapor- liquid saturation curve, in the saturation region there is a definite relation between the saturation temperature and the saturation pressure, hence if pressure is given then the saturation temperature is specified for example water at 0.1 MPa has a saturation temperature of 99.6 ^{o}C.
- Figure 3.2 gives an example of such relation.



Critical point

- Heating water at various constant pressures, will produce similar curves, know connecting the points of saturated liquid together and the point of saturated vapor together will produce a curve that has a maximum point such as point N in figure 3.3. this point is know as the critical point.
- Above critical point we cannot distinguish between the liquid and vapor phases and the substance is known as fluid.
- The temperature is known as the critical temperature while the pressure is the critical pressure



Critical point

- Each substance has a unique critical point
- Typical points are given in table 3.1 and more are given in table A.2 in the appendix.

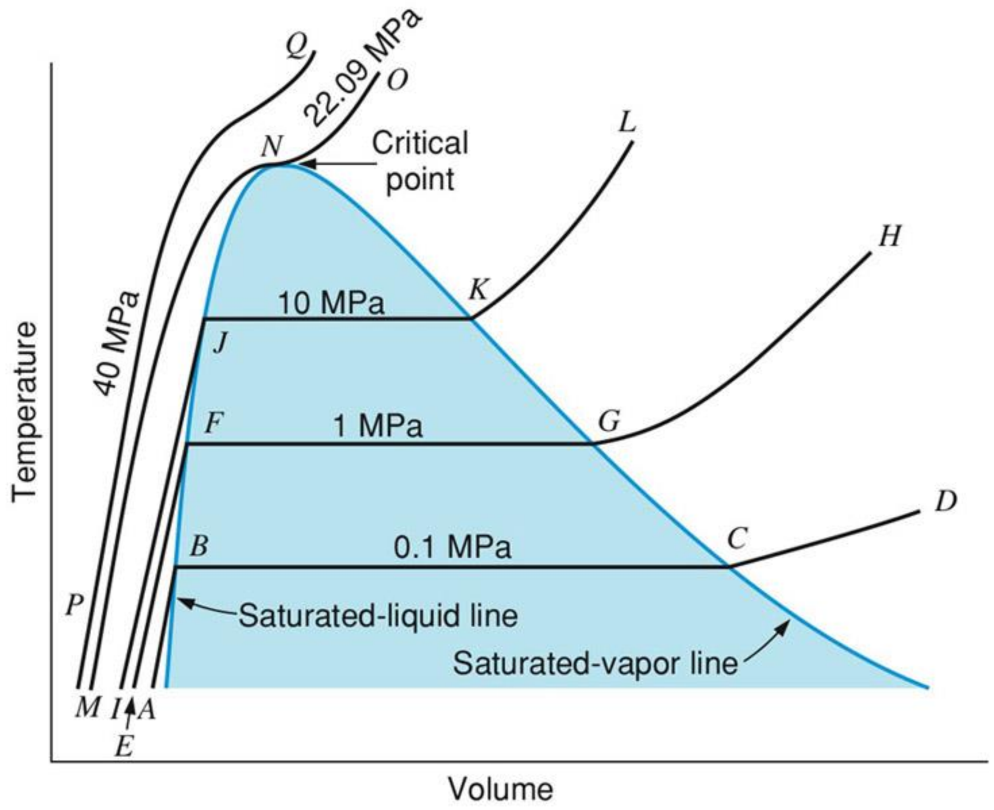
TABLE 2.2

Some Critical-Point Data

	Critical Temperature, °C	Critical Pressure, MPa	Critical Volume, m/kg
Water	374.14	22.09	0.003 155
Carbon dioxide	31.05	7.39	0.002 143
Oxygen	−118.35	5.08	0.002 438
Hydrogen	−239.85	1.30	0.032 192

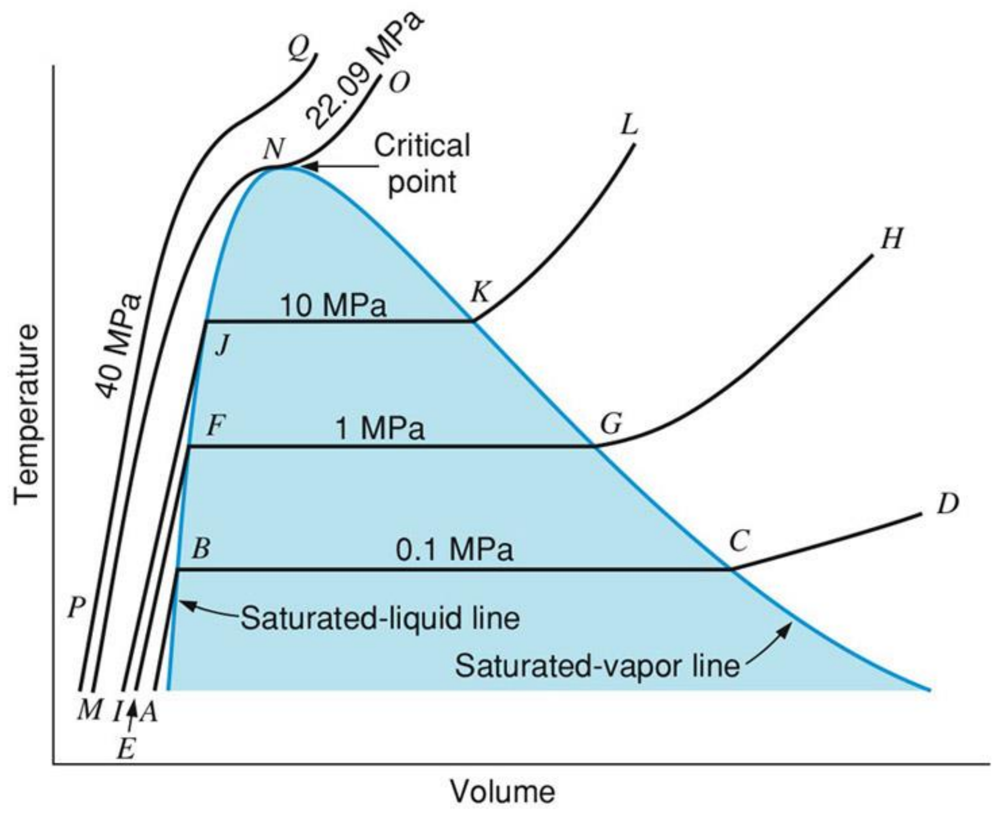
Three regions

- Two curves
  - Saturated liquid curve (B-F-J-N)
  - Saturated vapor curve (C-G-K-N)
- 3 regions
  - Subcooled liquid region
  - Saturation region
  - Superheated vapor region



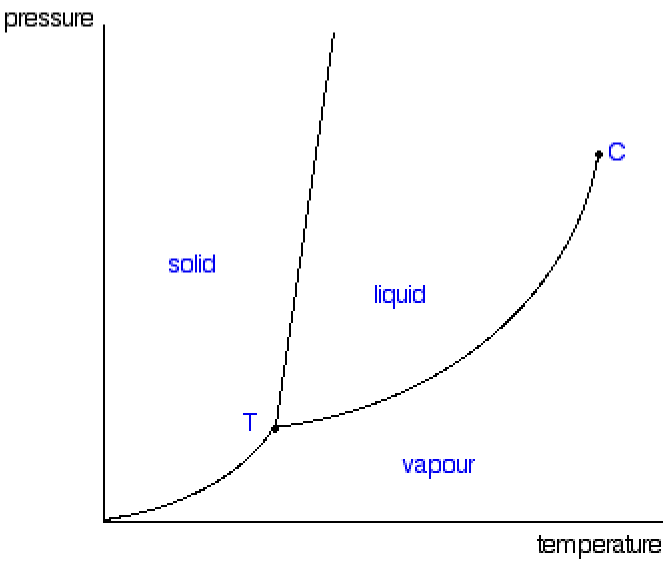
Constant lines (Iso- lines)

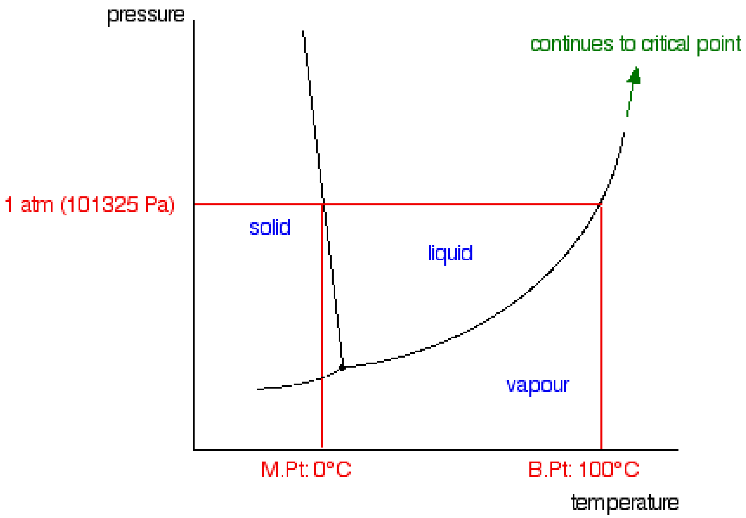
- a constant pressure line or isobar such as line A-B-C-D
- a constant temperature of isothermal line (horizontal)
- a constant specific volume line (a vertical line).



Solid liquid equilibrium

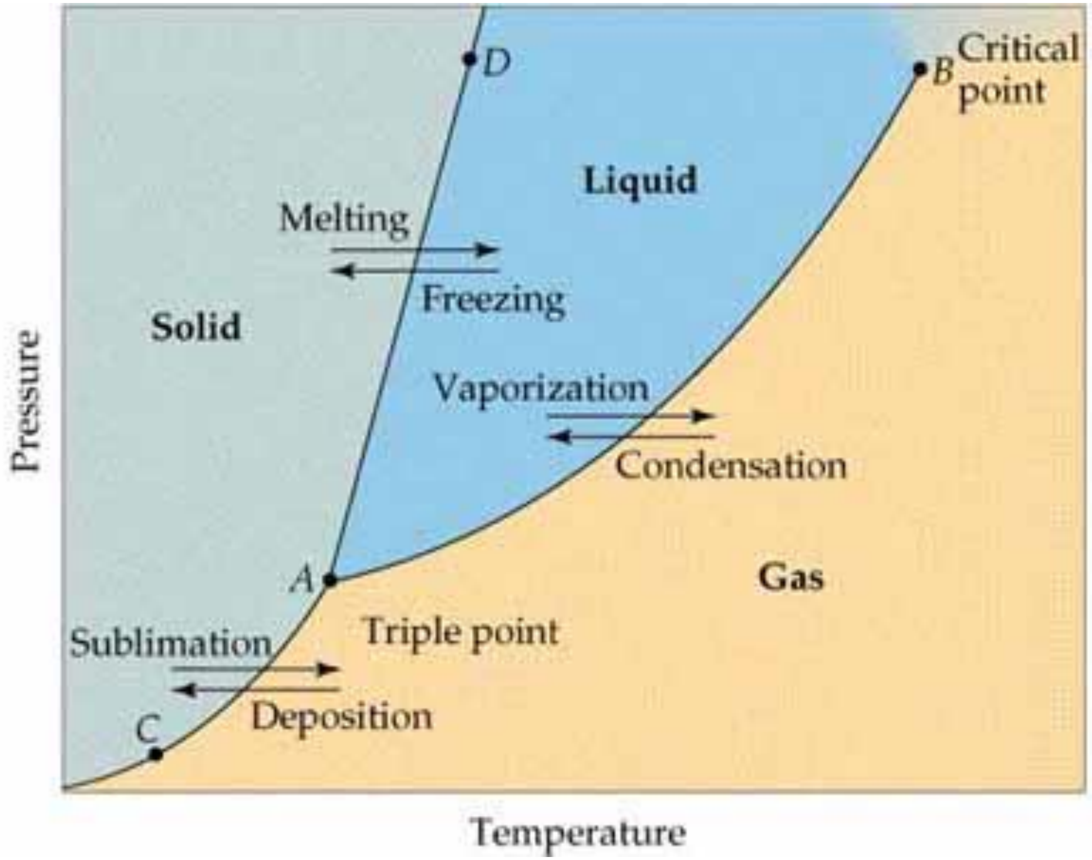
- Melting or freezing temperature of a substance depends on the pressure such conditions are also called saturation conditions.
- For most substances freezing temperature increases as the pressure is increased, positive slope of the saturation curve.
- For water and other substances which expand on freezing, increasing the pressure lowers the freezing temperature, a negative slope of the saturation curve (pressure versus temperature).





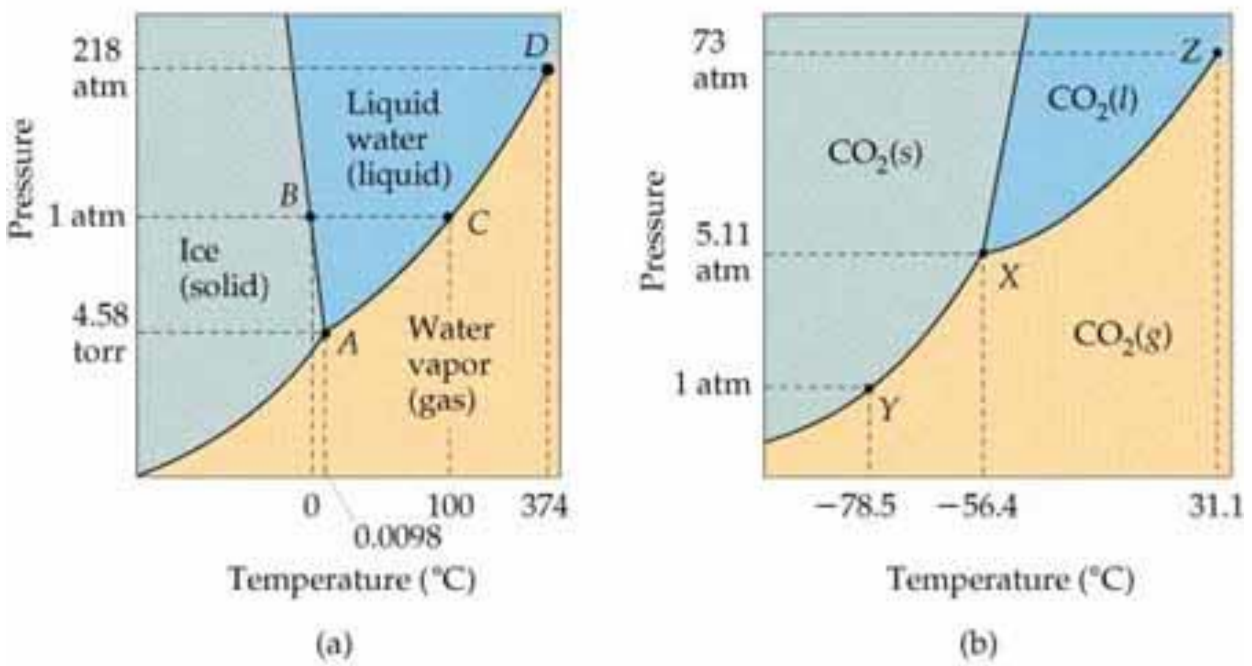
Solid –vapor equilibrium

- For most substances (except helium) there is some pressure below which liquid cannot exist. Below this pressure the solid and vapor phases can coexist together while liquid phase does not exist.
- The solid is transformed into vapor directly, and this process is known as sublimation. The saturation curve is known as the sublimation curve, see figure 3.4.



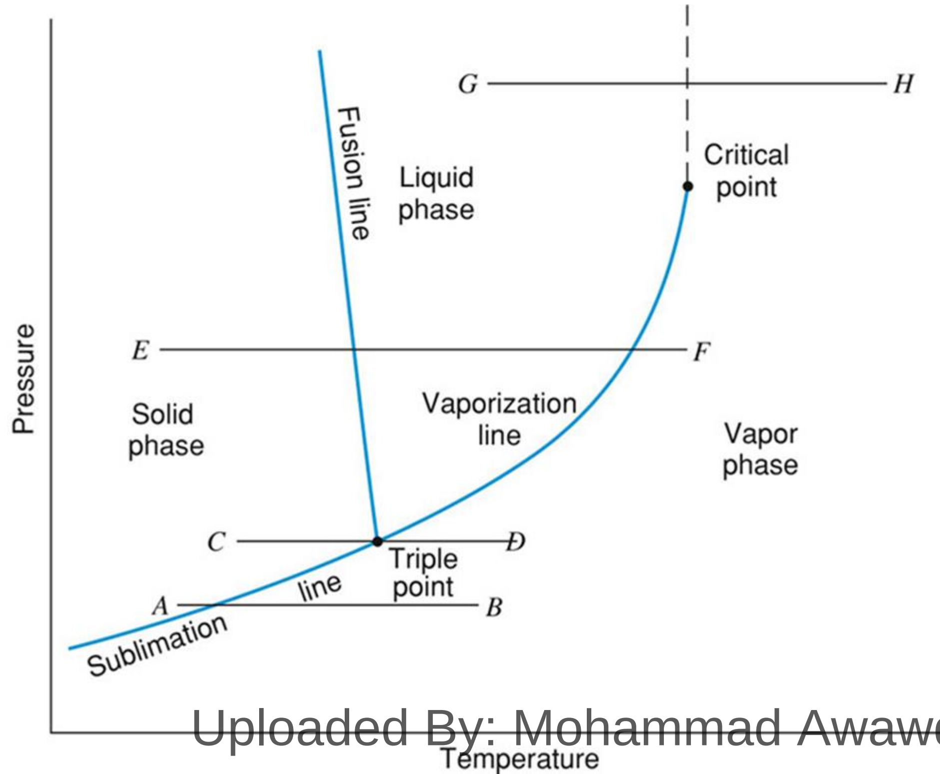
Triple point

- The point at which three phases (solid, liquid, vapor) coexist together is known as the triple point
- For water this point has temperature of 0.01 °C , pressure of 0.6113 kPa , table 3.2 shows some triple points for some substances

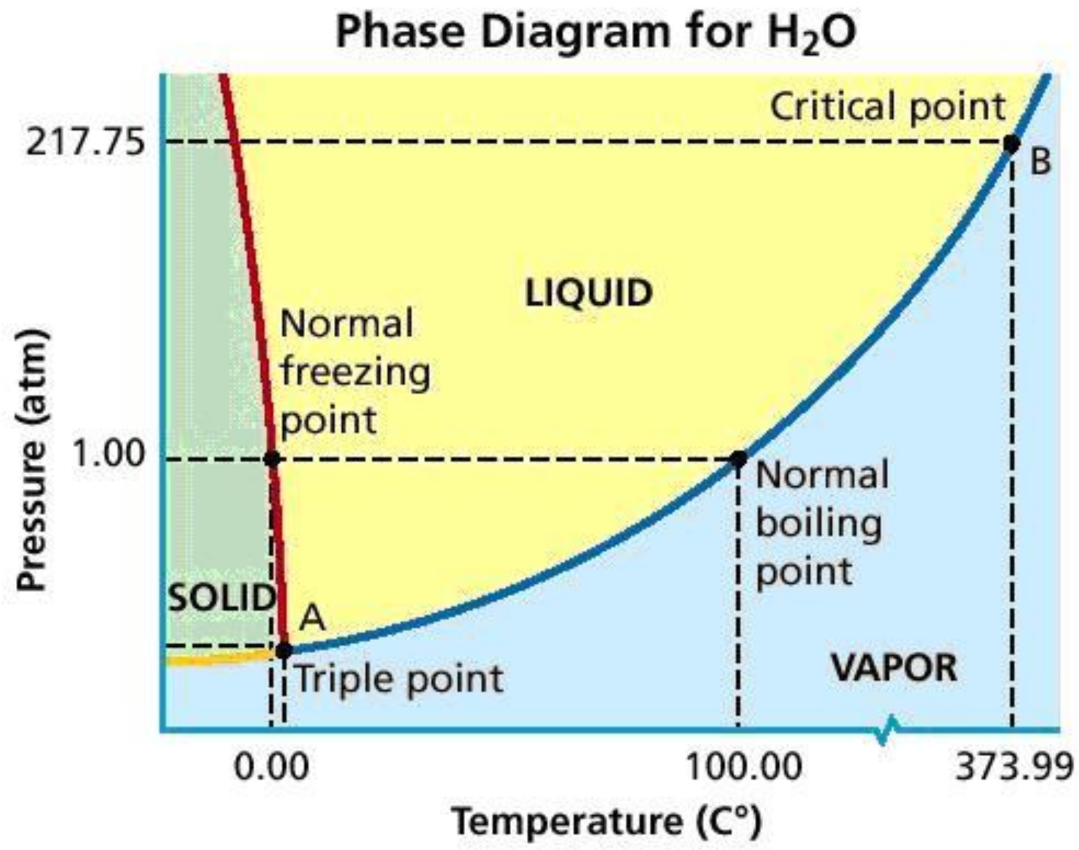


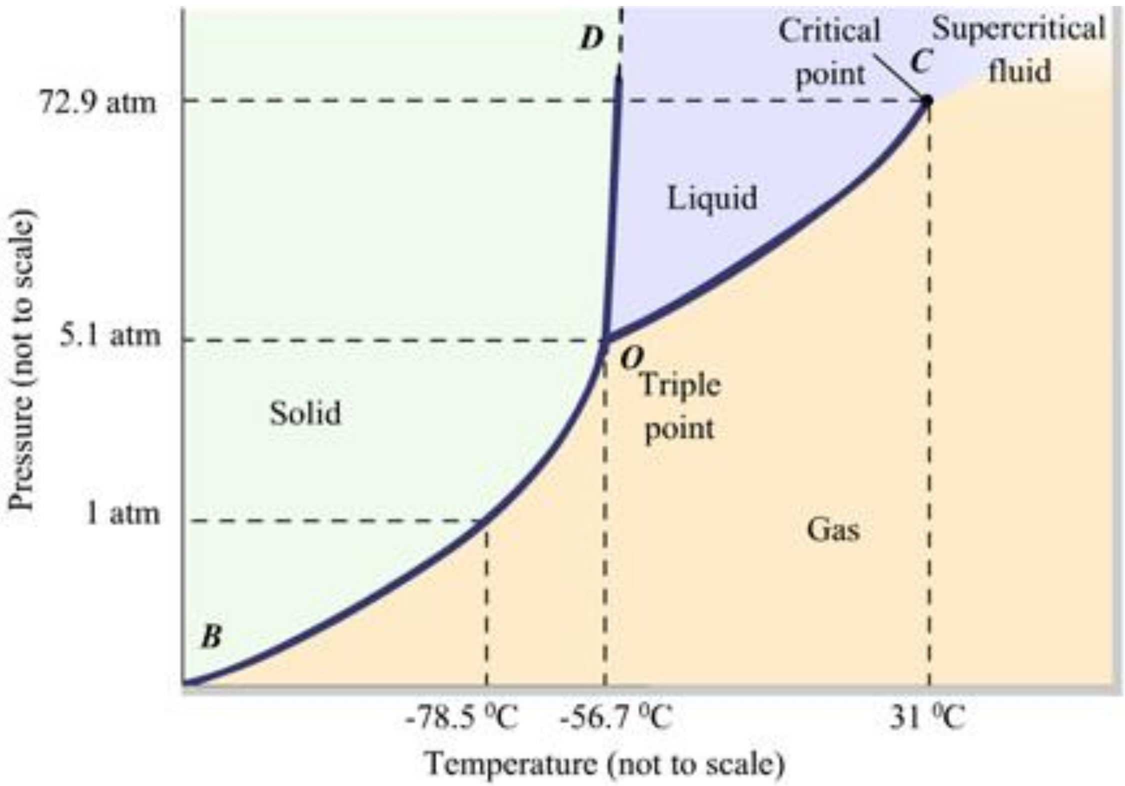
Phase diagram

- A phase diagram is a graphical way to summarize the equilibria between the different states of matter.
- The phase diagram is plot of pressure versus temperature showing all equilibrium curves and phases, and fixed points.
- Phase diagram of figure 3.4 note the following: the solid phase, liquid phase , vapor phase, solid to liquid transformation, liquid to vapor transformation, solid to vapor transformation, sublimation curve fusion or melting line, evaporation line, the critical point , and the triple point, also the slope of the fusion line.



