

**START 3336 FIRST**

Quality x

In the two phase parts, the quality is defined as

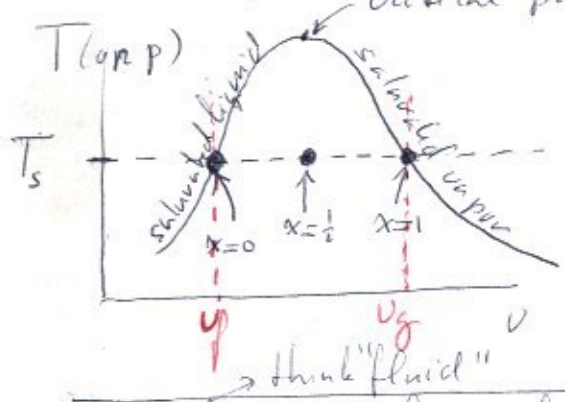
$$x = \frac{m_{\text{vapor}}}{m_{\text{total}}}$$

No vapor ( $m_{\text{vapor}} = 0$ )  $\rightarrow x = 0$

No liquid ( $m_{\text{vapor}} = m_{\text{total}}$ )  $\rightarrow x = 1$

In the p-v and T-v diagrams, x determines your relative location between saturated ~~vapor~~ liquid and saturated vapor:

Stopped here 1/17/06



$v_f$ : specific volume of the saturated liquid  
 $v_g$ : specific volume of the saturated vapor

from the saturated tables

$$v = v_f + x(v_g - v_f)$$

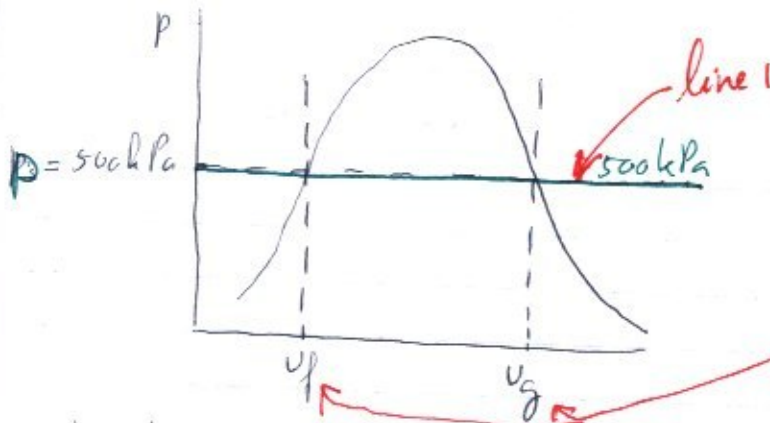
$$v_{fg} \equiv v_g - v_f$$

Quality is not defined outside the ~~saturated~~ 2 phase region.

3-33 b)  
3-21 b)

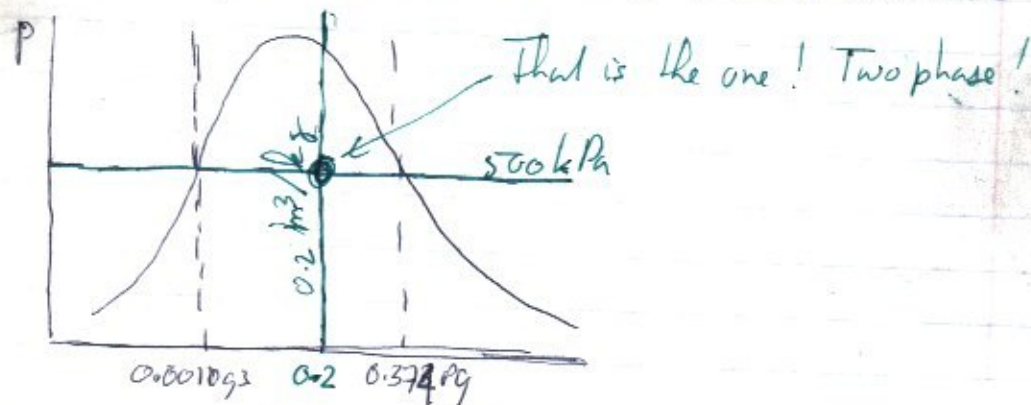
Given:  $H_2O$ , 500 kPa, 0.2 ~~kg~~  $m^3/kg$   
Asked:  $T?$ ,  $x$  if defined?

