Thermodynamica 1

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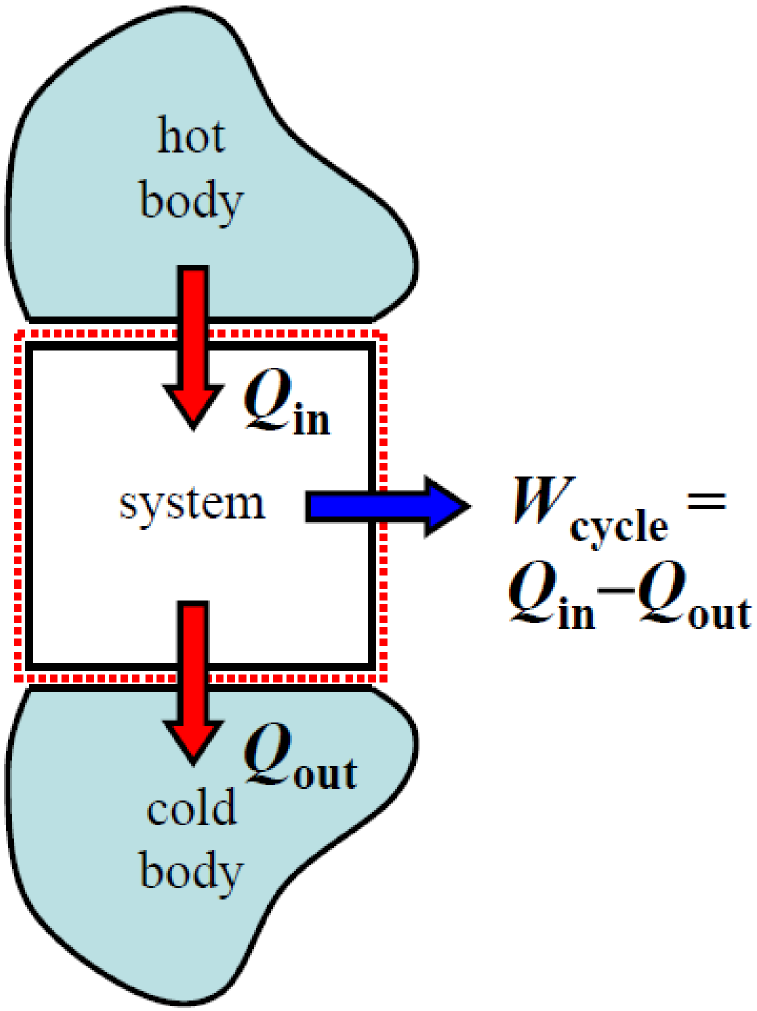
summary lecture 3

- internal energy, work, heat
- 1st Law of Thermodynamics
- cycles
  - $Q_{cycle} = W_{cycle}$
  - power cycle
  - refrigeration & heat pump cycle
- thermal efficiency, coefficient of performance
- examples of practical cycles
  - Otto cycle, Joule cycle

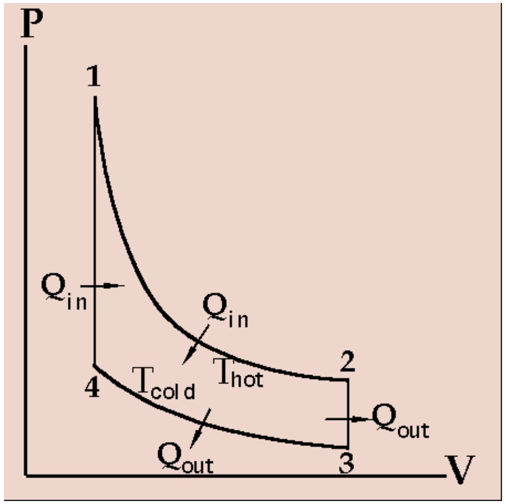
Power cycle

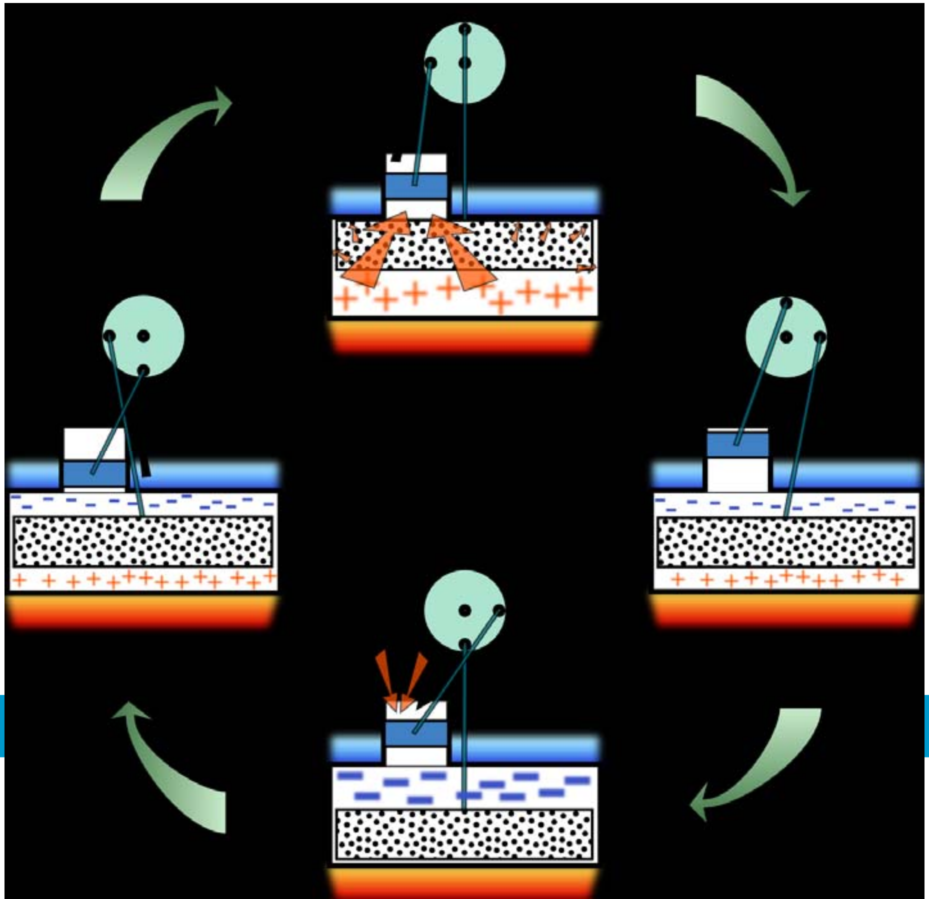


$$\eta = \frac{W_{cycle}}{Q_{in}} = \frac{Q_{in} - Q_{out}}{Q_{in}} = 1 - \frac{Q_{out}}{Q_{in}}$$

