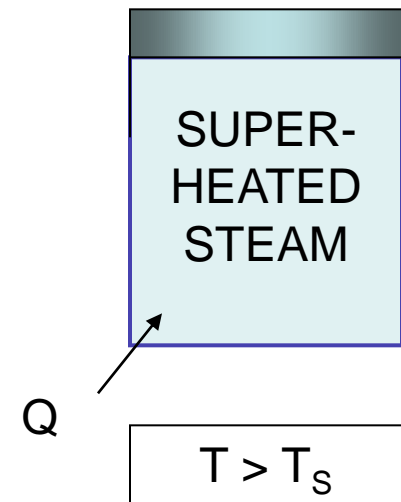
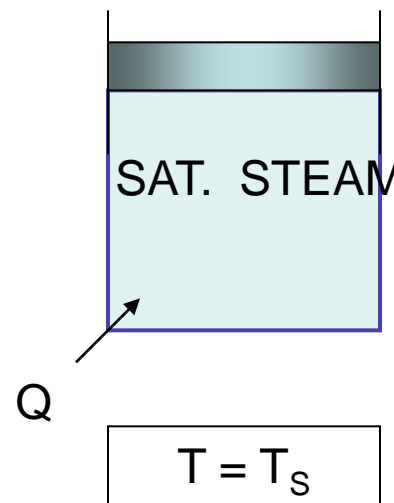
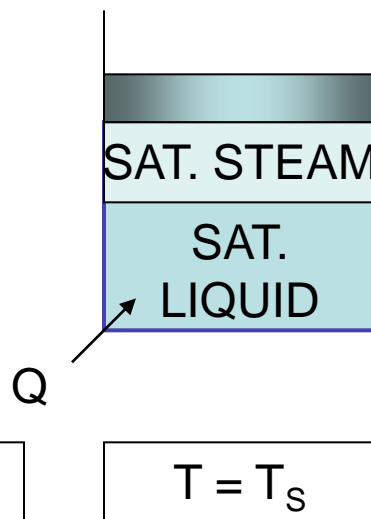
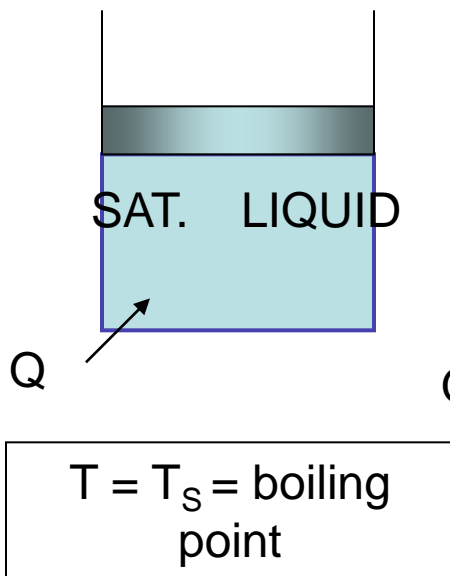
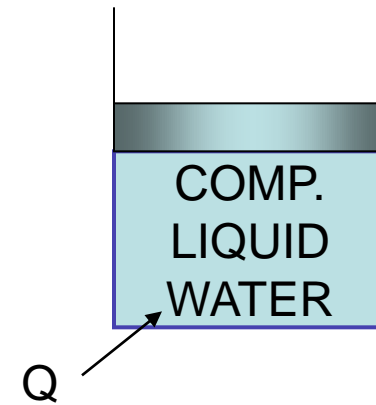
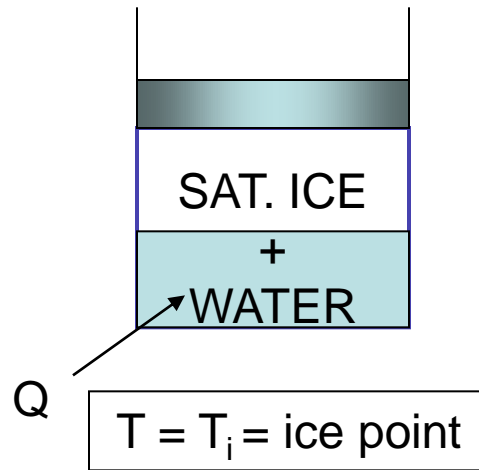
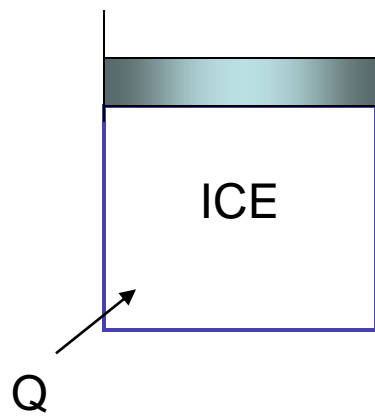