Answer: Since  $p$  is given, use  $p-v$ . Draw straight 500 kPa isobar first.



Look up  $v_f$  and  $v_g$  in table B.1.2 for  $p = 500$  kPa  
A.5 ← saturated tables → page  $\frac{679}{515}$

$v_f = 0.001093 \text{ m}^3/kg$      $v_g = 0.37409$      $v_f = 0.3730$      $T_s = 151.06$   
Mark in the graph and then draw  $v = 0.2$  isochore



Since  $0.001093 < 0.2 < 0.37409$ , the isochore is in between

$\Rightarrow$  2 phase  $\Rightarrow$  temperature is the saturated temperature  
at 500 kPa table B.1.2  $T = 151.06 \text{ }^\circ\text{C}$

Quality  $x$  exists, so I need to find it. Formula is

$$\cancel{v = v_f + x v_g} \quad v = v_f + x(v_g - v_f)$$

Put in the known numbers

$$0.2 \frac{\text{m}^3}{\text{kg}} = 0.001093 \frac{\text{m}^3}{\text{kg}} + x \left( 0.37483 - 0.001093 \right) \frac{\text{m}^3}{\text{kg}}$$

1 equation, 1 unknown. Divide out  $\frac{\text{m}^3}{\text{kg}}$  and regroup

$$-x \cdot 0.3730 \frac{\text{m}^3}{\text{kg}} =$$

$$-x \cdot 0.3730 = 0.001093 - 0.2$$

$$x = \frac{0.001093 - 0.2}{-0.3730} = \underline{\underline{0.532}}$$

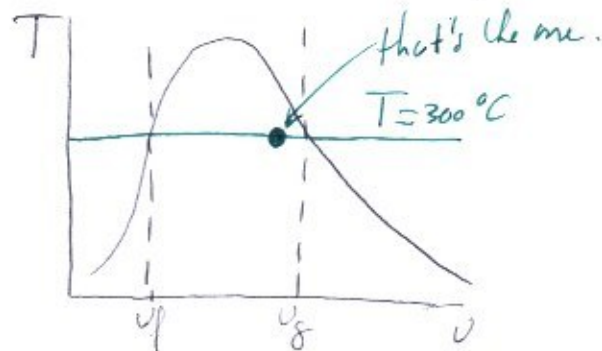
SKIP

3-11

3.33 d) Water:  $T = 300^\circ\text{C}$   $x = 0.0$   
 Asked:  $p?$   $v?$

Answer using  $Tv$ :

Since  $x$  exists, it must be 2 phase.



Since it is saturated  $p$  must be the saturated pressure at  $300^\circ\text{C}$ ; Table B.1.1.  $\rightarrow p = \underline{0.501.0}$

Also at that position:  $v_f = 0.001404 \text{ m}^3/\text{kg}$   $v_g = 0.02067 \text{ m}^3/\text{kg}$   
 $v_s = 0.02027 \text{ m}^3/\text{kg}$