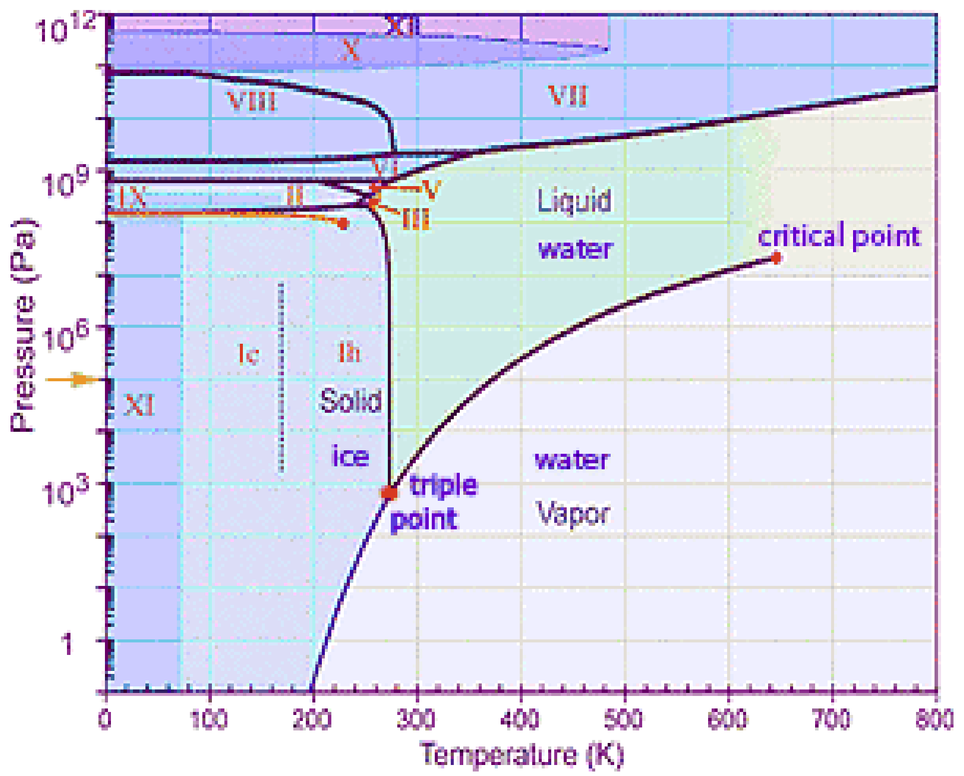
Phase diagram

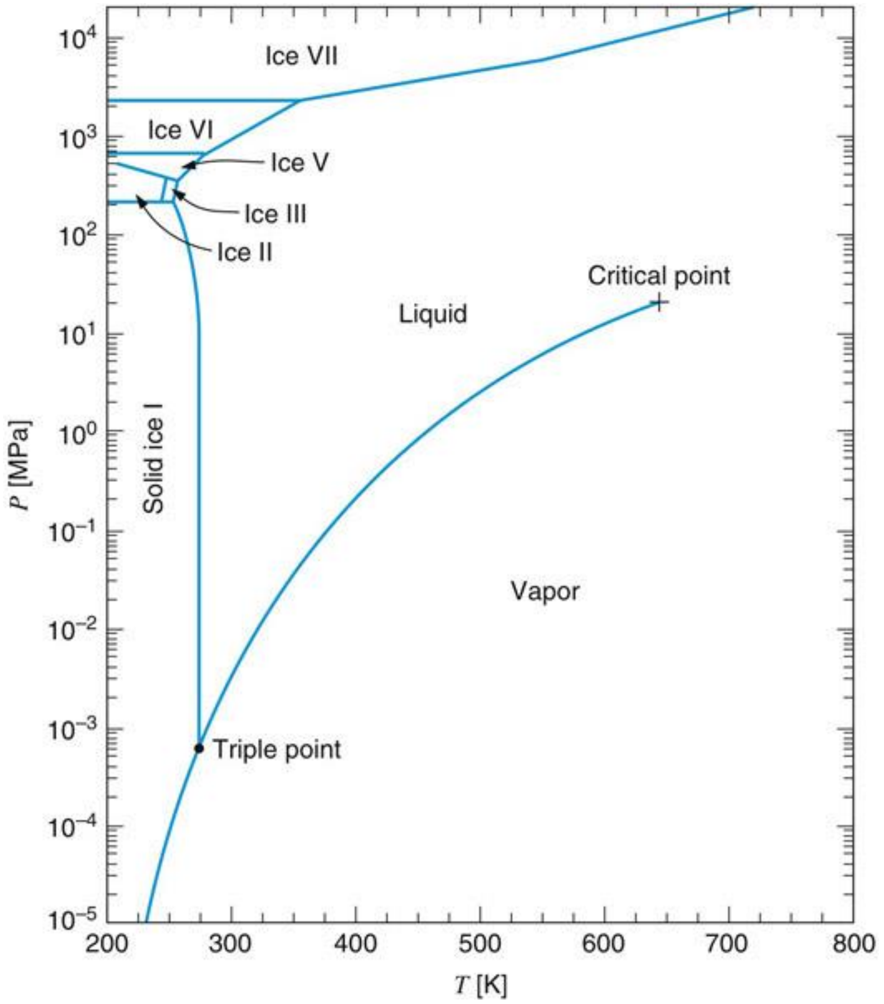




Allotropic transformation

- It is a transition from one solid phase to another solid phase e.g. see figure 3.6 for water.





Independent properties of pure substance

- The state of pure substance is specified by the value of two independent properties.
- For example in the subcooled or superheated regions may use: (v,T), (P,T), (P,v).
- In the saturation region such as liquid vapor mixture cannot use (T,P) since those are dependent properties, but may use (T,v) or (P,v).
- Air can be treated as pure substance and its state can be specified by value of two properties as long as it is in the gaseous phase, for example (T,P) or (T,v) , or (P,v).

Equation of state

- A relationship between the thermodynamic properties at a given state e.g $P = f(T,V)$ is known as equation of state.
- Such relationship could be simple with one constant such as the ideal gas equation or complex with many constants such as the Benedict-Webb-Rubin equation with 8 constants.
- Examples of equation of state:
  - Ideal gas equation
  - Real gas or compressibility factor
  - Benedict-Webb-Rubin equation

Ideal gas

- Many gases can be treated as ideal gases at certain conditions,
- in general ideal gas can be assumed for gases at low pressure or low density.
- Assumptions involved in ideal gas equation are,
  - neglecting intermolecular forces
  - neglecting volume occupied by molecules
- such assumptions are true for low density.

$$PV = mRT \qquad \rho = P/RT$$

where P is pressure, V is the volume, m is the mass and T is the absolute temperature

Ideal gas

$$PV = n\bar{R}T$$

- where n is the number of moles and $\bar{R}$ is the universal gas constant which has the value of 8.3134 kg/kg-mole.K and it is the same for all gases while the gas constant R depends on the type of gas, and those are related as,

$$R = \bar{R}/M$$

and M is the molecular weight of the gas.

- Ideal gas equation can be written per unit mass (specific volume) as

$$v = RT/P$$

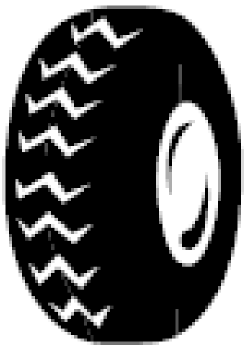
Ideal gas

- Make sure state is in the gaseous phase or superheated vapor. If compressed liquid or in saturation region cannot assume ideal gas.
- When to assume ideal gas:
  - If pressure is much lower than critical regardless of temperature,
  - At high temperature greater than twice the critical temperature even if pressure is as high as 4 times critical value.

Example ideal gas

- Air in an automobile tire is initially at −10°C and 190 kPa. After the automobile is driven awhile, the temperature gets up to 10°C. Find the new pressure. assuming constant volume?

$$m = \frac{P1V1}{RT1} = \frac{P2V2}{RT2}$$



P2 = P1 × T2/T1

P2= 190 × 283.15263.15 = **204.4 kPa**

Real gas equation

- The real gas or non-ideal gas is characterized by a compressibility factor, z, which is defined as

$$z = Pv / RT$$

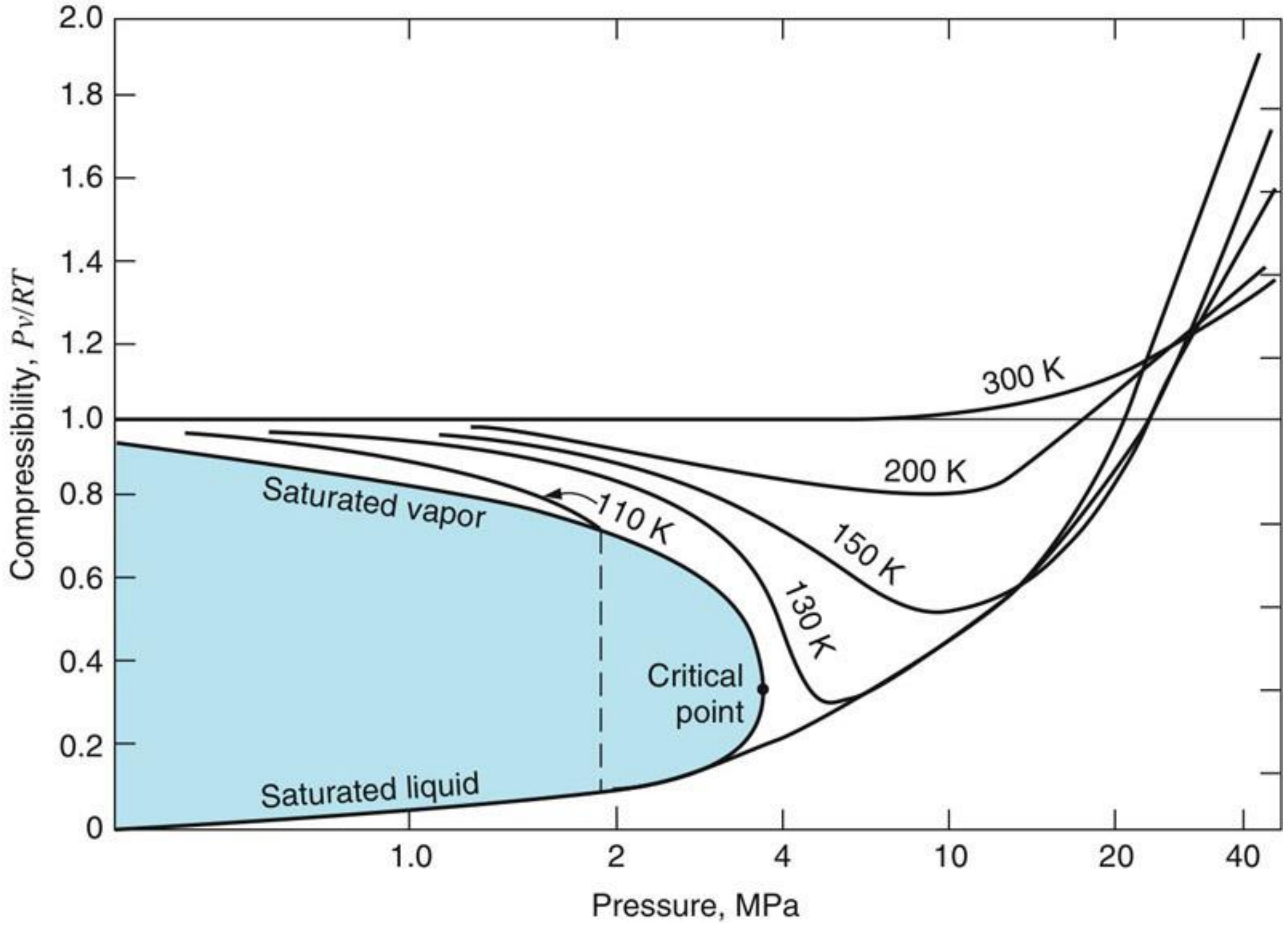
$$v = RT / P$$

- equation may be written as

$$Pv = zRT$$

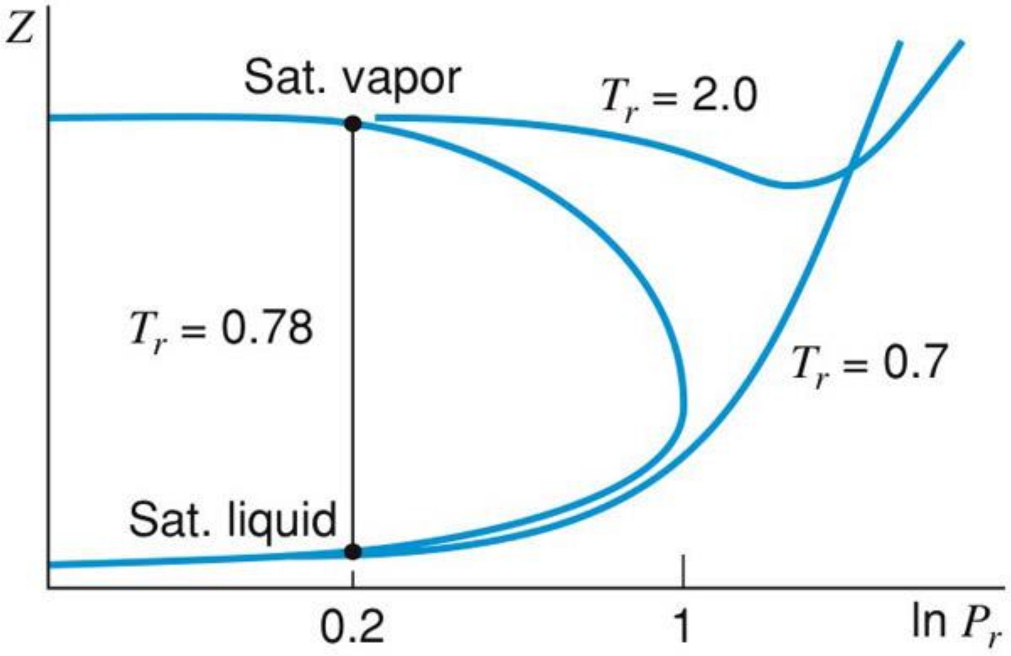
- the compressibility factor is a function of temperature and pressure and usually is determined experimentally. See figure 3.7 p.49 for a typical figure for the nitrogen.
- For ideal gas z=1=Pv/RT

Compressibility factor for Nitrogen

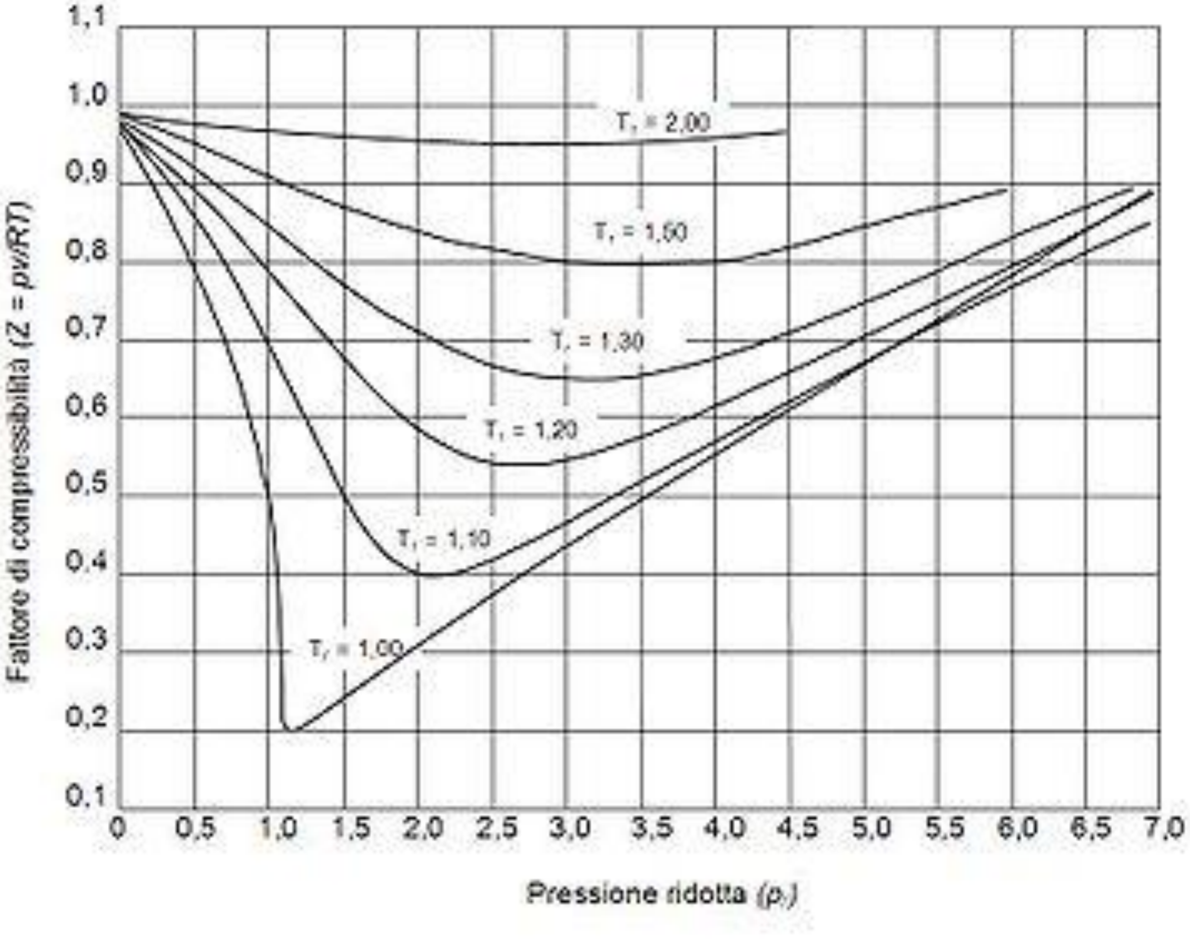


Generalized Compressibility

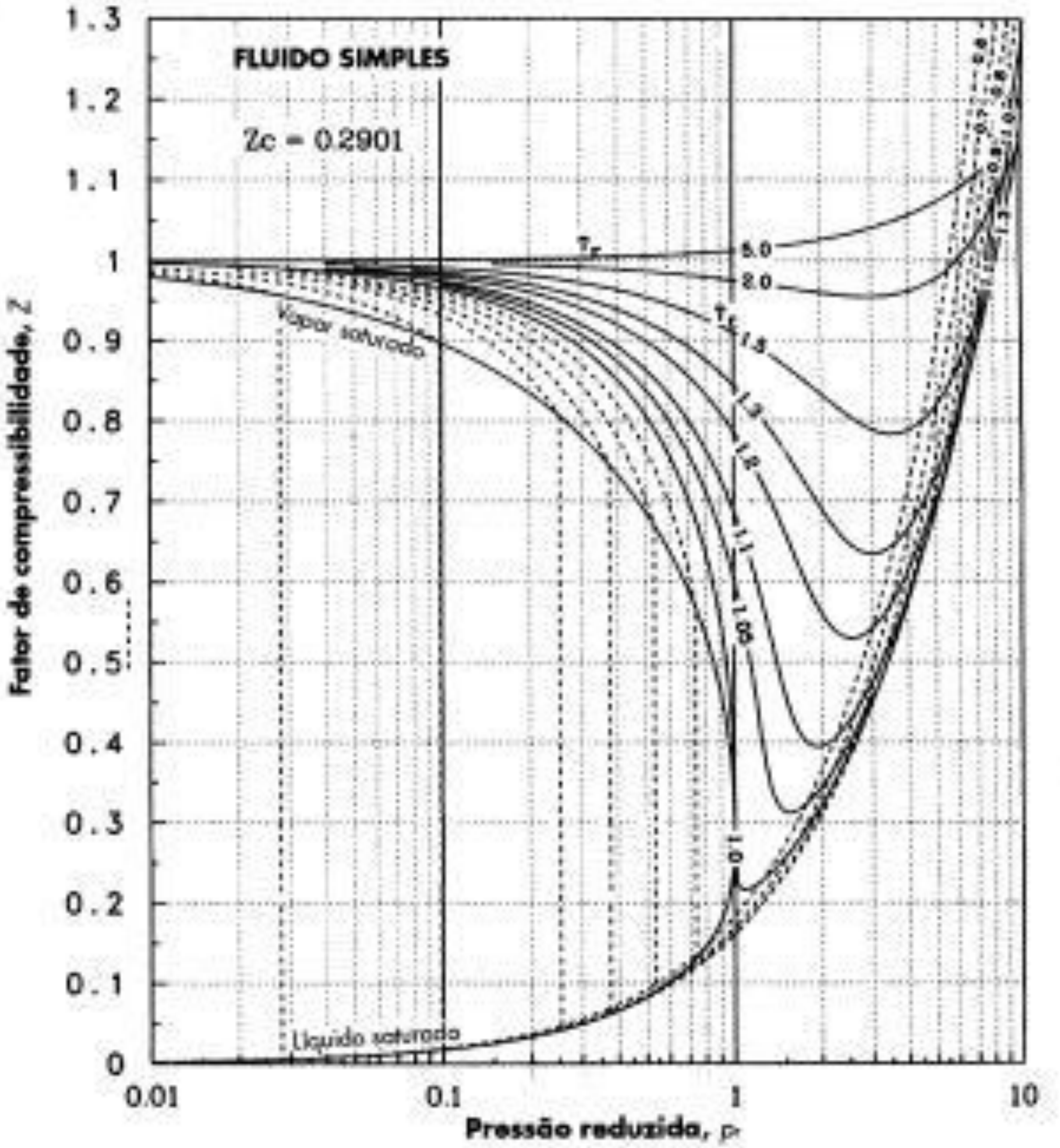
- It is found that if such factor is plotted versus a reduced pressure and reduced temperature then a single graph can be used for all gases and as such it is known as a generalized compressibility chart.
- Reduced pressure is the pressure divided by the critical pressure similarly reduced temperature is temperature divided by critical temperature.
- $P_r = P/P_c$, $T_r = T/T_c$ note T absolute degrees Kelvin
- An example of such graph is shown in figure D.1 page 763 in the appendix.



