

PROPRIEDADES TERMODINÂMICAS E DIAGRAMAS DE EQUILÍBRIO

Paulo Seleglim Jr.
Universidade de São Paulo



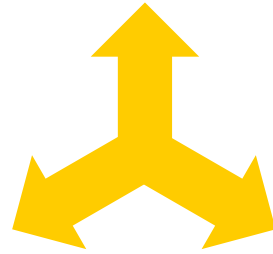


entropia ↓

substâncias



transformações



trocas energéticas



Como explicitar a vinculação entre diferentes propriedades termodinâmicas para uma "substância material" genérica ?

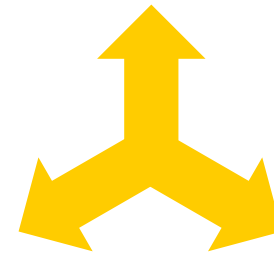


entropia ↓

substâncias



transformações



trocas energéticas

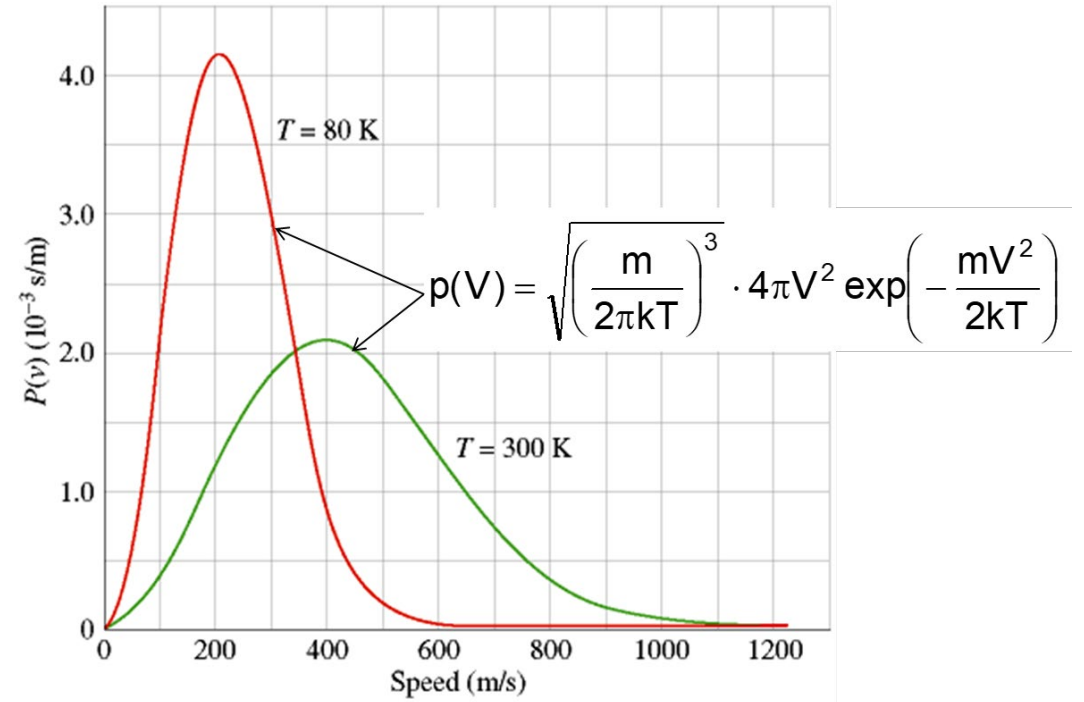
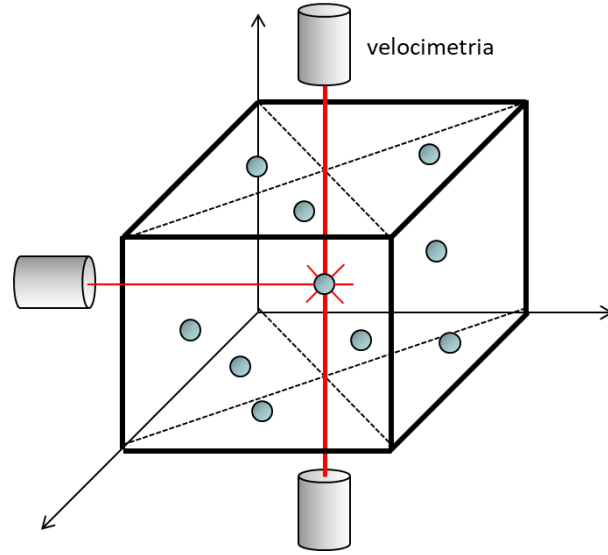
O que são “substâncias materiais” ?





Boltzmann: 1886

$$S = k \cdot \log W$$

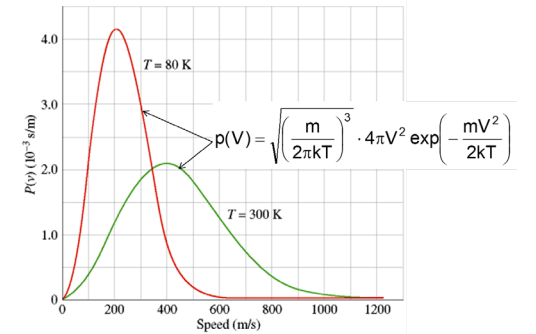


$$\text{PROP. MACROSCÓPICA} = \int_0^{\infty} f(\cdot) p(v) dv$$

temperatura
pressão
densidade
etc.



propriedades da distribuição de velocidades



temperatura, pressão, densidade, etc.

equações de estado

APLICAÇÕES PRÁTICAS



Demonstração do uso de "tabelas eletrônicas"...



refprop mini

Todas Shopping Vídeos Imagens Notícias Mais Configurações Ferramentas

Aproximadamente 22.200 resultados (0,46 segundos)

<https://trc.nist.gov> > MINIREF > Traduzir esta página

mini-REFPROP - NIST

5 de fev. de 2020 — The mini-REFPROP program is a free sample version of the full REFPROP program (located at www.nist.gov/srd/refprop) and is meant for use ...
Você já visitou esta página várias vezes. Última visita: 01/11/20

<https://refprop-mini.software.informer.com> > Traduzir esta página

REFPROP Mini Download - The mini-REFPROP program is a ...

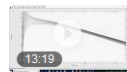
14 de fev. de 2021 — REFPROP Mini (REFPROPEXE). The mini-REFPROP program is a sample version of the full REFPROP program and is meant for use as a ...

<https://refprop-mini.software.informer.com> > ... > Traduzir esta página

REFPROP Mini 9.1 Download (Free) - REFPROP.EXE

14 de fev. de 2021 — REFPROP Mini 9.1 ... The mini-REFPROP program is a sample version of the full REFPROP program and is meant for use as a teaching tool in the ...
★★★★★ Avaliação: 3,9 - 28 votos - Gratuito - Windows

Vídeos



MINI-REFPROP - Como baixar, instalar e usar...

YouTube · Professor Cleiton
17 de mai. de 2020



me4293 download and setup mini refprop for students

YouTube · Randall Manteufel
23 de set. de 2020

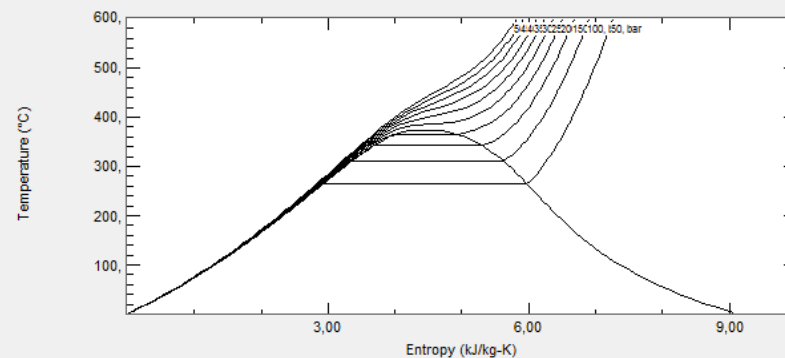
REFPROP (water) - NIST Reference Fluid Properties

File Edit Options Substance Calculate Plot Window Help Cautions

2: water: V/L sat. T=0,02 to 370, °C

	Temperature (°C)	Pressure (bar)	Liquid Density (kg/m ³)	Vapor Density (kg/m ³)	Liquid Enthalpy (kJ/kg)	Vapor Enthalpy (kJ/kg)	Liquid Entropy (kJ/kg-K)	Vapor Entropy (kJ/kg-K)
1	0,020000	0,0061210	999,79	0,0048579	0,042811	2500,9	0,00015448	9,1552
2	5,0200	0,0087379	999,92	0,0068112	21,104	2510,1	0,076556	9,0243
3	10,020	0,012298	999,65	0,0094190	42,105	2519,2	0,15138	8,8993
4	15,020	0,017080	999,05	0,012857	63,065	2528,4	0,22475	8,7798
5	20,020	0,023422	998,16	0,017334	83,998	2537,5	0,29677	8,6655
6	25,020	0,031737	997,00	0,023101	104,91	2546,5	0,36751	8,5562
7	30,020	0,042518	995,60	0,030448	125,82	2555,6	0,43703	8,4516
8	35,020	0,056352	993,98	0,039716	146,72	2564,6	0,50540	8,3513
9	40,020	0,073928	992,17	0,051294	167,62	2573,5	0,57267	8,2552
10	45,020	0,096049	990,16	0,065628	188,52	2582,5	0,63888	8,1630

1: Temperature vs. Entropy plot: water



water - H2O (CAS# 7732-18-5)

Molar mass	Triple pt. temp.	Normal boiling pt.	Gas phase dipole at NBP
18,015 kg/kmol	0,01 °C	99,974 °C	1,855 debye

Critical Point	Temperature	Pressure	Density	Acentric factor
	373,95 °C	220,64 bar	322, kg/m ³	0,3443

Range of applicability	Minimum temp.	Maximum temp.	Maximum pressure	Maximum density
	0,01 °C	1726,9 °C	10000, bar	1332,4 kg/m ³

NIST Rec: FEQ Helmholtz equation of state for water of Wagner and Pruss [2002].
LITERATURE REFERENCE
Wagner, W. and Pruss, A.,
"The IAPWS Formulation 1995 for the Thermodynamic Properties of Ordinary Water Substance for General and Scientific Use,"
J. Phys. Chem. Ref. Data, 31(2):387-535, 2002.

The uncertainty in density of the equation of state is 0.0001% at 1 atm in the liquid phase, and 0.001% at other liquid states at pressures up to 10 MPa and temperatures to 423 K. In the vapor phase, the uncertainty

Equation of State	Viscosity	Thermal Conductivity		
Surface tension	Melting Line	Sublimation Line		
OK	Cancel	Print	Copy	Copy All

Demonstração do uso de "tabelas eletrônicas"...



thermodynamic properties calculator

Todas Imagens Notícias Vídeos Shopping Mais Configurações Ferramentas

Aproximadamente 640.000 resultados (0,54 segundos)

<https://irc.wisc.edu> > properties > Traduzir esta página

The Industrial Refrigeration Consortium is a collaborative ...

This complimentary **calculator** is provided for all to use but it receives minimal ... If you require a reliable source of **thermodynamic properties**, we recommend ...

<https://www.steamtablesonline.com> > ... > Traduzir esta página

Steam Tables Calculator - Steam Tables Online

Calculate online **thermodynamic** and transport **properties** of water and steam, based on industrial (IAPWS-IF97) or scientific (IAPWS-95) formulation. Mollier ...

<https://www.peacesoftware.de> > was... > Traduzir esta página

Online calculation of properties of water and steam

The following **thermodynamic properties** are calculated: density water, dynamic viscosity water, kinematic viscosity water, specific inner energy water, specific ...

<https://diren.mines-paristech.fr> > a... > Traduzir esta página

Applet: Calculator of thermodynamic properties - Online ...

Applet: **Calculator of thermodynamic properties** - 1) select the type of fluid you wish to **calculate** (ideal gas or vapor) - 2) select the fluid name.

<https://app.knovel.com> > ... > Traduzir esta página

Knovel Steam Calculators Home Page

Knovel's steam **calculators** provide a full implementation of the 2012 cumulative update to IAPWS Industrial Formulation 1997 for the **Thermodynamic Properties** ...

Steam Tables Online

STEAM TABLES ONLINE

- ✓ INCLUDES FREE STEAM TABLES CALCULATOR - BASIC PACKAGE **FREE**
- ✓ FORMULATIONS: INDUSTRIAL (IAPWS-IF97), SCIENTIFIC (IAPWS 95)
- ✓ MOLLIER DIAGRAMS, STEAM TURBINE, FLASH EVAPORATOR
- ✓ PROPERTIES OF COMBUSTION GASES
- ✓ SUPPORT FOR MOBILE PLATFORMS
- ✓ SAVE DATA TO EXCEL, CSV OR OPEN OFFICE FILE FORMAT

RUN CALCULATOR

RUN SPREADSHEET

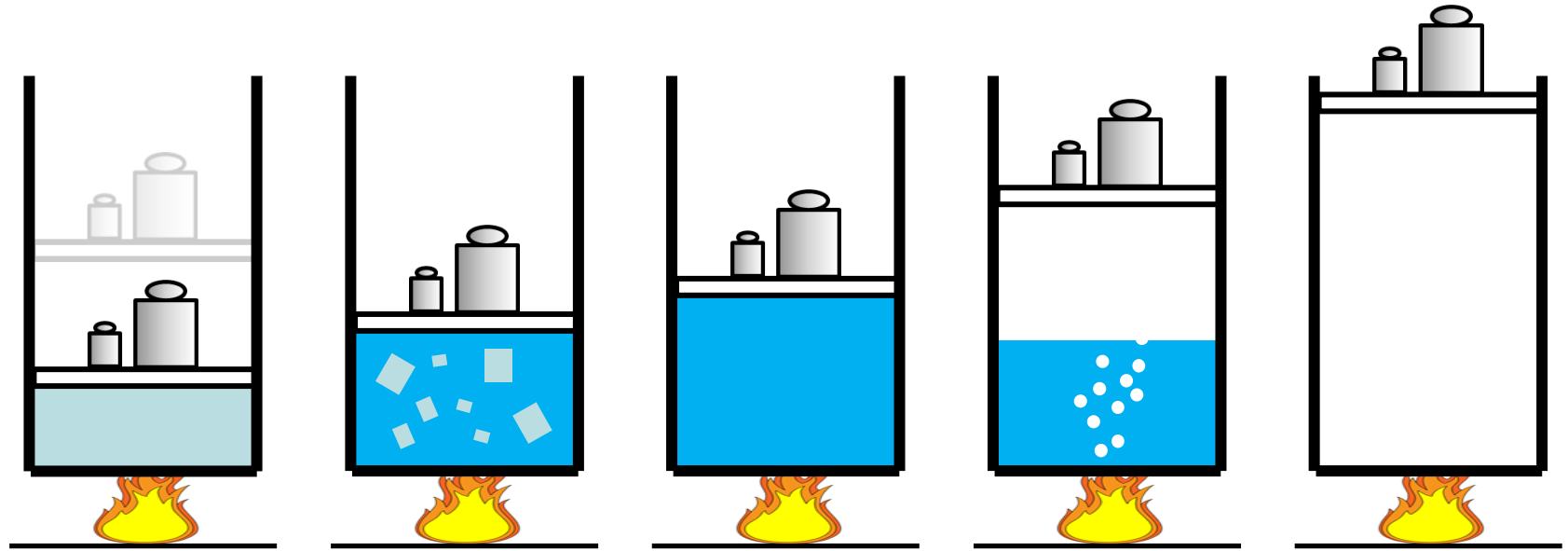
H2O

- Home
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Como os diagramas de estado são
construídos ?