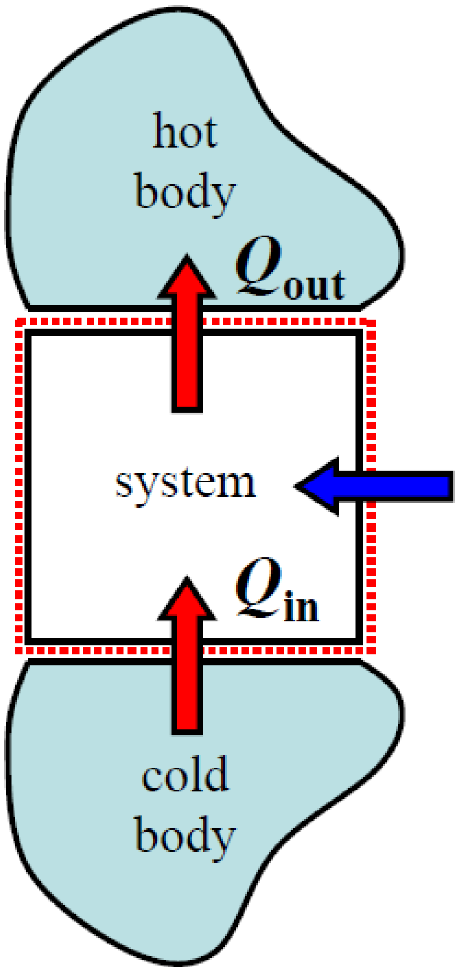
$$\eta < 1$$

Example: Stirling engine
Closed system





Heat pump



$W_{cycle} = Q_{out} - Q_{in}$

$$\gamma = \frac{Q_{out}}{W_{cycle}} = \frac{Q_{out}}{Q_{out} - Q_{in}} = \frac{1}{1 - Q_{in} / Q_{out}}$$

$$\gamma > 1$$

Opgave 2.20 (antwoord = 1.84 kJ/kg)

- 1→2 Polytropic compression
- 2—3 Constant pressure

Voor de oplettende lezer vergelijk formule 3.54 met voorbeeld 2.1

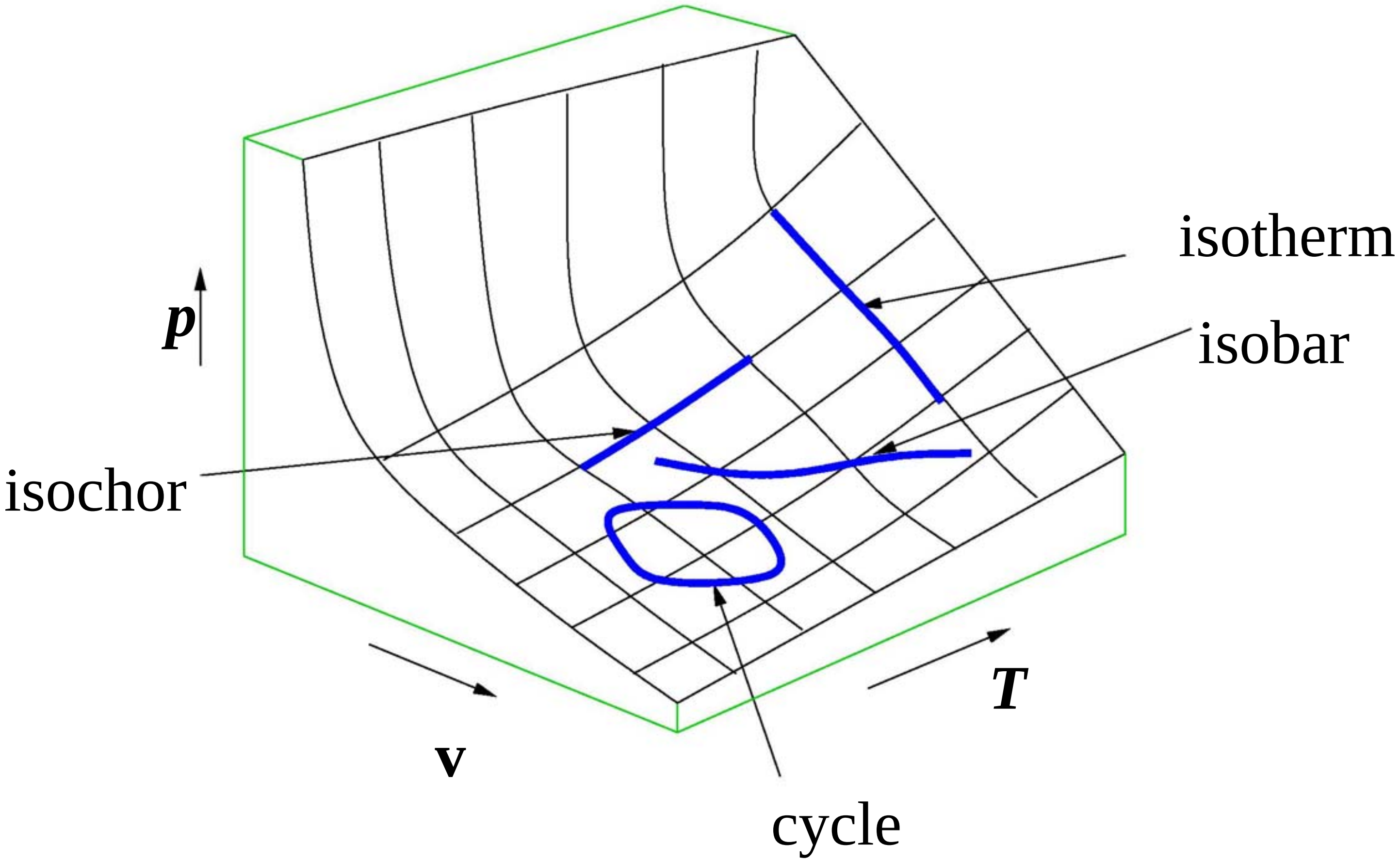
properties of matter

- **pure:** invariable chemical composition, but different phases (thus no combustion!)
- only work through compression/expansion
- thermodynamic equilibrium: consider properties of state
- quasi-static processes: consider properties of state during process