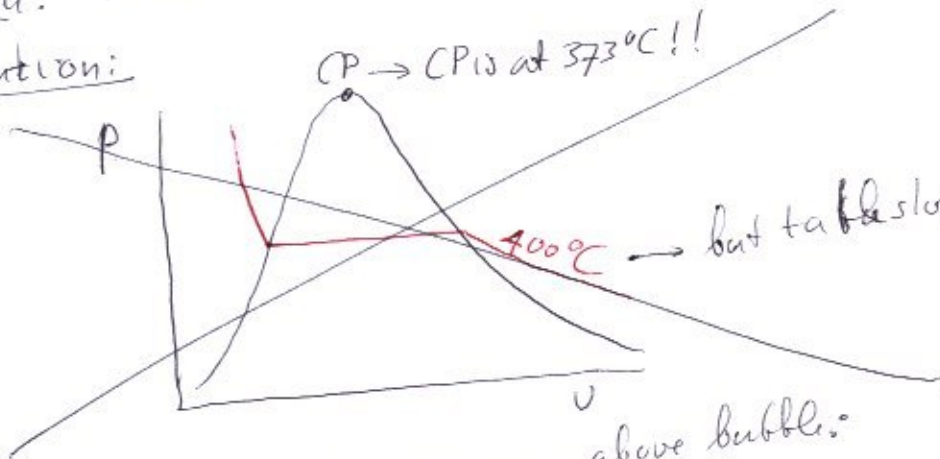
Formula:  $v = v_f + x v_g$

Put in known numbers:  $v = 0.001404 \text{ m}^3/\text{kg} + 0.0 \cdot 0.02067 \text{ m}^3/\text{kg}$   
 $= \underline{0.001404 \text{ m}^3/\text{kg}}$

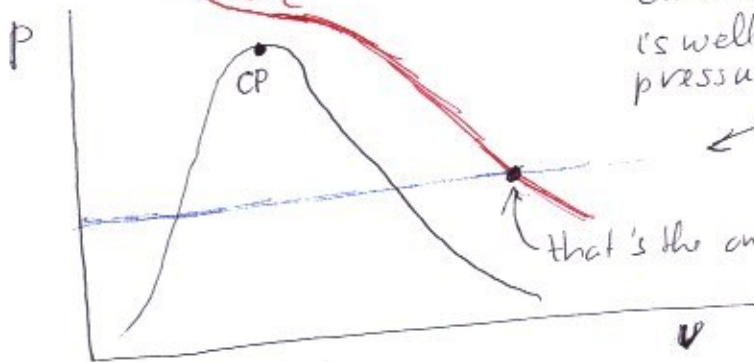
Given : Water  $T = 400^\circ\text{C}$   $P = 200\text{ kPa}$

Asked : Phase in Pv using T first

Solution :



Correct isotherm at  $400^\circ\text{C}$  goes above bubble:

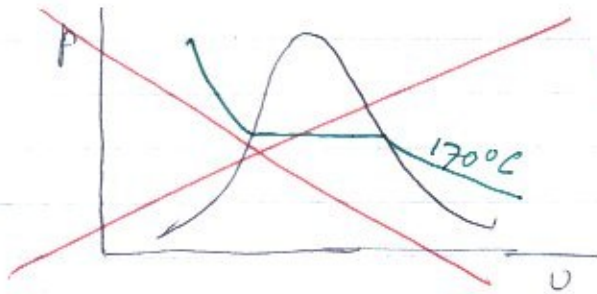


On the other hand, the  $200\text{ kPa}$  is well below the  $22064\text{ kPa}$  critical pressure

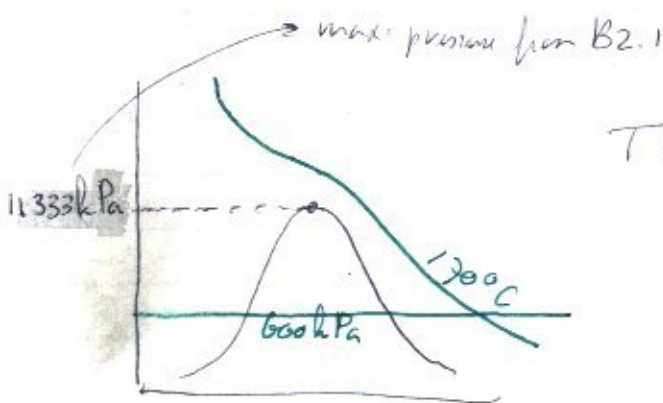
Not in Geysel

3.12

3.20c | Given: ammonia,  $\text{NH}_3$  @  $T = 170^\circ\text{C}$  and  $p = 600\text{ kPa}$   
Asked: phase  
Draw broken isotherm first.