Fases de uma substância pura: aquecimento a $P = \text{cte}$



- ✓ Fase sólida: seu volume tem forma própria
- ✓ Fase líquida: ocupa parcialmente o volume do recipiente
- ✓ Fase gasosa: ocupa totalmente o volume do recipiente

Construção empírica do diagrama de equilíbrio

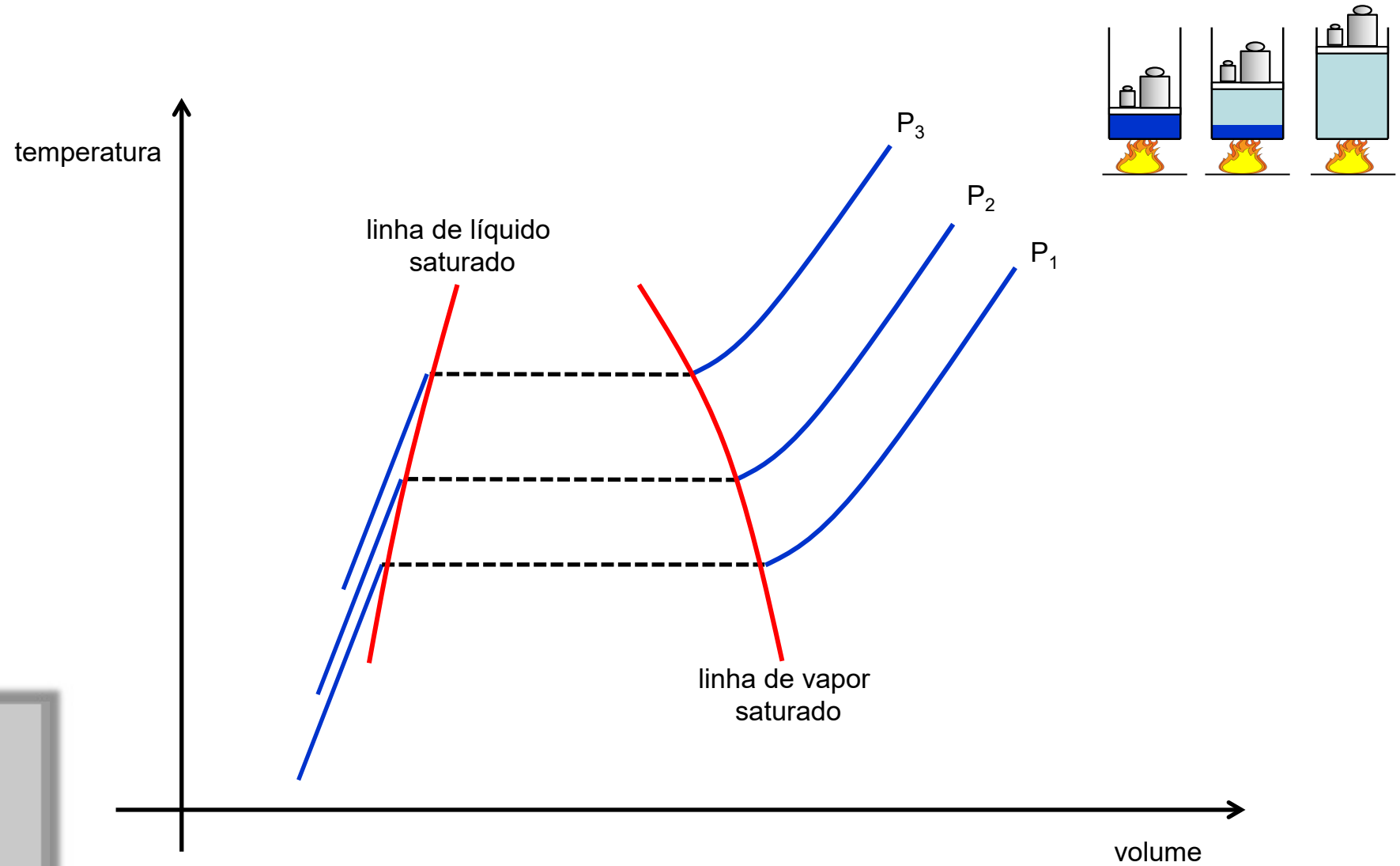


Diagrama de equilíbrio da água (Refprop)

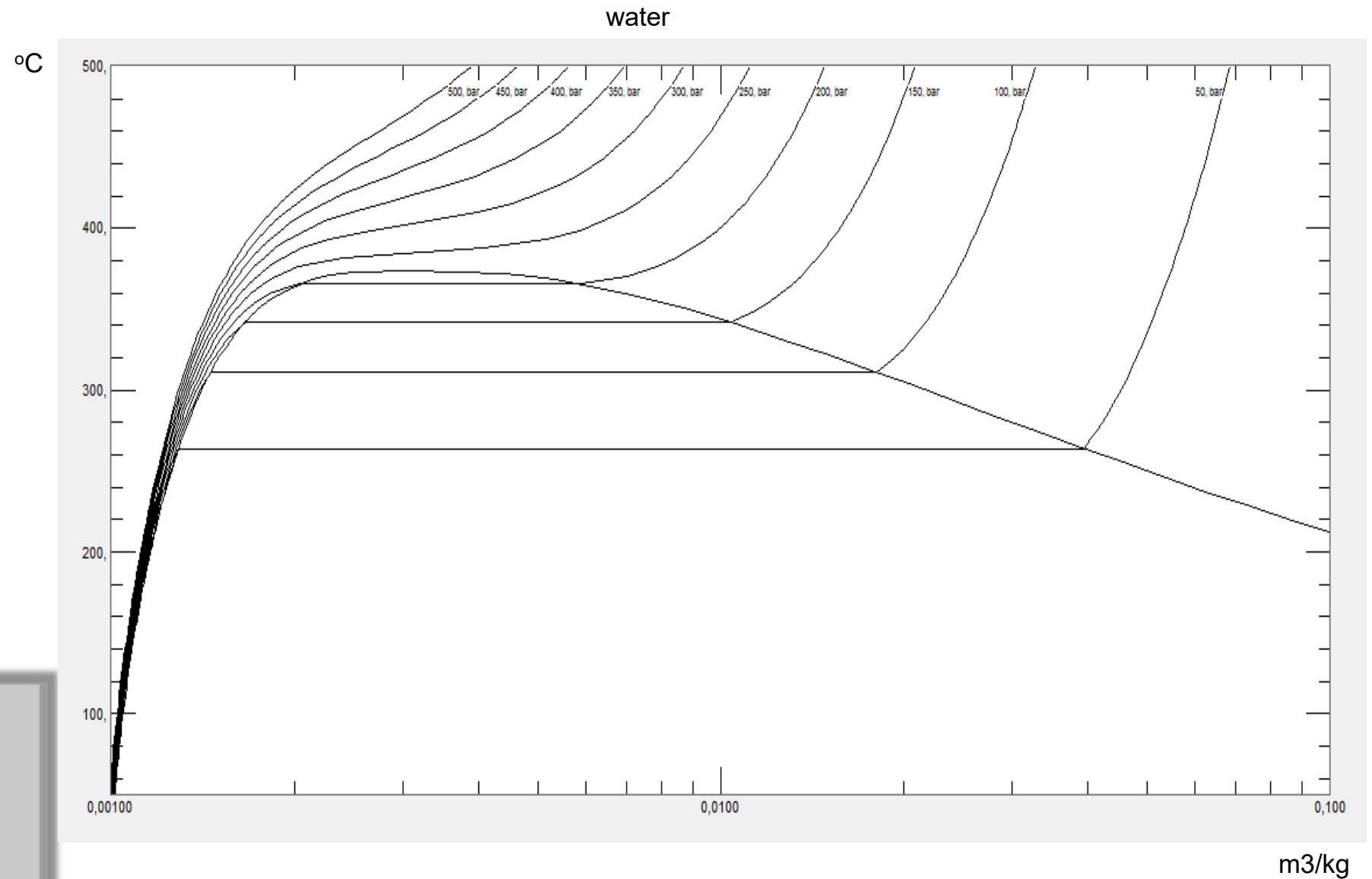
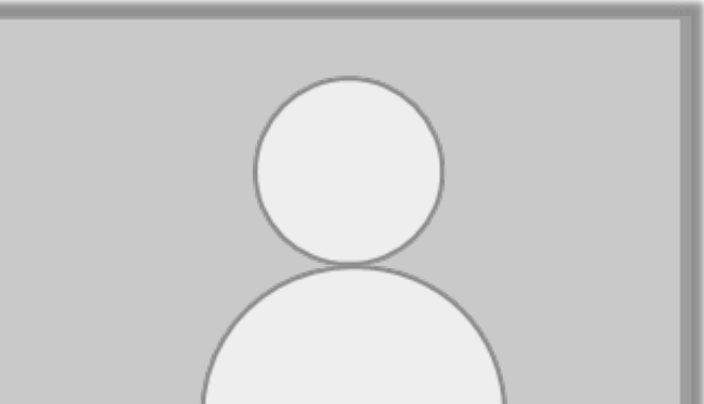
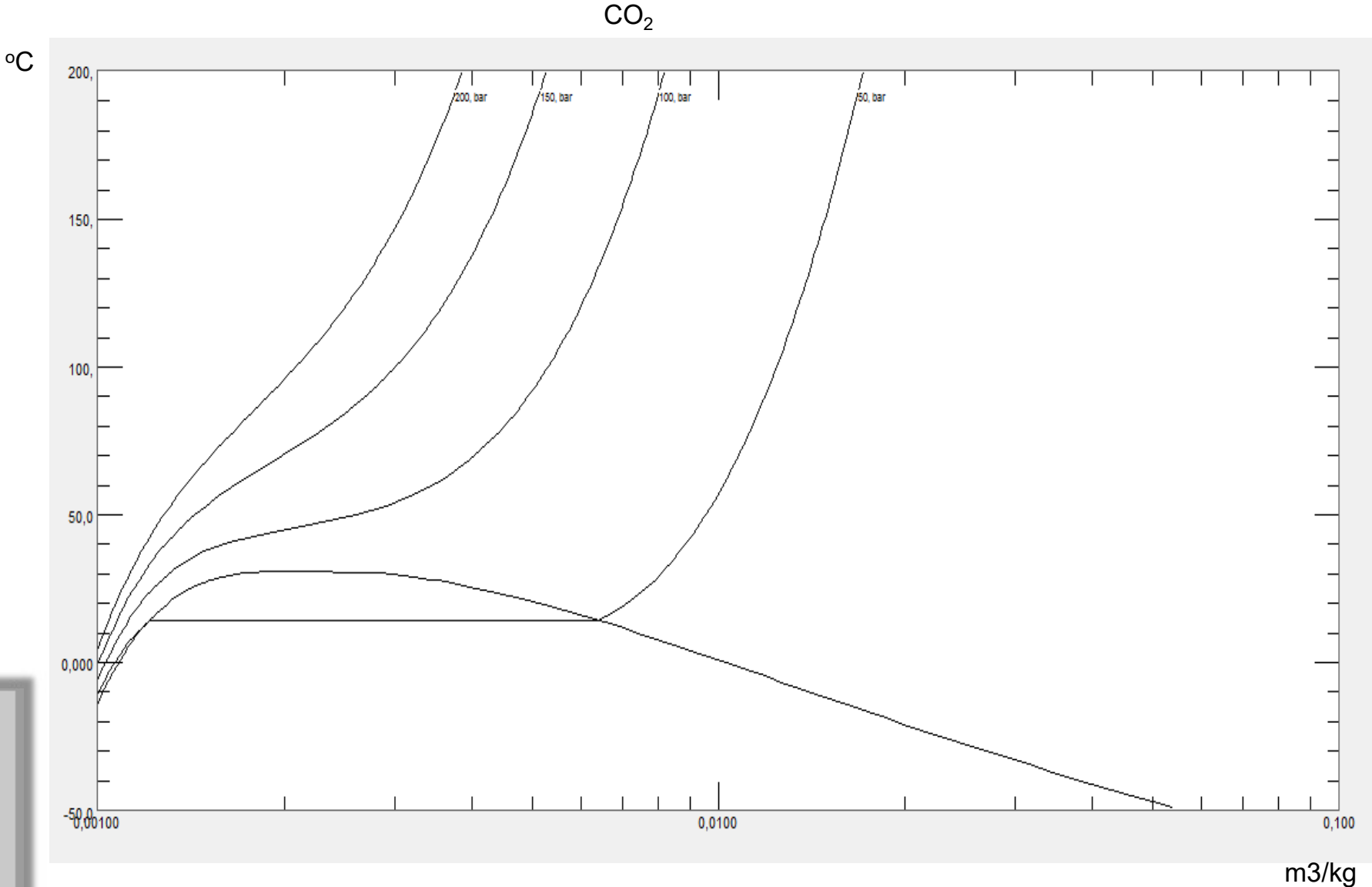
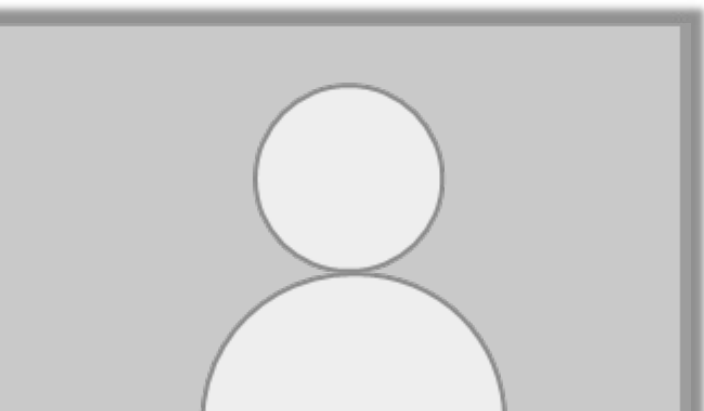
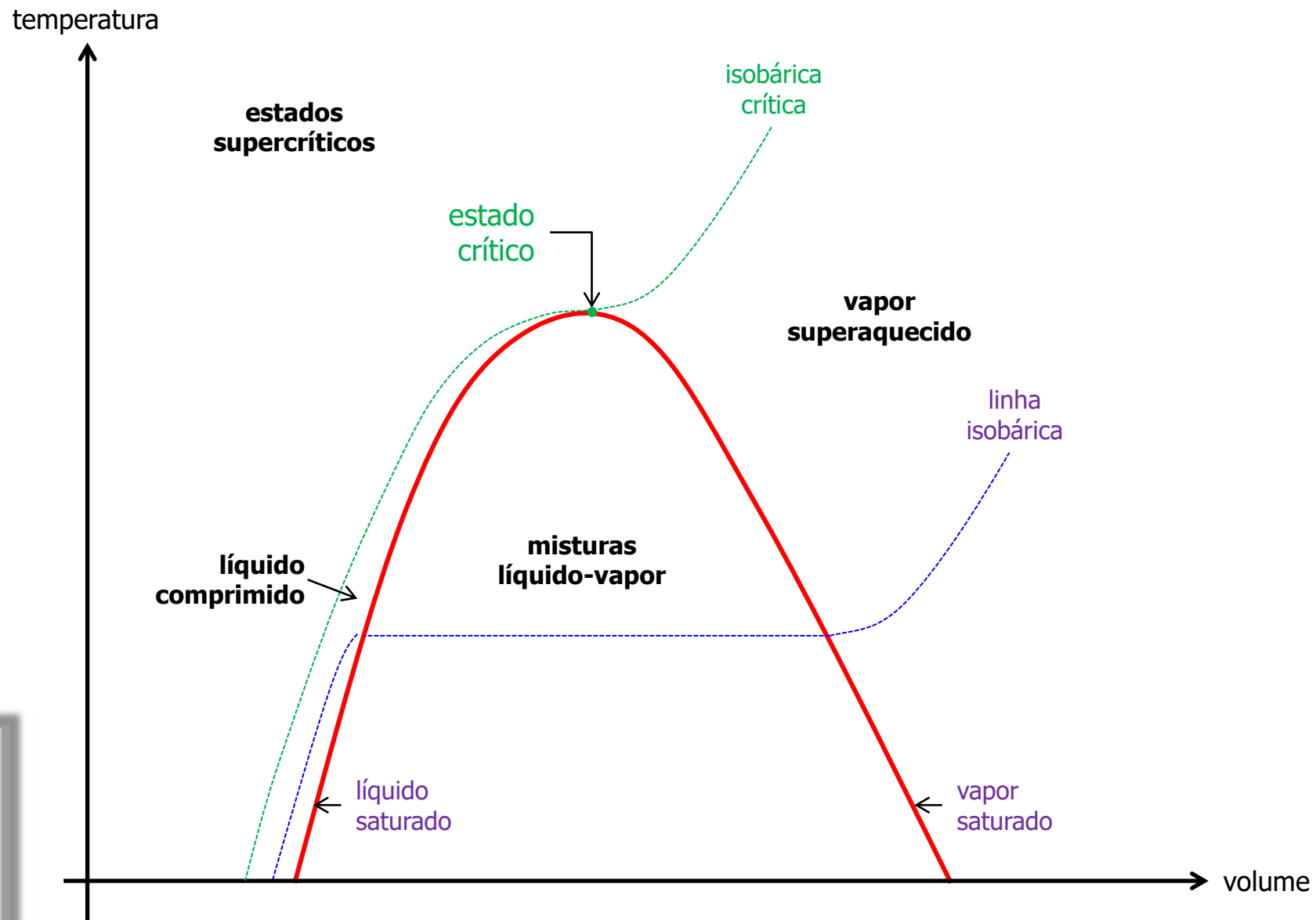
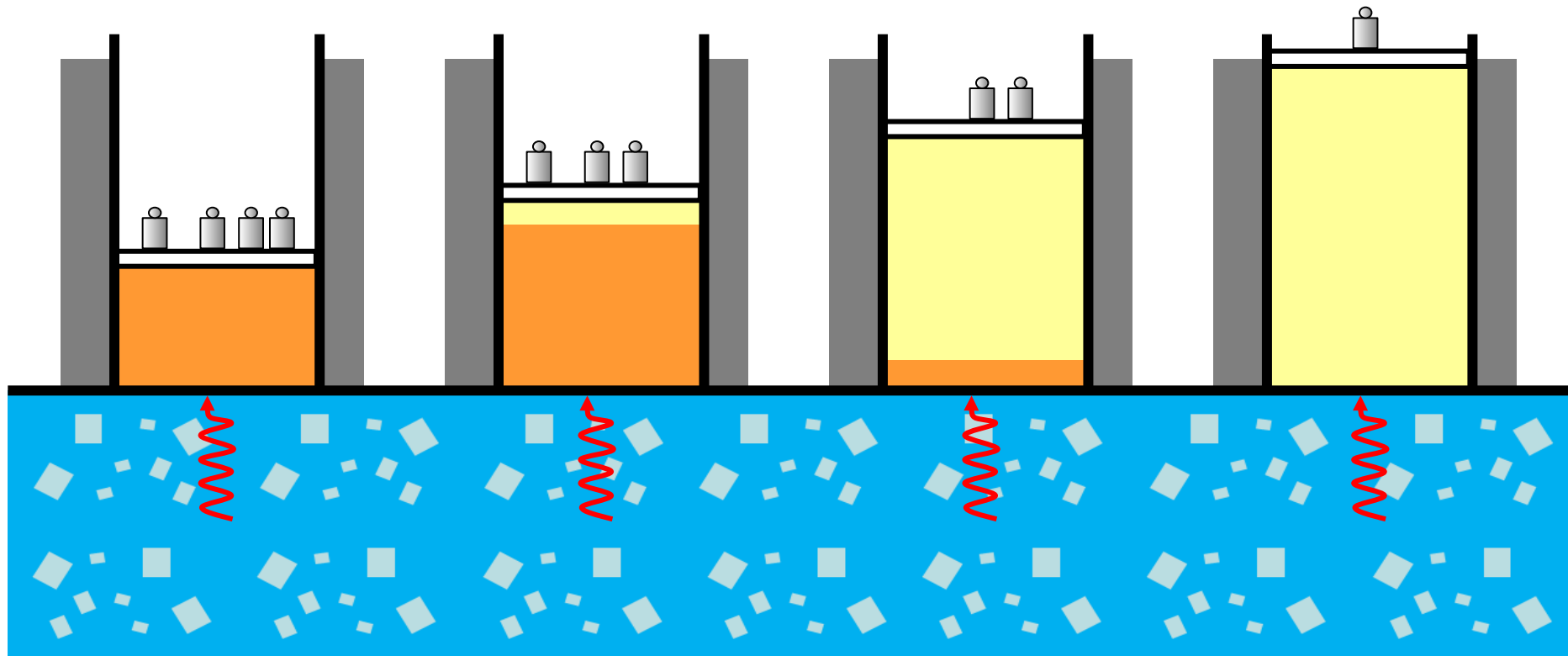