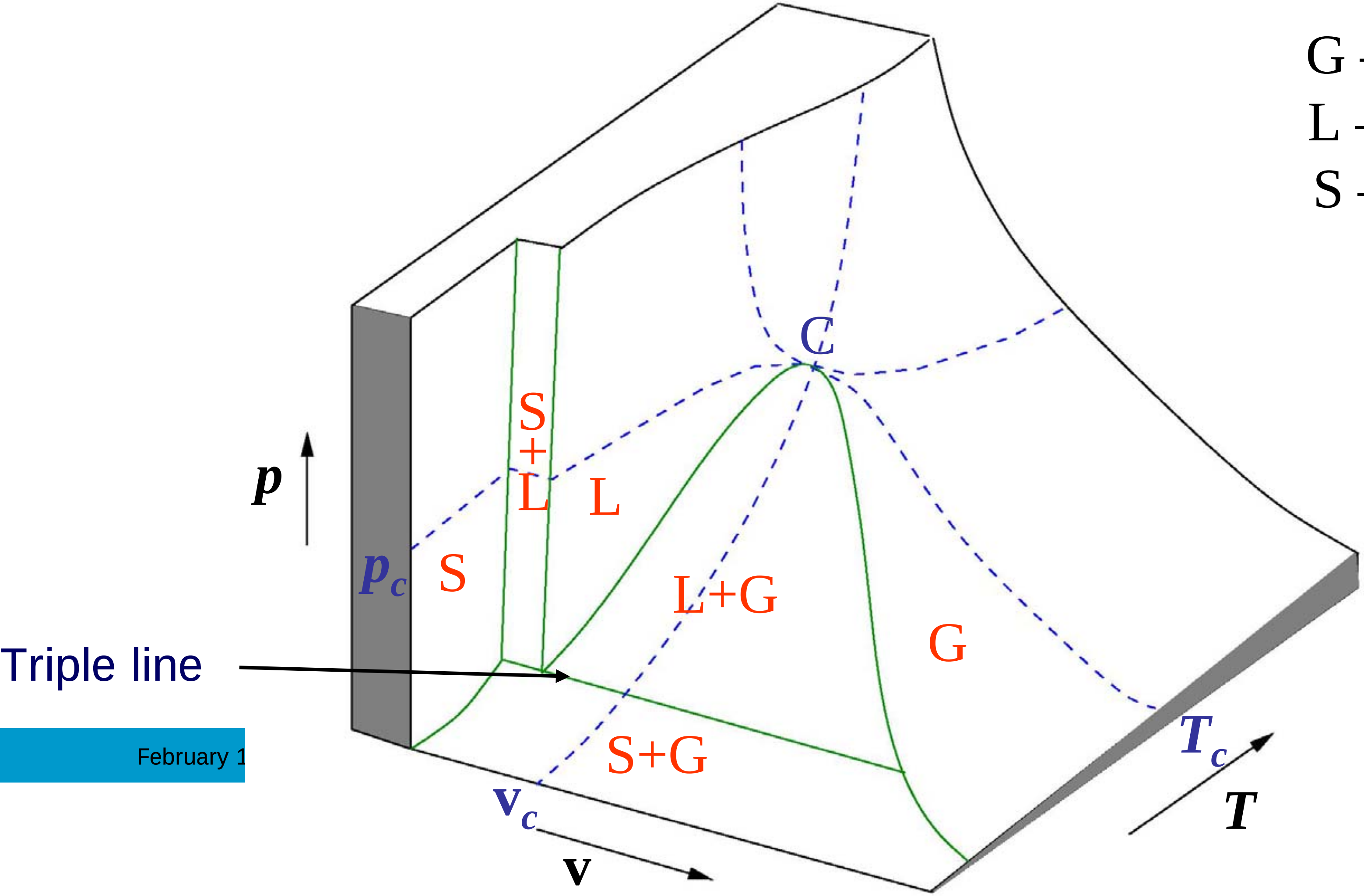
Two independent properties:

- one mechanical (V), one thermal (T)
- E.g., $p = p(T, V)$ and $U = U(T, V)$

p-v-*T* surface (gas)

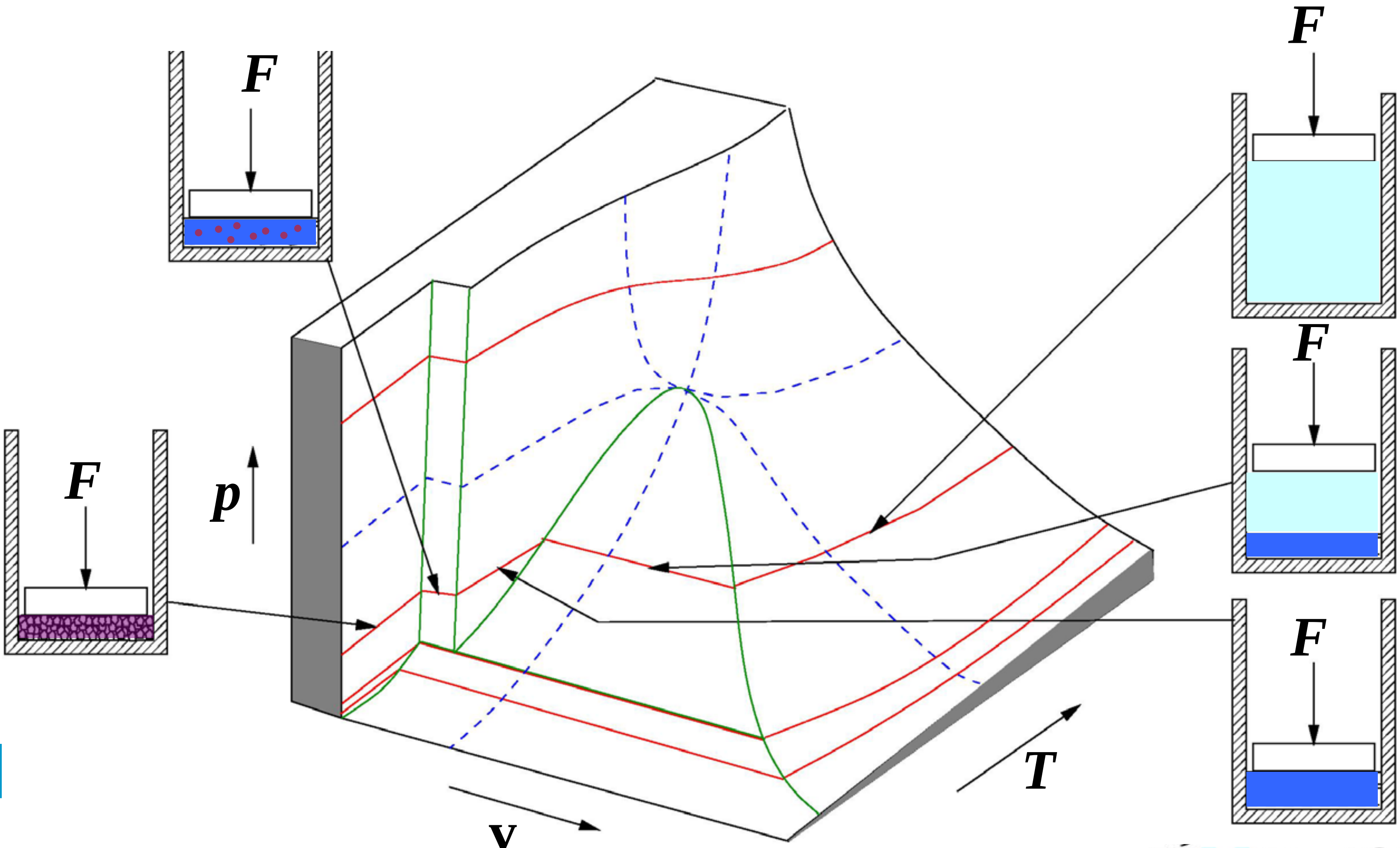


p-v-*T* diagram (solid, liquid & gas)