$P_{r\,\mathrm{sat}} = 0.2$,
$Z_f = 0.035$,
$Z_g = 0.83$



T, = 2,00
T, = 1,50
T, = 1,30
T, = 1,20
T, = 1,10
T, = 1,00
Fattore di compressibilità (Z = pv/RT)
Pressione ridotta (p,)



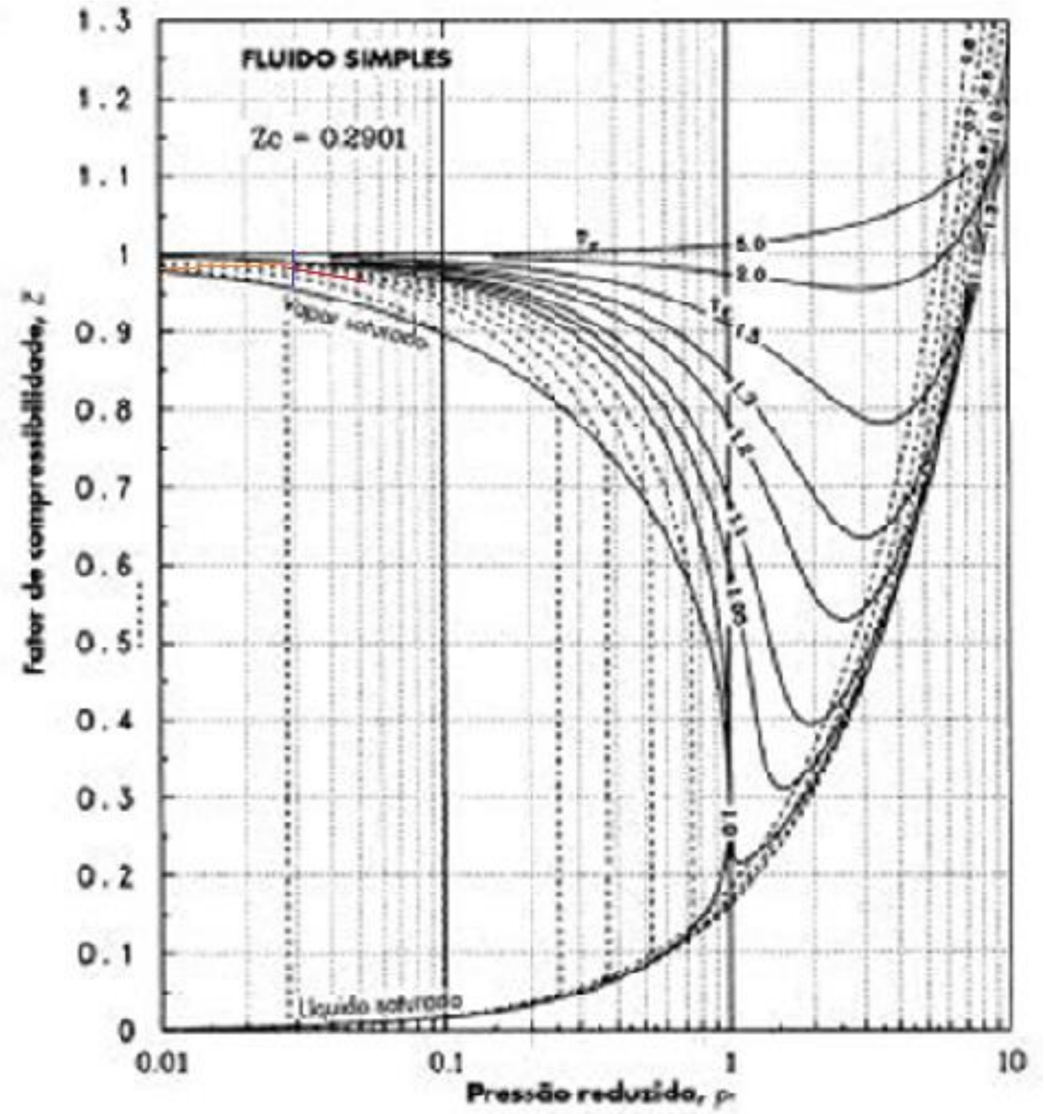
FLUIDO SIMPLES
Zc = 0.2901
Vapor saturado
Líquido saturado
Fator de compressibilidade, Z
Pressão reduzida, pr

Example

- Find z for propane gas at room conditions (101 kPa, 293 K).
- From Table A.2 Pc = 4250 kPa, Tc = 370 K
- The reduced properties:

  Pr = 101/4250 = 0.024,

  Tr = 293l370 = 0.792
- From Fig. D.1: Z = 0.98
- Can be assumed ideal gas.



Equation of state

- van der Waals equation

$(P + a / Vm^2)(Vm - b) = R T$

P = pressure Vm = molar volume R = ideal gas constant T = temperature

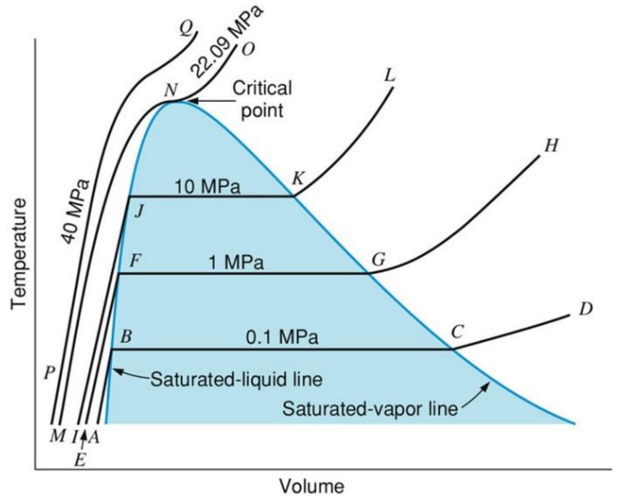
- Beattie-Bridgeman equation

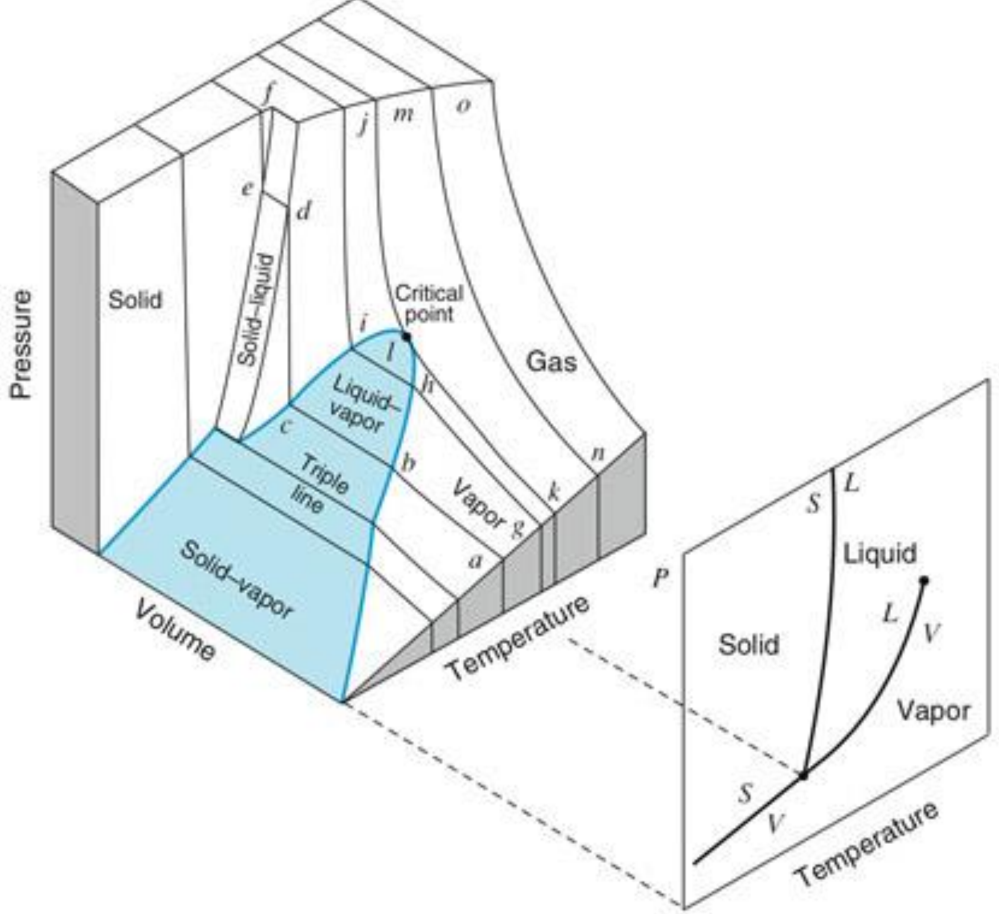
$P = R T d + (B R T - A - R c / T^2) d^2 + (- B b R T + A a - R B c / T^2) d^3 + R B b c d^4 / T^2$

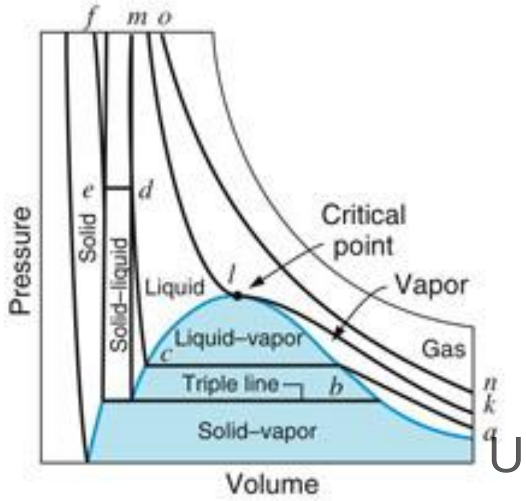
P = pressure R = ideal gas constant T = temperature d = molal density a, b, c, A, B = empirical parameters

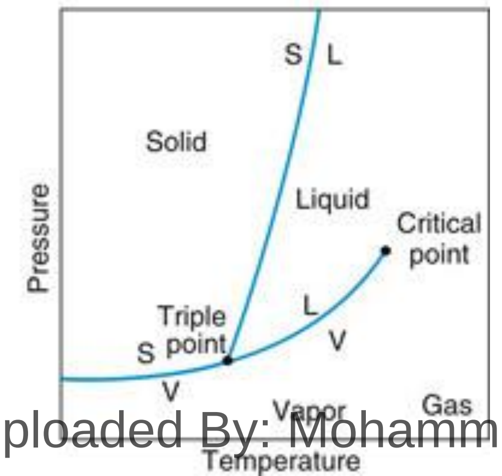
P-v-T surfaces

T-v diagram
P- T diagram
P-v diagram







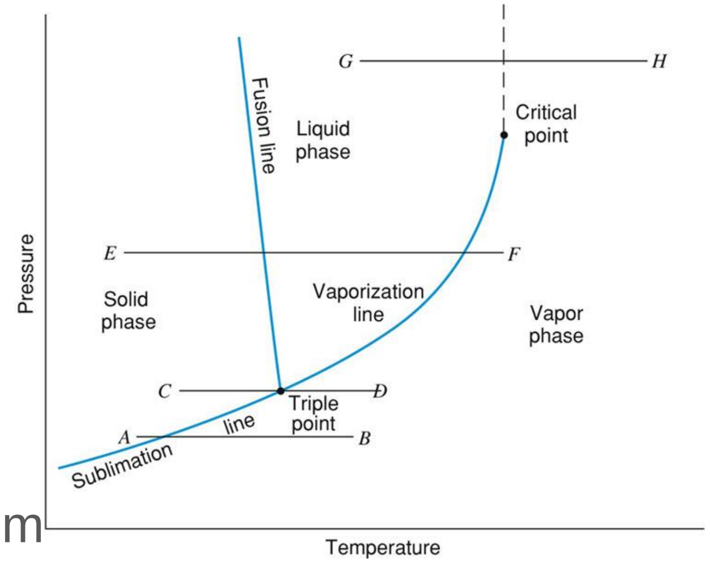


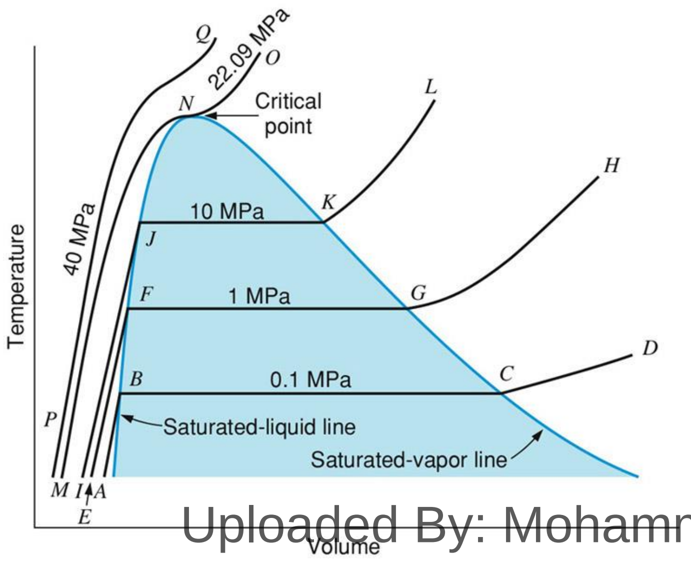
Thermodynamic Tables

- State of pure substance is specified by the value of its properties.
- Properties are related to each other by some state relationship, the ideal gas, real gas and Beatie-Bridgeman equations are some examples of such equations.
- Thermodynamic tables present properties of pure substances at various states.
- Thermodynamic tables are obtained from some complex equation of state such as the Beatie- Bridgeman equation.
- Examples of thermodynamic tables include steam tables, and tables of various refrigerants.

Steam tables

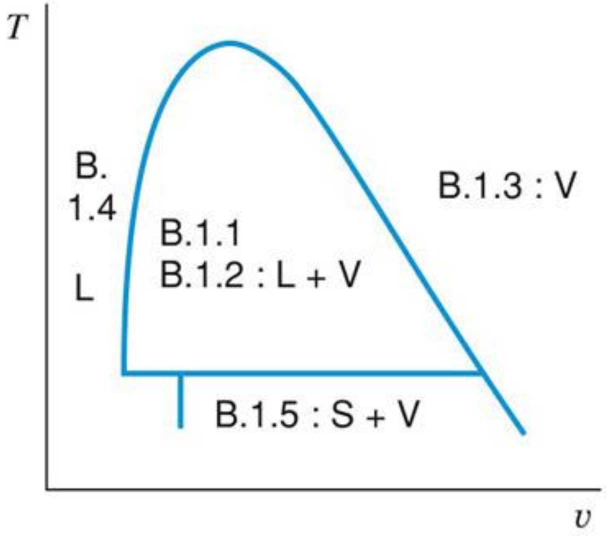
- The state and properties in the table is specified by two independent properties,
- Targeted properties; temperature, pressure and specific volume while other properties will be added on in the next chapters.
- water contains three regions, sub-cooled liquid, saturation region and the superheated vapor, hence each region will be presented in a separate table. In addition to the sublimation equilibrium.





Steam tables

- All thermodynamic tables are included in the appendices, starting in appendix B.
- The first tables are for water, then the refrigerants, for example table B.1.1 SI is the one for water in the saturation region and in the SI units.



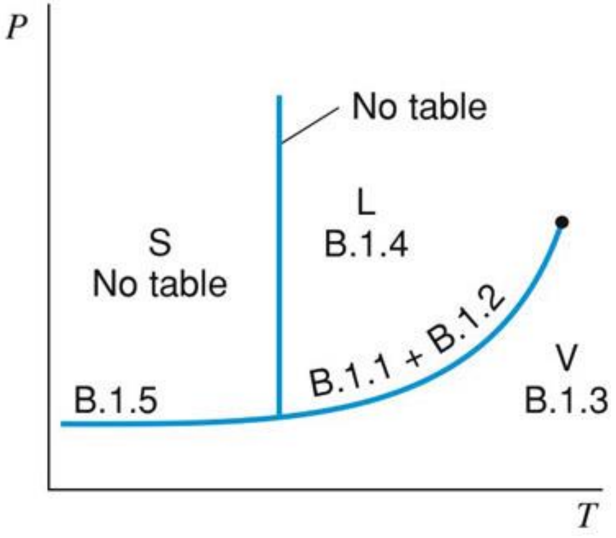


Table B.1.1.SI Saturated water- temperature table

- This table includes the saturation temperature as the first column in ^oC and the corresponding saturation pressure in kPa or MPa in the second column, and the specific volumes in columns 3 , 4, and 5 in the 4 units of m^3/kg.
- The table starts from the triple point of water at .01 ^oC and goes up to the critical point of the water at 374^oC.

		Volume, m^3/kg		Energy, kJ/kg	
T, °C	P, MPa	v_f	v_g	u_f	u_g
0.010	0.0006113	0.001000	206.1	0.0	2375.3
2	0.0007056	0.001000	179.9	8.4	2378.1
5	0.0008721	0.001000	147.1	21.0	2382.2
10	0.001228	0.001000	106.4	42.0	2389.2
15	0.001705	0.001001	77.93	63.0	2396.0
20	0.002338	0.001002	57.79	83.9	2402.9
25	0.003169	0.001003	43.36	104.9	2409.8
30	0.004246	0.001004	32.90	125.8	2416.[illegible]

Saturation temperature and pressure

		Volume, m^3/kg		Energy, kJ/kg		Enthalpy, kJ/kg			Entropy, kJ/kg·K		
T, °C	P, MPa	v_f	v_g	u_f	u_g	h_f	h_{fg}	h_g	s_f	s_{fg}	s_g
0.010	0.0006113	0.001000	206.1	0.0	2375.3	0.0	2501.3	2501.3	0.0000	9.1571	9.1571
2	0.0007056	0.001000	179.9	8.4	2378.1	8.4	2496.6	2505.0	0.0305	9.0738	9.1043
5	0.0008721	0.001000	147.1	21.0	2382.2	21.0	2489.5	2510.5	0.0761	8.9505	9.0266
10	0.001228	0.001000	106.4	42.0	2389.2	42.0	2477.7	2519.7	0.1510	8.7506	8.9016
15	0.001705	0.001001	77.93	63.0	2396.0	63.0	2465.9	2528.9	0.2244	8.5578	8.7822
20	0.002338	0.001002	57.79	83.9	2402.9	83.9	2454.2	2538.1	0.2965	8.3715	8.6680
25	0.003169	0.001003	43.36	104.9	2409.8	104.9	2442.3	2547.2	0.3672	8.1916	8.5588
30	0.004246	0.001004	32.90	125.8	2416.6	125.8	2430.4	2556.2	0.4367	8.0174	8.4541
35	0.005628	0.001006	25.22	146.7	2423.4	146.7	2418.6	2565.3	0.5051	7.8488	8.3539
40	0.007383	0.001008	19.52	167.5	2430.1	167.5	2406.8	2574.3	0.5723	7.6855	8.2578
45	0.009593	0.001010	15.26	188.4	2436.8	188.4	2394.8	2583.2	0.6385	7.5271	8.1656
50	0.01235	0.001012	12.03	209.3	2443.5	209.3	2382.8	2592.1	0.7036	7.3735	8.0771
55	0.01576	0.001015	9.569	230.2	2450.1	230.2	2370.7	2600.9	0.7678	7.2243	7.9921
60	0.01994	0.001017	7.671	251.1	2456.6	251.1	2358.5	2609.6	0.8310	7.0794	7.9104
65	0.02503	0.001020	6.197	272.0	2463.1	272.0	2346.2	2618.2	0.8934	6.9384	7.8318
70	0.03119	0.001023	5.042	292.9	2469.5	293.0	2333.8	2626.8	0.9549	6.8012	7.7561
75	0.03858	0.001026	4.131	313.9	2475.9	313.9	2321.4	2635.3	1.0155	6.6678	7.6833
80	0.04739	0.001029	3.407	334.8	2482.2	334.9	2308.8	2643.7	1.0754	6.5376	7.6130
85	0.05783	0.001032	2.828	355.8	2488.4	355.9	2296.0	2651.9	1.1344	6.4109	7.5453
90	0.07013	0.001036	2.361	376.8	2494.5	376.9	2283.2	2660.1	1.1927	6.2872	7.4799
95	0.08455	0.001040	1.982	397.9	2500.6	397.9	2270.2	2668.1	1.2503	6.1664	7.4167

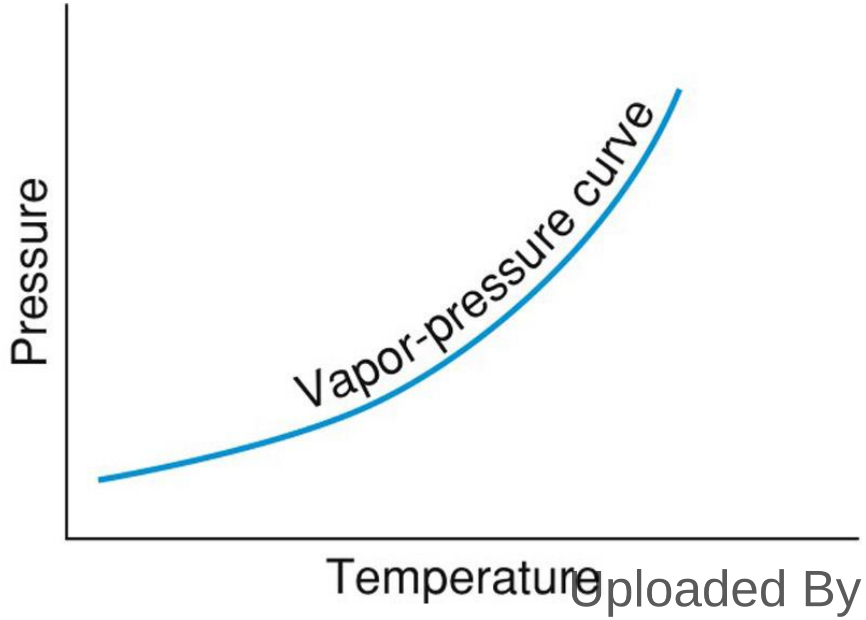
https://www.chegg.com/homework-help/definitions/steam-tables-5

		Volume, m^3/kg		Energy, kJ/kg		Enthalpy, kJ/kg			Entropy, kJ/kg·K		
T, °C	P, MPa	v_f	v_g	u_f	u_g	h_f	h_{fg}	h_g	s_f	s_{fg}	s_g
100	0.1013	0.001044	1.673	418.9	2506.5	419.0	2257.0	2676.0	1.3071	6.0486	7.3557
110	0.1433	0.001052	1.210	461.1	2518.1	461.3	2230.2	2691.5	1.4188	5.8207	7.2395
120	0.1985	0.001060	0.8919	503.5	2529.2	503.7	2202.6	2706.3	1.5280	5.6024	7.1304
130	0.2701	0.001070	0.6685	546.0	2539.9	546.3	2174.2	2720.5	1.6348	5.3929	7.0277
140	0.3613	0.001080	0.5089	588.7	2550.0	589.1	2144.8	2733.9	1.7395	5.1912	6.9307
150	0.4758	0.001090	0.3928	631.7	2559.5	632.2	2114.2	2746.4	1.8422	4.9965	6.8387
160	0.6178	0.001102	0.3071	674.9	2568.4	675.5	2082.6	2758.1	1.9431	4.8079	6.7510
170	0.7916	0.001114	0.2428	718.3	2576.5	719.2	2049.5	2768.7	2.0423	4.6249	6.6672
180	1.002	0.001127	0.1941	762.1	2583.7	763.2	2015.0	2778.2	2.1400	4.4466	6.5866
190	1.254	0.001141	0.1565	806.2	2590.0	807.5	1978.8	2786.4	2.2363	4.2724	6.5087
200	1.554	0.001156	0.1274	850.6	2595.3	852.4	1940.8	2793.2	2.3313	4.1018	6.4331
210	1.906	0.001173	0.1044	895.5	2599.4	897.7	1900.8	2798.5	2.4253	3.9340	6.3593
220	2.318	0.001190	0.08620	940.9	2602.4	943.6	1858.5	2802.1	2.5183	3.7686	6.2869
230	2.795	0.001209	0.07159	986.7	2603.9	990.1	1813.9	2804.0	2.6105	3.6050	6.2155
240	3.344	0.001229	0.05977	1033.2	2604.0	1037.3	1766.5	2803.8	2.7021	3.4425	6.1446
250	3.973	0.001251	0.05013	1080.4	2602.4	1085.3	1716.2	2801.5	2.7933	3.2805	6.0738
260	4.688	0.001276	0.04221	1128.4	2599.0	1134.4	1662.5	2796.9	2.8844	3.1184	6.0028
270	5.498	0.001302	0.03565	1177.3	2593.7	1184.5	1605.2	2789.7	2.9757	2.9553	5.9310
280	6.411	0.001332	0.03017	1227.4	2586.1	1236.0	1543.6	2779.6	3.0674	2.7905	5.8579
290	7.436	0.001366	0.02557	1278.9	2576.0	1289.0	1477.2	2766.2	3.1600	2.6230	5.7830
300	8.580	0.001404	0.02168	1332.0	2563.0	1344.0	1405.0	2749.0	3.2540	2.4513	5.7053
310	9.856	0.001447	0.01835	1387.0	2546.4	1401.3	1326.0	2727.3	3.3500	2.2739	5.6239
320	11.27	0.001499	0.01549	1444.6	2525.5	1461.4	1238.7	2700.1	3.4487	2.0883	5.5370
330	12.84	0.001561	0.01300	1505.2	2499.0	1525.3	1140.6	2665.9	3.5514	1.8911	5.4425
340	14.59	0.001638	0.01080	1570.3	2464.6	1594.2	1027.9	2622.1	3.6601	1.6765	5.3366
350	16.51	0.001740	0.008815	1641.8	2418.5	1670.6	893.4	2564.0	3.7784	1.4338	5.2122
360	18.65	0.001892	0.006947	1725.2	2351.6	1760.5	720.7	2481.2	3.9154	1.1382	5.0536
370	21.03	0.002213	0.004931	1844.0	2229.0	1890.5	442.2	2332.7	4.1114	0.6876	4.7990
374.136	22.088	0.003155	0.003155	2029.6	2029.6	2099.3	0.0	2099.3	4.4305	0.0000	4.4305

Sources: Keenan, Keyes, Hill, and Moore, *Steam Tables*, Wiley, New York, 1969; G. J. Van Wylen and R. E. Sonntag, *Fundamentals of Classical Thermodynamics*, Wiley, New York, 1973.