Diagrama de equilíbrio do CO₂ (Refprop)

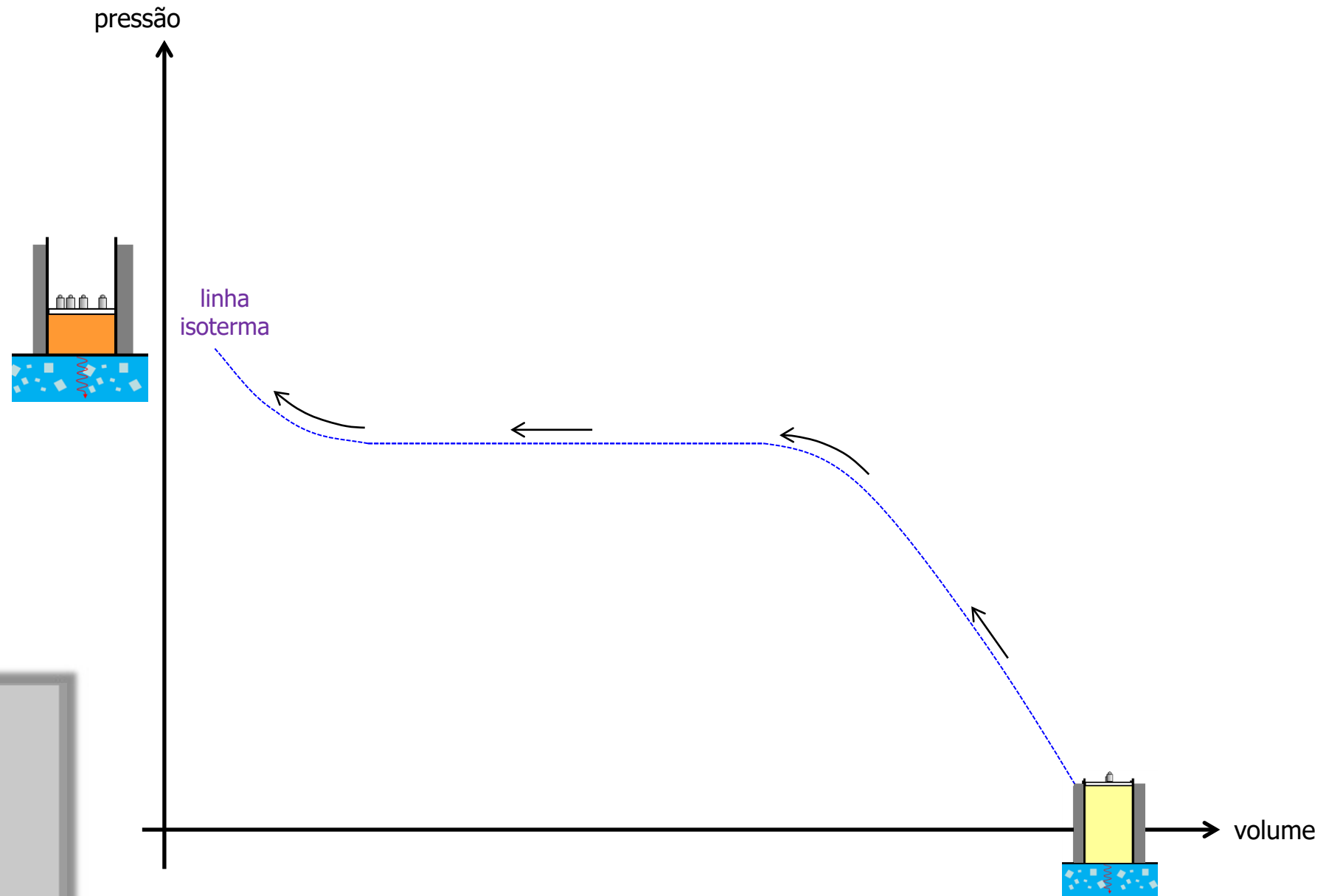


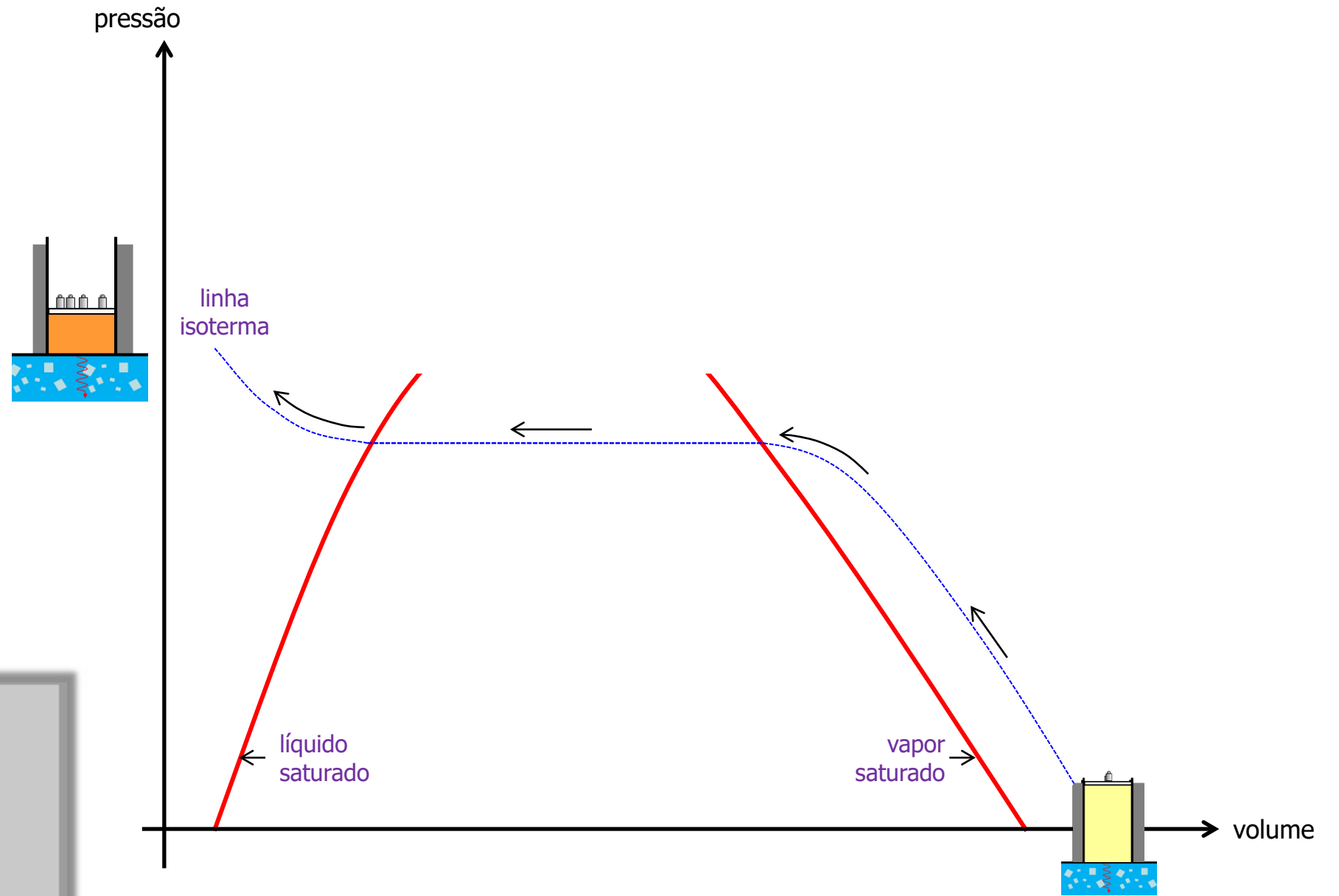


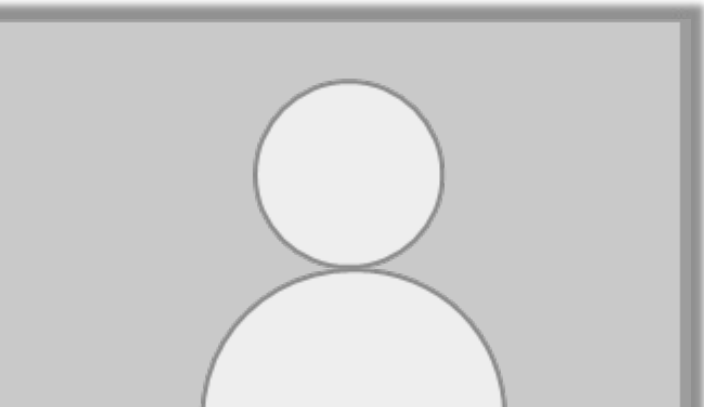
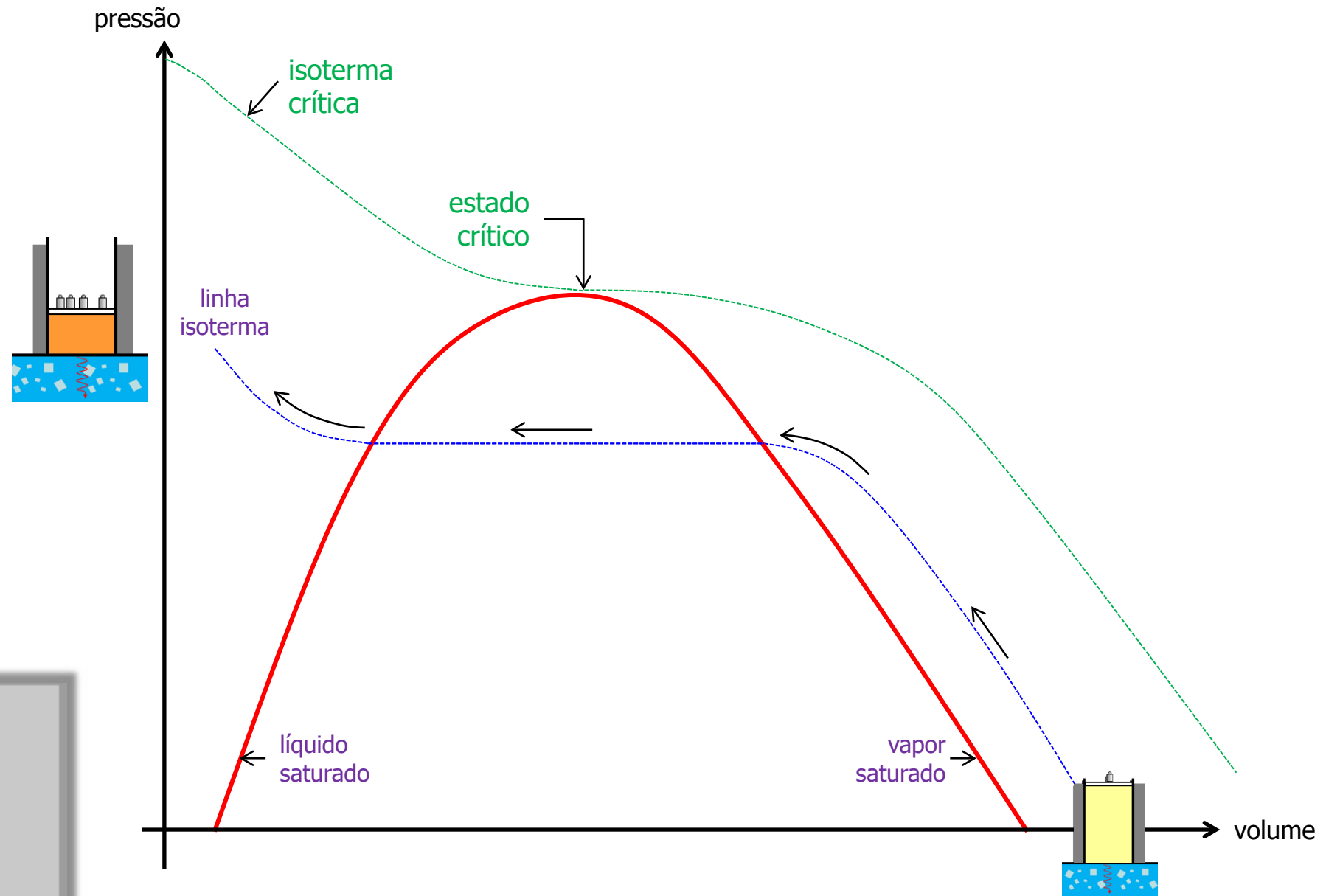
Fases de uma substância pura, pressurização a $T = cte$

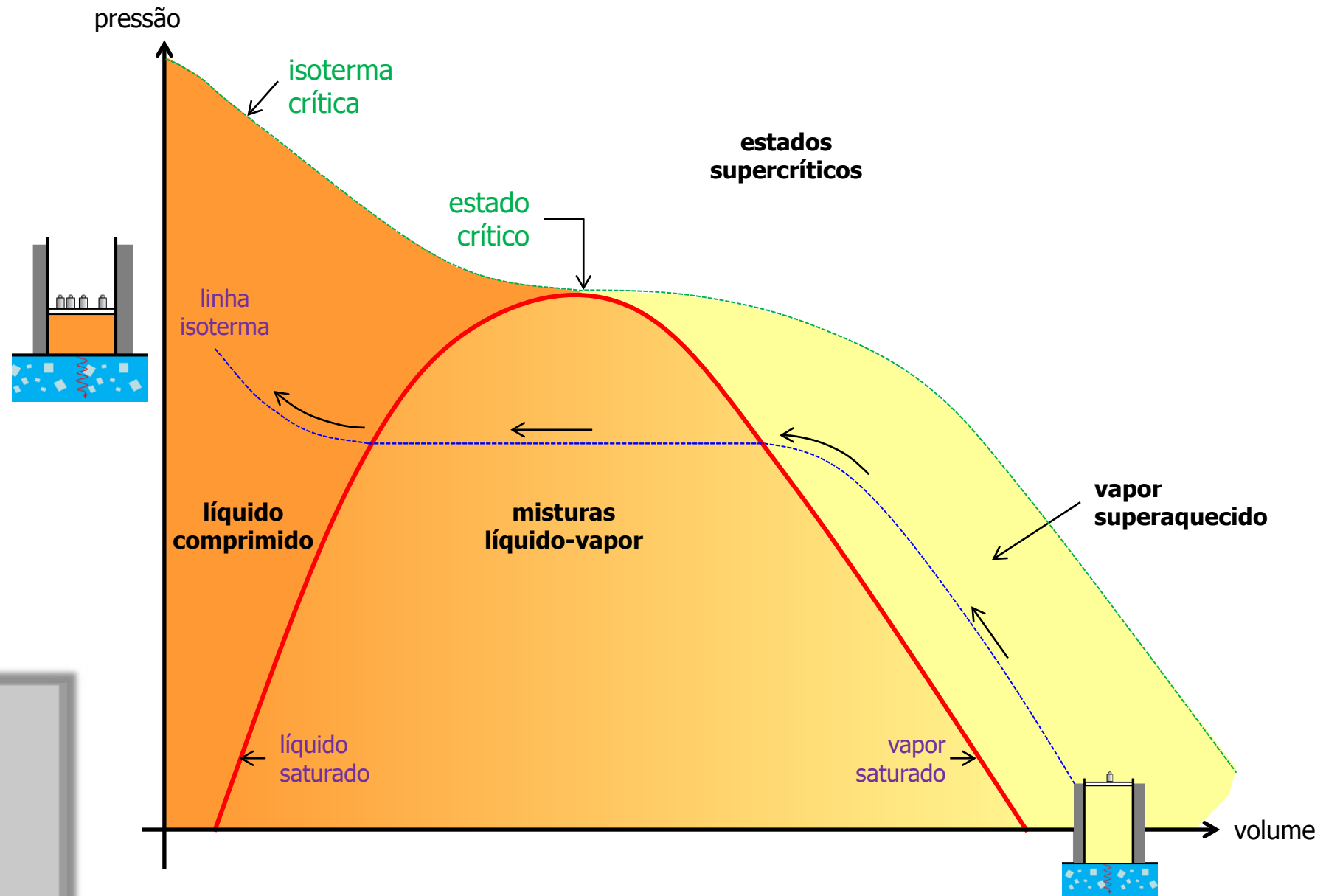


Meio com capacidade infinita de absorver de calor, i.e absorve calor sem alterar sua temperatura.









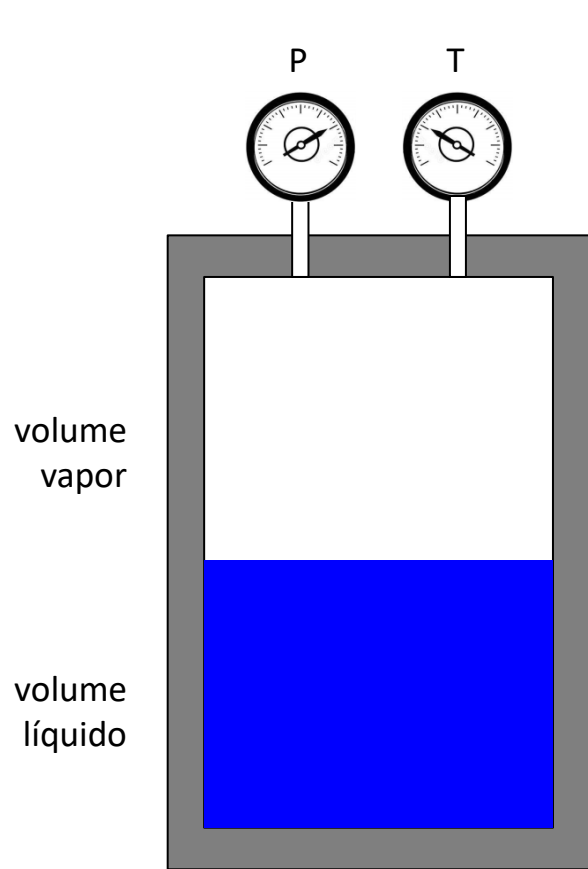
Exemplo de aplicação prática ?



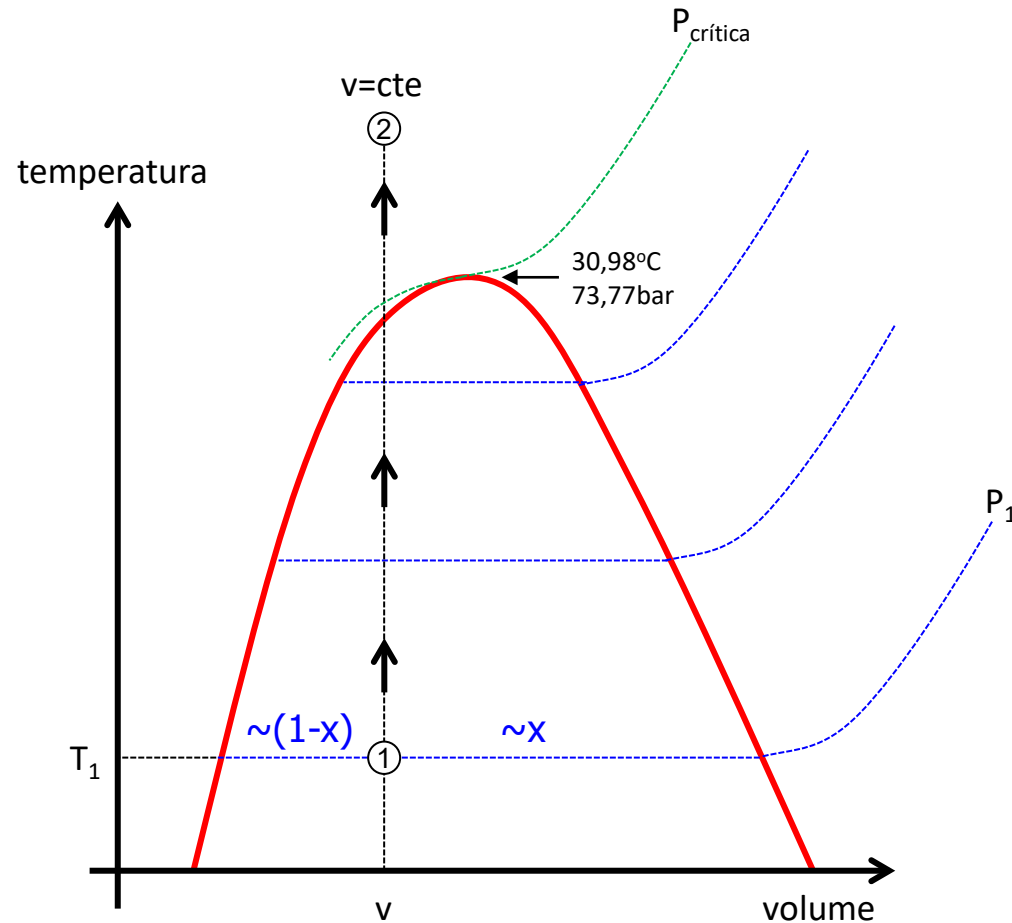
Sistema de extração com CO₂ supercrítico



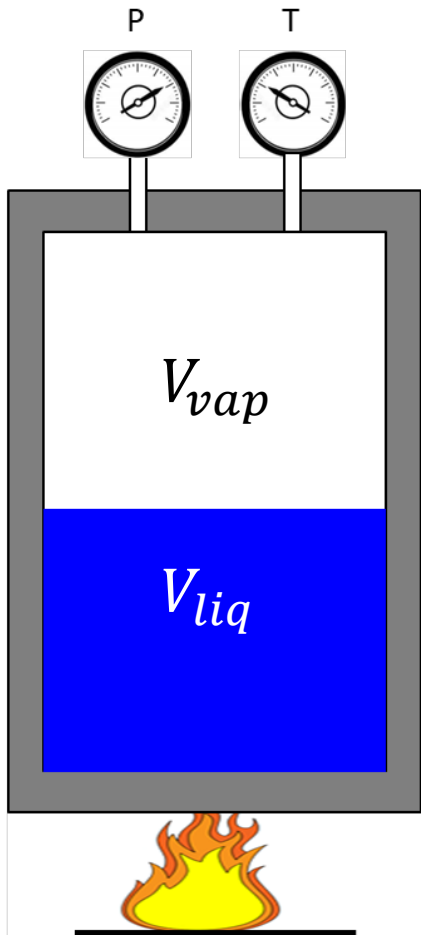
Produção de scCO₂: aquecimento isocórico (v=cte)



$$x \stackrel{\text{def}}{=} \frac{m_{\text{vap}}}{m_{\text{liq}} + m_{\text{vap}}}$$