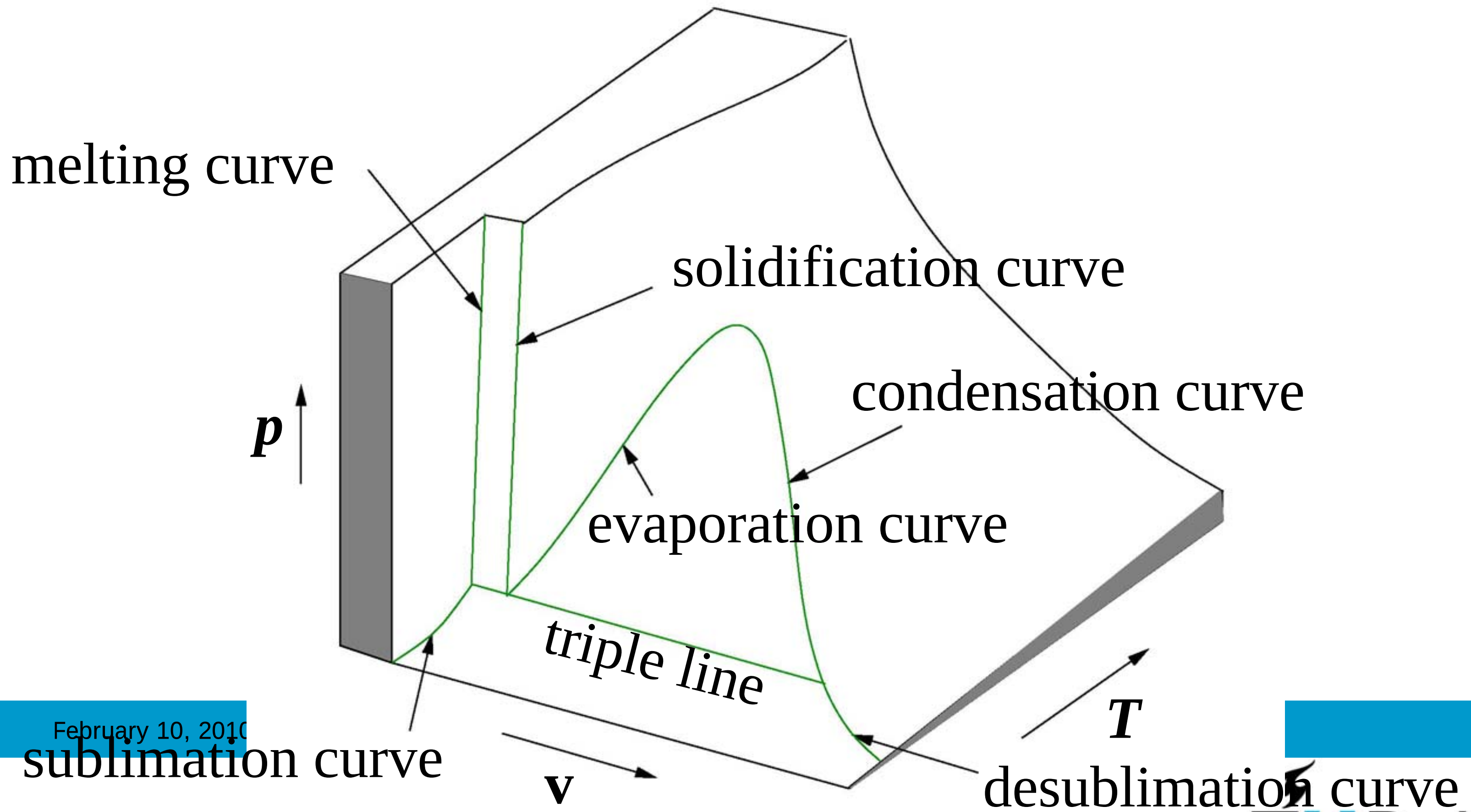


G – vapor
L – liquid
S – solid

Extracting heat at constant pressure

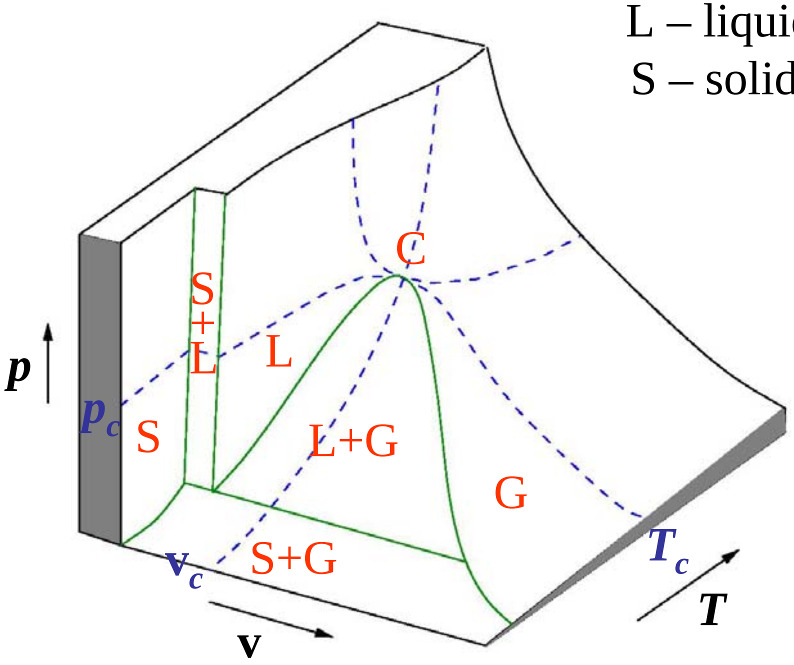


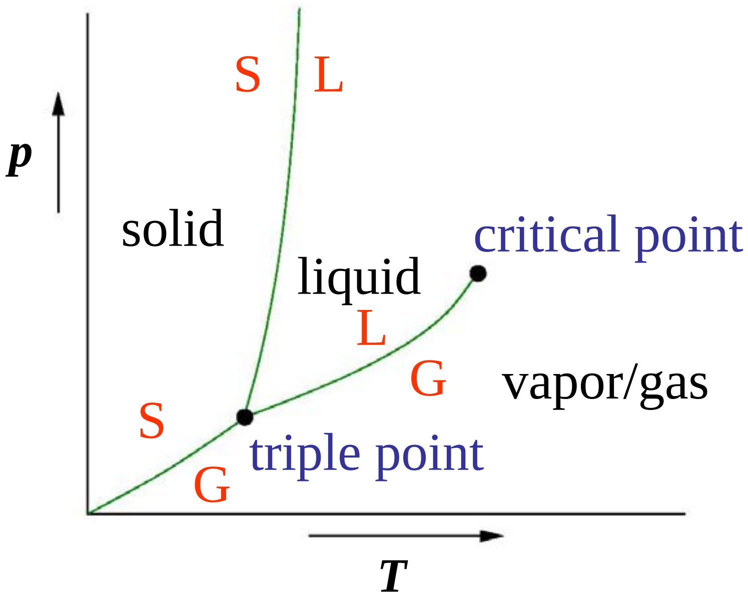
phase transition curves



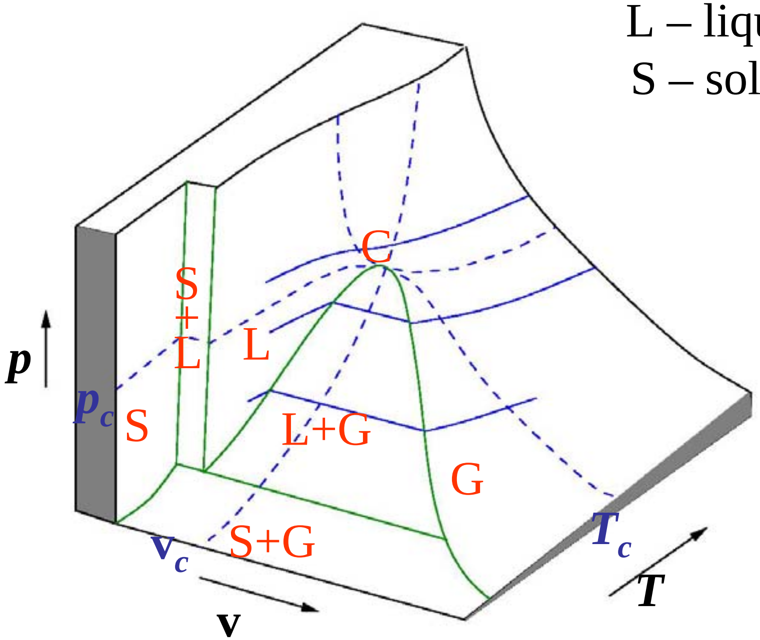
phase diagram

G – vapor
L – liquid
S – solid

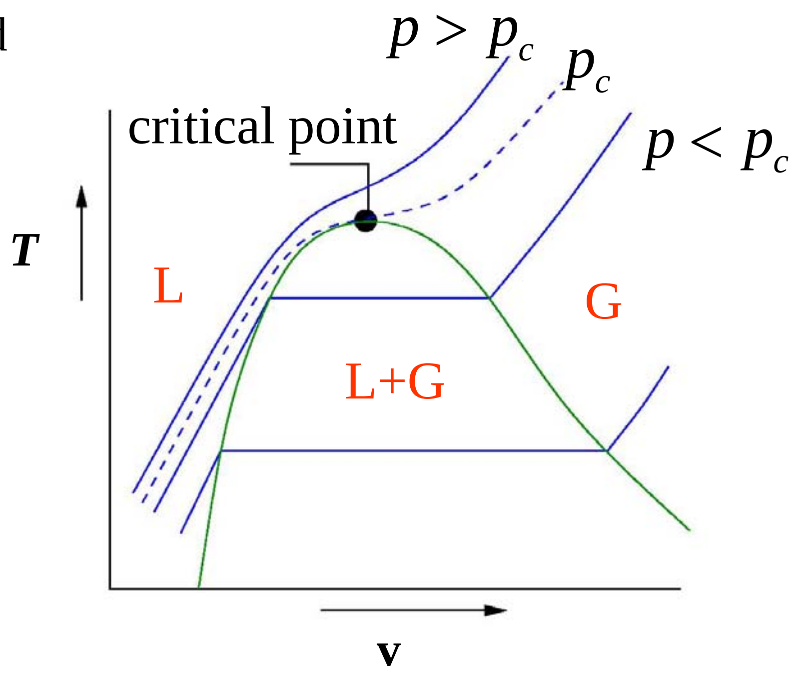




T-v diagram

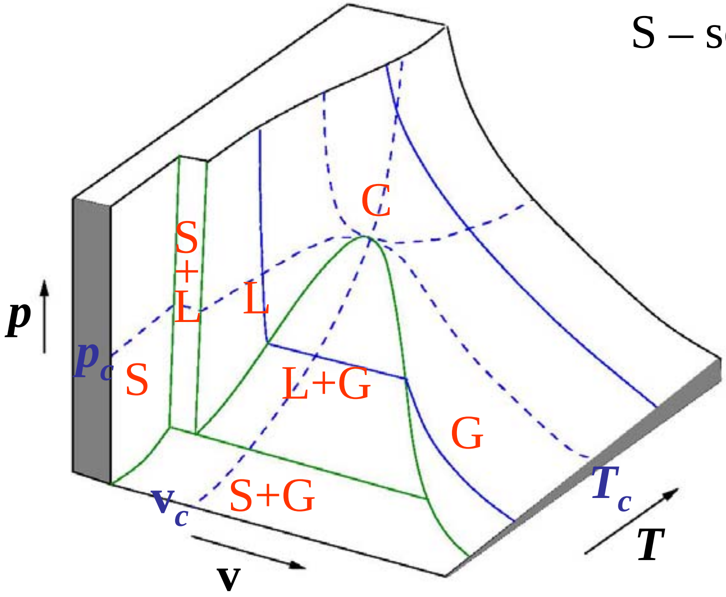


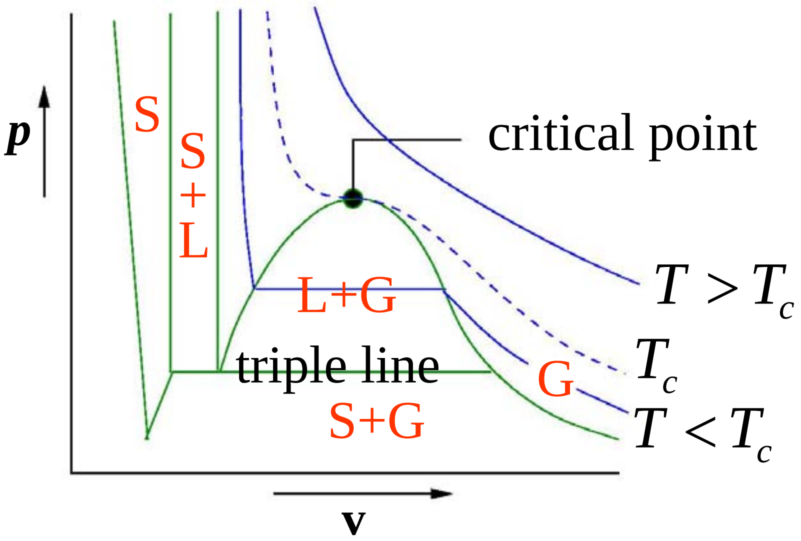