Examples

- For example at 10 °C the saturation pressure is 1.2276 kPa,
- similarly at 100 °C the saturation pressure is 101.3 kPa which is the boiling point of water at standard atmospheric pressure.
- *Question: find the saturation pressure at 70 °C, 270 °C and 374.1 °C, comment on the relation between the saturation pressure and the temperature.*
- at 70 31.19 kPa
- At 270 5498 kPa
- At 374.1 22.088 MPa



		Volume, m³/kg		Energy, kJ/kg		Enthalpy, kJ/kg			Entropy, kJ/kg·K		
T, °C	P, MPa	v_f	v_g	u_f	u_g	h_f	h_{fg}	h_g	s_f	s_{fg}	s_g
100	0.1013	0.001044	1.673	418.9	2506.5	419.0	2257.0	2676.0	1.3071	6.0486	7.3557
110	0.1433	0.001052	1.210	461.1	2518.1	461.3	2230.2	2691.5	1.4188	5.8207	7.2395
120	0.1985	0.001060	0.8919	503.5	2529.2	503.7	2202.6	2706.3	1.5280	5.6024	7.1304
130	0.2701	0.001070	0.6685	546.0	2539.9	546.3	2174.2	2720.5	1.6348	5.3929	7.0277
140	0.3613	0.001080	0.5089	588.7	2550.0	589.1	2144.8	2733.9	1.7395	5.1912	6.9307
150	0.4758	0.001090	0.3928	631.7	2559.5	632.2	2114.2	2746.4	1.8422	4.9965	6.8387
160	0.6178	0.001102	0.3071	674.9	2568.4	675.5	2082.6	2758.1	1.9431	4.8079	6.7510
170	0.7916	0.001114	0.2428	718.3	2576.5	719.2	2049.5	2768.7	2.0423	4.6249	6.6672
180	1.002	0.001127	0.1941	762.1	2583.7	763.2	2015.0	2778.2	2.1400	4.4466	6.5866
190	1.254	0.001141	0.1565	806.2	2590.0	807.5	1978.8	2786.4	2.2363	4.2724	6.5087
200	1.554	0.001156	0.1274	850.6	2595.3	852.4	1940.8	2793.2	2.3313	4.1018	6.4331
210	1.906	0.001173	0.1044	895.5	2599.4	897.7	1900.8	2798.5	2.4253	3.9340	6.3593
220	2.318	0.001190	0.08620	940.9	2602.4	943.6	1858.5	2802.1	2.5183	3.7686	6.2869
230	2.795	0.001209	0.07159	986.7	2603.9	990.1	1813.9	2804.0	2.6105	3.6050	6.2155
240	3.344	0.001229	0.05977	1033.2	2604.0	1037.3	1766.5	2803.8	2.7021	3.4425	6.1446
250	3.973	0.001251	0.05013	1080.4	2602.4	1085.3	1716.2	2801.5	2.7933	3.2805	6.0738
260	4.688	0.001276	0.04221	1128.4	2599.0	1134.4	1662.5	2796.9	2.8844	3.1184	6.0028
270	5.498	0.001302	0.03565	1177.3	2593.7	1184.5	1605.2	2789.7	2.9757	2.9553	5.9310
280	6.411	0.001332	0.03017	1227.4	2586.1	1236.0	1543.6	2779.6	3.0674	2.7905	5.8579
290	7.436	0.001366	0.02557	1278.9	2576.0	1289.0	1477.2	2766.2	3.1600	2.6230	5.7830
300	8.580	0.001404	0.02168	1332.0	2563.0	1344.0	1405.0	2749.0	3.2540	2.4513	5.7053
310	9.856	0.001447	0.01835	1387.0	2546.4	1401.3	1326.0	2727.3	3.3500	2.2739	5.6239
320	11.27	0.001499	0.01549	1444.6	2525.5	1461.4	1238.7	2700.1	3.4487	2.0883	5.5370
330	12.84	0.001561	0.01300	1505.2	2499.0	1525.3	1140.6	2665.9	3.5514	1.8911	5.4425
340	14.59	0.001638	0.01080	1570.3	2464.6	1594.2	1027.9	2622.1	3.6601	1.6765	5.3366
350	16.51	0.001740	0.008815	1641.8	2418.5	1670.6	893.4	2564.0	3.7784	1.4338	5.2122
360	18.65	0.001892	0.006947	1725.2	2351.6	1760.5	720.7	2481.2	3.9154	1.1382	5.0536
370	21.03	0.002213	0.004931	1844.0	2229.0	1890.5	442.2	2332.7	4.1114	0.6876	4.7990
374.136	22.088	0.003155	0.003155	2029.6	2029.6	2099.3	0.0	2099.3	4.4305	0.0000	4.4305

SOURCES: Keenan, Keyes, Hill, and Moore, *Steam Tables*, Wiley, New York, 1969; G. J. Van Wylen and R. E. Sonntag, *Fundamentals of Classical Thermodynamics*, Wiley, New York, 1973.

Table B.1.2.SI Saturated water- pressure entry

- This table contains the same data in the previous table, but its first column is the saturated pressure and not the saturated temperature as in the previous table.
- Here, also the table starts at the triple point (0.6113 kPa) and extends to the critical point at 22.09 MPa.
- **Example:** determine the saturation temperature of saturated liquid and saturated vapor at 100 kPa?
- From the table at 100 kPa the saturated temperature is 99.6 ^oC and

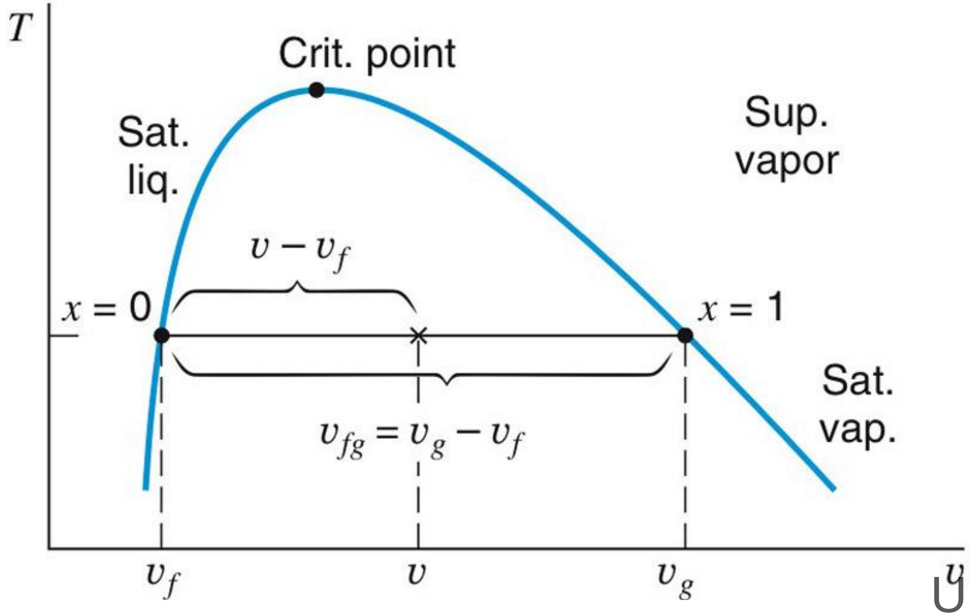
Table B.1.2.SI Saturated water- pressure entry

		Volume, m³/kg		Energy, kJ/kg		Enthalpy, kJ/kg			Entropy, kJ/kg-K		
P, MPa	T, °C	v_f	v_g	u_f	u_g	h_f	h_{fg}	h_g	s_f	s_{fg}	s_g
0.000611	0.01	0.001000	206.1	0.0	2375.3	0.0	2501.3	2501.3	0.0000	9.1571	9.1571
0.0008	3.8	0.001000	159.7	15.8	2380.5	15.8	2492.5	2508.3	0.0575	9.0007	9.0582
0.001	7.0	0.001000	129.2	29.3	2385.0	29.3	2484.9	2514.2	0.1059	8.8706	8.9765
0.0012	9.7	0.001000	108.7	40.6	2388.7	40.6	2478.5	2519.1	0.1460	8.7639	8.9099
0.0014	12.0	0.001001	93.92	50.3	2391.9	50.3	2473.1	2523.4	0.1802	8.6736	8.8538
0.0016	14.0	0.001001	82.76	58.9	2394.7	58.9	2468.2	2527.1	0.2101	8.5952	8.8053
0.0018	15.8	0.001001	74.03	66.5	2397.2	66.5	2464.0	2530.5	0.2367	8.5259	8.7626
0.002	17.5	0.001001	67.00	73.5	2399.5	73.5	2460.0	2533.5	0.2606	8.4639	8.7245
0.003	24.1	0.001003	45.67	101.0	2408.5	101.0	2444.5	2545.5	0.3544	8.2240	8.5784
0.004	29.0	0.001004	34.80	121.4	2415.2	121.4	2433.0	2554.4	0.4225	8.0529	8.4754
0.006	36.2	0.001006	23.74	151.5	2424.9	151.5	2415.9	2567.4	0.5208	7.8104	8.3312
0.008	41.5	0.001008	18.10	173.9	2432.1	173.9	2403.1	2577.0	0.5924	7.6371	8.2295
0.01	45.8	0.001010	14.67	191.8	2437.9	191.8	2392.8	2584.6	0.6491	7.5019	8.1510
0.012	49.4	0.001012	12.36	206.9	2442.7	206.9	2384.1	2591.0	0.6961	7.3910	8.0871
0.014	52.6	0.001013	10.69	220.0	2446.9	220.0	2376.6	2596.6	0.7365	7.2968	8.0333
0.016	55.3	0.001015	9.433	231.5	2450.5	231.5	2369.9	2601.4	0.7719	7.2149	7.9868
0.018	57.8	0.001016	8.445	241.9	2453.8	241.9	2363.9	2605.8	0.8034	7.1425	7.9459
0.02	60.1	0.001017	7.649	251.4	2456.7	251.4	2358.3	2609.7	0.8319	7.0774	7.9093
0.03	69.1	0.001022	5.229	289.2	2468.4	289.2	2336.1	2625.3	0.9439	6.8256	7.7695
0.04	75.9	0.001026	3.993	317.5	2477.0	317.6	2319.1	2636.7	1.0260	6.6449	7.6709
0.06	85.9	0.001033	2.732	359.8	2489.6	359.8	2293.7	2653.5	1.1455	6.3873	7.5328
0.08	93.5	0.001039	2.087	391.6	2498.8	391.6	2274.1	2665.7	1.2331	6.2023	7.4354
0.1	99.6	0.001043	1.694	417.3	2506.1	417.4	2258.1	2675.5	1.3029	6.0573	7.3602
0.12	104.8	0.001047	1.428	439.2	2512.1	439.3	2244.2	2683.5	1.3611	5.9378	7.2980
0.14	109.3	0.001051	1.237	458.2	2517.3	458.4	2232.0	2690.4	1.4112	5.8360	7.2472
0.16	113.3	0.001054	1.091	475.2	2521.8	475.3	2221.2	2696.5	1.4553	5.7472	7.2025
0.18	116.9	0.001058	0.9775	490.5	2525.9	490.7	2211.1	2701.8	1.4948	5.6683	7.1631
0.2	120.2	0.001061	0.8857	504.5	2529.5	504.7	2201.9	2706.6	1.5305	5.5975	7.1280
0.3	133.5	0.001073	0.6058	561.1	2543.6	561.5	2163.8	2725.3	1.6722	5.3205	6.9927
0.4	143.6	0.001084	0.4625	604.3	2553.6	604.7	2133.8	2738.5	1.7770	5.1197	6.8967
0.6	158.9	0.001101	0.3157	669.9	2567.4	670.6	2086.2	2756.8	1.9316	4.8293	6.7609
0.8	170.4	0.001115	0.2404	720.2	2576.8	721.1	2048.0	2769.1	2.0466	4.6170	6.6636
1	179.9	0.001127	0.1944	761.7	2583.6	762.8	2015.3	2778.1	2.1391	4.4482	6.5873
1.2	188.0	0.001139	0.1633	797.3	2588.8	798.6	1986.2	2784.8	2.2170	4.3072	6.5242
1.4	195.1	0.001149	0.1408	828.7	2592.8	830.3	1959.7	2790.0	2.2847	4.1854	6.4701
1.6	201.4	0.001159	0.1238	856.9	2596.0	858.8	1935.2	2794.0	2.3446	4.0780	6.4226
1.8	207.2	0.001168	0.1104	882.7	2598.4	884.8	1912.3	2797.1	2.3986	3.9816	6.3802
2	212.4	0.001177	0.09963	906.4	2600.3	908.8	1890.7	2799.5	2.4478	3.8939	6.3417
3	233.9	0.001216	0.06668	1004.8	2604.1	1008.4	1795.7	2804.1	2.6462	3.5416	6.1878
4	250.4	0.001252	0.04978	1082.3	2602.3	1087.3	1714.1	2801.4	2.7970	3.2739	6.0709
6	275.6	0.001319	0.03244	1205.4	2589.7	1213.3	1571.0	2784.3	3.0273	2.8627	5.8900
8	295.1	0.001384	0.02352	1305.6	2569.8	1316.6	1441.4	2758.0	3.2075	2.5365	5.7440
10	311.1	0.001452	0.01803	1393.0	2544.4	1407.6	1317.1	2724.7	3.3603	2.2546	5.6149
12	324.8	0.001527	0.01426	1472.9	2513.7	1491.3	1193.6	2684.9	3.4970	1.9963	5.4933
14	336.8	0.001611	0.01149	1548.6	2476.8	1571.1	1066.5	2637.6	3.6240	1.7486	5.3726
16	347.4	0.001711	0.009307	1622.7	2431.8	1650.0	930.7	2580.7	3.7468	1.4996	5.2464
18	357.1	0.001840	0.007491	1698.9	2374.4	1732.0	777.2	2509.2	3.8722	1.2332	5.1054
20	365.8	0.002036	0.005836	1785.6	2293.2	1826.3	583.7	2410.0	4.0146	0.9135	4.9281
22.088	374.136	0.003155	0.003155	2029.6	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	4.4[illegible]

SOURCES: Keenan, Keyes, Hill, and Moore, *Steam Tables*, Wiley, New York, 1969; G. J. Van Wylen and R. E. Sonntag, *Fundamentals of*

Specific volume

- In the saturation region which this table represents; saturated liquid and saturated vapor exist at the same time.
- The specific volumes in this table include the specific volume for saturated liquid v_f, specific volume for saturated vapor, v_g and the change of specific volume during evaporation v_{fg} . Note that v_{fg} equals $v_g - v_f$



Two –phase states

- In the saturation region the property of the mixture (liquid and vapor) is given in term of the quality, x, and the properties of the two phases as follows:

$$z = z_g .x + (1-x).z_f$$

or

$$z = z_f + x\, z_{fg}$$

or

$$z = z_g-(1-x).z_{fg}$$

Subscript, f, indicates saturated liquid phase, and, g, saturated vapor phase.

Specific volume -two phase

- When this relation is applied to the specific volume it gives,

  $v = x.v_g + (1-x)\ v_f = v_f + x\ .\ V_{fg}$

- Example; find specific volume for saturated water at 200^oC with 70% quality ?
- From table B.1.1.SI at $200\ ^oC$

  $v_f = .001156\ m^3/kg$

  $v_g = 0.12736$ and $v_{fg} = 0.12620\ m^3/kg$

- Using the above equation

  $v = 0.70(0.12736) + 0.3\ (0.001156) = 0.089152\ m^3/kg$

Example specific volume

- Find the specific volume of saturated liquid and saturated water vapor at 80^{o}C ?
- From table B.1.1.SI (p.664) at T sat = 80 ^{o}C the specific volumes are,

v_f = 0.001029 m^3/kg

v_g = 3.40715 m^3/kg

v_{fg} = 3.40612 m^3/kg note that v_{fg} equals v_g - v_f .

		Volume, m^3/kg		Energy, kJ/kg		Enthalpy, kJ/kg			Entropy, kJ/kg·K		
T, °C	P, MPa	v_f	v_g	u_f	u_g	h_f	h_{fg}	h_g	s_f	s_{fg}	s_g
0.010	0.0006113	0.001000	206.1	0.0	2375.3	0.0	2501.3	2501.3	0.0000	9.1571	9.1571
2	0.0007056	0.001000	179.9	8.4	2378.1	8.4	2496.6	2505.0	0.0305	9.0738	9.1043
5	0.0008721	0.001000	147.1	21.0	2382.2	21.0	2489.5	2510.5	0.0761	8.9505	9.0266
10	0.001228	0.001000	106.4	42.0	2389.2	42.0	2477.7	2519.7	0.1510	8.7506	8.9016
15	0.001705	0.001001	77.93	63.0	2396.0	63.0	2465.9	2528.9	0.2244	8.5578	8.7822
20	0.002338	0.001002	57.79	83.9	2402.9	83.9	2454.2	2538.1	0.2965	8.3715	8.6680
25	0.003169	0.001003	43.36	104.9	2409.8	104.9	2442.3	2547.2	0.3672	8.1916	8.5588
30	0.004246	0.001004	32.90	125.8	2416.6	125.8	2430.4	2556.2	0.4367	8.0174	8.4541
35	0.005628	0.001006	25.22	146.7	2423.4	146.7	2418.6	2565.3	0.5051	7.8488	8.3539
40	0.007383	0.001008	19.52	167.5	2430.1	167.5	2406.8	2574.3	0.5723	7.6855	8.2578
45	0.009593	0.001010	15.26	188.4	2436.8	188.4	2394.8	2583.2	0.6385	7.5271	8.1656
50	0.01235	0.001012	12.03	209.3	2443.5	209.3	2382.8	2592.1	0.7036	7.3735	8.0771
55	0.01576	0.001015	9.569	230.2	2450.1	230.2	2370.7	2600.9	0.7678	7.2243	7.9921
60	0.01994	0.001017	7.671	251.1	2456.6	251.1	2358.5	2609.6	0.8310	7.0794	7.9104
65	0.02503	0.001020	6.197	272.0	2463.1	272.0	2346.2	2618.2	0.8934	6.9384	7.8318
70	0.03119	0.001023	5.042	292.9	2469.5	293.0	2333.8	2626.8	0.9549	6.8012	7.7561
75	0.03858	0.001026	4.131	313.9	2475.9	313.9	2321.4	2635.3	1.0155	6.6678	7.6833
80	0.04739	0.001029	3.407	334.8	2482.2	334.9	2308.8	2643.7	1.0754	6.5376	7.6130
85	0.05783	0.001032	2.828	355.8	2488.4	355.9	2296.0	2651.9	1.1344	6.4109	7.5453
90	0.07013	0.001036	2.361	376.8	2494.5	376.9	2283.2	2660.1	1.1927	6.2872	7.4799
95	0.08455	0.001040	1.982	397.9	2500.6	397.9	2270.2	2668.1	1.2503	6.1664	7.4167

Example specific volume

- Saturated water at 10MPa and 60% quality, determine the specific volume and the saturation temperature?
- From table B.1.2.SI at 10 MPa
- T_{sat} = 311.06 ^{o}C
- v_f = .001452 m^3/kg
- v_{fg} = .01657 m^3/kg
- Then $v = v_f + x.\ v_{fg} = 0.001452 + 0.6(.01657) = 0.009942$ m^3/kg

		Volume, m³/kg		Energy, kJ/kg		Enthalpy, kJ/kg			Entropy, kJ/kg·K		
P, MPa	T, °C	v_f	v_g	u_f	u_g	h_f	h_{fg}	h_g	s_f	s_{fg}	s_g
0.000611	0.01	0.001000	206.1	0.0	2375.3	0.0	2501.3	2501.3	0.0000	9.1571	9.1571
0.0008	3.8	0.001000	159.7	15.8	2380.5	15.8	2492.5	2508.3	0.0575	9.0007	9.0582
0.001	7.0	0.001000	129.2	29.3	2385.0	29.3	2484.9	2514.2	0.1059	8.8706	8.9765
0.0012	9.7	0.001000	108.7	40.6	2388.7	40.6	2478.5	2519.1	0.1460	8.7639	8.9099
0.0014	12.0	0.001001	93.92	50.3	2391.9	50.3	2473.1	2523.4	0.1802	8.6736	8.8538
0.0016	14.0	0.001001	82.76	58.9	2394.7	58.9	2468.2	2527.1	0.2101	8.5952	8.8053
0.0018	15.8	0.001001	74.03	66.5	2397.2	66.5	2464.0	2530.5	0.2367	8.5259	8.7626
0.002	17.5	0.001001	67.00	73.5	2399.5	73.5	2460.0	2533.5	0.2606	8.4639	8.7245
0.003	24.1	0.001003	45.67	101.0	2408.5	101.0	2444.5	2545.5	0.3544	8.2240	8.5784
0.004	29.0	0.001004	34.80	121.4	2415.2	121.4	2433.0	2554.4	0.4225	8.0529	8.4754
0.006	36.2	0.001006	23.74	151.5	2424.9	151.5	2415.9	2567.4	0.5208	7.8104	8.3312
0.008	41.5	0.001008	18.10	173.9	2432.1	173.9	2403.1	2577.0	0.5924	7.6371	8.2295
0.01	45.8	0.001010	14.67	191.8	2437.9	191.8	2392.8	2584.6	0.6491	7.5019	8.1510
0.012	49.4	0.001012	12.36	206.9	2442.7	206.9	2384.1	2591.0	0.6961	7.3910	8.0871
0.014	52.6	0.001013	10.69	220.0	2446.9	220.0	2376.6	2596.6	0.7365	7.2968	8.0333
0.016	55.3	0.001015	9.433	231.5	2450.5	231.5	2369.9	2601.4	0.7719	7.2149	7.9868
0.018	57.8	0.001016	8.445	241.9	2453.8	241.9	2363.9	2605.8	0.8034	7.1425	7.9459
0.02	60.1	0.001017	7.649	251.4	2456.7	251.4	2358.3	2609.7	0.8319	7.0774	7.9093
0.03	69.1	0.001022	5.229	289.2	2468.4	289.2	2336.1	2625.3	0.9439	6.8256	7.7695
0.04	75.9	0.001026	3.993	317.5	2477.0	317.6	2319.1	2636.7	1.0260	6.6449	7.6709
0.06	85.9	0.001033	2.732	359.8	2489.6	359.8	2293.7	2653.5	1.1455	6.3873	7.5328
0.08	93.5	0.001039	2.087	391.6	2498.8	391.6	2274.1	2665.7	1.2331	6.2023	7.4354
0.1	99.6	0.001043	1.694	417.3	2506.1	417.4	2258.1	2675.5	1.3029	6.0573	7.3602
0.12	104.8	0.001047	1.428	439.2	2512.1	439.3	2244.2	2683.5	1.3611	5.9378	7.2980
0.14	109.3	0.001051	1.237	458.2	2517.3	458.4	2232.0	2690.4	1.4112	5.8360	7.2472
0.16	113.3	0.001054	1.091	475.2	2521.8	475.3	2221.2	2696.5	1.4553	5.7472	7.2025
0.18	116.9	0.001058	0.9775	490.5	2525.9	490.7	2211.1	2701.8	1.4948	5.6683	7.1631
0.2	120.2	0.001061	0.8857	504.5	2529.5	504.7	2201.9	2706.6	1.5305	5.5975	7.1280
0.3	133.5	0.001073	0.6058	561.1	2543.6	561.5	2163.8	2725.3	1.6722	5.3205	6.9927
0.4	143.6	0.001084	0.4625	604.3	2553.6	604.7	2133.8	2738.5	1.7770	5.1197	6.8967
0.6	158.9	0.001101	0.3157	669.9	2567.4	670.6	2086.2	2756.8	1.9316	4.8293	6.7609
0.8	170.4	0.001115	0.2404	720.2	2576.8	721.1	2048.0	2769.1	2.0466	4.6170	6.6636
1	179.9	0.001127	0.1944	761.7	2583.6	762.8	2015.3	2778.1	2.1391	4.4482	6.5873
1.2	188.0	0.001139	0.1633	797.3	2588.8	798.6	1986.2	2784.8	2.2170	4.3072	6.5242
1.4	195.1	0.001149	0.1408	828.7	2592.8	830.3	1959.7	2790.0	2.2847	4.1854	6.4701
1.6	201.4	0.001159	0.1238	856.9	2596.0	858.8	1935.2	2794.0	2.3446	4.0780	6.4226
1.8	207.2	0.001168	0.1104	882.7	2598.4	884.8	1912.3	2797.1	2.3986	3.9816	6.3802
2	212.4	0.001177	0.09963	906.4	2600.3	908.8	1890.7	2799.5	2.4478	3.8939	6.3417
3	233.9	0.001216	0.06668	1004.8	2604.1	1008.4	1795.7	2804.1	2.6462	3.5416	6.1878
4	250.4	0.001252	0.04978	1082.3	2602.3	1087.3	1714.1	2801.4	2.7970	3.2739	6.0709
6	275.6	0.001319	0.03244	1205.4	2589.7	1213.3	1571.0	2784.3	3.0273	2.8627	5.8900
8	295.1	0.001384	0.02352	1305.6	2569.8	1316.6	1441.4	2758.0	3.2075	2.5365	5.7440
10	311.1	0.001452	0.01803	1393.0	2544.4	1407.6	1317.1	2724.7	3.3603	2.2546	5.6149
12	324.8	0.001527	0.01426	1472.9	2513.7	1491.3	1193.6	2684.9	3.4970	1.9963	5.4933
14	336.8	0.001611	0.01149	1548.6	2476.8	1571.1	1066.5	2637.6	3.6240	1.7486	5.3726
16	347.4	0.001711	0.009307	1622.7	2431.8	1650.0	930.7	2580.7	3.7468	1.4996	5.2464
18	357.1	0.001840	0.007491	1698.9	2374.4	1732.0	777.2	2509.2	3.8722	1.2332	5.1054
20	365.8	0.002036	0.005836	1785.6	2293.2	1826.3	583.7	2410.0	4.0146	0.9135	4.9281
22.088	374.136	0.003155	0.003155	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Saturated water at 10MPa