$$\left\{ \begin{array}{l} v = x \cdot v_{\text{vap}} + (1 - x) \cdot v_{\text{liq}} \\ \rho = x \cdot \rho_{\text{vap}} + (1 - x) \cdot \rho_{\text{liq}} \end{array} \right.$$



$$V = V_{liq} + V_{vap} \rightarrow mv = m_{liq}v_{liq} + m_{vap}v_{vap}$$

$$mv = (m - m_{vap})v_{liq} + m_{vap}v_{vap}$$

$$v = \frac{(m - m_{vap})}{m}v_{liq} + \frac{m_{vap}}{m}v_{vap}$$

$$\Rightarrow v = (1 - x)v_{liq} + xv_{vap}$$

$$s = (1 - x)s_{liq} + xs_{vap}$$

$$\rho \neq (1 - x)\rho_{liq} + x\rho_{vap}$$

$$V = V_{liq} + V_{vap}$$

$$mv = m_{liq}v_{liq} + m_{vap}v_{vap}$$

$$mv = (m - m_{vap})v_{liq} + m_{vap}v_{vap}$$

$$v = \frac{(m - m_{vap})}{m}v_{liq} + \frac{m_{vap}}{m}v_{vap}$$

$$v = (1 - x)v_{liq} + xv_{vap}$$

Variação de ρ_{liq} e ρ_{vap} com a pressão e a temperatura...