G – vapor
L – liquid
S – solid



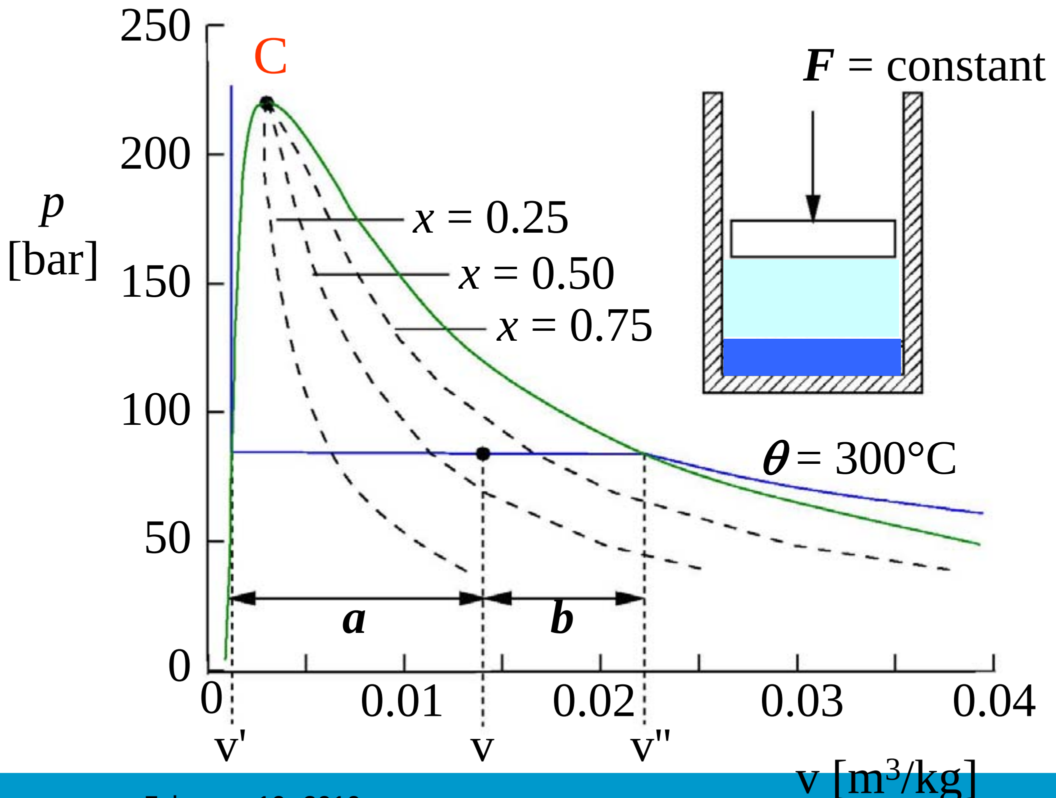
p-v diagram

G – vapor
L – liquid
S – solid





quality



$$m = m' + m''$$

m' : mass of water

m'' : mass of vapor

quality:

$$x = \frac{m''}{m} \Rightarrow \frac{m'}{m} = 1 - x$$

total volume:

$$m\mathrm{v} = m'\mathrm{v}' + m''\mathrm{v}''$$

$$\mathrm{v} = (1-x)\mathrm{v}' + x\mathrm{v}'' = \mathrm{v}' + x(\mathrm{v}'' - \mathrm{v}')$$