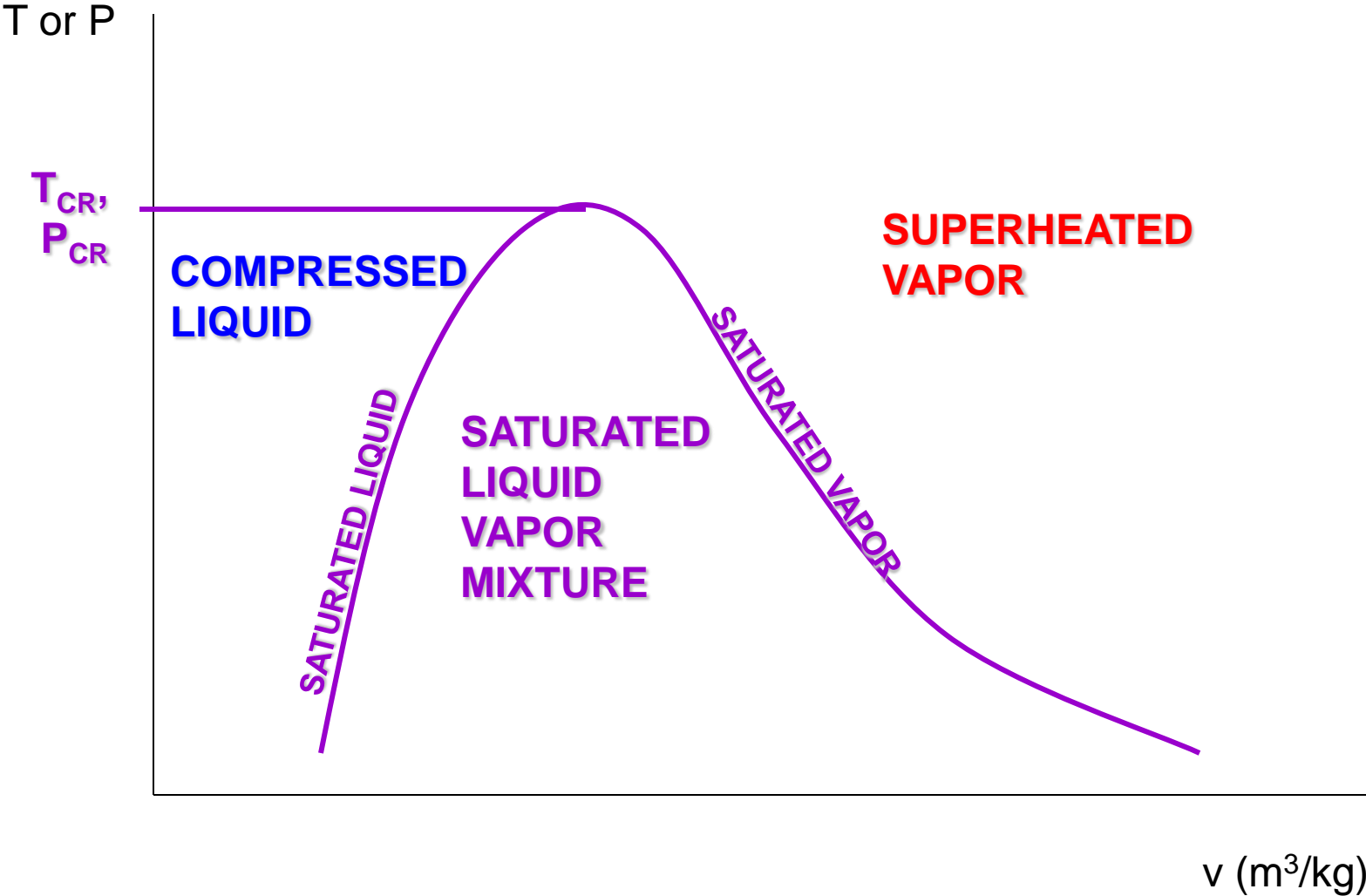
AREN 2110: PROPERTIES OF PURE SUBSTANCES WITH PHASE CHANGE

- STATE INFORMATION FOR LIQUID, SATURATED LIQUID-SATURATED VAPOR PHASE MIXTURES, AND SUPERHEATED STEAM
- P-v AND T-v DIAGRAMS
- SATURATED LIQUID-VAPOR AND STEAM TABLE EXAMPLES