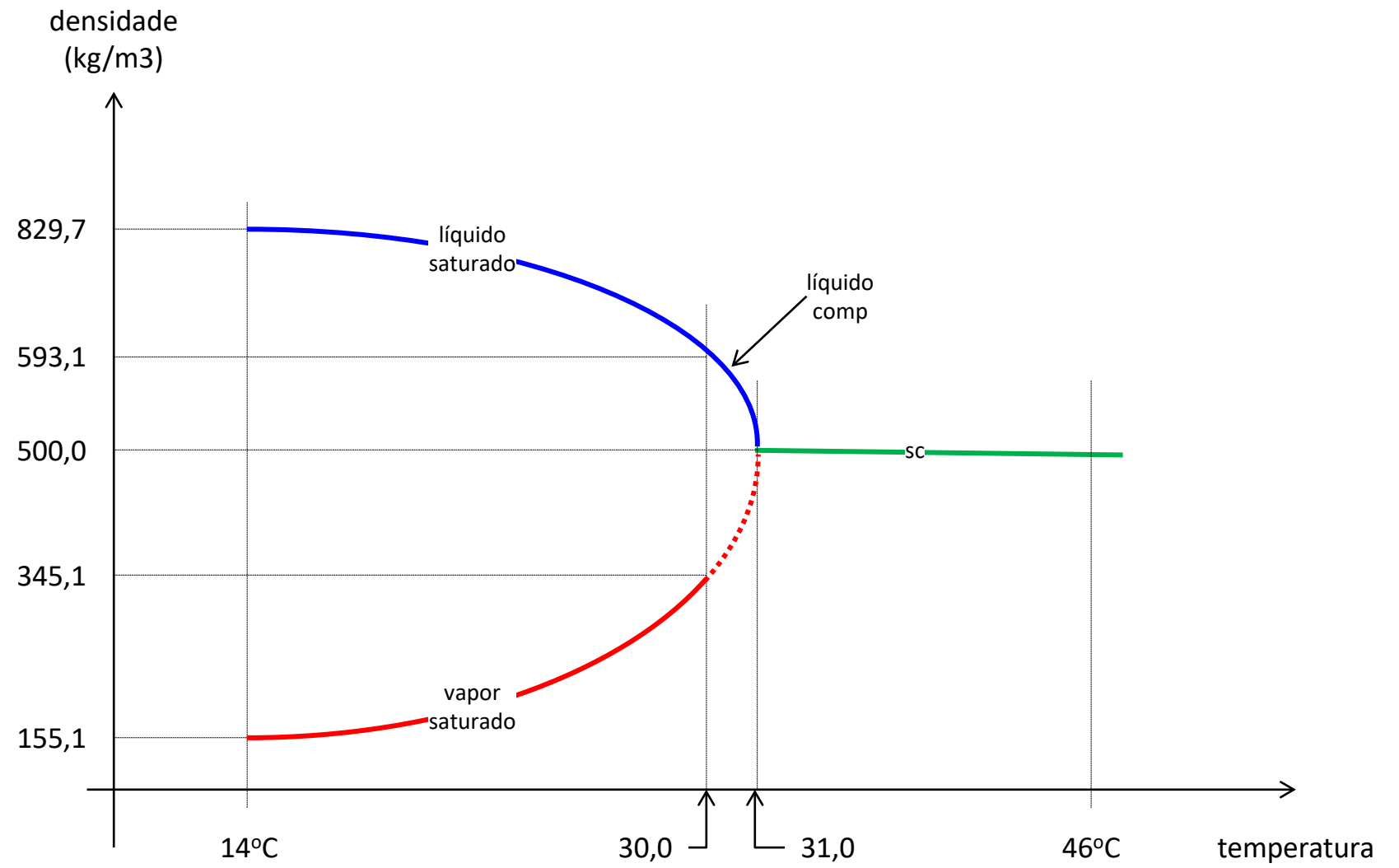
REFPROP (carbon dioxide) - NIST Reference Fluid Properties

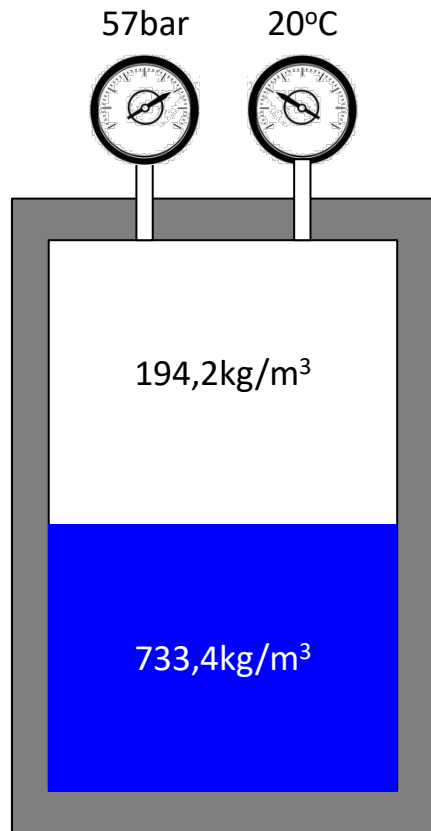
File Edit Options Substance Calculate Plot Window Help Cautions

11: carbon dioxide rho = 500, kg/m³

	Temperature (°C)	Pressure (bar)	Density (kg/m ³)	Liquid Density (kg/m ³)	Vapor Density (kg/m ³)	Volume (m ³ /kg)	Liquid Volume (m ³ /kg)	Vapor Volume (m ³ /kg)
1	14,000	49,658	500,00	829,70	155,11	0,0020000	0,0012053	0,0064472
2	15,000	50,871	500,00	821,21	160,73	0,0020000	0,0012177	0,0062216
3	16,000	52,108	500,00	812,41	166,66	0,0020000	0,0012309	0,0060003
4	17,000	53,368	500,00	803,27	172,93	0,0020000	0,0012449	0,0057828
5	18,000	54,651	500,00	793,76	179,57	0,0020000	0,0012598	0,0055688
6	19,000	55,958	500,00	783,81	186,64	0,0020000	0,0012758	0,0053578
7	20,000	57,291	500,00	773,39	194,20	0,0020000	0,0012930	0,0051493
8	21,000	58,648	500,00	762,40	202,32	0,0020000	0,0013116	0,0049427
9	22,000	60,031	500,00	750,77	211,08	0,0020000	0,0013320	0,0047375
10	23,000	61,440	500,00	738,36	220,62	0,0020000	0,0013543	0,0045326
11	24,000	62,877	500,00	725,02	231,10	0,0020000	0,0013793	0,0043272
12	25,000	64,342	500,00	710,50	242,73	0,0020000	0,0014075	0,0041198
13	26,000	65,837	500,00	694,46	255,86	0,0020000	0,0014400	0,0039083
14	27,000	67,361	500,00	676,36	271,01	0,0020000	0,0014785	0,0036898
15	28,000	68,918	500,00	655,28	289,11	0,0020000	0,0015261	0,0034589
16	29,000	70,509	500,00	629,36	312,03	0,0020000	0,0015889	0,0032048
17	30,000	72,137	500,00	593,31	345,10	0,0020000	0,0016855	0,0028977
18	30,963	73,748	500,00	500,00	437,72	0,0020000	0,0020000	0,0022846
19	31,000	73,812	500,00	500,00	Undefined	0,0020000	0,0020000	Undefined
20	32,000	75,609	500,00	500,00	Undefined	0,0020000	0,0020000	Undefined

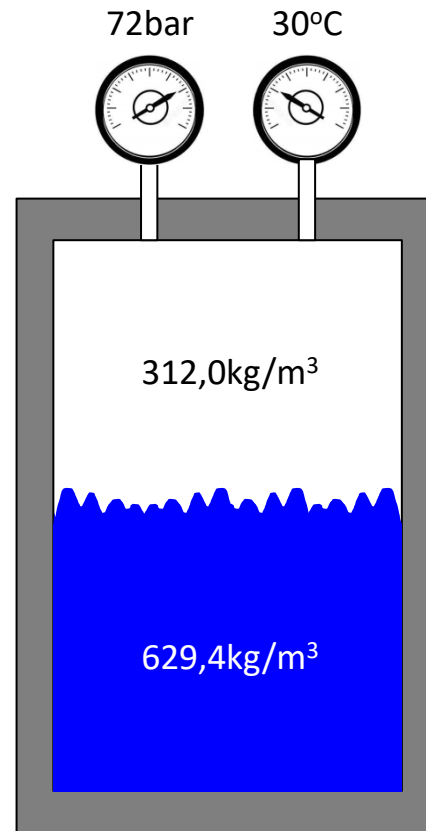
Varição de ρ_{liq} e ρ_{vap} com a pressão e a temperatura...





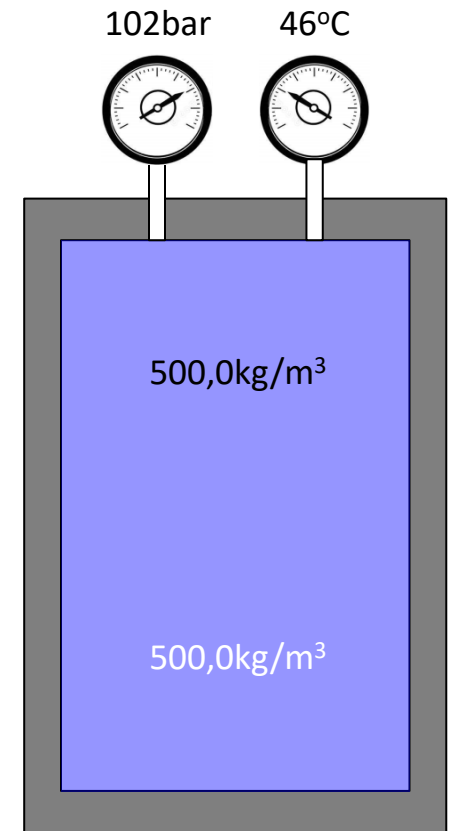
$$x = \frac{500,0 - 733,4}{194,2 - 733,4}$$

$$x = 0,433$$



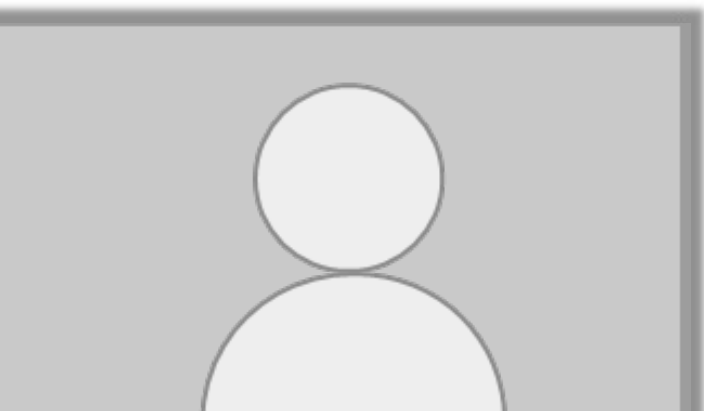
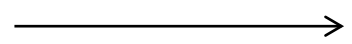
$$x = \frac{500,0 - 629,4}{312,0 - 629,4}$$

$$x = 0,408$$



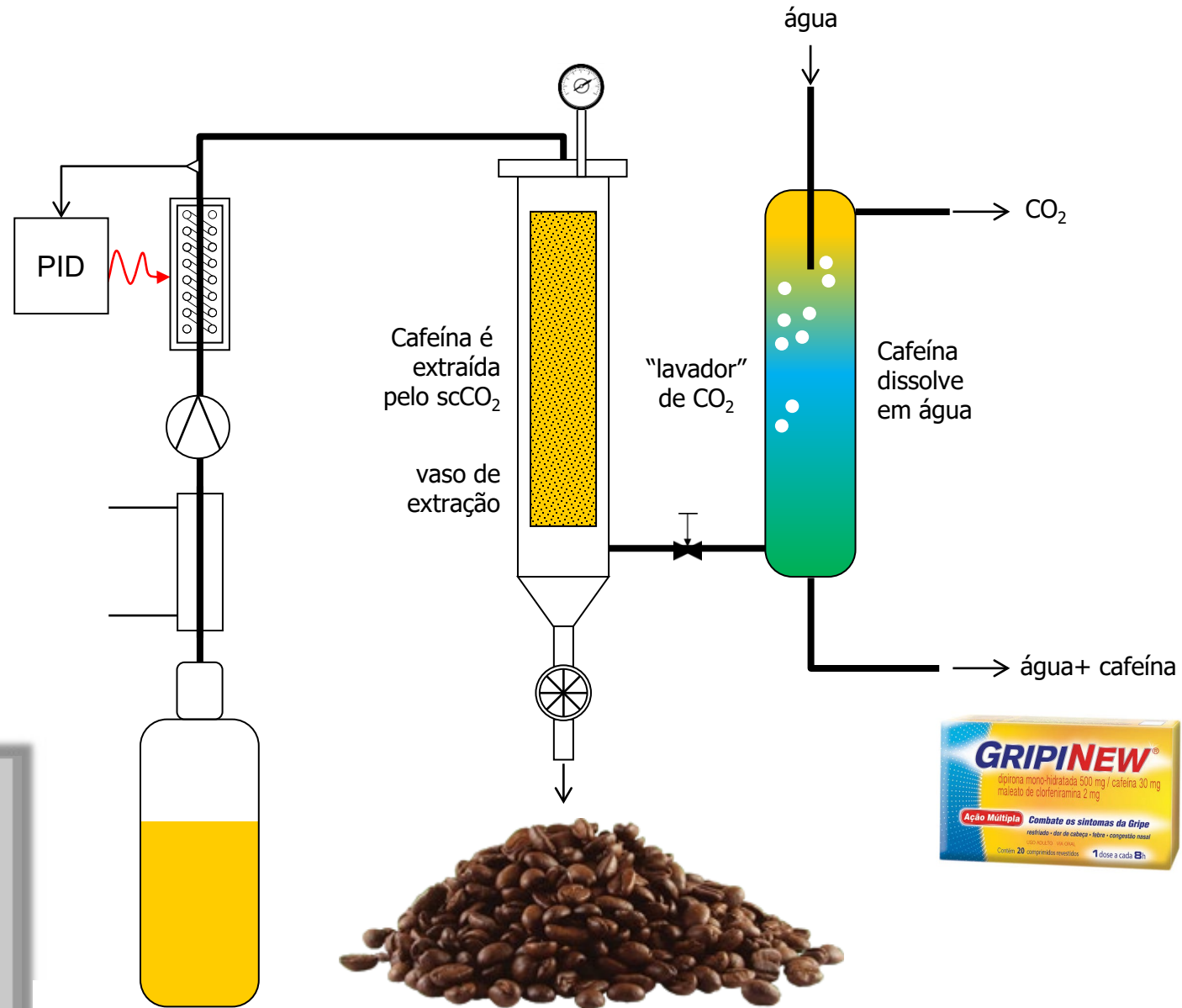
$$x = \frac{500,0 - 500,0}{500,0 - 500,0}$$