$$\Rightarrow \boxed{x = a/(a+b)}$$

water, vapor, ice

atmospheric pressure

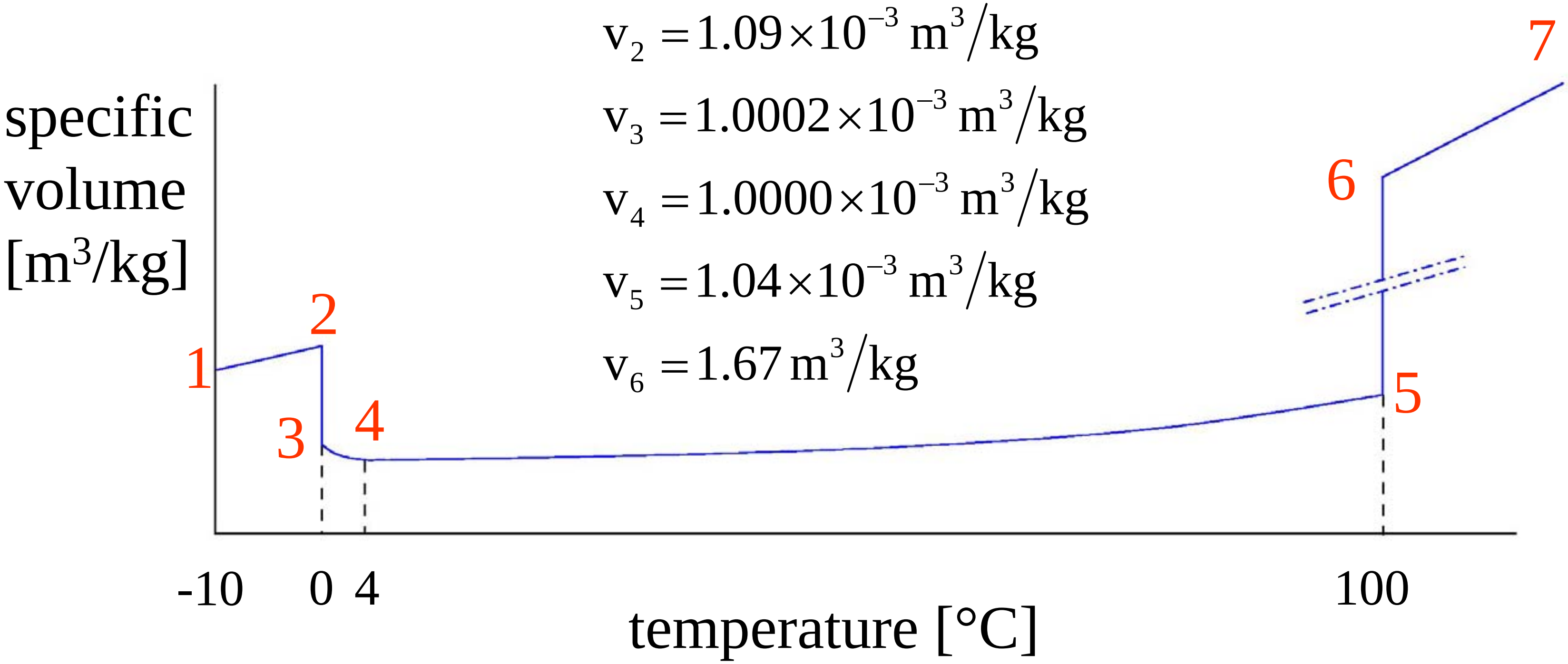
$$v_2 = 1.09 \times 10^{-3}\ m^3/kg$$

$$v_3 = 1.0002 \times 10^{-3}\ m^3/kg$$

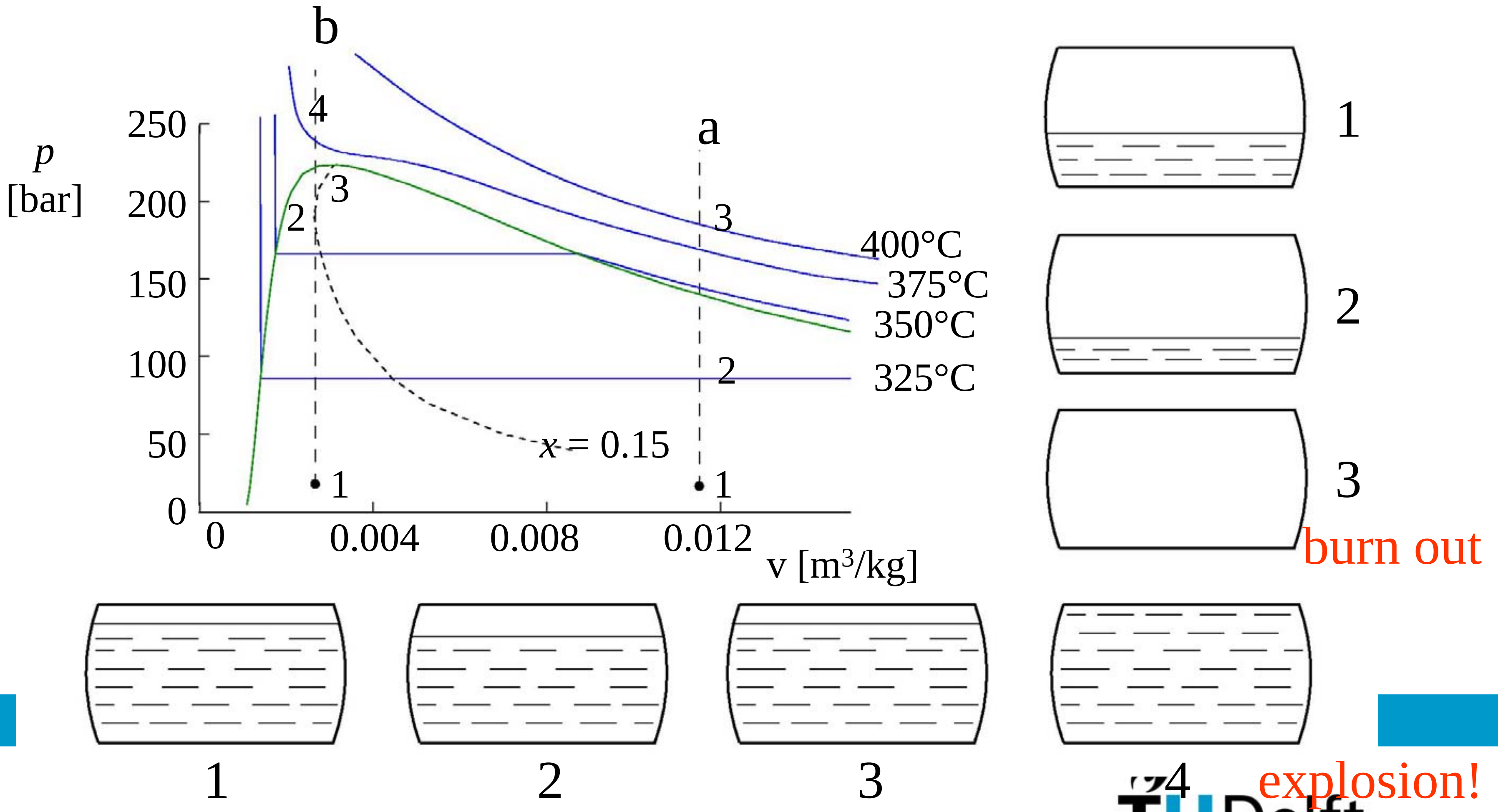
$$v_4 = 1.0000 \times 10^{-3}\ m^3/kg$$

$$v_5 = 1.04 \times 10^{-3}\ m^3/kg$$

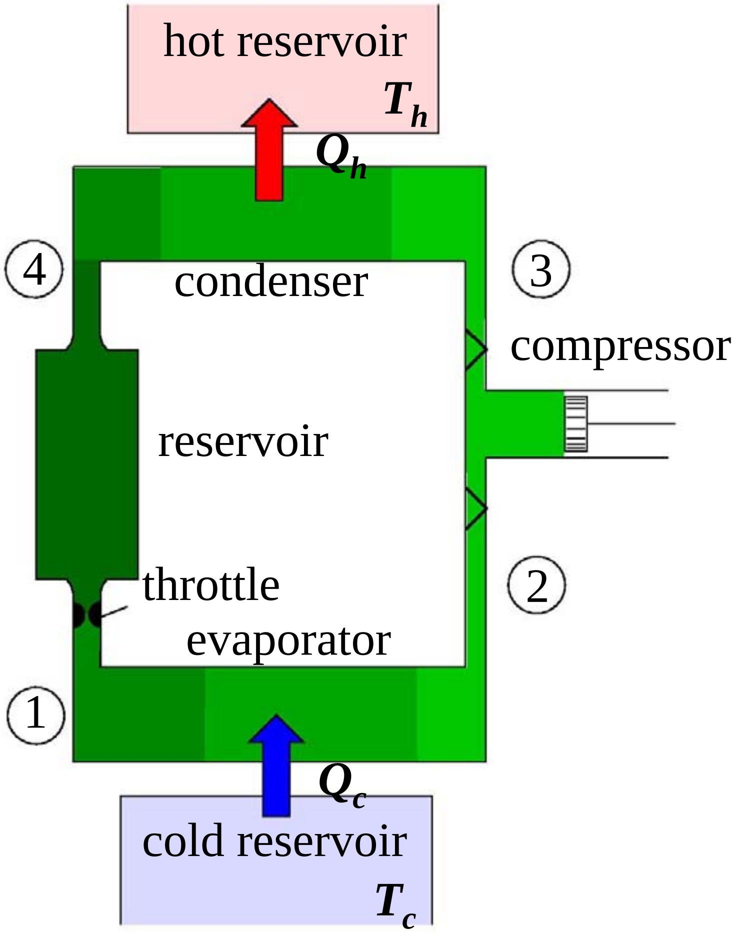
$$v_6 = 1.67\ m^3/kg$$

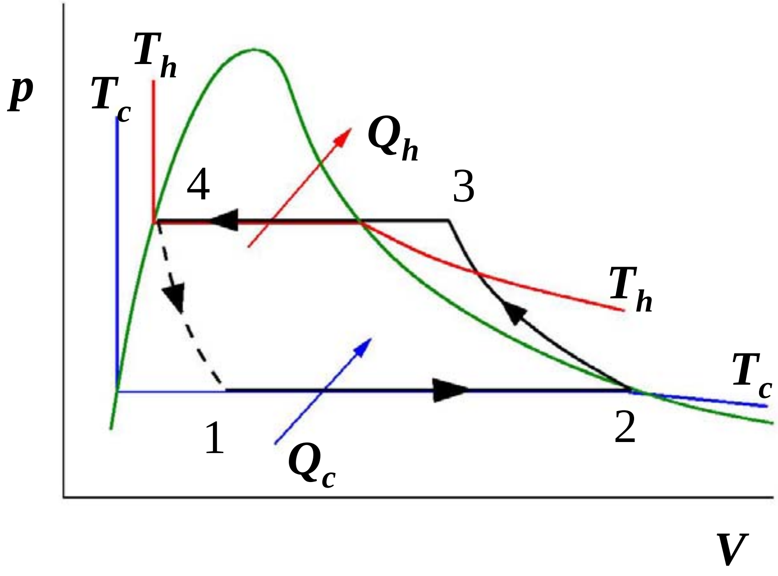


Heating water at constant volume



Refrigerator met smoorklep





coefficient of performance:

$$COP = \beta = \frac{Q_{\text{cold}}}{W_{\text{cycle}}} = \frac{Q_{\text{cold}}}{Q_{\text{hot}} - Q_{\text{cold}}}$$

Stoomtabellen (editie 5 of blackboard)

De oudere edities van het boek bevatten de zgn. stoomtabellen. Deze tabellen zijn nodig voor het maken van de opgaves. We hebben alle tabellen op blackboard gezet.