Phase Equilibrium Conditions and Associated Temperature Points (Drawn volumes are not to scale)

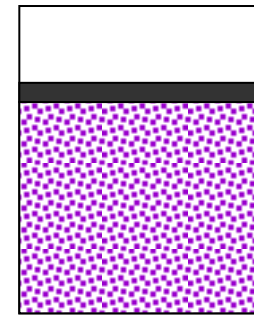
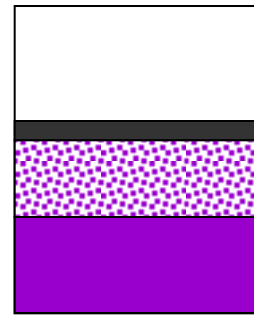
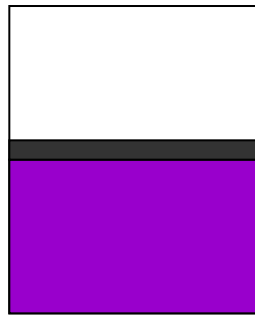
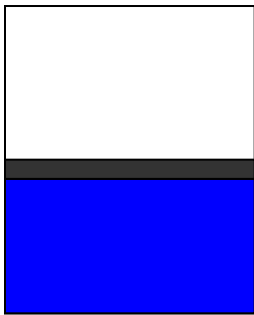


PHASE DIAGRAM POINTS OF INTEREST



TWO IMPORTANT PROCESSES

1. LIQUID → VAPOR PHASE CHANGE AND EXPANSION AT **CONSTANT PRESSURE**
2. LIQUID → VAPOR PHASE CHANGE AND EXPANSION AT **CONSTANT TEMPERATURE**



STATE 1:
 PURE LIQUID H₂O;
 T = 20 C
 P = 1 ATM
"COMPRESSED LIQUID"

(Add heat) T increases. P held constant, $\Delta V > 0$ but very small

STATE 2:
 PURE LIQUID H₂O;
 When T = 100 C and
 P = 1 ATM
"SATURATED LIQUID"

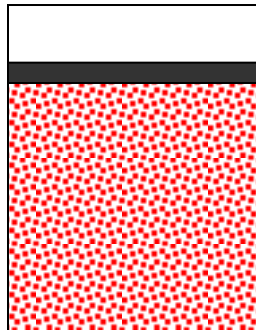
IF any heat added, liquid vaporizes. P constant, $\Delta V > 0$ but small

STATE 3:
 2-PHASE MIXTURE
 T = 100 C
 P = 1 ATM
"SATURATED LIQUID-VAPOR MIXTURE"

Add heat, more liquid \rightarrow vapor, $\Delta T = 0$, $\Delta V > 0$ and large

STATE 4:
 ALL H₂O-VAPOR
 T = 100 C
 P = 1 ATM
"SATURATED VAPOR"