$$x \stackrel{H}{=} 0,408$$





Produção industrial de grãos de café descafeinado

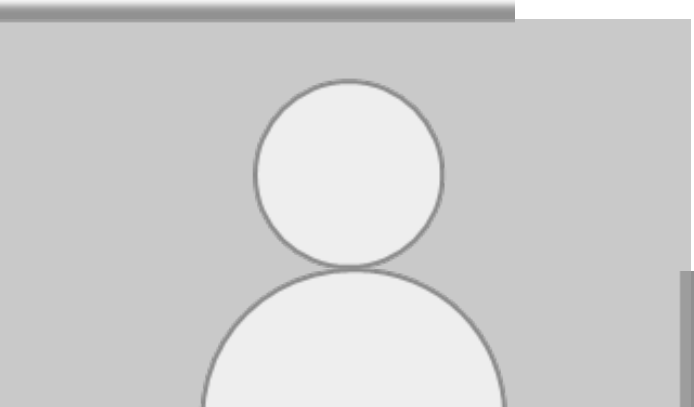
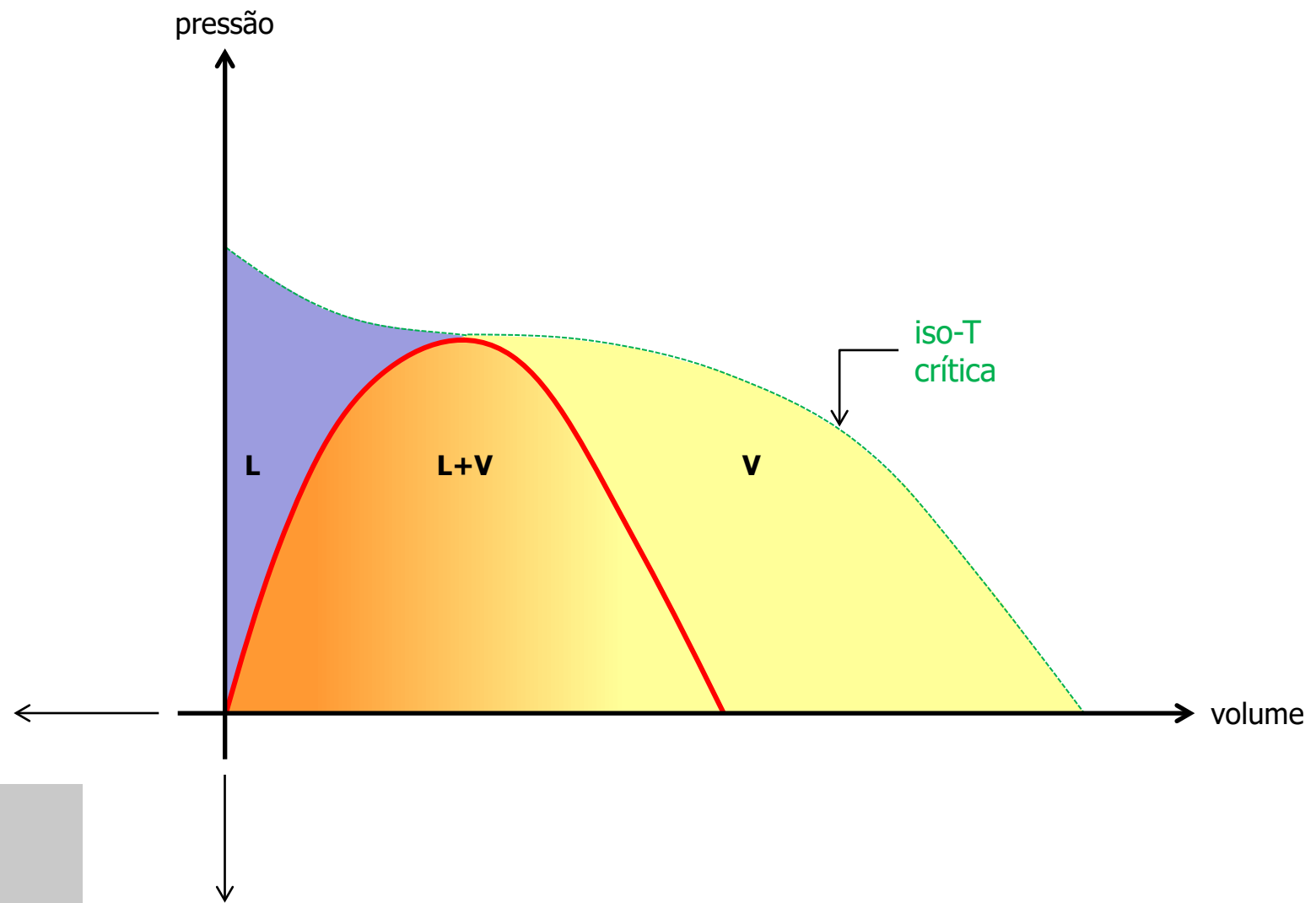


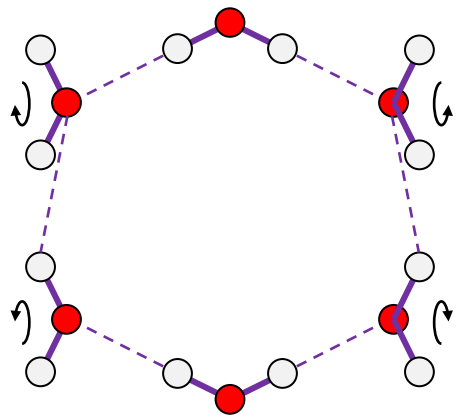
O que são as fases de uma substância?



Diagramas de equilibrio sólido-líquido-vapor



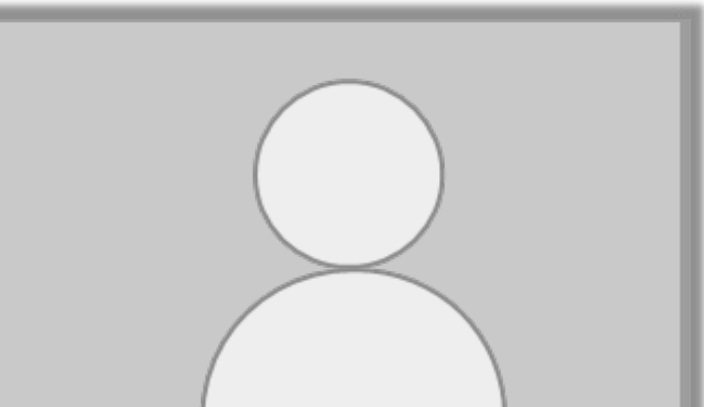
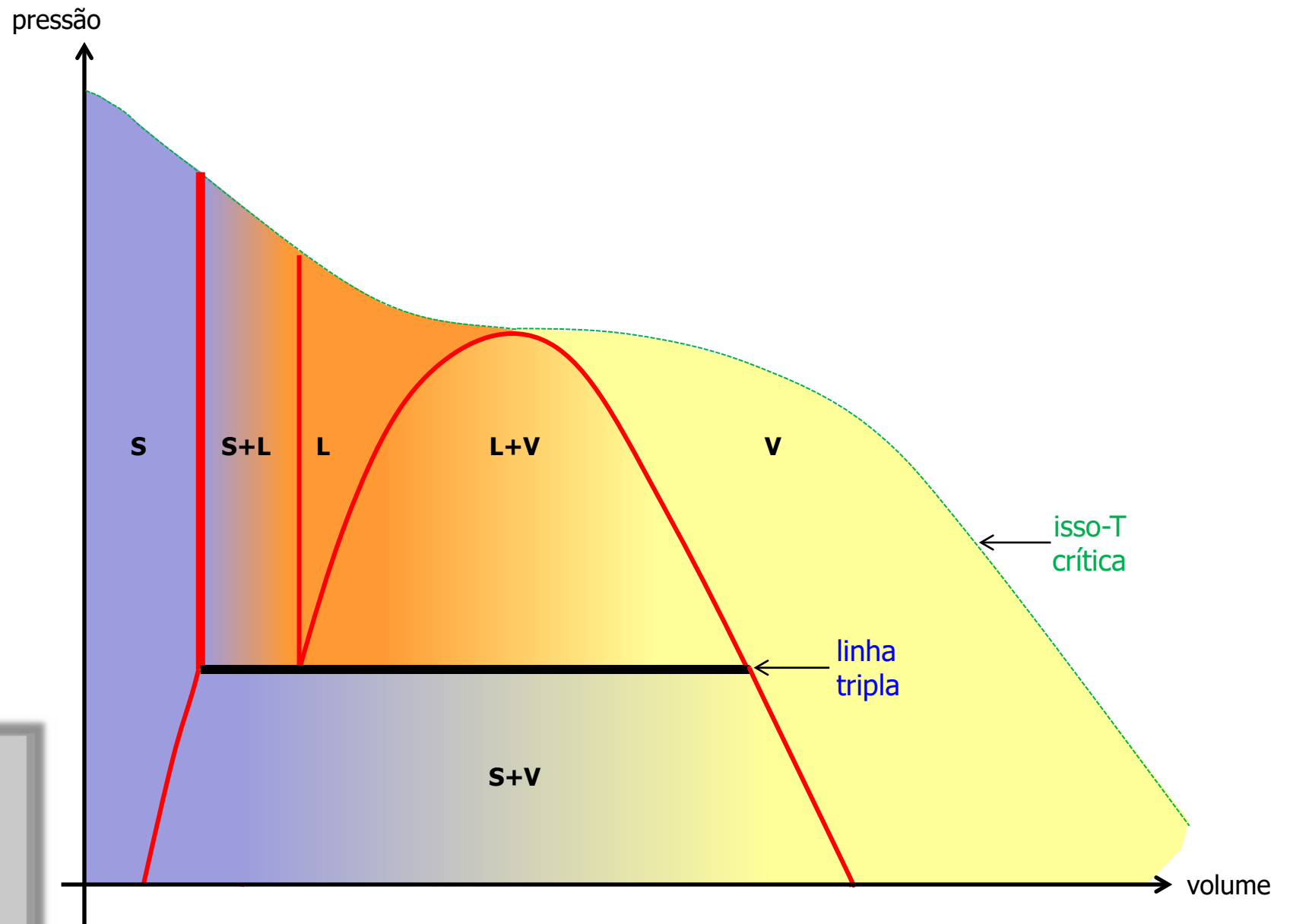


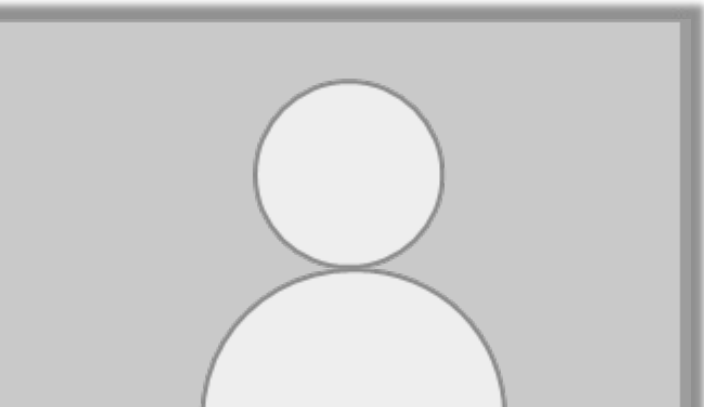
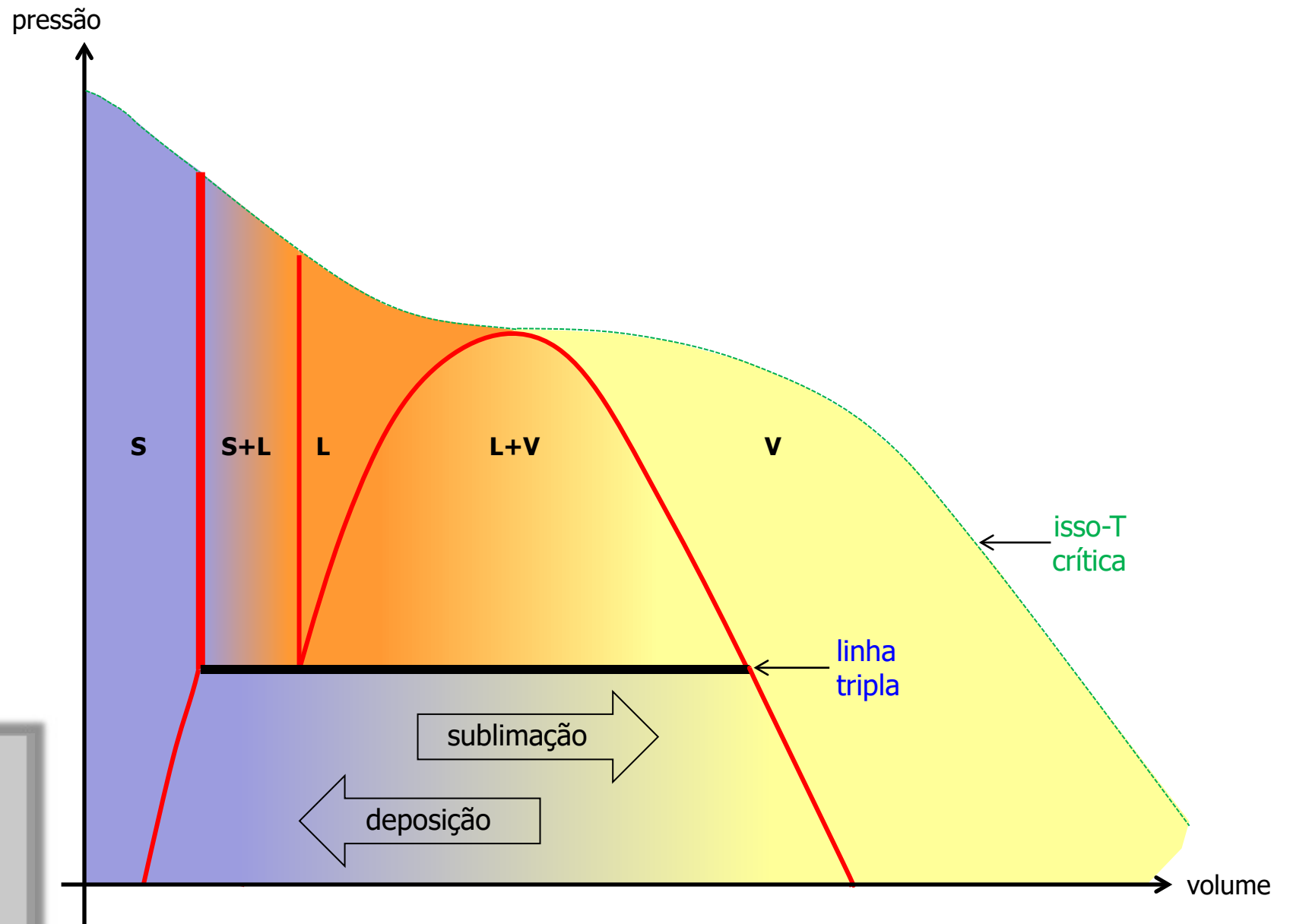