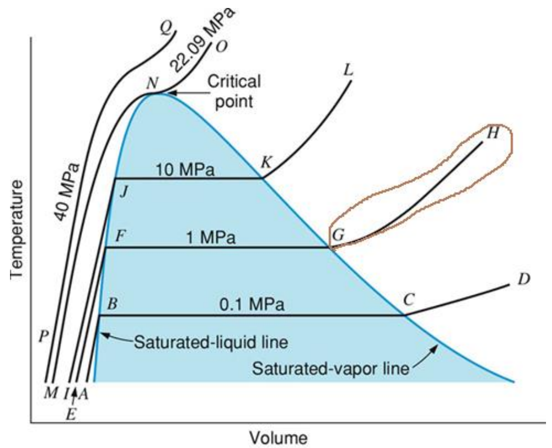
SOURCES: Keenan, Keyes, Hill, and Moore, *Steam Tables*, Wiley, New York, 1969; G. J. Van Wylen and R. E. Sonntag, *Fundamentals of*

Questions

- *Question1: for saturated water at 180 ^{o}C, determine the saturation pressure and the specific volumes of saturated liquid and saturated vapor? Show the above value on a T-v diagram.*
- *Question2: for saturated water at 374.1 ^{o}C, find the saturated liquid and saturated vapor specific volumes? Comment on the found values? Locate the values on a T-v diagram.*
- *Question: for saturated steam at 180 ^{o}C determine, the pressure, and specific volume? Show this state on a T-v diagram.*
- *Question: for saturated liquid water at 2000 kPa find the temperature, the specific volume and the quality? Show this state on a T-v diagram.*

Table B.1.3.SI Superheated Vapor Water

- This table presents the water properties in the superheated vapor region.
- In this region temperature and pressure are independent.
- Properties are given for each isobar (constant pressure) and for various temperatures, starting from the low of 10 kPa to a pressure of 60 MPa.
- The first temperature at a given pressure is the saturation temperature indicated as sat. in the first column of the table.
- This temperature represents the saturation temperature at the given pressure and it is given in brackets next to the pressure. For example at 10 kPa such value is 45.81 ^oC , this can be checked in table B.1.2.SI.



T	v	u	h	s	v	u	h	s	v	u	h	s
	P = 0.010 MPa (45.81°C)				P = 0.050 MPa (81.33°C)				P = 0.10 MPa (99.63°C)			
Sat.	14.674	2437.9	2584.7	8.1502	3.240	2483.9	2645.9	7.5939	1.6940	2506.1	2675.5	7.3594
50	14.869	2443.9	2592.6	8.1749								
100	17.196	2515.5	2687.5	8.4479	3.418	2511.6	2682.5	7.6947	1.6958	2506.7	2676.2	7.3614
150	19.512	2587.9	2783.0	8.6882	3.889	2585.6	2780.1	7.9401	1.9364	2582.8	2776.4	7.6134
200	21.825	2661.3	2879.5	8.9038	4.356	2659.9	2877.7	8.1580	2.172	2658.1	2875.3	7.8343
250	24.136	2736.0	2977.3	9.1002	4.820	2735.0	2976.0	8.3556	2.406	2733.7	2974.3	8.0333
300	26.445	2812.1	3076.5	9.2813	5.284	2811.3	3075.5	8.5373	2.639	2810.4	3074.3	8.2158
400	31.063	2968.9	3279.6	9.6077	6.209	2968.5	3278.9	8.8642	3.103	2967.9	3278.2	8.5435
500	35.679	3132.3	3489.1	9.8978	7.134	3132.0	3488.7	9.1546	3.565	3131.6	3483.1	8.8342
600	40.295	3302.5	3705.4	10.1608	8.057	3302.2	3705.1	9.4178	4.028	3301.9	3704.7	9.0976
700	44.911	3479.6	3928.7	10.4028	8.981	3479.4	3928.5	9.6599	4.490	3479.2	3928.2	9.3398
800	49.526	3663.8	4159.0	10.6281	9.904	3663.6	4158.9	9.8852	4.952	3663.5	4158.6	9.5652
900	54.141	3855.0	4396.4	10.8396	10.828	3854.9	4396.3	10.0967	5.414	3854.8	4396.1	9.7767
1000	58.757	4053.0	4640.6	11.0393	11.751	4052.9	4640.5	10.2964	5.875	4052.8	4640.3	9.9764
1100	63.372	4257.5	4891.2	11.2287	12.674	4257.4	4891.1	10.4859	6.337	4257.3	4891.0	10.1659
1200	67.987	4467.9	5147.8	11.4091	13.597	4467.8	5147.7	10.6662	6.799	4467.7	5147.6	10.3463
1300	72.602	4683.7	5409.7	11.5811	14.521	4683.6	5409.6	10.8382	7.260	4683.5	5409.5	10.5183
	P = 0.20 MPa (120.23°C)				P = 0.30 MPa (133.55°C)				P = 0.40 MPa (143.63°C)			
Sat.	.8857	2529.5	2706.7	7.1272	.6058	2543.6	2725.3	6.9919	.4625	2553.6	2738.6	6.8959
150	.9596	2576.9	2768.8	7.2795	.6339	2570.8	2761.0	7.0778	.4708	2564.5	2752.8	6.9299
200	1.0803	2654.4	2870.5	7.5066	.7163	2650.7	2865.6	7.3115	.5342	2646.8	2860.5	7.1706
250	1.1988	2731.2	2971.0	7.7086	.7964	2728.7	2967.6	7.5166	.5951	2726.1	2964.2	7.3789
300	1.3162	2808.6	3071.8	7.8926	.8753	2806.7	3069.3	7.7022	.6548	2804.8	3066.8	7.5662
400	1.5493	2966.7	3276.6	8.2218	1.0315	2965.6	3275.6	8.0330	.7726	2964.4	3273.4	7.8985
500	1.7814	3130.8	3487.1	8.5133	1.1867	3130.0	3486.0	8.3251	.8893	3129.2	3484.9	8.1913
600	2.013	3301.4	3704.0	8.7770	1.3414	3300.8	3703.2	8.5892	1.0055	3300.2	3702.4	8.4558
700	2.244	3478.8	3927.6	9.0194	1.4957	3478.4	3927.1	8.8319	1.1215	3477.9	3926.5	8.6987
800	2.475	3663.1	4158.2	9.2449	1.6499	3662.9	4157.8	9.0576	1.2372	3662.4	4157.3	8.9244
900	2.706	3854.5	4395.8	9.4566	1.8041	3854.2	4395.4	9.2692	1.3529	3853.9	4395.1	9.1362
1000	2.937	4052.5	4640.0	9.6563	1.9581	4052.3	4639.7	9.4690	1.4685	4052.0	4639.4	9.3360
1100	3.168	4257.0	4890.7	9.8458	2.1121	4256.5	4890.4	9.6585	1.5840	4256.5	4890.2	9.5256
1200	3.399	4467.5	5147.3	10.0262	2.2661	4467.2	5147.1	9.8389	1.6996	4467.0	5146.8	9.7060
1300	3.630	4683.2	5409.3	10.1982	2.4201	4683.0	5409.0	10.0110	1.8151	4682.8	5408.8	9.8780
	P = 0.50 MPa (151.86°C)				P = 0.60 MPa (158.85°C)				P = 0.80 MPa (170.43°C)			
Sat.	.3749	2561.2	2748.7	6.8213	.3157	2567.4	2756.8	6.7600	.2404	2576.8	2769.1	6.6628
200	.4249	2642.9	2855.4	7.0592	.3520	2638.9	2850.1	6.9665	.2608	2630.6	2839.3	6.8158
250	.4744	2723.5	2960.7	7.2709	.3938	2720.9	2957.2	7.1816	.2931	2715.5	2950.0	7.0384
300	.5226	2802.9	3064.2	7.4599	.4344	2801.0	3061.6	7.3724	.3241	2797.2	3056.5	7.2328
350	.5701	2882.6	3167.7	7.6329	.4742	2881.2	3165.7	7.5464	.3544	2878.2	3161.7	7.4089
400	.6173	2963.2	3271.9	7.7938	.5137	2962.1	3270.3	7.7079	.3843	2959.7	3267.1	7.5716
500	.7109	3128.4	3483.9	8.0873	.5920	3127.6	3482.8	8.0021	.4433	3126.0	3480.6	7.8673
600	.8041	3299.6	3701.7	8.3522	.6697	3299.1	3700.9	8.2674	.5018	3297.9	3699.4	8.1333
700	.8969	3477.5	3925.9	8.5952	.7472	3477.0	3925.3	8.5107	.5601	3476.2	3924.2	8.3770
800	.9896	3662.1	4156.9	8.8211	.8245	3661.8	4156.5	8.7367	.6181	3661.1	4155.6	8.6033
900	1.0822	3853.6	4394.7	9.0329	.9017	3853.4	4394.4	8.9486	.6761	3852.8	4393.7	8.8153
1000	1.1747	4051.8	4639.1	9.2328	.9788	4051.5	4638.8	9.1485	.7340	4051.0	4638.2	9.0153
1100	1.2672	4256.3	4889.9	9.4224	1.0559	4256.1	4889.6	9.3381	.7919	4255.6	4889.1	9.2050
1200	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	5146.3	9.5185	.8497	4466.1	5145.9	9.3855
1300	1.4521	4682.5	5408.6	9.7749	1.2101	4682.3	5408.3	9.6906	.9076	4681.8	5407.9	9.5575

T	v	u	h	s	v	u	h	s	v	u	h	s
	P = 1.00 MPa (179.91°C)				P = 1.20 MPa (187.99°C)				P = 1.40 MPa (195.07°C)			
Sat.	.19 444	2583.6	2778.1	6.5865	.163 33	2588.8	2784.8	6.5233	.140 84	2592.8	2790.0	6.4693
200	.2060	2621.9	2827.9	6.6940	.169 30	2612.8	2815.9	6.5898	.143 02	2603.1	2803.3	6.4975
250	.2327	2709.9	2942.6	6.9247	.192 34	2704.2	2935.0	6.8294	.163 50	2698.3	2927.2	6.7467
300	.2579	2793.2	3051.2	7.1229	.2138	2789.2	3045.8	7.0317	.182 28	2785.2	3040.4	6.9534
350	.2825	2875.2	3157.7	7.3011	.2345	2872.2	3153.6	7.2121	.2003	2869.2	3149.5	7.1360
400	.3066	2957.3	3263.9	7.4651	.2548	2954.9	3260.7	7.3774	.2178	2952.5	3257.5	7.3026
500	.3541	3124.4	3478.5	7.7622	.2946	3122.8	3476.3	7.6759	.2521	3321.1	3474.1	7.6027
600	.4011	3296.8	3697.9	8.0290	.3339	3295.6	3696.3	7.9435	.2860	3294.4	3694.8	7.8710
700	.4478	3475.3	3923.1	8.2731	.3729	3474.4	3922.0	8.1881	.3195	3473.6	3920.8	8.1160
800	.4943	3660.4	4154.7	8.4996	.4118	3659.7	4153.8	8.4148	.3528	3659.0	4153.0	8.3431
900	.5407	3852.2	4392.9	8.7118	.4505	3851.6	4392.2	8.6272	.3861	3851.1	4391.5	8.5556
1000	.5871	4050.5	4637.6	8.9119	.4892	4050.0	4637.0	8.8274	.4192	4049.5	4636.4	8.7559
1100	.6335	4255.1	4888.6	9.1017	.5278	4254.6	4888.0	9.0172	.4524	4254.1	4887.5	8.9457
1200	.6798	4465.6	5145.4	9.2822	.5665	4465.1	5144.9	9.1977	.4855	4464.7	5144.4	9.1262
1300	.7261	4681.3	5407.4	9.4543	.6051	4680.9	5407.0	9.3698	.5186	4680.4	5406.5	9.2984
	P = 1.60 MPa (201.41°C)				P = 1.80 MPa (207.15°C)				P = 1.80 MPa (207.15°C)			
Sat.	.123 80	2596.0	2794.0	6.4218	.110 42	2598.4	2797.1	6.3794	.099 63	2600.3	2799.5	6.3409
225	.132 87	2644.7	2857.3	6.5518	.136 73	2636.6	2846.7	6.4808	.103 77	2628.3	2835.8	6.4147
250	.141 84	2692.3	2919.2	6.6732	.124 97	2686.0	2911.0	6.6066	.111 44	2679.6	2902.5	6.5453
300	.158 62	2781.1	3034.8	6.8844	.140 21	2776.9	3029.2	6.8226	.125 47	2772.6	3023.5	6.7664
350	.174 56	2866.1	3145.4	7.0694	.154 57	2863.0	3141.2	7.0100	.138 57	2859.8	3137.0	6.9563
400	.190 05	2950.1	3254.2	7.2374	.168 47	2947.7	3250.9	7.1794	.151 20	2945.2	3247.6	7.1271
500	.2203	3119.5	3472.0	7.5390	.195 50	3117.9	3469.8	7.4825	.175 68	3116.2	3467.6	7.4317
600	.2500	3293.3	3693.2	7.8080	.2220	3292.1	3691.7	7.7523	.199 60	3290.9	3690.1	7.7024
700	.2794	3472.7	3919.7	8.0535	.2482	3471.8	3918.5	7.9983	.2232	3470.9	3917.4	7.9487
800	.3086	3658.3	4152.1	8.2808	.2742	3657.6	4151.2	8.2258	.2467	3657.0	4150.3	8.1765
900	.3377	3850.5	4390.8	8.4935	.3001	3849.9	4390.1	8.4386	.2700	3849.3	4389.4	8.3895
1000	.5668	4049.0	4635.8	8.6938	.3260	4048.5	4635.2	8.6391	.2933	4048.0	4634.6	8.5901
1100	.3958	4253.7	4887.0	8.8837	.3518	4253.2	4886.4	8.8290	.3166	4252.7	4885.9	8.7800
1200	.4248	4464.2	5143.9	9.0643	.3776	4463.7	5143.4	9.0096	.3398	4463.3	5142.9	8.9607
1300	.4538	4679.9	5406.0	9.2364	.4034	4679.5	5405.6	9.1818	.3631	4679.0	5405.1	9.1329
	P = 2.50 MPa (233.99°C)				P = 3.00 MPa (233.90°C)				P = 3.50 MPa (242.60°C)			
Sat.	.079 98	2603.1	2803.1	6.2575	.066 68	2604.1	2804.2	6.1869	.05707	2603.7	2803.4	6.1253
225	.080 27	2605.6	2806.3	6.2639								
250	.087 00	2662.6	2880.1	6.4085	.070 58	2644.0	2855.8	6.2872	.058 72	2623.7	2829.2	6.1749
300	.098 90	2761.6	3008.8	6.6438	.081 14	2750.1	2993.5	6.5390	.068 42	2738.0	2977.5	6.4461
350	.109 76	2851.9	3126.3	6.8403	.090 53	2843.7	3115.3	6.7428	.076 78	2835.3	3104.0	6.6579
400	.120 10	2939.1	3239.3	7.0148	.099 36	2932.8	3230.9	6.9212	.084 53	2926.4	3222.3	6.8405
450	.130 14	3025.5	3350.8	7.1746	.107 87	3020.4	3344.0	7.0834	.091 96	3015.3	3337.2	7.0052
500	.139 98	3112.1	3462.1	7.3234	.116 19	3108.0	3456.5	7.2338	.099 18	3103.0	3450.9	7.1572
600	.159 30	3288.0	3686.3	7.5960	.132 43	3285.0	3682.3	7.5085	.113 24	3282.1	3678.4	7.4339
700	.178 32	3468.7	3914.5	7.8435	.148 38	3466.5	3911.7	7.7571	.126 99	3464.3	3908.8	7.6837
800	.197 16	3655.3	4148.2	8.0720	.164 14	3653.5	4145.9	7.9862	.140 56	3651.8	4143.7	7.9134
900	.215 90	3847.9	4387.6	8.2853	.179 80	3846.5	4385.9	8.1999	.154 02	3845.0	4384.1	8.1276
1000	.2346	4046.7	4633.1	8.4861	.195 41	4045.4	4631.6	8.4009	.167 43	4044.1	4630.1	8.3288
1100	.2532	4251.5	4884.6	8.6762	.210 98	4250.3	4883.3	8.5912	.180 80	4249.2	4881.9	8.5192
1200	.2718	4462.1	5141.7	8.8569	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1300	.2905	4677.8	5404.0	9.0291	[illegible]	4676.6	5402.8	8.9442	.207 49	4675.5	5401.7	8.8723

T	v	u	h	s	v	u	h	s	v	u	h	s
	P = 4.0 MPa (250.40°C)				P = 4.5 MPa (257.49°C)				P = 5.0 MPa (263.99°C)			
Sat.	.049 78	2602.3	2801.4	6.0701	.044 06	2600.1	2798.3	6.0198	.039 44	2597.1	2794.3	5.9734
275	.054 57	2667.9	2886.2	6.2285	.047 30	2650.3	2863.2	6.1401	.041 41	2631.3	2838.3	6.0544
300	.058 84	2725.3	2960.7	6.3615	.051 35	2712.0	2943.1	6.2828	.045 32	2698.0	2924.5	6.2084
350	.066 45	2826.7	3092.5	6.5821	.058 40	2817.8	3080.6	6.5131	.051 94	2808.7	3068.4	6.4493
400	.073 41	2919.9	3213.6	6.7690	.064 75	2913.3	3204.7	6.7047	.057 81	2906.6	3195.7	6.6459
450	.080 02	3010.2	3330.3	6.9363	.070 74	3005.0	3323.3	6.8746	.063 30	2999.7	3316.2	6.8186
500	.086 43	3099.5	3445.3	7.0901	.076 51	3095.3	3439.6	7.0301	.068 57	3091.0	3433.8	6.9759
600	.098 85	3279.1	3674.4	7.3688	.087 65	3276.0	3670.5	7.3110	.078 69	3273.0	3666.5	7.2589
700	.110 95	3462.1	3905.9	7.6198	.098 47	3459.9	3903.0	7.5631	.088 49	3457.6	3900.1	7.5122
800	.122 87	3650.0	4141.5	7.8502	.109 11	3648.3	4139.3	7.7942	.098 11	3646.6	4137.1	7.7440
900	.134 69	3843.6	4382.3	8.0647	.119 65	3842.2	4380.6	8.0091	.107 62	3840.7	4378.8	7.9593
1000	.146 45	4042.9	4628.7	8.2662	.130 13	4041.6	4627.2	8.2108	.117 07	4040.4	4625.7	8.1612
1100	.158 17	4248.0	4880.6	8.4567	.140 56	4246.8	4879.3	8.4015	.126 48	4245.6	4878.0	8.3520
1200	.169 87	4458.6	5138.1	8.6376	.150 98	4457.5	5136.9	8.5825	.135 87	4456.3	5135.7	8.5331
1300	.181 56	4674.3	5400.5	8.8100	.161 39	4673.1	5399.4	8.7549	.145 26	4672.0	5398.2	8.7055
	P = 6.0 MPa (275.64°C)				P = 7.0 MPa (285.88°C)				P = 8.0 MPa (295.06°C)			
Sat.	.032 44	2589.7	2784.3	5.8892	.027 37	2580.5	2772.1	5.8133	.023 52	2569.8	2758.0	5.7432
300	.036 16	2667.2	2884.2	6.0674	.029 47	2632.2	2838.4	3.9305	.024 26	2590.9	2785.0	5.7906
350	.042 23	2789.6	3043.0	6.3335	.035 24	2769.4	3016.0	6.2283	.029 95	2747.7	2987.3	6.1301
400	.047 39	2892.9	3177.2	6.5408	.039 93	2878.6	3158.1	6.4478	.034 32	2863.8	3138.3	6.3634
450	.052 14	2988.9	3301.8	6.7193	.044 16	2978.0	3287.1	6.6327	.038 17	2966.7	3272.0	6.5551
500	.056 65	3082.2	3422.2	6.8803	.048 14	3073.4	3410.3	6.7975	.041 75	3064.3	3398.3	6.7240
550	.061 01	3174.6	3540.6	7.0288	.051 95	3167.2	3530.9	6.9486	.045 16	3159.8	3521.0	6.8778
600	.065 25	3266.9	3658.4	7.1677	.055 65	3260.7	3650.3	7.0894	.048 45	3254.4	3642.0	7.0206
700	.073 52	3453.1	3894.2	7.4234	.062 83	3448.5	3888.3	7.3476	.054 81	3443.9	3882.4	7.2812
800	.081 60	3643.1	4132.7	7.6566	.069 81	3639.5	4128.2	7.5822	.060 97	3636.0	4123.8	7.5173
900	.089 58	3837.8	4375.3	7.8727	.076 69	3835.0	4371.8	7.7991	.067 02	3832.1	4368.3	7.7351
1000	.097 49	4037.8	4622.7	8.0751	.083 50	4035.3	4619.8	8.0020	.073 01	4032.8	4616.9	7.9384
1100	.105 36	4243.3	4875.4	8.2661	.090 27	4240.9	4872.8	8.1933	.078 96	4238.6	4870.3	8.1300
1200	.113 21	4454.0	5133.3	8.4474	.097 03	4451.7	5130.9	8.3747	.084 89	4449.5	5128.5	8.3115
1300	.121 06	4669.6	5396.0	8.6199	.103 77	4667.3	5393.7	8.5473	.090 80	4665.0	5391.5	8.4842
	P = 9.0 MPa (303.40°C)				P = 10.0 MPa (311.06°C)				P = 12.5 MPa (327.89°C)			
Sat.	.020 48	2557.8	2742.1	5.6772	.018 026	2544.4	2724.7	5.6141	.013 495	2505.1	2673.8	5.4624
325	.023 27	2646.6	2856.0	5.8712	.019 861	2610.4	2809.1	5.7568				
350	.025 80	2724.4	2956.6	6.0361	.022 42	2699.4	2923.4	5.9443	.016 126	2624.6	2826.2	5.7118
406	.029 93	2848.4	3117.8	6.2854	.026 41	2832.4	3096.5	6.2120	.020 00	2789.3	3039.3	6.0417
450	.033 50	2955.2	3256.6	6.4844	.029 75	2943.4	3240.9	6.4190	.022 99	2912.5	3199.8	6.2719
500	.036 77	3055.2	3336.1	6.6576	.032 79	3045.8	3373.7	6.5966	.025 60	3021.7	3341.8	6.4618
550	.039 87	3152.2	3511.0	6.8142	.035 64	3144.6	3500.9	6.7561	.028 01	3125.0	3475.2	6.6290
600	.042 85	3248.1	3633.7	6.9589	.038 37	3241.7	3625.3	6.9029	.030 29	3225.4	3604.0	6.7810
650	.045 74	3343.6	3755.3	7.0943	.041 01	3338.2	3748.2	7.0398	.032 48	3324.4	3730.4	6.9218
700	.048 57	3439.3	3876.5	7.2221	.043 58	3434.7	3870.5	7.1687	.034 60	3422.9	3855.3	7.0536
800	.054 09	3632.5	4119.3	7.4596	.048 59	3628.9	4114.8	7.4077	.038 69	3620.0	4103.6	7.2965
900	.059 50	3829.2	4364.3	7.6783	.053 49	3826.3	4361.2	7.6272	.042 67	3819.1	4352.5	7.5182
1000	.064 85	4030.3	4614.0	7.8821	.058 32	4027.8	4611.0	7.8315	.046 58	4021.6	4603.8	7.7237
1100	.070 16	4236.3	4867.7	8.0740	.063 12	4234.0	4865.1	8.0237	.050 45	4228.2	4858.8	7.9165
1200	[illegible]	[illegible]	5126.2	8.2556	.067 89	4444.9	5123.8	8.2055	.054 30	4439.3	5118.0	8.0987
1300	[illegible]	[illegible]	[illegible]	[illegible]	.072 65	4460.5	5387.0	8.3783	.058 13	4654.8	5381.4	8.2717