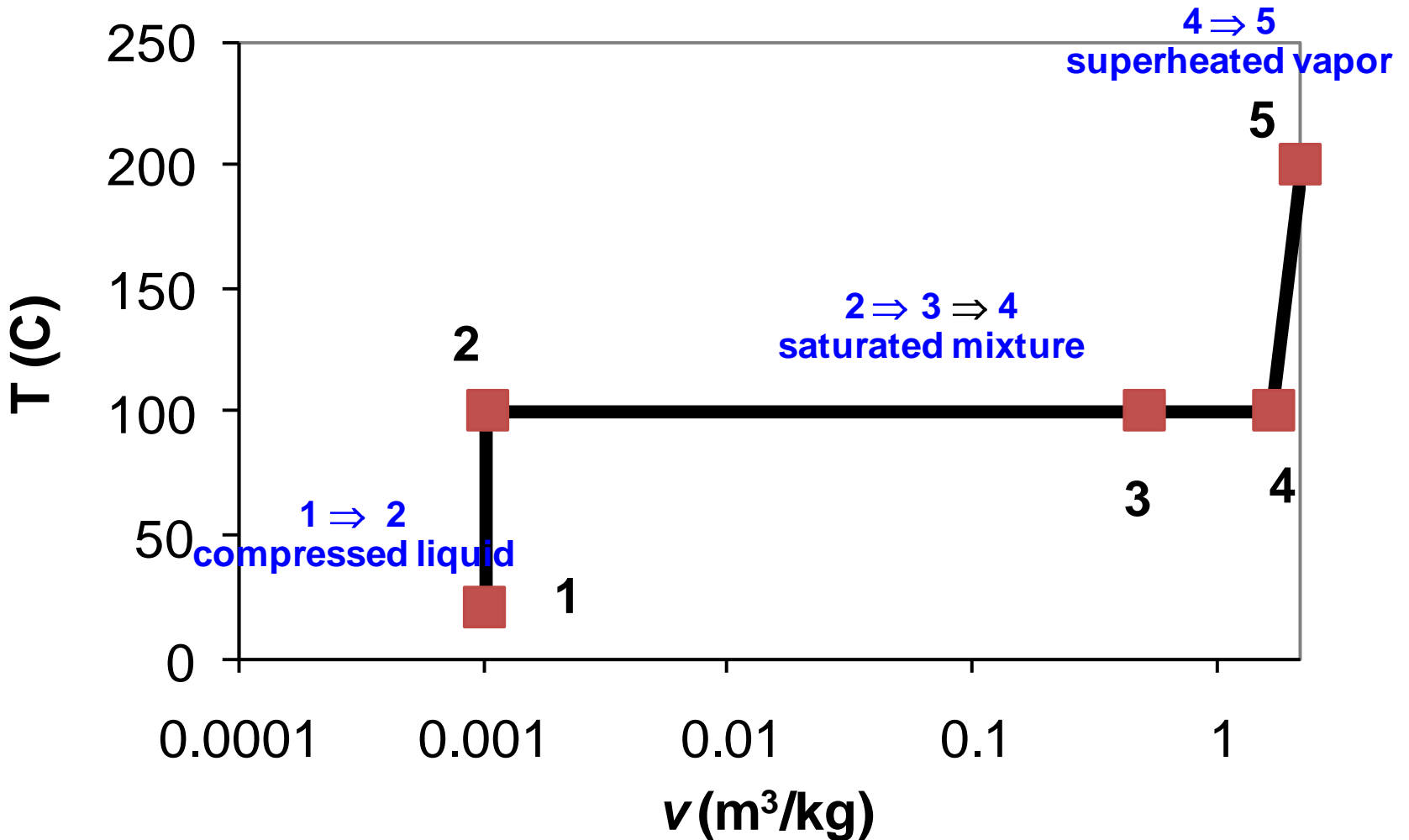
IF any heat lost, vapor will condense ($\Delta T = 0$, $\Delta V < 0$). If heat added, $\Delta T > 0$, $\Delta V > 0$ and large



STATE 5:
 ALL H₂O-VAPOR
 T = 200 C
 P = 1 ATM
"SUPERHEATED VAPOR"
 IF some heat lost, but T > 100 C, no condensation, $\Delta T < 0$, $\Delta V < 0$. IF heat added, $\Delta T > 0$, $\Delta V > 0$

STATES FOR WATER LIQUID-VAPOR PHASES IN CONSTANT PRESSURE EXPANSION PROCESS INCLUDING PHASE CHANGE. DIRECTION IS INCREASING TEMPERATURE FOR PROCESSES 1 \rightarrow 2 AND 4 \rightarrow 5.