oops: table B.2.1  
(saturated ammonia)  
stops at  $132.3^\circ\text{C}$

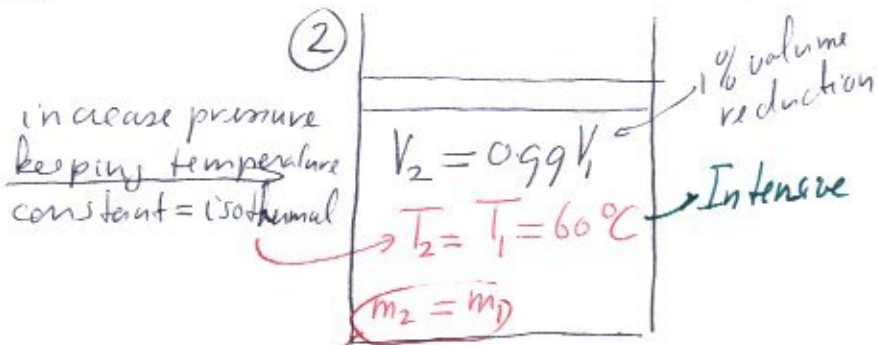
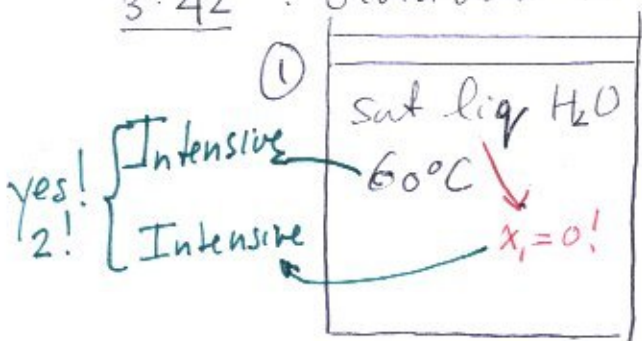


$T > T_c$ : superheated vapor

Note on subcooled/compressed liquids: If you don't have a compressed liquid table, use the saturated table at the correct temperature (but wrong pressure)  
(Also do this if you would have to interpolate between the subcooled and saturated tables; don't try interpolating using two different tables)

# Example of process

3.42 : Given data in black



mass conservation: always write

Asked:  $p_2$

Solution: Have only one intensive variable,  $T_2 = 60^\circ C$ , at state ②. Need a second before I can find  $p_2$ .

Since given  $V_2 = 0.99 V_1$ , can I maybe find  $v_2$ ??

$$v_2 = \frac{V_2}{m_2} = \frac{0.99 V_1}{m_1} = 0.99 v_1$$

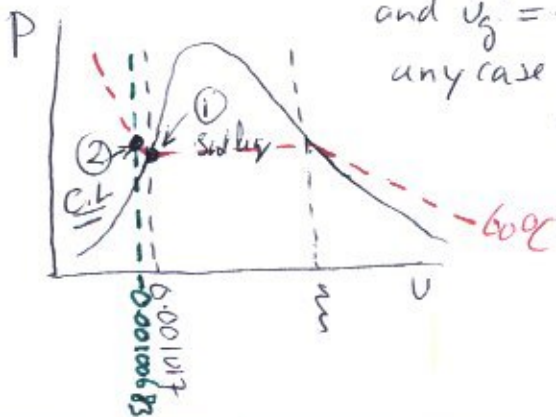
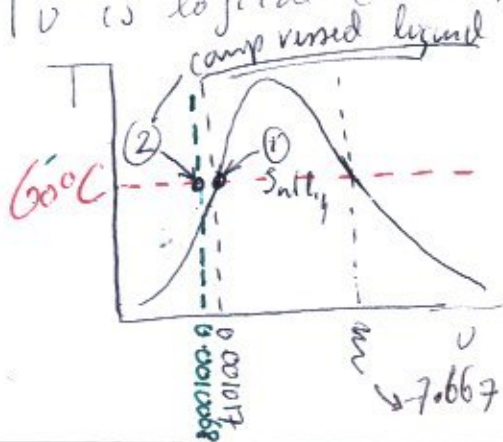
So I can find  $v_2$  if I can find  $v_1$ . And I can find  $v_1$ , since I have 2 intensive variables at ①. In fact  $v_1$  is just  $v_f$  at  $60^\circ C$ , since ① is saturated liquid at  $60^\circ C$ . Look in table B.1.1 at  $60^\circ C$