T	v	u	h	s	v	u	h	s	v	u	h	s
	P = 15.0 MPa (342.24°C)				P = 17.5 MPa (354.75°C)				P = 20.0 MPa (365.81°C)			
Sat.	.010 337	2455.5	2610.5	5.3098	.0079 20	2390.2	2528.8	5.1419	.005 834	2293.0	2409.7	4.9269
350	.011 470	2520.4	2692.4	5.4421								
400	.015 649	2740.7	2975.5	5.8811	.012 447	2685.0	2902.9	5.7213	.009 942	2619.3	2818.1	5.5540
450	.018 445	2879.5	3156.2	6.1404	.015 174	2844.2	3109.7	6.0184	.012 695	2806.2	3060.1	5.9017
500	.020 80	2996.6	3308.6	6.3443	.017 358	2970.3	3274.1	6.2383	.014 768	2942.9	3238.2	6.1401
550	.022 93	3104.7	3448.6	6.5199	.019 288	3083.9	3421.4	6.4230	.016 555	3062.4	3393.5	6.3348
600	.024 91	3208.6	3582.3	6.6776	.021 06	3191.5	3560.2	6.5866	.018 178	3174.0	3537.6	6.5048
650	.026 80	3310.3	3712.3	6.8224	.022 74	3296.0	3693.9	6.7357	.019 693	3281.4	3675.3	6.6582
700	.028 61	3410.9	3840.1	6.9572	.024 34	3398.7	3824.6	6.8736	.021 13	3386.4	3809.0	6.7993
800	.032 10	3610.9	4092.4	7.2040	.027 38	3601.8	4081.1	7.1244	.023 85	3592.7	4069.7	7.0544
900	.035 46	3811.9	4343.8	7.4279	.030 31	3804.7	4335.1	7.3507	.026 45	3797.5	4326.4	7.2830
1000	.038 75	4015.4	4596.6	7.6348	.033 16	4009.3	4589.5	7.5589	.028 97	4003.1	4582.5	7.4925
1100	.042 00	4222.6	4852.6	7.8283	.035 97	4216.9	4846.4	7.7531	.031 45	4211.3	4840.2	7.6874
1200	.045 23	4433.8	5112.3	8.0108	.038 76	4428.3	5106.6	7.9360	.033 91	4422.8	5101.0	7.8707
1300	.048 45	4649.1	5376.0	8.1840	.041 54	4643.5	5370.5	8.1093	.036 36	4638.0	5365.1	8.0442
	P = 25.0 MPa				P = 30.0 MPa				P = 40.0 MPa			
375	.001 9731	1798.7	1848.0	4.0320	.001 789 2	1737.8	1791.5	3.9305	.001 640 7	1677.1	1742.8	3.8290
400	.006 004	2430.1	2580.2	5.1418	.002 790	2067.4	2151.1	4.4728	.001 907 7	1854.6	1930.9	4.1135
425	.007 881	2609.2	2806.3	5.4723	.005 303	2455.1	2614.2	5.1504	.002 532	2096.9	2198.1	4.5029
450	.009 162	2720.7	2949.7	5.6744	.006 735	2619.3	2821.4	5.4424	.003 693	2365.1	2512.8	4.9459
500	.011 123	2884.3	3162.4	5.9592	.008 678	2820.7	3081.1	5.7905	.005 622	2678.4	2903.3	5.4700
550	.012 724	3017.5	3335.6	6.1765	.010 168	2970.3	3275.4	6.0342	.006 984	2869.7	3149.1	5.7785
600	.014 137	3137.9	3491.4	6.3602	.011 446	3100.5	3443.9	6.2331	.008 094	3022.6	3346.4	6.0114
650	.015 433	3251.6	3637.4	6.5229	.012 596	3221.0	3598.9	6.4058	.009 063	3158.0	3520.6	6.2054
700	.016 646	3361.3	3777.5	6.6707	.013 661	3335.8	3745.6	6.5606	.009 941	3283.6	3681.2	6.3750
800	.018 912	3574.3	4047.1	6.9345	.015 623	3555.5	4024.2	6.8332	.011 523	3517.8	3978.7	6.6662
900	.021 045	3783.0	4309.1	7.1680	.017 448	3768.5	4291.9	7.0718	.012 962	3739.4	4257.9	6.9150
1000	.023 10	3990.9	4568.5	7.3802	.019 196	3978.8	4554.7	7.2867	.014 324	3954.6	4527.6	7.1356
1100	.025 12	4200.2	4828.2	7.5765	.020 903	4189.2	4816.3	7.4845	.015 642	4167.4	4793.1	7.3364
1200	.027 11	4412.0	5089.9	7.7605	.022 589	4401.3	5079.0	7.6692	.016 940	4380.1	5057.7	7.5224
1300	.029 10	4626.9	5354.4	7.9342	.024 266	4616.0	5344.0	7.8432	.018 229	4594.3	5323.5	7.6969

SOURCES: Keenan, Keyes, Hill, and Moore, *Steam Tables*, Wiley, New York, 1969; G. J. Van Wylen and R. E. Sonntag, *Fundamentals of Classical Thermodynamics*, Wiley, New York, 1973.

Example: superheated vapor

- Find the specific volume for the following states of superheated vapor: (800^{o}C, 200kPa), (400 ^{o}C, 1000kPa), and (1000 ^{o}C, 40 MPa)?
- Solution:
- From table B.1.3.SI:
- For 800^{o}C, 200kPa v = 2.47539 m^3/kg
- For 400 ^{o}C, 1000kPa v = 0.30659 m^3/kg
- For 1000 ^{o}C, 40 MPa v = 0.014324 m^3/kg.

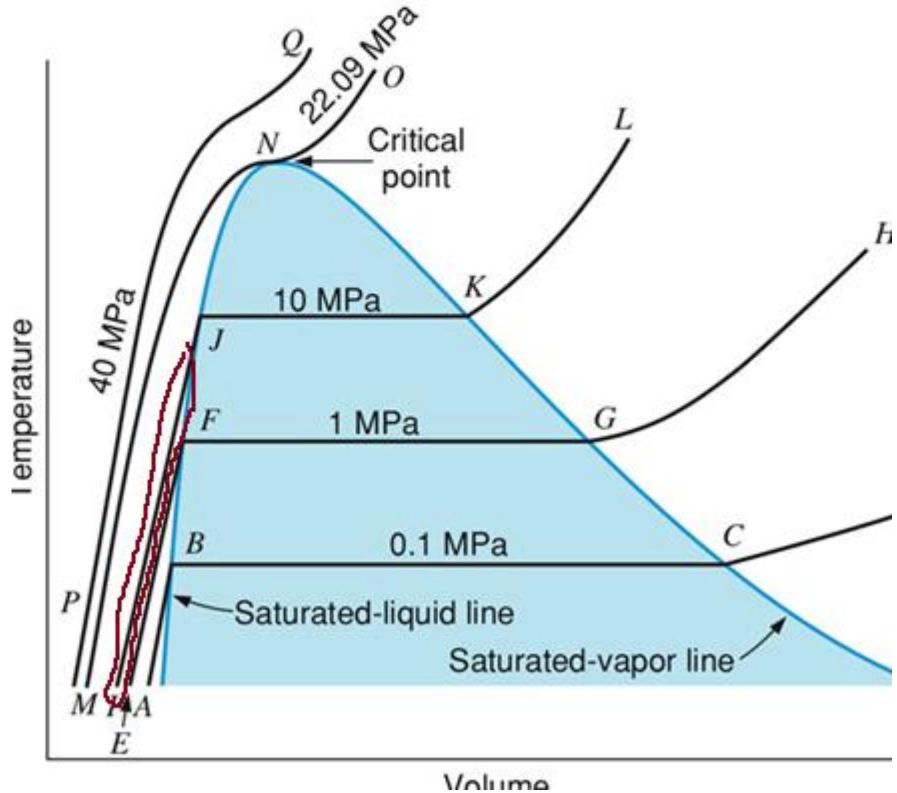
T	v	u	h	s	v	u	h	s	v	u	h	s
	P = 0.20 MPa (120.23 °C)				P = 0.30 MPa (133.55 °C)				P = 0.40 MPa (143.63 °C)			
Sat.	.8857	2529.5	2706.7	7.1272	.6058	2543.6	2725.3	6.9919	.4625	2553.6	2738.6	6.8959
150	.9596	2576.9	2768.8	7.2795	.6339	2570.8	2761.0	7.0778	.4708	2564.5	2752.8	6.9299
200	1.0803	2654.4	2870.5	7.5066	.7163	2650.7	2865.6	7.3115	.5342	2646.8	2860.5	7.1706
250	1.1988	2731.2	2971.0	7.7086	.7964	2728.7	2967.6	7.5166	.5951	2726.1	2964.2	7.3789
300	1.3162	2808.6	3071.8	7.8926	.8753	2806.7	3069.3	7.7022	.6548	2804.8	3066.8	7.5662
400	1.5493	2966.7	3276.6	8.2218	1.0315	2965.6	3275.6	8.0330	.7726	2964.4	3273.4	7.8985
500	1.7814	3130.8	3487.1	8.5133	1.1867	3130.0	3486.0	8.3251	.8893	3129.2	3484.9	8.1913
600	2.013	3301.4	3704.0	8.7770	1.3414	3300.8	3703.2	8.5892	1.0055	3300.2	3702.4	8.4558
700	2.244	3478.8	3927.6	9.0194	1.4957	3478.4	3927.1	8.8319	1.1215	3477.9	3926.5	8.6987
800	2.475	3663.1	4158.2	9.2449	1.6499	3662.9	4157.8	9.0576	1.2372	3662.4	4157.3	8.9244
900	2.706	3854.5	4395.8	9.4566	1.8041	3854.2	4395.4	9.2692	1.3529	3853.9	4395.1	9.1362
1000	2.937	4052.5	4640.0	9.6563	1.9581	4052.3	4639.7	9.4690	1.4685	4052.0	4639.4	9.3360
1100	3.168	4257.0	4890.7	9.8458	2.1121	4256.5	4890.4	9.6585	1.5840	4256.5	4890.2	9.5256
1200	3.399	4467.5	5147.3	10.0262	2.2661	4467.2	5147.1	9.8389	1.6996	4467.0	5146.8	9.7060
1300	3.630	4683.2	5409.3	10.1982	2.4201	4683.0	5409.0	10.0110	1.8151	4682.8	5408.8	9.8780

T	v	u	h	s	v	u	h	s	v	u	h	s
	P = 1.00 MPa (179.91 °C)				P = 1.20 MPa (187.99 °C)				P = 1.40 MPa (195.07 °C)			
Sat.	.19 444	2583.6	2778.1	6.5865	.163 33	2588.8	2784.8	6.5233	.140 84	2592.8	2790.0	6.4693
200	.2060	2621.9	2827.9	6.6940	.169 30	2612.8	2815.9	6.5898	.143 02	2603.1	2803.3	6.4975
250	.2327	2709.9	2942.6	6.9247	.192 34	2704.2	2935.0	6.8294	.163 50	2698.3	2927.2	6.7467
300	.2579	2793.2	3051.2	7.1229	.2138	2789.2	3045.8	7.0317	.182 28	2785.2	3040.4	6.9534
350	.2825	2875.2	3157.7	7.3011	.2345	2872.2	3153.6	7.2121	.2003	2869.2	3149.5	7.1360
400	.3066	2957.3	3263.9	7.4651	.2548	2954.9	3260.7	7.3774	.2178	2952.5	3257.5	7.3026
500	.3541	3124.4	3478.5	7.7622	.2946	3122.8	3476.3	7.6759	.2521	3321.1	3474.1	7.6027
600	.4011	3296.8	3697.9	8.0290	.3339	3295.6	3696.3	7.9435	.2860	3294.4	3694.8	7.8710
700	.4478	3475.3	3923.1	8.2731	.3729	3474.4	3922.0	8.1881	.3195	3473.6	3920.8	8.1160
800	.4943	3660.4	4154.7	8.4996	.4118	3659.7	4153.8	8.4148	.3528	3659.0	4153.0	8.8431
900	.5407	3852.2	4392.9	8.7118	.4505	3851.6	4392.2	8.6272	.3861	3851.1	4391.5	8.5556
1000	.5871	4050.5	4637.6	8.9119	.4892	4050.0	4637.0	8.8274	.4192	4049.5	4636.4	8.7559
1100	.6335	4255.1	4888.6	9.1017	.5278	4254.6	4888.0	9.0172	.4524	4254.1	4887.5	8.9457
1200	.6798	4465.6	5145.4	9.2822	.5665	4465.1	5144.9	9.1977	.4855	4464.7	5144.4	9.1262
1300	.7261	4681.3	5407.4	9.4543	.6051	4680.9	5407.0	9.3698	.5186	4680.4	5406.5	9.2984

Table B.1.4.SI Compressed Liquid Water

- In this table properties of compressed or sub-cooled water are included.
- The table is arranged in similar to the superheated vapor table, where properties are given for various temperatures along a given pressure or isobar.
- Similarly to previous table first temperature at a given pressure is the saturation temperature and its value is placed in brackets next to the pressure.
- Note that the table starts at pressure of 5 MPa, later you will be given how to deal with values less that 5 MPa for the compressed liquid

Compressed Liquid



T	P = 5 MPa (263.99°C) v	u	h	s	P = 10 MPa (311.06°C) v	u	h	s	P = 15 MPa (342.42°C) v	u	h	s
0	0.000 997 7	0.04	5.04	0.0001	0.000 995 2	0.09	10.04	0.0002	0.000 992 8	0.15	15.05	0.0004
20	0.000 999 5	83.65	88.65	0.2956	0.000 997 2	83.36	93.33	0.2945	0.000 995 0	83.06	97.99	0.2934
40	0.001 005 6	166.95	171.97	0.5705	0.001 003 4	166.35	176.38	0.5686	0.001 001 3	165.76	180.78	0.5666
60	0.001 014 9	250.23	255.30	0.8285	0.001 012 7	249.36	259.49	0.8258	0.001 010 5	248.51	263.67	0.8232
80	0.001 026 8	333.72	338.85	1.0720	0.001 024 5	332.59	342.83	1.0688	0.001 022 2	331.48	346.81	1.0656
100	0.001 041 0	417.52	422.72	1.3030	0.001 038 5	416.12	426.50	1.2992	0.001 036 1	414.74	430.28	1.2955
120	0.001 057 6	501.80	507.09	1.5233	0.001 054 9	500.08	510.64	1.5189	0.001 052 2	498.40	514.19	1.5145
140	0.001 076 8	586.76	592.15	1.7343	0.001 073 7	584.68	595.42	1.7292	0.001 070 7	582.66	598.72	1.7242
160	0.001 098 8	672.62	678.12	1.9375	0.001 095 3	670.13	681.08	1.9317	0.001 091 8	667.71	684.09	1.9260
180	0.001 124 0	759.63	765.25	2.1341	0.001 119 9	756.65	767.84	2.1275	0.001 115 9	753.76	770.50	2.1210
200	0.001 153 0	848.1	853.9	2.3255	0.001 148 0	844.5	856.0	2.3178	0.001 143 3	841.0	858.2	2.3104
220	0.001 186 6	938.4	944.4	2.5128	0.001 180 5	934.1	945.9	2.5039	0.001 174 8	929.9	947.5	2.4953
240	0.001 226 4	1031.4	1037.5	2.6979	0.001 218 7	1026.0	1038.1	2.6872	0.001 211 4	1020.8	1039.0	2.6771
260	0.001 274 9	1127.9	1134.3	2.8830	0.001 264 5	1121.1	1133.7	2.8699	0.001 255 0	1114.6	1133.4	2.8576

T	P = 20 MPa (365.81°C) v	u	h	s	P = 30 MPa v	u	h	s	P = 50 MPa v	u	h	s
0	0.000 990 4	0.19	20.01	0.0004	0.000 985 6	0.25	29.82	0.0001	0.000 976 6	0.20	49.03	0.0014
20	0.000 992 8	82.77	102.62	0.2923	0.000 988 6	82.17	111.84	0.2899	0.000 980 4	81.00	130.02	0.2848
40	0.000 999 2	165.17	185.16	0.5646	0.000 995 1	164.04	193.89	0.5607	0.000 987 2	161.86	211.21	0.5527
60	0.001 008 4	247.68	267.85	0.8206	0.001 004 2	246.06	276.19	0.8154	0.000 996 2	242.98	292.79	0.8052
80	0.001 019 9	330.40	350.80	1.0624	0.001 015 6	328.30	358.77	1.0561	0.001 007 3	324.34	374.70	1.0440
100	0.001 033 7	413.39	434.06	1.2917	0.001 029 0	410.78	441.66	1.2844	0.001 020 1	405.88	456.89	1.2703
120	0.001 049 6	496.76	517.76	1.5102	0.001 044 5	493.59	524.93	1.5018	0.001 034 8	487.65	539.39	1.4857
140	0.001 067 8	580.69	602.04	1.7193	0.001 062 1	576.88	608.75	1.7098	0.001 051 5	569.77	622.35	1.6915
160	0.001 088 5	665.35	687.12	1.9204	0.001 082 1	660.82	693.28	1.9096	0.001 070 3	652.41	705.92	1.8891
180	0.001 112 0	750.95	773.20	2.1147	0.001 104 7	745.59	778.73	2.1024	0.001 091 2	735.69	790.25	2.0794
200	0.001 138 8	837.7	860.5	2.3031	0.001 130 2	831.4	865.3	2.2893	0.001 114 6	819.7	875.5	2.2634
240	0.001 204 6	1016.0	1040.0	2.6674	0.001 192 0	1006.9	1042.6	2.6490	0.001 170 2	990.7	1049.2	2.6158
280	0.001 296 5	1204.7	1230.6	3.0248	0.001 275 5	1190.7	1229.0	2.9986	0.001 241 5	1167.2	1229.3	2.9537
320	0.001 443 7	1415.7	1444.6	3.3979	0.001 399 7	1390.7	1432.7	3.3539	0.001 338 8	1353.3	1420.2	3.2868
360	0.001 822 6	1702.8	1739.3	3.8772	0.001 626 5	1626.6	1675.4	3.7494	0.001 483 8	1556.0	1630.2	3.6291

SOURCES: Keenan, Keyes, Hill, and Moore, *Steam Tables*, Wiley, New York, 1969; G. J. Van Wylen and R. E. Sonntag, *Fundamentals of Classical Thermodynamics*, Wiley, New York, 1973.

Example: Liquid

- Find the specific volume of water at 10000 kPa and 260 ^oC?
- Answer: Using table B.1.4.SI compressed liquid

  $v = 0.0012645\ m^3/kg.$

	P = 5 MPa (263.99°C)				P = 10 MPa (311.06°C)				P = 15 MPa (342.42°C)			
T	v	u	h	s	v	u	h	s	v	u	h	s
0	0.000 997 7	0.04	5.04	0.0001	0.000 995 2	0.09	10.04	0.0002	0.000 992 8	0.15	15.05	0.0004
20	0.000 999 5	83.65	88.65	0.2956	0.000 997 2	83.36	93.33	0.2945	0.000 995 0	83.06	97.99	0.2934
40	0.001 005 6	166.95	171.97	0.5705	0.001 003 4	166.35	176.38	0.5686	0.001 001 3	165.76	180.78	0.5666
60	0.001 014 9	250.23	255.30	0.8285	0.001 012 7	249.36	259.49	0.8258	0.001 010 5	248.51	263.67	0.8232
80	0.001 026 8	333.72	338.85	1.0720	0.001 024 5	332.59	342.83	1.0688	0.001 022 2	331.48	346.81	1.0656
100	0.001 041 0	417.52	422.72	1.3030	0.001 038 5	416.12	426.50	1.2992	0.001 036 1	414.74	430.28	1.2955
120	0.001 057 6	501.80	507.09	1.5233	0.001 054 9	500.08	510.64	1.5189	0.001 052 2	498.40	514.19	1.5145
140	0.001 076 8	586.76	592.15	1.7343	0.001 073 7	584.68	595.42	1.7292	0.001 070 7	582.66	598.72	1.7242
160	0.001 098 8	672.62	678.12	1.9375	0.001 095 3	670.13	681.08	1.9317	0.001 091 8	667.71	684.09	1.9260
180	0.001 124 0	759.63	765.25	2.1341	0.001 119 9	756.65	767.84	2.1275	0.001 115 9	753.76	770.50	2.1210
200	0.001 153 0	848.1	853.9	2.3255	0.001 148 0	844.5	856.0	2.3178	0.001 143 3	841.0	858.2	2.3104
220	0.001 186 6	938.4	944.4	2.5128	0.001 180 5	934.1	945.9	2.5039	0.001 174 8	929.9	947.5	2.4953
240	0.001 226 4	1031.4	1037.5	2.6979	0.001 218 7	1026.0	1038.1	2.6872	0.001 211 4	1020.8	1039.0	2.6771
[illegible]	[illegible]	[illegible]127.9	1134.3	2.8830	0.001 264 5	1121.1	1133.7	2.8699	0.001 25[illegible]	[illegible]	[illegible]	[illegible]

Table B.1.5 SI Saturated Solid – Saturated Vapor Water

- This table presents properties of water solid - vapor equilibrium or at the sublimation line.
- Sublimation starts below the triple point, which has the value of 0.01 ^oC and 0.6113 kPa.
- This table is similar to the saturated water in table B.1.1.SI the first column is the saturation temperature, the second column is the saturated pressure at the given temperature, then specific volume is given for the saturated solid as v_i, for saturated vapor vg and for the evaporation v_{ig}.
- Quality of mixture is defined in same way in the saturated liquid vapor, hence property of mixture will found using the same previous relations used in the saturated liquid vapor mixture.