(De nieuwe editie heeft geen tabellen meer die zitten nu verwerkt in het computer programma "Interactive Thermodynamics" . Dit programma kost echter 78 euro en voegt niet veel toe)

problem 3.16 (gebruik stoomtabellen)

Steam is contained in a closed rigid container with a volume of $1 m^3$

Initially, the pressure and temperature of the steam are 7 bars and 500°C, respectively.

The temperature drops as a result of heat transfer to the surroundings.

a) Determine the temperature at which condensation first occurs, in celsius, and
b) the fraction of the total mass that has condensed when the pressure reaches 0.5bar
c) What percentage of the volume is occupied by saturated liquid at the final state?

Table A-4

TABLE A-4 *(Continued)*

T °C	v m³/kg	u kJ/kg	h kJ/kg	s kJ/kg · K	v m³/kg	u kJ/kg	h kJ/kg	s kJ/kg · K
	p = 5.0 bar = 0.50 MPa (T_{sat} = 151.86°C)				p = 7.0 bar = 0.70 MPa (T_{sat} = 164.97°C)			
Sat.	0.3749	2561.2	2748.7	6.8213	0.2729	2572.5	2763.5	6.7080
180	0.4045	2609.7	2812.0	6.9656	0.2847	2599.8	2799.1	6.7880
200	0.4249	2642.9	2855.4	7.0592	0.2999	2634.8	2844.8	6.8865
240	0.4646	2707.6	2939.9	7.2307	0.3292	2701.8	2932.2	7.0641
280	0.5034	2771.2	3022.9	7.3865	0.3574	2766.9	3017.1	7.2233
320	0.5416	2834.7	3105.6	7.5308	0.3852	2831.3	3100.9	7.3697
360	0.5796	2898.7	3188.4	7.6660	0.4126	2895.8	3184.7	7.5063
400	0.6173	2963.2	3271.9	7.7938	0.4397	2960.9	3268.7	7.6350
440	0.6548	3028.6	3356.0	7.9152	0.4667	3026.6	3353.3	7.7571
500	0.7109	3128.4	3483.9	8.0873	0.5070	3126.8	3481.7	7.9299
600	0.8041	3299.6	3701.7	8.3522	0.5738	3298.5	3700.2	8.1956
700	0.8969	3477.5	3925.9	8.5952	0.6403	3476.6	3924.8	8.4391

TABLE A-3 Properties of Saturated Water (Liquid–Vapor): Pressure Table

Press. bar	Temp. °C	Specific Volume m^3/kg Sat. Liquid $v_f \times 10^3$	Sat. Vapor v_g	Internal Energy kJ/kg Sat. Liquid u_f	Sat. Vapor u_g	Enthalpy kJ/kg Sat. Liquid h_f	Evap. h_{fg}	Sat. Vapor h_g	Entropy kJ/kg · K Sat. Liquid s_f	Sat. Vapor s_g	Press. bar
0.04	28.96	1.0040	34.800	121.45	2415.2	121.46	2432.9	2554.4	0.4226	8.4746	0.04
0.06	36.16	1.0064	23.739	151.53	2425.0	151.53	2415.9	2567.4	0.5210	8.3304	0.06
0.08	41.51	1.0084	18.103	173.87	2432.2	173.88	2403.1	2577.0	0.5926	8.2287	0.08
0.10	45.81	1.0102	14.674	191.82	2437.9	191.83	2392.8	2584.7	0.6493	8.1502	0.10
0.20	60.06	1.0172	7.649	251.38	2456.7	251.40	2358.3	2609.7	0.8320	7.9085	0.20
0.30	69.10	1.0223	5.229	289.20	2468.4	289.23	2336.1	2625.3	0.9439	7.7686	0.30
0.40	75.87	1.0265	3.993	317.53	2477.0	317.58	2319.2	2636.8	1.0259	7.6700	0.40
0.50	81.33	1.0300	3.240	340.44	2483.9	340.49	2305.4	2645.9	1.0910	7.5939	0.50
0.60	85.94	1.0331	2.732	359.79	2489.6	359.86	2293.6	2653.5	1.1453	7.5320	0.60
0.70	89.95	1.0360	2.365	376.63	2494.5	376.70	2283.3	2660.0	1.1919	7.4797	0.70
0.80	93.50	1.0380	2.087	391.58	2498.8	391.66	2274.1	2665.8	1.2329	7.4346	0.80
0.90	96.71	1.0410	1.869	405.06	2502.6	405.15	2265.7	2670.9	1.2695	7.3949	0.90
1.00	99.63	1.0432	1.694	417.36	2506.1	417.46	2258.0	2675.5	1.3026	7.3594	1.00
1.50	111.4	1.0528	1.159	466.94	2519.7	467.11	2226.5	2693.6	1.4336	7.2233	1.50
2.00	120.2	1.0605	0.8857	504.49	2529.5	504.70	2201.9	2706.7	1.5301	7.1271	2.00
2.50	127.4	1.0672	0.7187	535.10	2537.2	535.37	2181.5	2716.9	1.6072	7.0527	2.50
3.00	133.6	1.0732	0.6058	561.15	2543.6	561.47	2163.8	2725.3	1.6718	6.9919	3.00
3.50	138.9	1.0786	0.5243	583.95	2546.9	584.33	2148.1	2732.4	1.7275	6.9405	3.50
4.00	143.6	1.0836	0.4625	604.31	2553.6	604.74	2133.8	2738.6	1.7766	6.8959	4.00
4.50	147.9	1.0882	0.4140	622.25	2557.6	623.25	2120.7	2743.9	1.8207	6.8565	4.50
5.00	151.9	1.0926	0.3749	639.68	2561.2	640.23	2108.5	2748.7	1.8607	6.8212	5.00
6.00	158.9	1.1006	0.3157	669.90	2567.4	670.56	2086.3	2756.8	1.9312	6.7600	6.00
7.00	165.0	1.1080	0.2729	696.44	2572.5	697.22	2066.3	2763.5	1.9922	6.7080	7.00

directions for home study

- Ch. 1, Ch. 2 (except §2.4.2) & Ch. 3 till §3.3.1 have been treated; **read thoroughly**!
- Do problem 3.1; do problems 3.2-3.21
- Next lecture: remainder of Ch. 3.