$$\rightarrow v_1 = v_f = 0.001017 \text{ m}^3/\text{kg}$$

$$v_2 = 0.99 v_1 = 0.99 \cdot 0.001017 \text{ m}^3/\text{kg} = 0.00100683 \text{ Intensive}$$

Figure out the phase of ② given  $T_2 = 60^\circ C$ ,  $v_2 = 0.00100683$ .

$T_v$  is logical choice, but let's do both. (Table B.1.1 at  $60^\circ C$  gives  $v_f = 0.001017 \text{ m}^3/\text{kg}$  and  $v_g = \dots$ , in any case,  $v_2 = 0.99 v_f$  is less than  $v_f$ )



From either T-v diagram or p-v diagram, we see that state B is compressed liquid  $\rightarrow$  use table B.1 to find B

page 609: Need to find the point  $T_2 = 60$   $v_2 = 0.00100683$   
A-7

Temp	v	u	h	s	v	u	h	s
	15,000 kPa				20,000 kPa			
60	0.001011				0.001008			
	30,000 kPa				50,000 kPa			
60	0.001004				0.000996			

$v_2 = 0.00100683$  is not in the table. The two closest values are 0.001008 (just above 0.00100683) and 0.001004 (just below 0.00100683), which would give  $p_2 = 20$  MPa, and 0.001004 (just below 0.00100683), which would give  $p_2 = 30$  MPa.

Neither value is particularly accurate. You must use "linear interpolation" to find a ~~better~~ more accurate value.



DONE

3.16

Linear interpolation (web page under study aids)

$$d = d_1 + \frac{g - g_1}{g_2 - g_1} (d_2 - d_1)$$

$g$ : given value       $g_1, g_2$ : closest values in table  
 $d$ : desired value       $d_1, d_2$ : table values for  $g_1, g_2$

In this example:

$$g = v = 0.00100603 \text{ m}^3/\text{kg} \quad \text{given (known)}$$

$d$ : pressure

$$\text{Table values: } g_1 = 0.001000 \text{ m}^3/\text{kg} \rightarrow d_1 = 20,000 \text{ hPa}$$