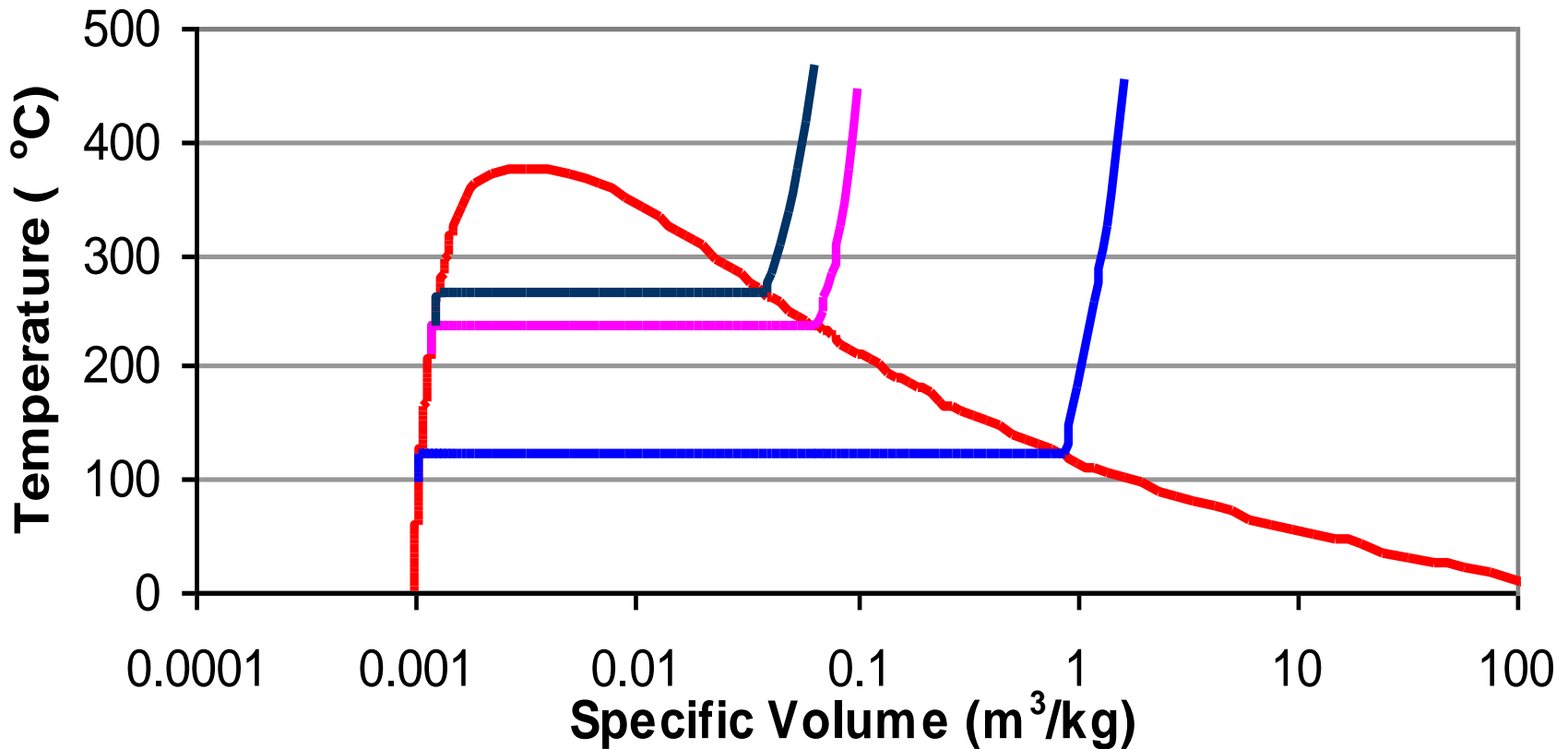
T-v diagram for water heating and boiling, pressure constant (1 atm.)

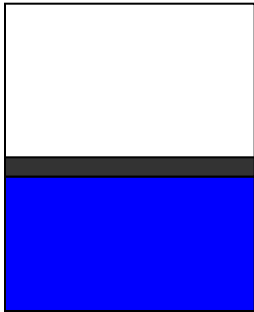


PLOT OF MULTIPLE **ISOBARIC** PHASE CHANGE T-v LINES TO PRODUCE COMPLETE LIQUID WATER-STEAM T-v DIAGRAM FOR H₂O

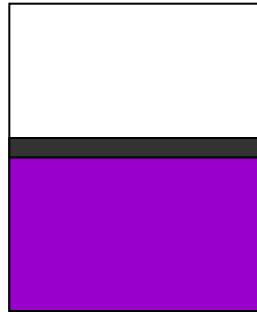
Liquid, Sat Liquid/Steam (Tables A-4, A-5, A-6, A-7)

— Saturation Lines — 200 kPa (T_{sat}=120C) — 3 MPa (T_{sat}=234C) — 5 MPa (T_{sat}=264C)