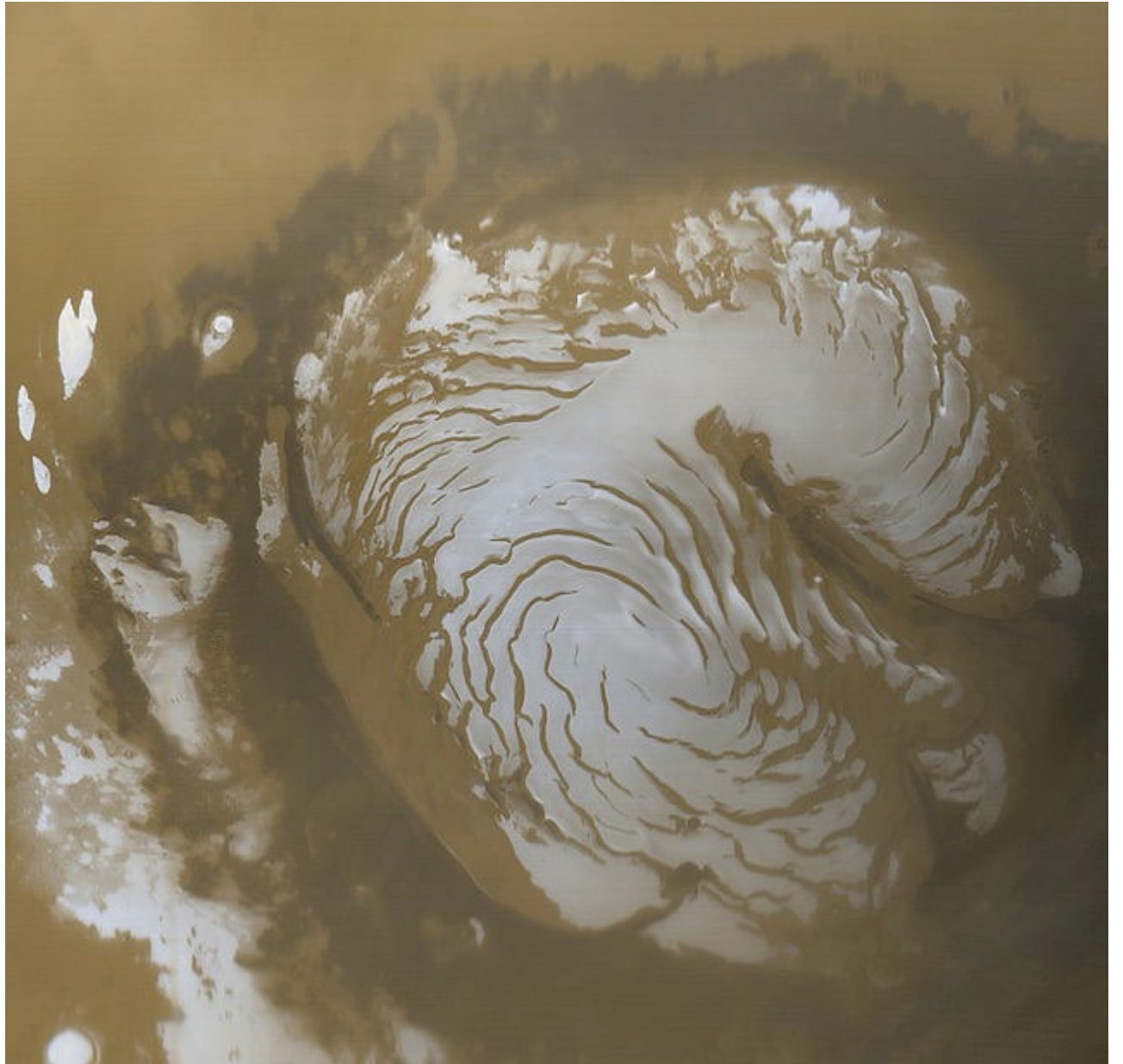
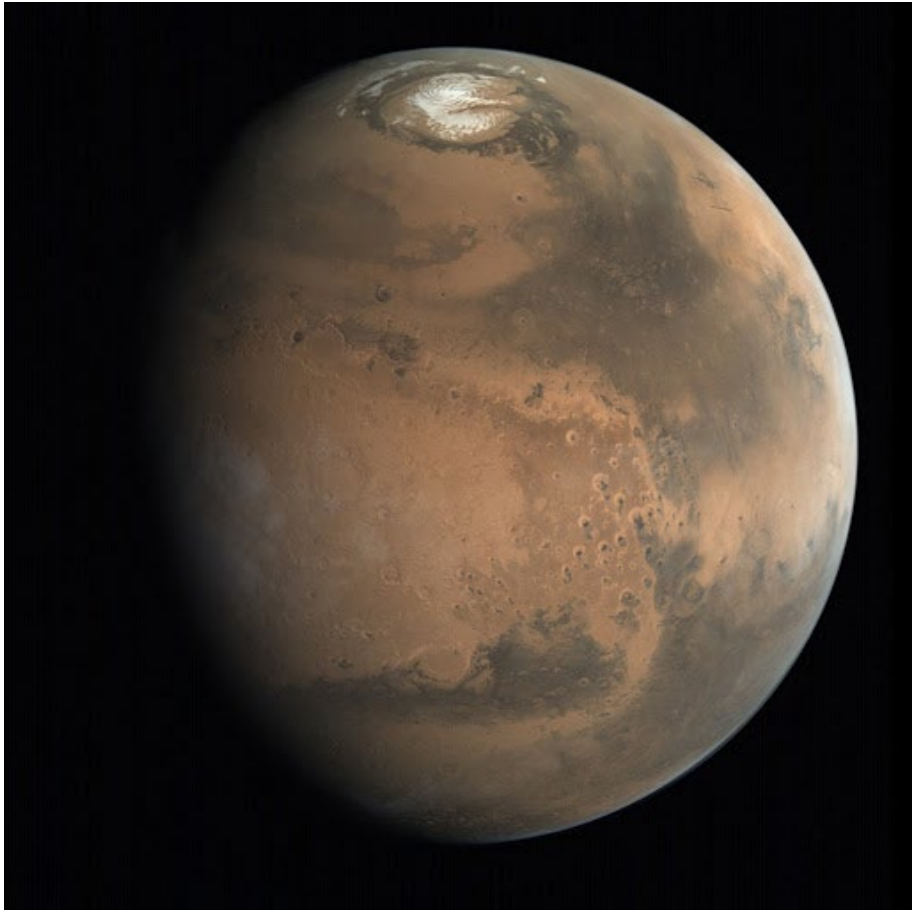
Massimo Delle Piane
Published on Mar 19, 2015

Ab initio molecular dynamics (AIMD) of a $14 \times 14 \times 14 \text{ \AA}$ water box at 300K. Computational code: CP2K. Level of theory: PBE-D2/TZV-P. Hydrogen bonds are in magenta. The shown trajectory corresponds to 10 ps of simulation, smoothed to remove fast vibrational motions. Rendered through VMD.

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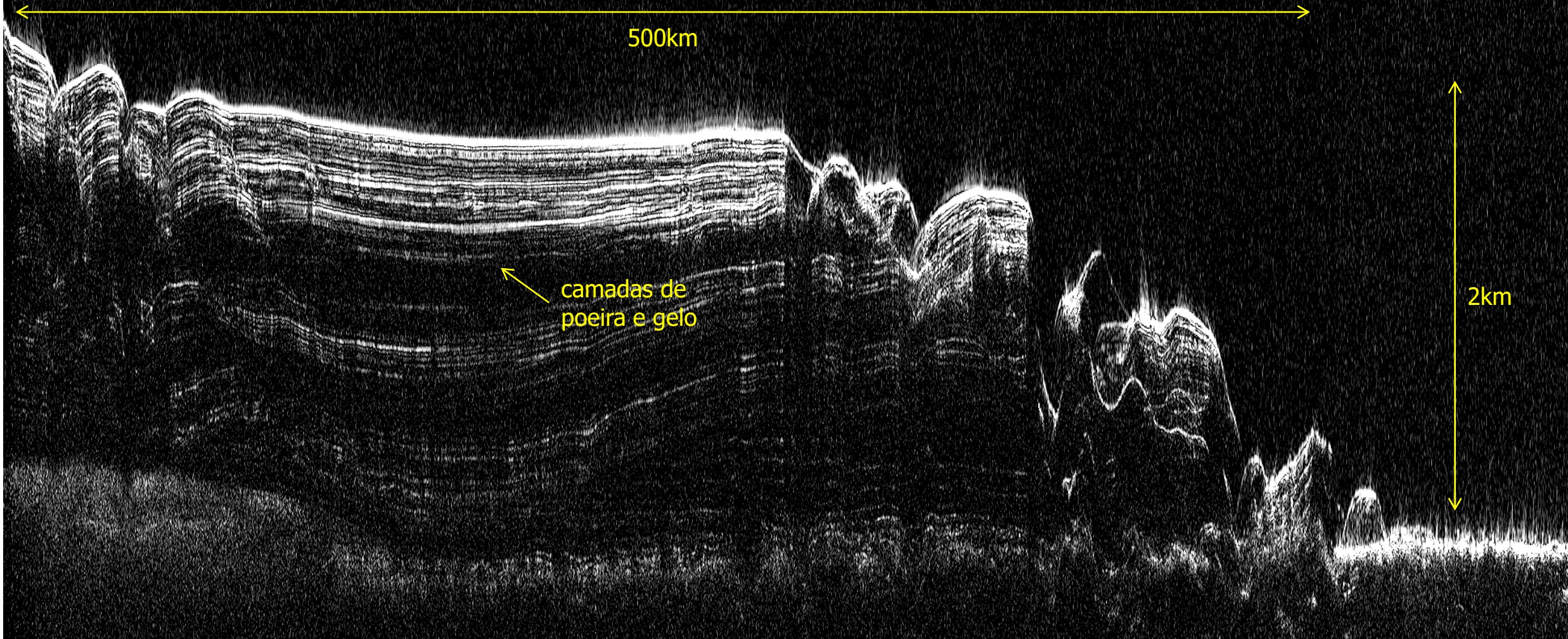




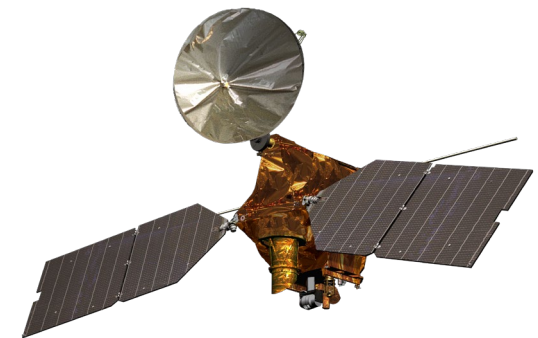


Mars Global Surveyor
March, 1999





Camada superficial de CO₂ forma-se no inverno e sublima "explosivamente" no verão. Isto gera ventos de ~400km/h que transportam partículas do solo, transportando-as por todo o planeta. (Mars Reconnaissance Orbiter)





Campamento
Los Guardas

Retração das Geleiras



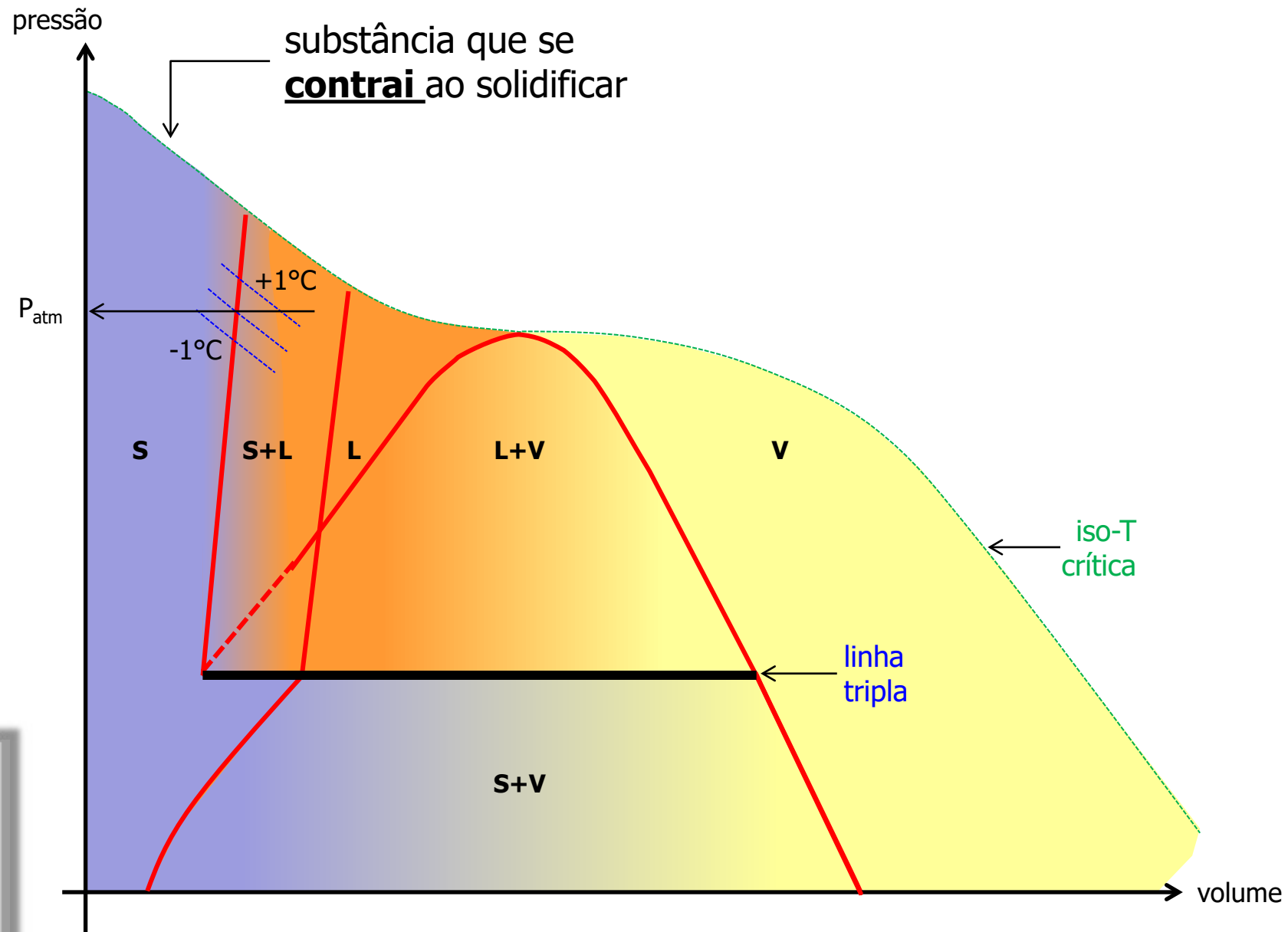
Glaciar Grey, Campo de Gelo Patagônico Sul