$$g_2 = 0.001004 \text{ m}^3/\text{kg} \rightarrow d_2 = 30,000 \text{ hPa}$$

Formula

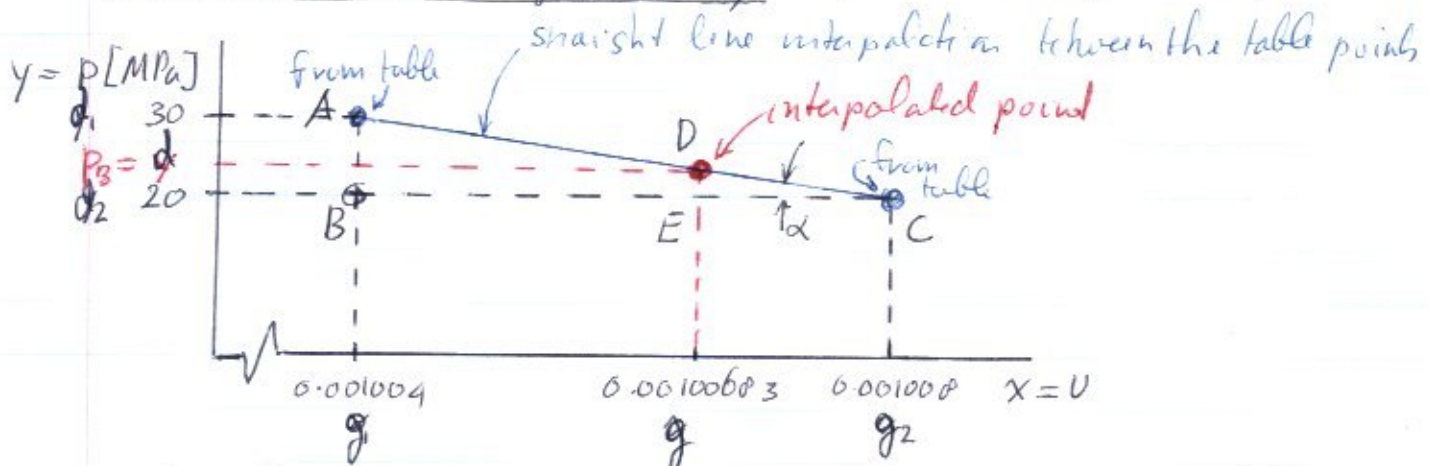
$$d = 20,000 \text{ hPa} + \frac{0.00100603 \text{ m}^3/\text{kg} - 0.001000 \text{ m}^3/\text{kg}}{0.001004 \text{ m}^3/\text{kg} - 0.001000 \text{ m}^3/\text{kg}} (30,000 \text{ hPa} - 20,000 \text{ hPa})$$
$$= 22,925 \text{ hPa} = \underline{\underline{22.9 \text{ MPa}}}$$

end 1/19/06 →

See example 3.3 in the book, in particular figure 3.14

3.17  
III (A)

Linear interpolation graphically (easier to remember?)



Similar triangles ABC and DEC  $\Rightarrow$

$$\tan \alpha = \frac{AB}{BC} = \frac{DE}{EC} \quad \text{i.e.} \quad \frac{30-20}{0.001008-0.001004} = \frac{P_B-20}{0.001008-0.0010063}$$

Gives same answer

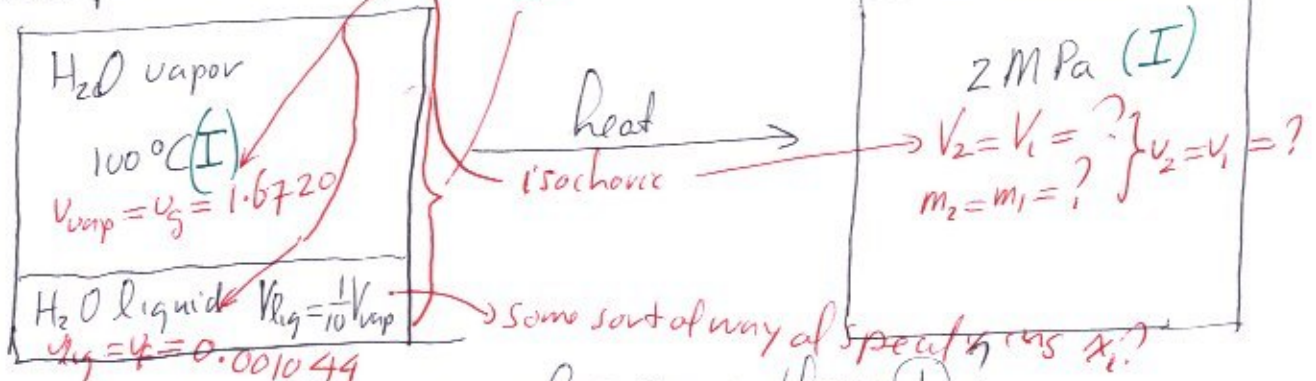
Note: for other substances than water, no pressure only; so interpolation is often needed in temperature only table even if the given p is a simple number

3.61  
3.42

Given: In black:

saturated: use B.1.1 @ 100°C  
A4

closed pressure cooker



Asked  $T_2$ . Has (2) more or less vapor than (1).