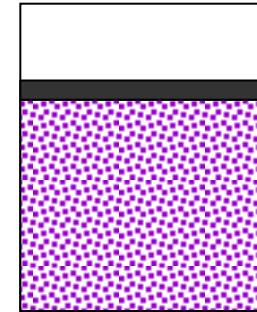
STATE 1:
 PURE LIQUID H₂O;
 T = 150 C
 P = 1000 kPa (~ 10 atm)
"COMPRESSED LIQUID"
 Lower pressure
 (decrease P_{atm}), T
 held constant, $\Delta v \sim 0$



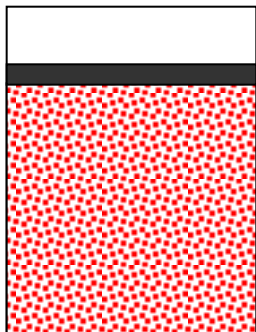
STATE 2:
 PURE LIQUID H₂O;
 T = 150 C
 P = P_{sat} = 476.16 kPa
"SATURATED LIQUID"
 Liquid begins to boil.
 $\Delta P = 0$, $\Delta v > 0$,
 (expands)



STATE 3:
 2-PHASE MIXTURE
 T = 150 C
 P = P_{sat} = 476.16 kPa
"SATURATED LIQUID-VAPOR MIXTURE"
 Boils, expands, $\Delta T = 0$,
 $\Delta P = 0$, $\Delta v > 0$



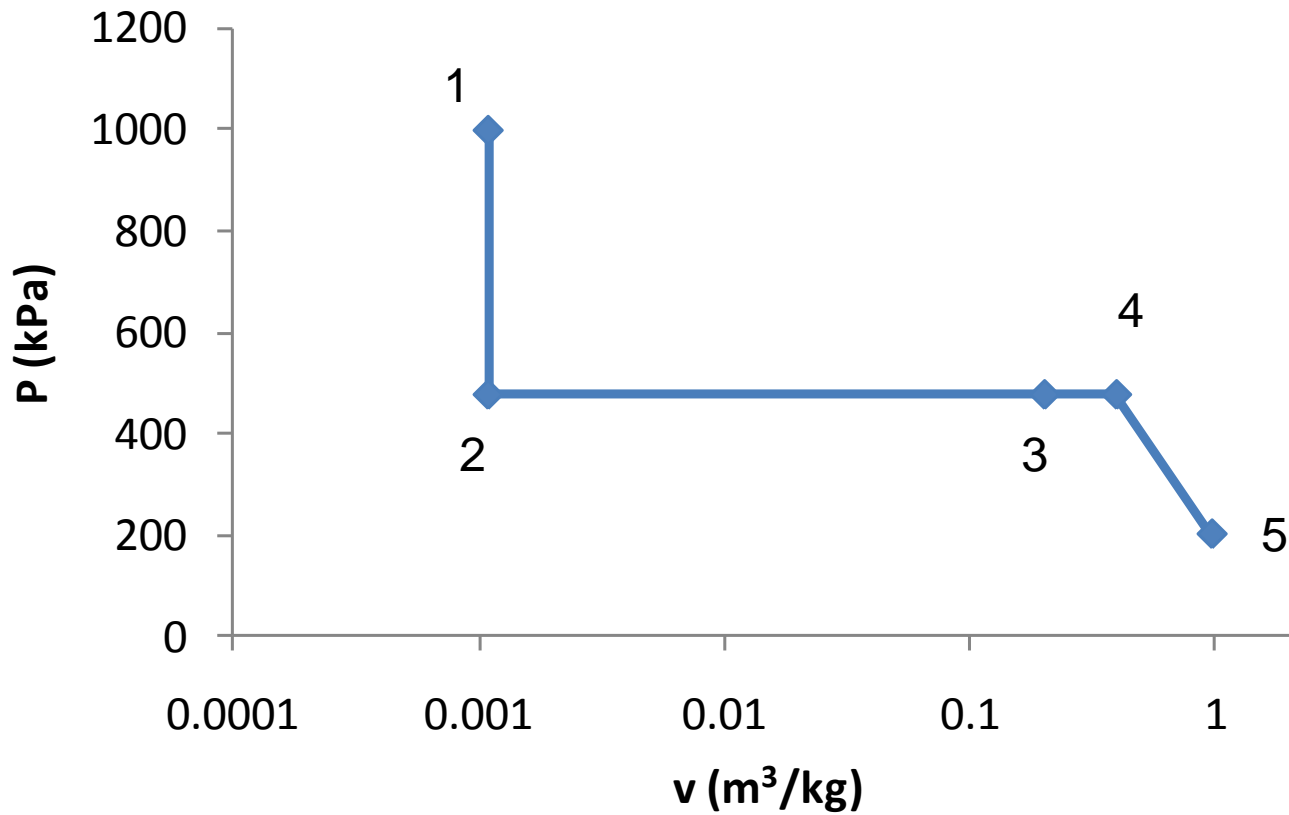
STATE 4:
 ALL SATURATED H₂O-VAPOR
 T = 150 C
 P = P_{sat} = 476.16 kPa
"SATURATED VAPOR"
 IF any expansion and
 $\Delta T = 0$, $\Delta v > 0$, $\Delta P < 0$