Saturated Solid—Vapor

		Volume, m^3/kg		Energy, kJ/kg			Enthalpy, kJ/kg			Entropy, kJ/kg·K		
T, °C	P, kPa	Sat. Solid $v_i \times 10^3$	Sat. Vapor v_g	Sat. Solid u_i	Subl. u_{ig}	Sat. Vapor u_g	Sat. Solid h_i	Subl. h_{ig}	Sat. Vapor h_g	Sat. Solid s_i	Subl. s_{ig}	Sat. Vapor s_g
0.01	0.6113	1.0908	206.1	−333.40	2708.7	2375.3	−333.40	2834.8	2501.4	−1.221	10.378	9.156
0	0.6108	1.0908	206.3	−333.43	2708.8	2375.3	−333.43	2834.8	2501.3	−1.221	10.378	9.157
−2	0.5176	1.0904	241.7	−337.62	2710.2	2372.6	−337.62	2835.3	2497.7	−1.237	10.456	9.219
−4	0.4375	1.0901	283.8	−341.78	2711.6	2369.8	−341.78	2835.7	2494.0	−1.253	10.536	9.283
−6	0.3689	1.0898	334.2	−345.91	2712.9	2367.0	−345.91	2836.2	2490.3	−1.268	10.616	9.348
−8	0.3102	1.0894	394.4	−350.02	2714.2	2364.2	−350.02	2836.6	2486.6	−1.284	10.698	9.414
−10	0.2602	1.0891	466.7	−354.09	2715.5	2361.4	−354.09	3837.0	2482.9	−1.299	10.781	9.481
−12	0.2176	1.0888	553.7	−358.14	2716.8	2358.7	−358.14	2837.3	2479.2	−1.315	10.865	9.550
−14	0.1815	1.0884	658.8	−362.15	2718.0	2355.9	−362.15	2837.6	2475.5	−1.331	10.950	9.619
−16	0.1510	1.0881	786.0	−366.14	2719.2	2353.1	−366.14	2837.9	2471.8	−1.346	11.036	9.690
−20	0.1035	1.0874	1128.6	−374.03	2721.6	2347.5	−374.03	2838.4	2464.3	−1.377	11.212	9.835
−24	0.0701	1.0868	1640.1	−381.80	2723.7	2342.0	−381.80	2838.7	2456.9	−1.408	11.394	9.985
−28	0.0469	1.0861	2413.7	−389.45	2725.8	2336.4	−389.45	2839.0	2449.5	−1.439	11.580	10.141
−32	0.0309	1.0854	3600	−396.98	2727.8	2330.8	−396.98	2839.1	2442.1	−1.471	11.773	10.303
−36	0.0201	1.0848	5444	−404.40	2729.6	2325.2	−404.40	2839.1	2434.7	−1.501	11.972	10.470
−40	0.0129	1.0841	8354	−411.70	2731.3	2319.6	−411.70	2838.9	2427.2	−1.532	12.176	10.644

Example: solid vapor

- For saturated solid vapor at –10 ^oC determine the saturation pressure, specific volume of saturated solid and vapor? And the specific volume of the mixture if quality is 80%?
- From table B.1.5.SI at –10 ^oC ,

P_{sat} = 0.2601 kPa

v_i = 0.0010891 m^3/kg

v_g = 466.757 m^3/kg

v_{ig} = 466.756 m^3/kg

Then $v = v_i + x.\ v_{ig}$ =0.0010891+ 0.8(466.756)= 373.40589 m^3/kg

$$V = V_{\text{liq}} + V_{\text{vap}} = m_{\text{liq}} v_f + m_{\text{vap}} v_g$$

The average specific volume of the system v is then

$$v = \frac{V}{m} = \frac{m_{\text{liq}}}{m} v_f + \frac{m_{\text{vap}}}{m} v_g = (1 - x) v_f + x v_g \tag{2.1}$$

in terms of the definition of quality $x = m_{\text{vap}}/m$.

Using the definition

$$v_{fg} = v_g - v_f$$

Eq. 2.1 can also be written as

$$v = v_f + x v_{fg} \tag{2.2}$$

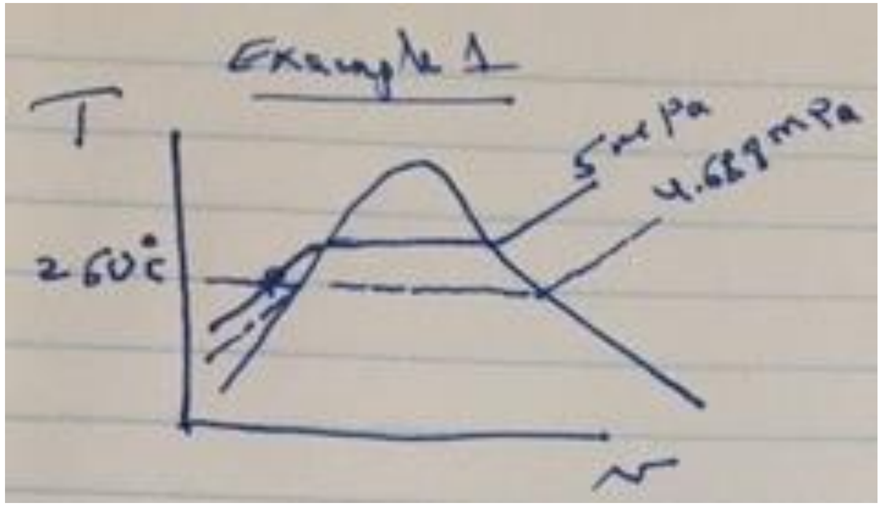
Determining the phase of the substance at a given state

- Given (T,P): when the state is specified by T,P
  - from the saturated table such as B.1.1.SI find the saturation pressure at the given temperature, then
  - compare it with the given pressure;
    - If the given pressure is greater than the saturation pressure as found from the table at the given temperature then the substance is compressed liquid.
    - If the given pressure is less than the saturation pressure then it is superheated vapor.
- Another approach is to
  - find the saturation temperature at the given pressure from the saturation table such as B.1.2.SI and
  - compare it with the given temperature;
    - If the given temperature is greater than the saturation temperature at the given pressure then it is superheated vapor,
    - if it is less then it is compressed liquid.

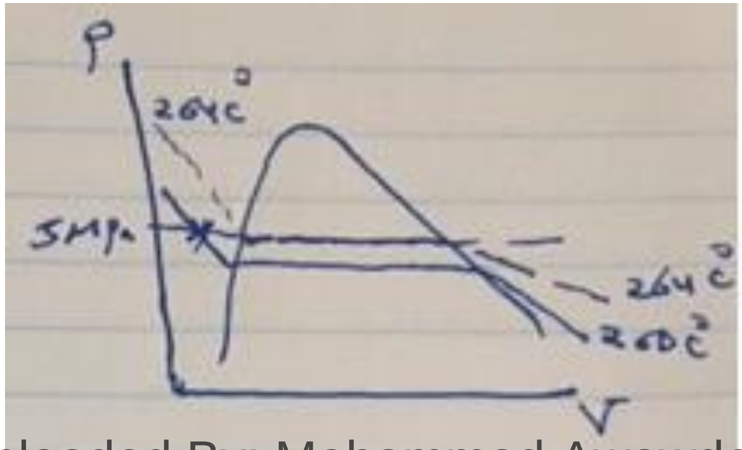
Determining the phase of the substance at a given state

- Given (T,v), or (P,v): when the state is specified by (T,v) or (P,v) then
- find from the saturation tables such as B.1.1.SI or B.1.2.SI the saturated liquid and saturated vapor specific volumes.
- Now if the;
  - given specific volume is less than vf , then is compressed liquid,
  - if the given specific volume is greater than vg then superheated vapor, and
  - if it is between vf and vg then it is in the saturation region.

Example 1- Given T & P

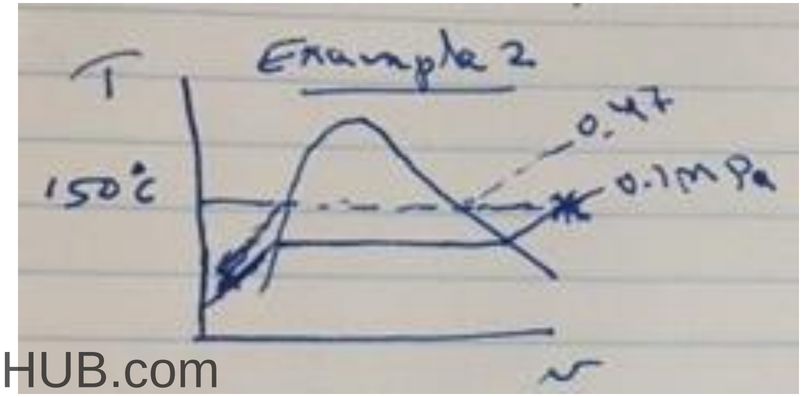


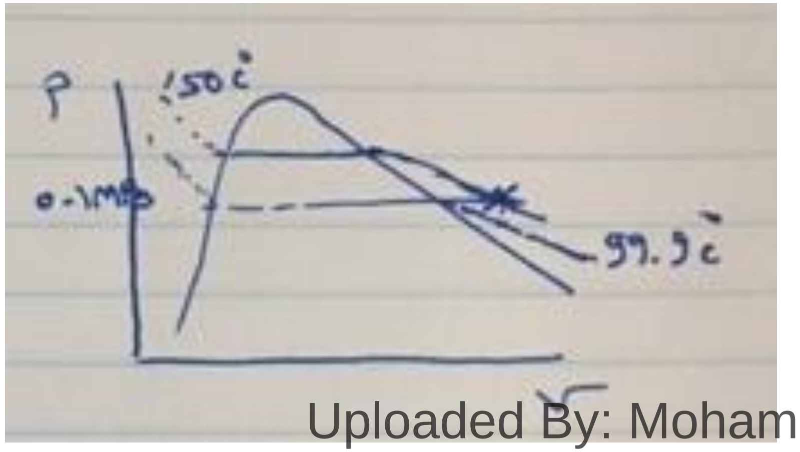
- Water at 260 °C, 5 MPa , find v?
- From table A.1. at 260 °C Psat = 4.688 MPa
- Since P given > P $_{sat}$ Then compressed liquid
- Or from table A1.2 at 5 MPa T $_{sat}$ = 263.99 °C since T $_{sat}$ < T given then subcooled or compressed liquid.
- Now from table A.1.4 compressed liquid at 260 °C, 5 MPa
  v = 0. 12749 m3/kg
- Show all above on T-v and P-v diagrams.



Example-2 superheated vapor

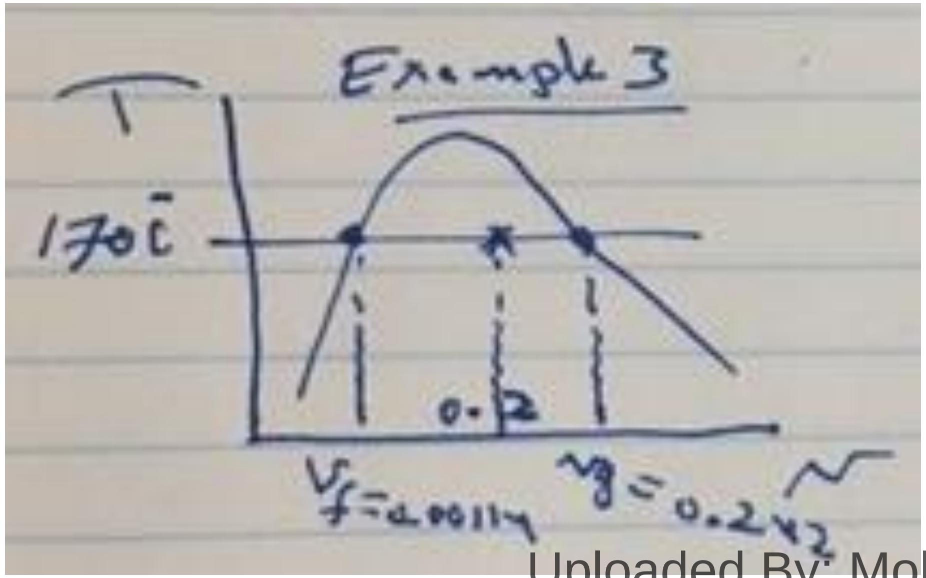
- Water at 150 ^{o}C , 0.1 MPa, find v ?
- At 150 ^{o}C the P_{sat} = 0.4759 MPa which is less than given pressure of 0.1MPa; hence superheated vapor.
- At 0.1 MPa the saturation temperature is 99.9 ^{o}C which is less than the given temperature of 150 ^{o}C then superheated vapor.
- From superheated table A.1.3 at 0.1 MPa , 150 ^{o}C; v= 1.9364 m^3/kg.
- Show above on T-v P-V diagrams.





Example-3 Saturation region

- Water at 170 °C , v=0.20 m^3/kg. Find pressure?
- From table A.1.1 at 170 °C v_f = 0.001114, v_g =0.24283, v_{fg} = 0.24171
- Since given specific volume between v_f and v_g it is in the saturation region and Pressure is the saturation pressure and equals 791.7 kPa
- Quality = x = (v-v_f)/v_{fg} = (0.20-0.001114)/(0.24161) = 0.823
- Show on T-v diagram



Example-4: compressed liquid

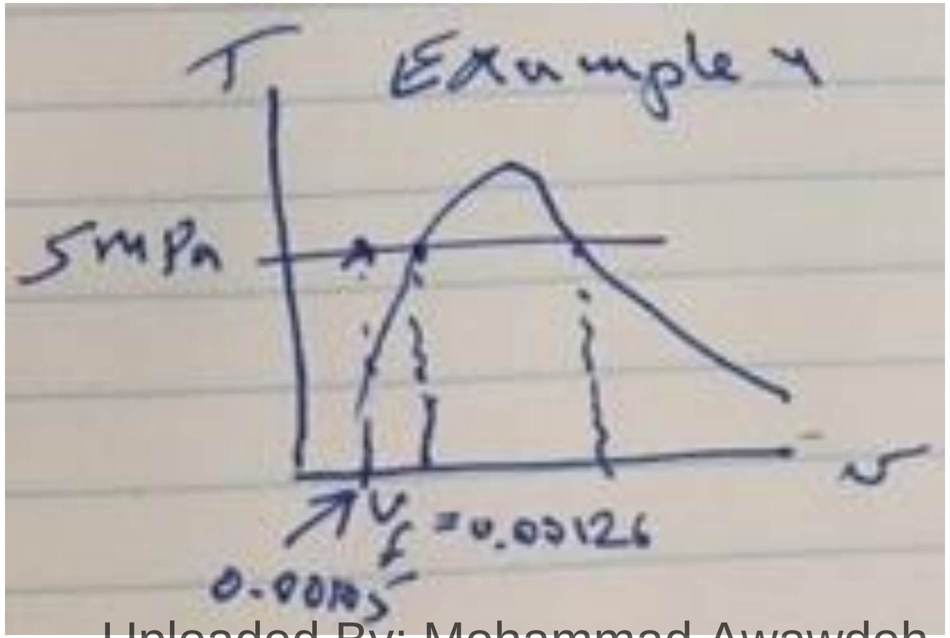
- Water at 5MPa, v= 0.001015 find T?
- From table A.1.1 at 5 MPa

  v_f =0.001286, v_g =0.03944

  Since v less than v_f then compressed liquid.

  From table A1.4 at 5MPa, v= 0.001015 T = 60^{o}C

  Show on T-v diagram



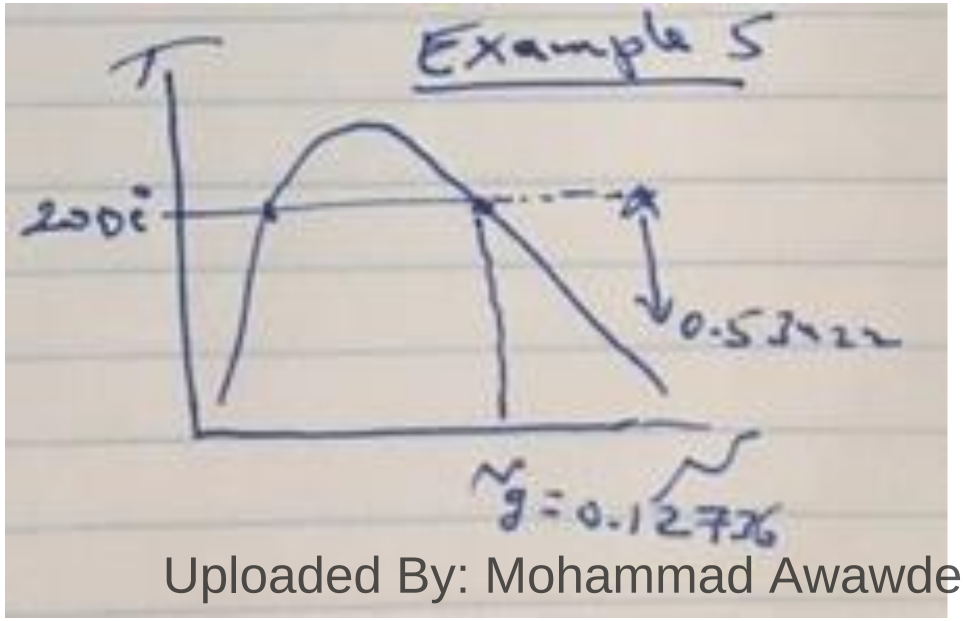
Example-5 superheated vapor

- Water at 200 °C , v=0.53422 m^3/kg. Find pressure?
- From table A1.1. at 200 °C ;

  v_f =0.001156, v_g =0.12736

Since v is greater than v_g It is superheated vapor

- From table A.1.3 at 200 °C , v=0.53422 read P = 400 kPa.
- Show states on –T-v and P-v diagrams.



Finding the phase summary

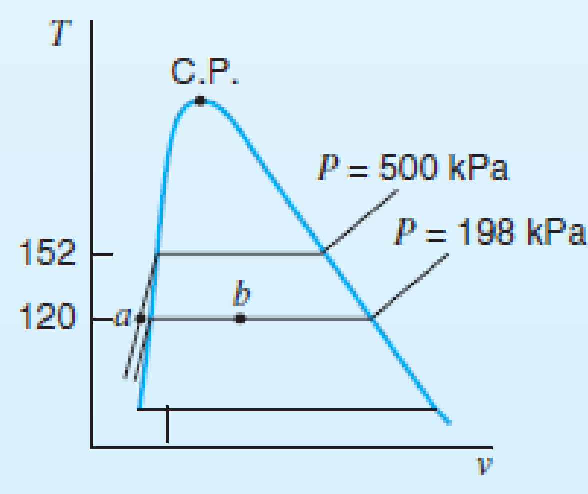
- If P given >P sat at given T → compressed liquid
- If P given < P sat at given T → superheated vapor
- If T given > T sat at given P → superheated vapor
- If T given < T sat at given P → compressed liquid
- If $v < v_f$ at given T or P → compressed liquid
- If $v > v_g$ at given T or P → superheated vapor
- If $v_f < v < v_g$ at given T or P → saturation region
- If temperature or pressure <u>below the triple point</u>, check for solid vapor equilibrium. For example water at -10 ^oC.

Example 2.1

Determine the phase for each of the following water states using the tables in Appendix B and indicate the relative position in the P–v, T–v, and P–T diagrams.

a. 120°C, 500 kPa

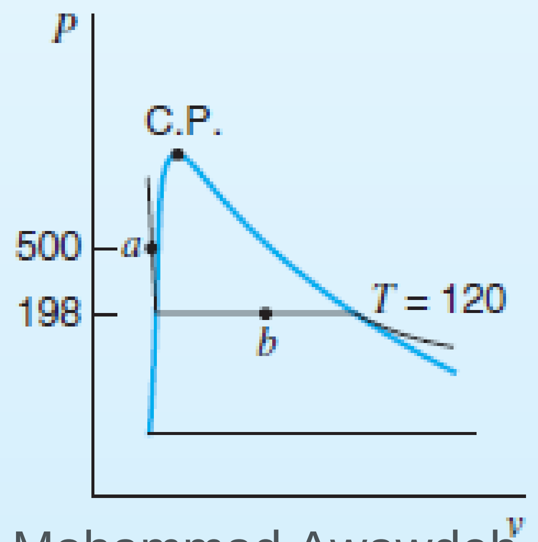
b. 120°C, 0.5 m³/kg



a. Enter Table B.1.1 with 120°C. The saturation pressure is 198.5 kPa, so we have a compressed liquid, point a in Fig. 2.11. That is above the saturation line for 120°C. We could also have entered Table B.1.2 with 500 kPa and found the saturation temperature as 151.86°C, so we would say that it is a subcooled liquid. That is to the left of the saturation line for 500 kPa, as seen in the P–T diagram.

b. Enter Table B.1.1 with 120°C and notice that

$$v_f = 0.001\,06 < v < v_g = 0.891\,86\ \mathrm{m^3/kg}$$



Example 2.3

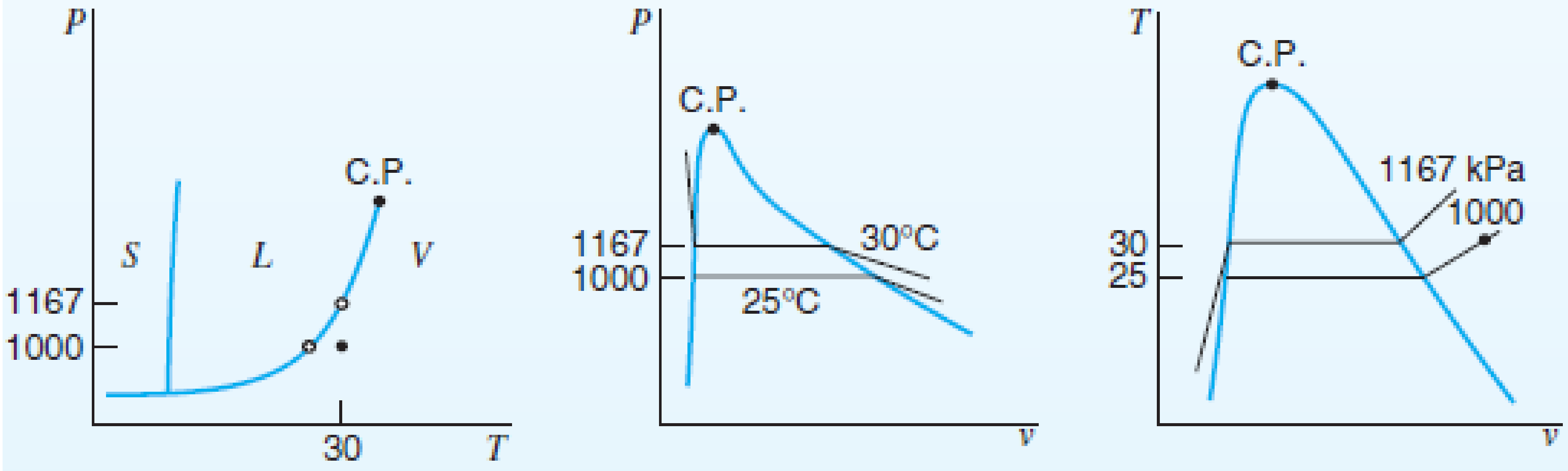
Determine the phase for each of the following states using the tables in Appendix B and indicate the relative position in the *P*–*v*, *T*–*v*, and *P*–*T* diagrams, as in Fig. 2.11.

a. Ammonia 30°C, 1000 kPa

b. R-134a 200 kPa, 0.125 m^3/kg

Solution

a. Enter Table B.2.1 with 30°C. The saturation pressure is 1167 kPa. As we have a lower *P* (see Fig. 2.13), it is a superheated vapor state. We could also have entered with 1000 kPa and found a saturation temperature of slightly less than 25°C, so we have a state that is superheated about 5°C.