Solution  $x_1 = \frac{m_{vap}}{m_{vap} + m_{liq}}$

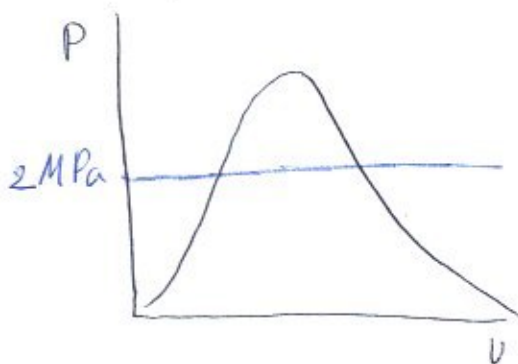
$m = \frac{V}{v}$  don't know anything about  $m$ , but do have some info on  $V$  and  $v$

$$x_1 = \frac{\frac{V_{vap}}{v_g}}{\frac{V_{vap}}{v_g} + \frac{V_{liq}}{v_f}} = \frac{\frac{V_{vap}}{v_g}}{\frac{V_{vap}}{v_g} + \frac{1}{10} \frac{V_{vap}}{v_f}} = \frac{1}{1.6720 + \frac{1}{10} \frac{1}{0.001049}} = 0.006202 \quad (I)$$

(can now compute  $v_1 = v_f + x(v_g - v_f) = 0.011413 \frac{m^3}{kg}$ )

$v_2 = 0.011413 \frac{m^3}{kg} \quad (I)$

Find phase of 2 in Pv



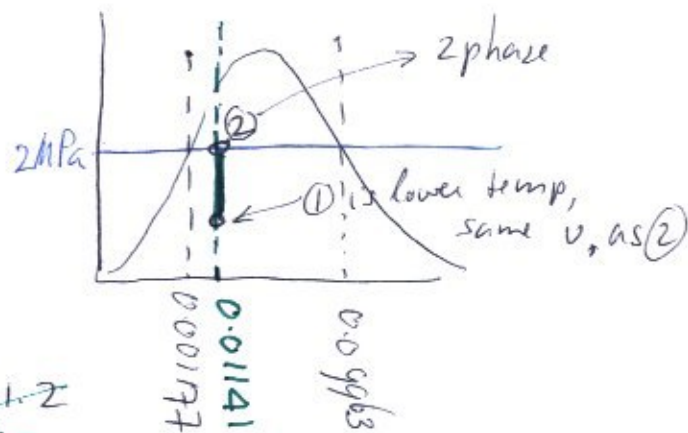
Sat table

B.1.2

at 2 MPa:

$$v_f = 0.001177 \frac{\text{m}^3}{\text{kg}}$$

$$v_g = 0.09963 \frac{\text{m}^3}{\text{kg}}$$



② is saturated, so  $T_2$  is in Table B.1.2  
at 2 MPa:  $T_2 = \underline{\underline{212.42^\circ\text{C}}}$

Find  $x_2$ :

$$v_2 = v_{f2} + x_2 (v_{g2} - v_{f2})$$

$$0.01141 = 0.001177 + x_2 (0.09963 - 0.001177) \rightarrow x_2 = 0.1039$$

$x_2 = 0.1039$  is greater than  $x_1 = 0.006202$ , and  $x$  is the mass fraction of vapor, so ② has a greater fraction of the mass in vapor. ② has more vapor mass.

How about the volumes?

$$\frac{V_{\text{liq}2}}{V_{\text{vap}2}} = \frac{m_{\text{liq}} v_{f2}}{m_{\text{vap}} v_{g2}} = \frac{(m_{\text{tot}} - m_{\text{vap}}) v_{f2} / m_{\text{tot}}}{m_{\text{vap}} v_{g2} / m_{\text{tot}}} = \frac{(1 - x_2) v_{f2}}{x_2 v_{g2}}$$

$$= 0.1018 > \frac{V_{\text{liq}1}}{V_{\text{vap}1}} = \frac{1}{10}$$

So state ② has more liquid volume, so the vapor volume of 2 is less. ② has less vapor volume.