STATE 5:
 SUPERHEATED
 STEAM
 T = 150 C
 P = 200 kPa
"SUPERHEATED VAPOR"
 IF $\Delta P < 0$, $\Delta v > 0$

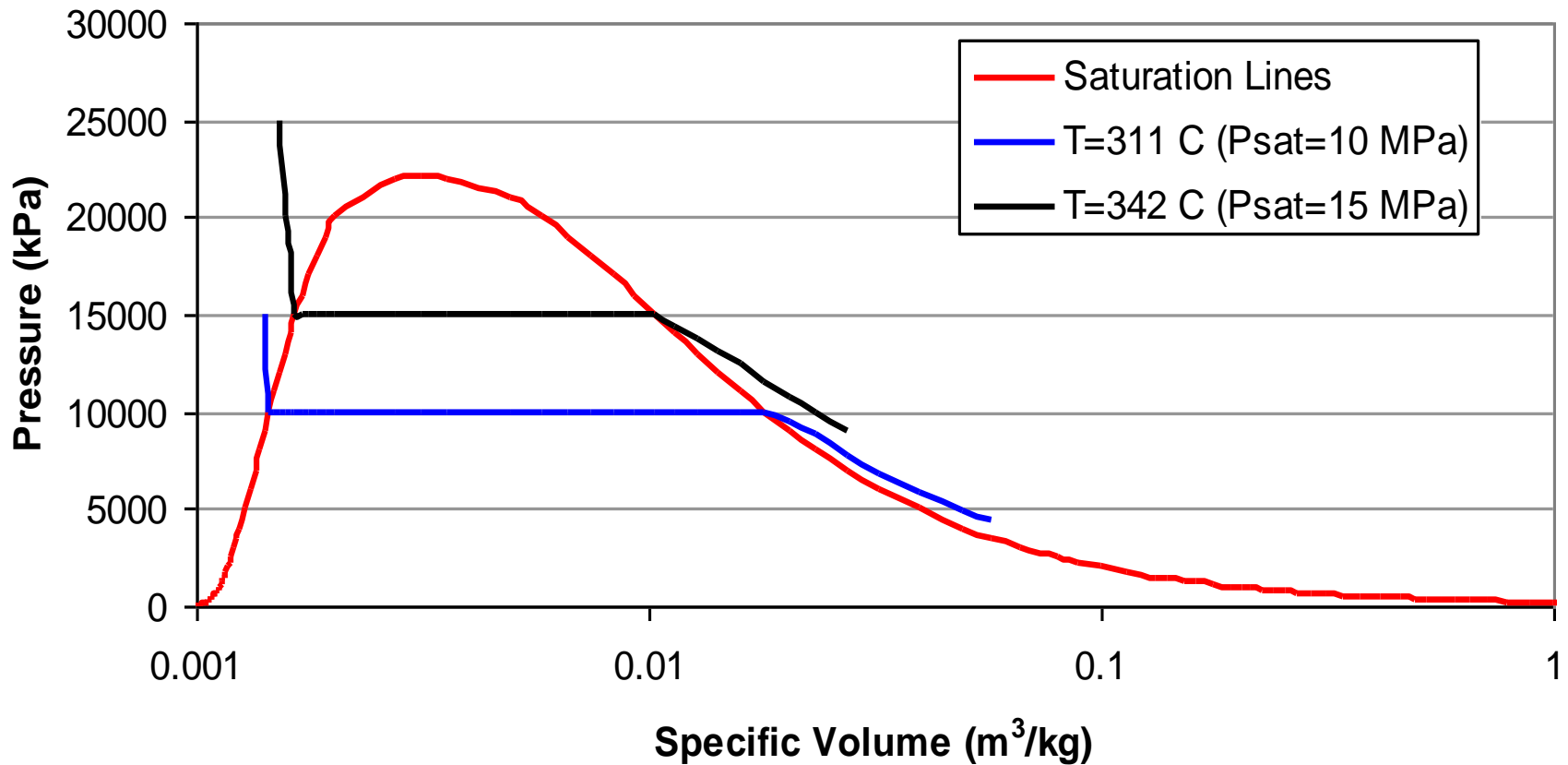
• STATES FOR WATER LIQUID-VAPOR PHASES IN CONSTANT TEMPERATURE (150 °C) EXPANSION PROCESS INCLUDING PHASE CHANGE, DIRECTION IS DECREASING PRESSURE IN STATES 1 → 2, AND 4 → 5.