Example 2.3

Determine the phase for each of the following states using the tables in Appendix B and indicate the relative position in the P–v, T–v, and P–T diagrams, as in Fig. 2.11.

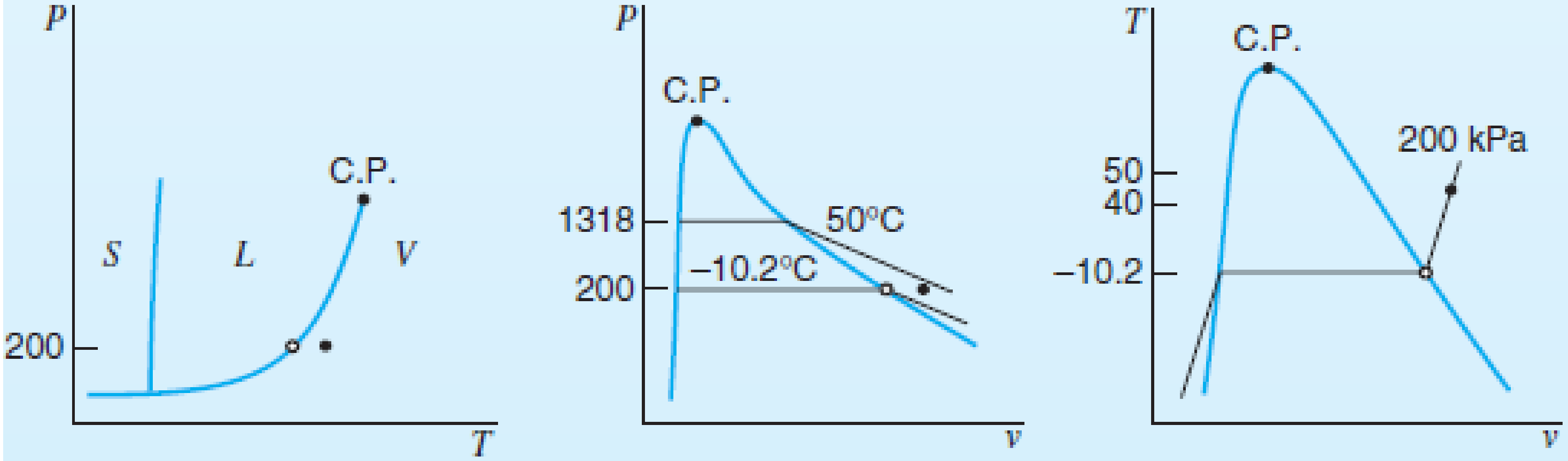
a. Ammonia 30°C, 1000 kPa

b. R-134a 200 kPa, 0.125 m^3/kg

b. Enter Table B.5.2 (or B.5.1) with 200 kPa and notice that

$$v > v_g = 0.1000 \text{ m}^3/\text{kg}$$

so from the P–v diagram in Fig. 2.14 the state is superheated vapor. We can find the state in Table B.5.2 between 40 and 50°C.



Example 2.2

A closed vessel contains 0.1 m^3 of saturated liquid and 0.9 m^3 of saturated vapor R-134a in equilibrium at 30°C. Determine the percent vapor on a mass basis.

Solution

Values of the saturation properties for R-134a are found from Table B.5.1. The mass–volume relations then give

$$V_{\text{liq}} = m_{\text{liq}} v_f, \qquad m_{\text{liq}} = \frac{0.1}{0.000\,843} = 118.6\text{ kg}$$

$$V_{\text{vap}} = m_{\text{vap}} v_g, \qquad m_{\text{vap}} = \frac{0.9}{0.026\,71} = 33.7\text{ kg}$$

$$m = 152.3\text{ kg}$$

$$x = \frac{m_{\text{vap}}}{m} = \frac{33.7}{152.3} = 0.221$$

That is, the vessel contains 90% vapor by volume but only 22.1% vapor by mass.

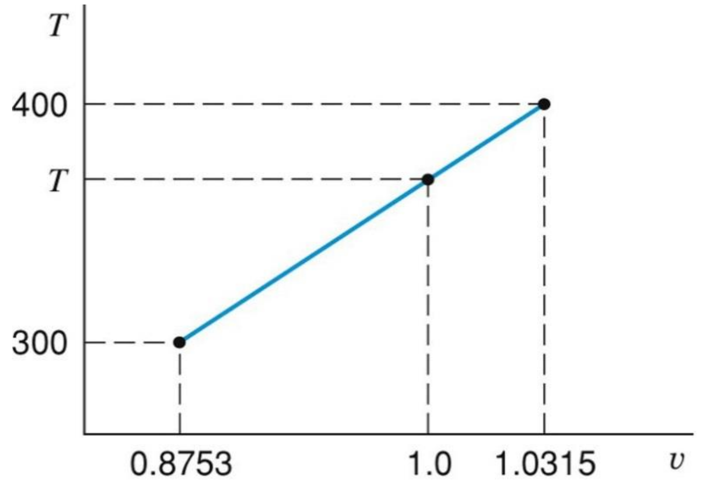
Approximation

- If substance is compressed liquid but state not found in table may be no such compressed table exist or pressure is below the first starting point, then
- use the saturated liquid values at the given temperature for the required property e.g. v?

- **Example:** water at 50 ^oC and 0.1 MPa is compressed liquid however the compressed table starts only at 5 MPa hence $v = v_{f\ at\ 50} = 0.001012 m^3/kg$.

Interpolation

- As the data in the tables is presented in discrete form for example every 10 ^{o} C for temperature then an interpolation is required for other data points not shown in the table.
- A linear relationship is assumed for purpose of interpolation in the tables. The general form of the relation ship is in the form



$$y = y_1 + \left(\frac{y_2 - y_1}{x_2 - x_1}\right)(x - x_1)$$

where (x_1,y_1) and (x_2,y_2) are two state point in the table and (x,y) is the required point of interpolation

Example interpolation

- Find the pressure of superheated ammonia at 40ºC and v = .1494 m^3/kg.
- From table B.2.2.SI at 40ºC the required specific volume is located in between the values of 0.1559 at 900 kPa and 0.1388 at 1000 kPa , hence interpolation is required between these two points.
- here $P_1 = 900$, $P_2 = 1000$ and $v_1 = .1559$, $v_2 = .1388$ while $v = .1494$ and $P = ?$
- Using the interpolation equation as follows,

$$P = P_1 + \left(\frac{P_2 - P_1}{v_2 - v_1}\right)(v - v_1)$$

$$P = 900 + \left(\frac{1000 - 900}{.1338 - .1559}\right)(.1494 - .1559)$$

- P = 938 kPa

Example 2.5

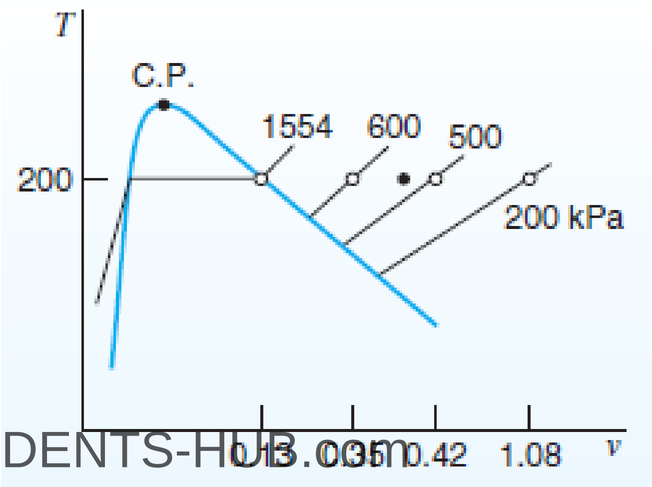
Determine the pressure for water at 200°C with $v = 0.4\ \mathrm{m^3/kg}$.

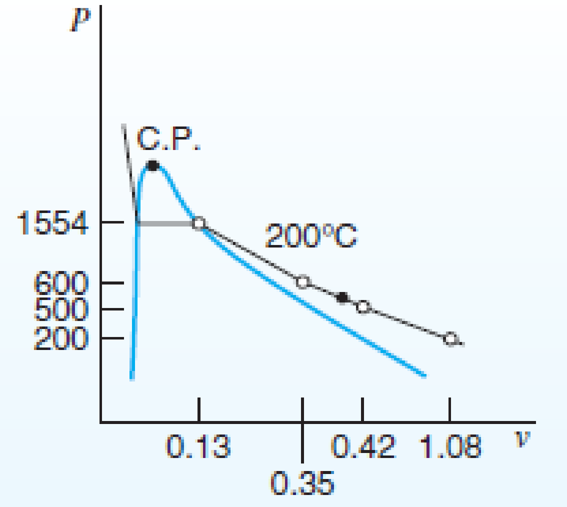
Solution

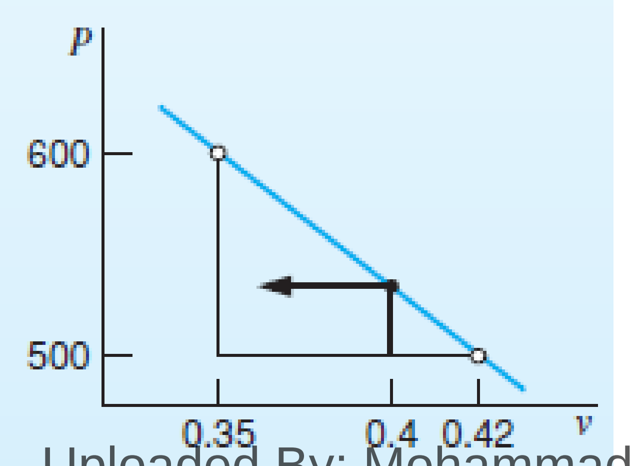
Start in Table B.1.1 with 200°C and note that $v > v_g = 0.127\ 36\ \mathrm{m^3/kg}$, so we have superheated vapor. Proceed to Table B.1.3 at any subsection with 200°C; suppose we start at 200 kPa. There $v = 1.080\ 34$, which is too large, so the pressure must be higher. For 500 kPa, $v = 0.424\ 92$, and for 600 kPa, $v = 0.352\ 02$, so it is bracketed. This is shown in Fig. 2.15.

A linear interpolation, Fig. 2.16, between the two pressures is done to get P at the desired v.

$$P = 500 + (600 - 500)\frac{0.4 - 0.424\ 92}{0.352\ 02 - 0.424\ 92} = 534.2\ \mathrm{kPa}$$

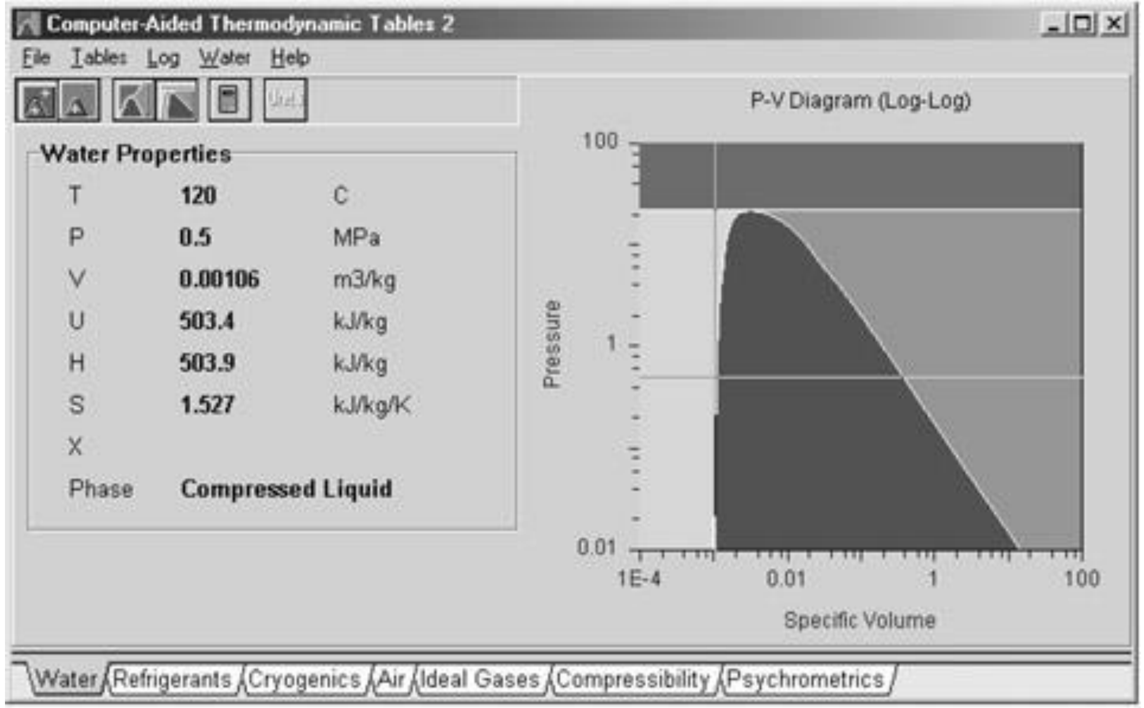






Computer Aided Thermodynamic Tables CATT

- Thermodynamic tables for various substances such as water and refrigerants, ideal gas and air are included in diskette a companying the text book.
- Those tables can be accessed from the window and it is friendly use type.
- Once you open the file just follow the tool bar to get the required information.


Computer-Aided Thermodynamic Tables 2
File Tables Log Water Help
Water Properties
T 120 C
P 0.5 MPa
V 0.00106 m3/kg
U 503.4 kJ/kg
H 503.9 kJ/kg
S 1.527 kJ/kg/K
X
Phase Compressed Liquid
P-V Diagram (Log-Log)
100
1
0.01
Pressure
1E-4
0.01
1
100
Specific Volume
Water Refrigerants Cryogenics Air Ideal Gases Compressibility Psychrometrics

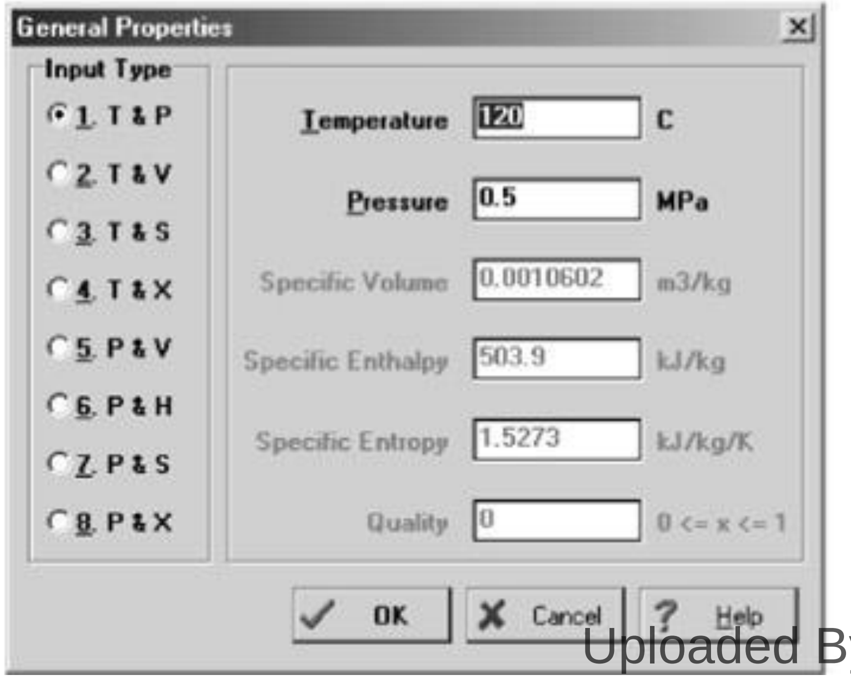

General Properties
Input Type
1. T & P
2. T & V
3. T & S
4. T & X
5. P & V
6. P & H
7. P & S
8. P & X
Temperature 120 C
Pressure 0.5 MPa
Specific Volume 0.0010602 m3/kg
Specific Enthalpy 503.9 kJ/kg
Specific Entropy 1.5273 kJ/kg/K
Quality 0 0 <= x <= 1
OK
Cancel
Help

TABLE B.1.1

Saturated Water

Temp. (°C)	Press. (kPa)	Specific Volume, m³/kg Sat. Liquid v_f	Evap. v_{fg}	Sat. Vapor v_g
0.01	0.6113	0.001000	206.131	206.132
5	0.8721	0.001000	147.117	147.118
10	1.2276	0.001000	106.376	106.377
15	1.705	0.001001	77.924	77.925
20	2.339	0.001002	57.7887	57.7897
25	3.169	0.001003	43.3583	43.3593
30	4.246	0.001004	32.8922	32.8932
35	5.628	0.001006	25.2148	25.2158
40	7.384	0.001008	19.5219	19.5229
45	9.593	0.001010	15.2571	15.2581
50	12.350	0.001012	12.0308	12.0318
55	15.758	0.001015	9.56734	9.56835
60	19.941	0.001017	7.66969	7.67071
65	25.03	0.001020	6.19554	6.19656
70	31.19	0.001023	5.04114	5.04217
75	38.58	0.001026	4.13021	4.13123
80	47.39	0.001029	3.40612	3.40715
85	57.83	0.001032	2.82654	2.82757
90	70.14	0.001036	2.35953	2.36056
95	84.55	0.001040	1.98082	1.98186
100	101.3	0.001044	1.67185	1.67290

TABLE B.1.2

Saturated Water Pressure Entry

Press. (kPa)	Temp. (°C)	Specific Volume, m³/kg Sat. Liquid v_f	Evap. v_{fg}	Sat. Vapor v_g
0.6113	0.01	0.001000	206.131	206.132
1	6.98	0.001000	129.20702	129.20802
1.5	13.03	0.001001	87.97913	87.98013
2	17.50	0.001001	67.00285	67.00385
2.5	21.08	0.001002	54.25285	54.25385
3	24.08	0.001003	45.66402	45.66502
4	28.96	0.001004	34.79915	34.80015
5	32.88	0.001005	28.19150	28.19251
7.5	40.29	0.001008	19.23674	19.23775
10	45.81	0.001010	14.67254	14.67355
15	53.97	0.001014	10.02117	10.02218
20	60.06	0.001017	7.64835	7.64937
25	64.97	0.001020	6.20322	6.20424
30	69.10	0.001022	5.22816	5.22918
40	75.87	0.001026	3.99243	3.99345
50	81.33	0.001030	3.23931	3.24034
75	91.77	0.001037	2.21607	2.21711
100	99.62	0.001043	1.69296	1.69400

TABLE B.2

Thermodynamic Properties of Ammonia

TABLE B.2.1

Saturated Ammonia

Temp. (°C)	Press. (kPa)	Specific Volume, m^3/kg Sat. Liquid v_f	Evap. v_{fg}	Sat. Vapor v_g
−50	40.9	0.001424	2.62557	2.62700
−45	54.5	0.001437	2.00489	2.00632
−40	71.7	0.001450	1.55111	1.55256
−35	93.2	0.001463	1.21466	1.21613
−30	119.5	0.001476	0.96192	0.96339
−25	151.6	0.001490	0.76970	0.77119
−20	190.2	0.001504	0.62184	0.62334
−15	236.3	0.001519	0.50686	0.50838
−10	290.9	0.001534	0.41655	0.41808
−5	354.9	0.001550	0.34493	0.34648
0	429.6	0.001566	0.28763	0.28920
5	515.9	0.001583	0.24140	0.24299
10	615.2	0.001600	0.20381	0.20541
15	728.6	0.001619	0.17300	0.17462
20	857.5	0.001638	0.14758	0.14922

TABLE B.2.2

Superheated Ammonia

Temp. (°C)	v (m^3/kg)
Sat.	2.1752
−30	2.3448
−20	2.4463
−10	2.5471
0	2.6474
10	2.7472
20	2.8466
30	2.9458
40	3.0447
50	3.1435
60	3.2421
70	3.3406
80	3.4390
100	3.6355
120	3.8318

TABLE B.2.2

Superheated Ammonia

Temp. (°C)	v (m^3/kg)	u (kJ/kg)	h (kJ/kg)
			50 kPa (−46.53°C)
Sat.	2.1752	1269.6	1378.3
−30	2.3448	1296.2	1413.4
−20	2.4463	1312.3	1434.6
−10	2.5471	1328.4	1455.7
0	2.6474	1344.5	1476.9
10	2.7472	1360.7	1498.1
20	2.8466	1377.0	1519.3
30	2.9458	1393.3	1540.6
40	3.0447	1409.8	1562.0
50	3.1435	1426.3	1583.5
60	3.2421	1443.0	1605.1
70	3.3406	1459.9	1626.9
80	3.4390	1476.9	1648.8
100	3.6355	1511.4	1693.2
120	3.8318	1546.6	1738.2

TABLE B.4

Thermodynamic Properties of R-410a

TABLE B.4.1

Saturated R-410a

Temp. (°C)	Press. (kPa)	Specific Volume, m^3/kg Sat. Liquid v_f	Evap. v_{fg}	Sat. Vapor v_g
−60	64.1	0.000727	0.36772	0.36845
−55	84.0	0.000735	0.28484	0.28558
−51.4	101.3	0.000741	0.23875	0.23949
−50	108.7	0.000743	0.22344	0.22418
−45	138.8	0.000752	0.17729	0.17804
−40	175.0	0.000762	0.14215	0.14291
−35	218.4	0.000771	0.11505	0.11582
−30	269.6	0.000781	0.09392	0.09470
−25	329.7	0.000792	0.07726	0.07805
−20	399.6	0.000803	0.06400	0.06480
−15	480.4	0.000815	0.05334	0.05416
−10	573.1	0.000827	0.04470	0.04553
−5	678.9	0.000841	0.03764	0.03848
0	798.7	0.000855	0.03182	0.03267

TABLE B.5

Thermodynamic Properties of R-134a

TABLE B.5.1

Saturated R-134a

Temp. (°C)	Press. (kPa)	Specific Volume, m^3/kg Sat. Liquid v_f	Evap. v_{fg}	Sat. Vapor v_g
−70	8.3	0.000675	1.97207	1.97274
−65	11.7	0.000679	1.42915	1.42983
−60	16.3	0.000684	1.05199	1.05268
−55	22.2	0.000689	0.78609	0.78678
−50	29.9	0.000695	0.59587	0.59657
−45	39.6	0.000701	0.45783	0.45853
−40	51.8	0.000708	0.35625	0.35696
−35	66.8	0.000715	0.28051	0.28122
−30	85.1	0.000722	0.22330	0.22402
−26.3	101.3	0.000728	0.18947	0.19020
−25	107.2	0.000730	0.17957	0.18030
−20	133.7	0.000738	0.14576	0.14649
−15	165.0	0.000746	0.11932	0.12007
−10	201.7	0.000755	0.09845	0.09921

KEY CONCEPTS AND FORMULAS

Phases	Solid, liquid, and vapor (gas)
Phase equilibrium	T_{sat}, P_{sat}, v_f, v_g, v_i
Multiphase boundaries	Vaporization, sublimation, and fusion lines: general (Fig. 2.3), water (Fig. 2.4), and CO_2 (Fig. 2.5)
	Triple point: Table 2.1
	Critical point: Table 2.2, Table A.2 (F.1)
Equilibrium state	Two independent properties (#1, #2)
Quality	$x = m_{vap}/m$ (vapor mass fraction)
	$1 - x = m_{liq}/m$ (liquid mass fraction)
Average specific volume	$v = (1 - x)v_f + xv_g$ (only two-phase mixture)
Equilibrium surface	P–v–T Tables or equation of state
Ideal gas law	$Pv = RT$ $\quad PV = mRT = n\bar{R}T$
Universal gas constant	$\bar{R} = 8.3145$ kJ/kmol K
Gas constant	$R = \bar{R}/M$ kJ/kg K, Table A.5 or M from Table A.2
	ft lbf/lbm R, Table F.4 or M from Table F.1
Compressibility factor Z	$Pv = ZRT$ Chart for Z in Fig. D.1
Reduced properties	$P_r = \dfrac{P}{P_c}$ $\quad T_r = \dfrac{T}{T_c}$ Entry to compressibility chart

End of Chapter 3