P-v diagram for water expansion and phase change under constant temperature conditions (150 C)



PLOT MULTIPLE **ISOTHERMAL** PHASE CHANGE P-v LINES TO PRODUCE COMPLETE LIQUID WATER-STEAM P-v DIAGRAM FOR H₂O

Liquid, Saturated Water, Steam (Tables A-4, A-5, A-6, A-7)



SATURATED WATER - TEMPERATURE TABLE (A-4)

T	P_{sat}	v_f	v_g	u_f	u_{fg}	u_g	h_f	h_{fg}	h_g	s_f	s_{fg}	s_g
(°C)	(kPa)	(m ³ /kg)	(m ³ /kg)	(kJ/kg)	(kJ/kg)	(kJ/kg)	(kJ/kg)	(kJ/kg)	(kJ/kg)	kJ/(kg-K)	kJ/(kg-K)	kJ/(kg-K)
0.01	0.611	0.001000	206.14	0.0	2375.3	2375.3	0.0	2501.3	2501.4	0.0000	9.1562	9.1562
:	:	:	:	:	:	:	:	:	:	:	:	:
70	31.19	0.001023	5.042	293.0	2176.6	2469.6	293.0	2333.8	2626.8	0.9549	6.8004	7.7553
:	(Mpa)	:	:	:	:	:	:	:	:	:	:	:
100	0.101	0.001044	1.6729	418.94	2087.6	2506.5	419.04	2257.0	2676.1	1.3069	6.0480	7.3549
:	:	:	:	:	:	:	:	:	:	:	:	:
374.1	22.09	0.003155	0.003155	2029.6	0.0	2029.6	2099.3	0.0	2099.3	4.4298	0.0	4.4298

SATURATED WATER - PRESSURE TABLE (A5)

P_{sat}	T	v_f	v_g	u_f	u_{fg}	u_g	h_f	h_{fg}	h_g	s_f	s_{fg}	s_g
(kPa)	(°C)	(m ³ /kg)	(m ³ /kg)	(kJ/kg)	(kJ/kg)	(kJ/kg)	(kJ/kg)	(kJ/kg)	(kJ/kg)	kJ/(kg-K)	kJ/(kg-K)	kJ/(kg-K)
0.611	0.01	0.001000	206.14	0.0	2375.3	2375.3	0.0	2501.3	2501.4	0.0000	9.1562	9.1562
:	:	:	:	:	:	:	:	:	:	:	:	:
30	69.1	0.001022	5.229	289.20	2179.2	2468.4	289.23	2336.1	2625.3	0.9439	6.8247	7.7686
(Mpa)	:	:	:	:	:	:	:	:	:	:	:	:
0.100	99.63	0.001043	1.6940	417.36	2088.7	2506.1	417.46	2258.0	2675.5	1.3026	6.0568	7.3594
:	:	:	:	:	:	:	:	:	:	:	:	:
22.09	374.1	0.003155	0.003155	2029.6	0.0	2029.6	2099.3	0.0	2099.3	4.4298	0.0	4.4298

SUPERHEATED VAPOR TABLES

T	v	u	h	s
°C	m ³ /kg	kJ/kg	kJ/kg	kJ/kgK

P=0.8 MPa (T _{sat} = 170.43 °C)				
Sat*	0.2404	2576.8	2769.1	6.6628
200	0.2608	2630.6	2839.3	6.8158
250	0.2931	2715.5	2950.0	7.0384
:	:	:	:	:
1300	0.9076	4681.8	5407.9	9.5575