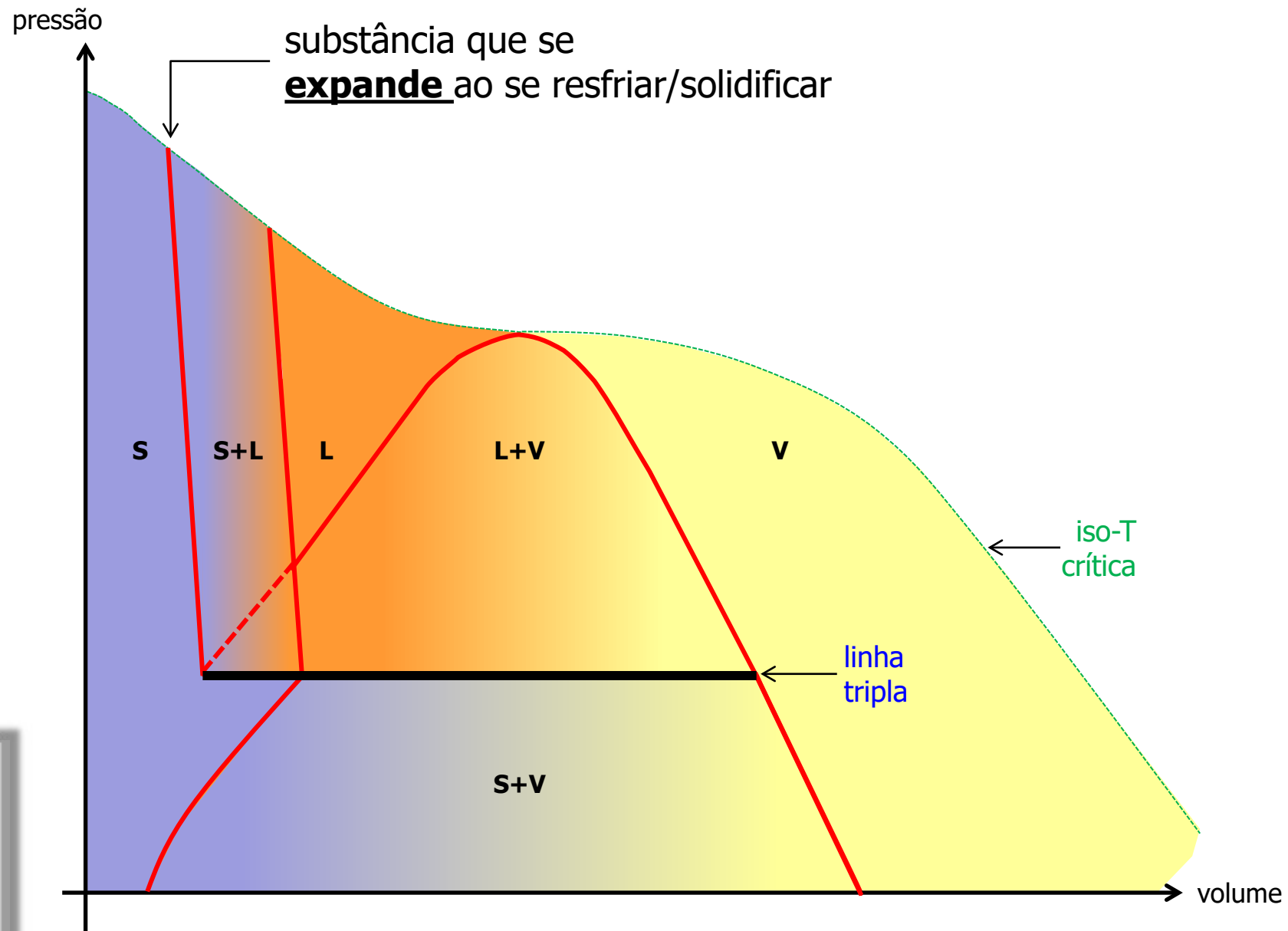
Retração das Geleiras

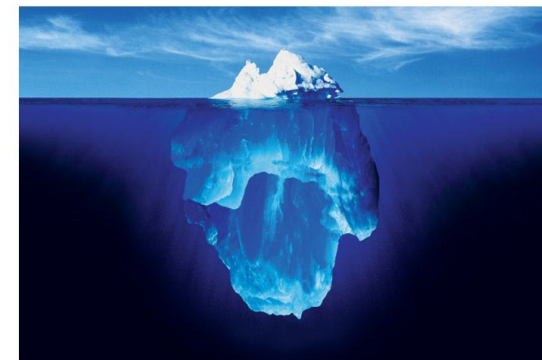
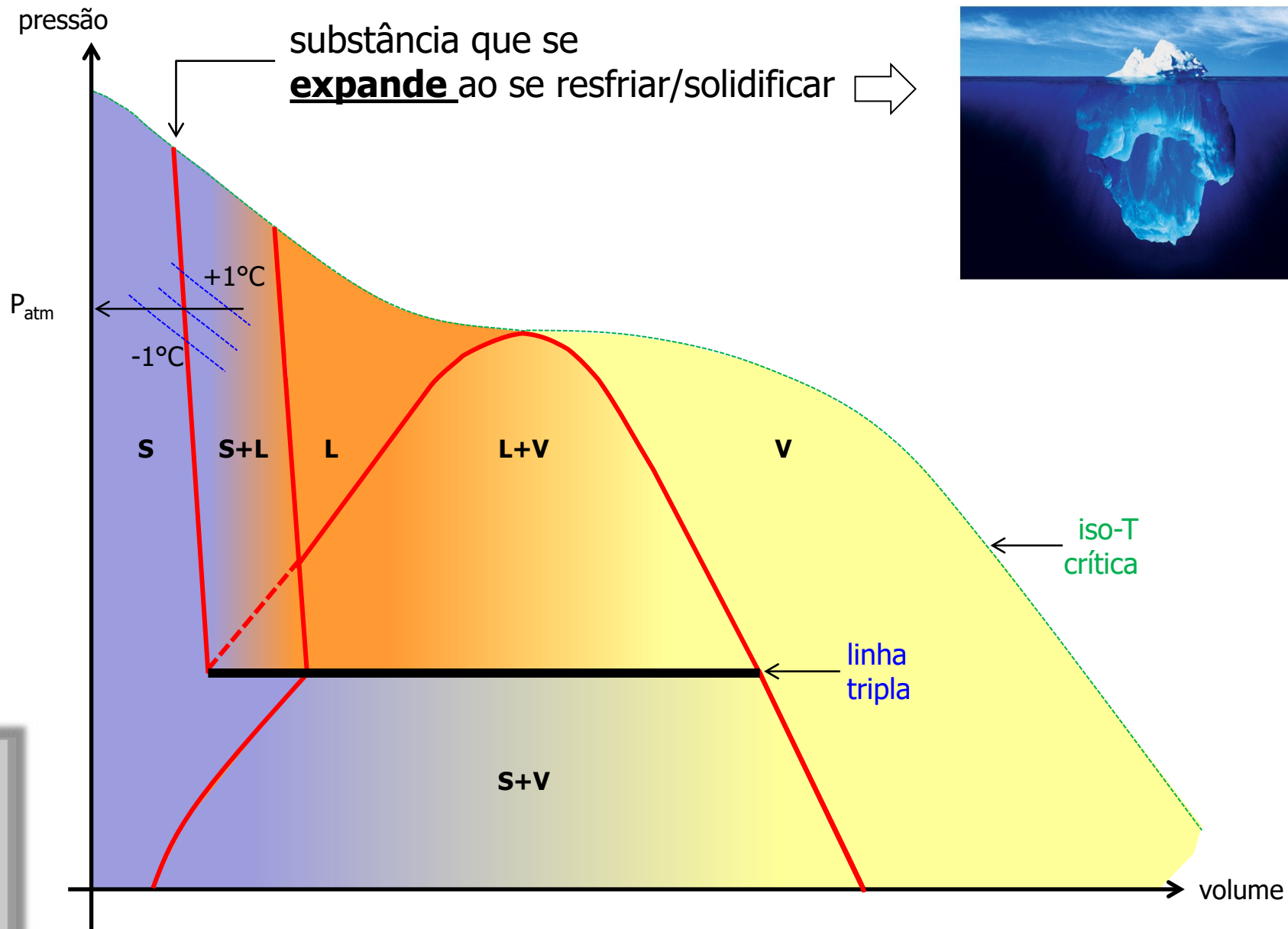


Glaciar Grey, Campo de Gelo Patagônico Sul







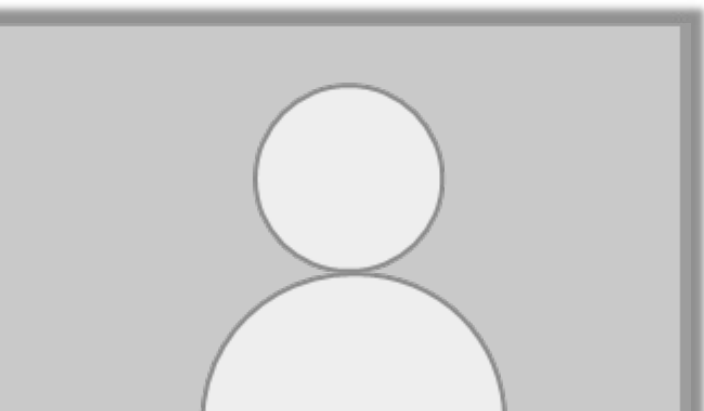
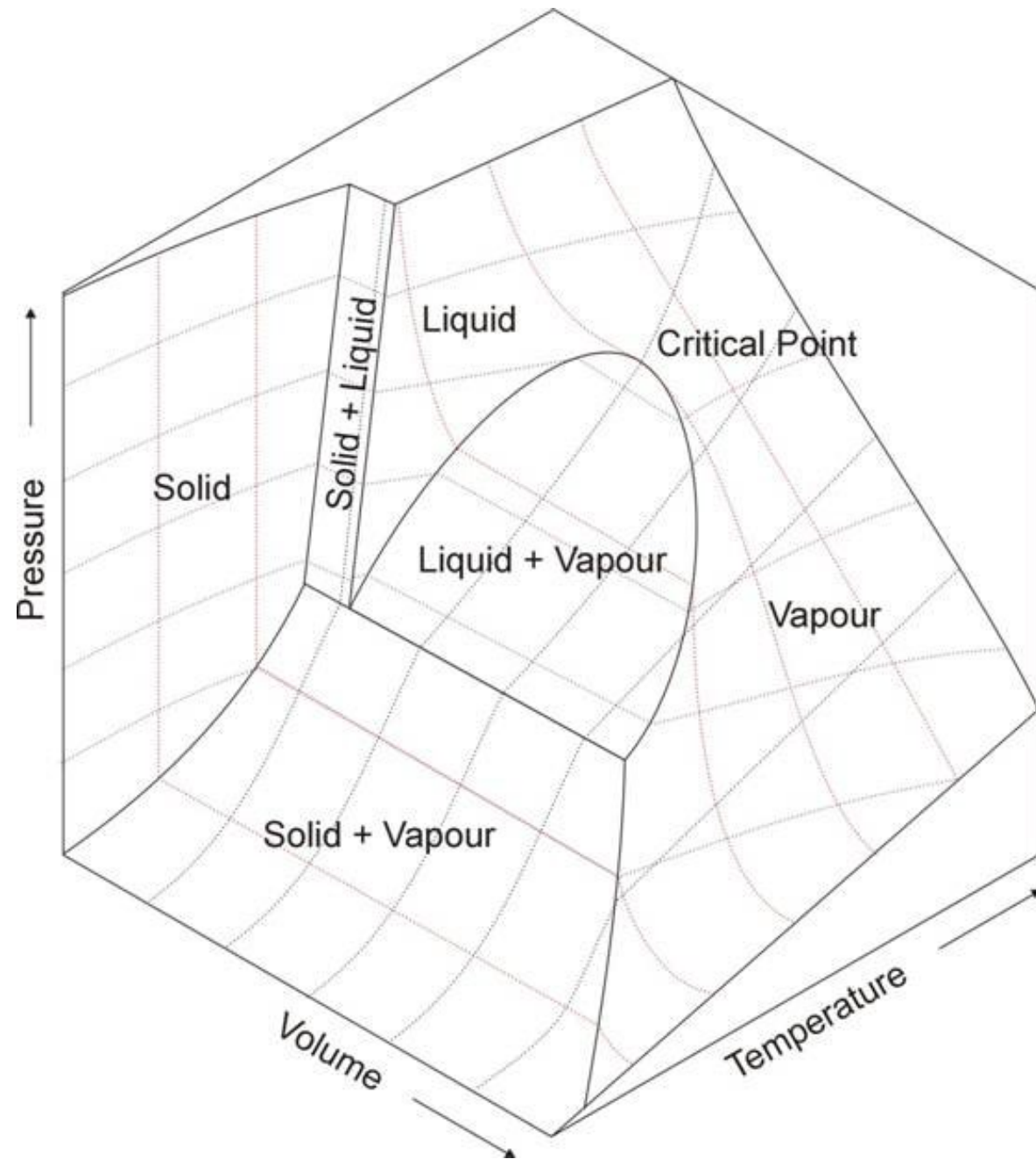


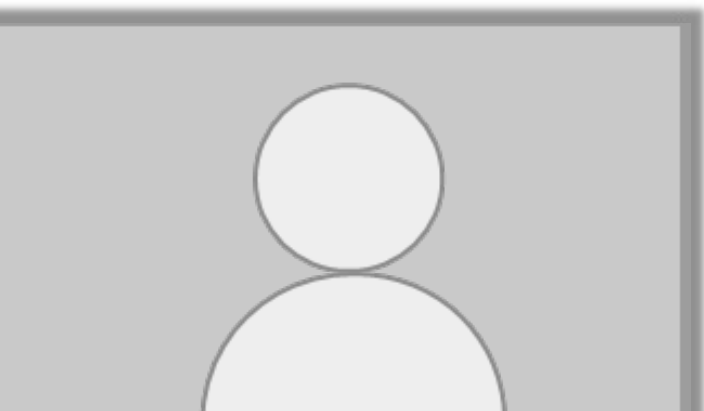
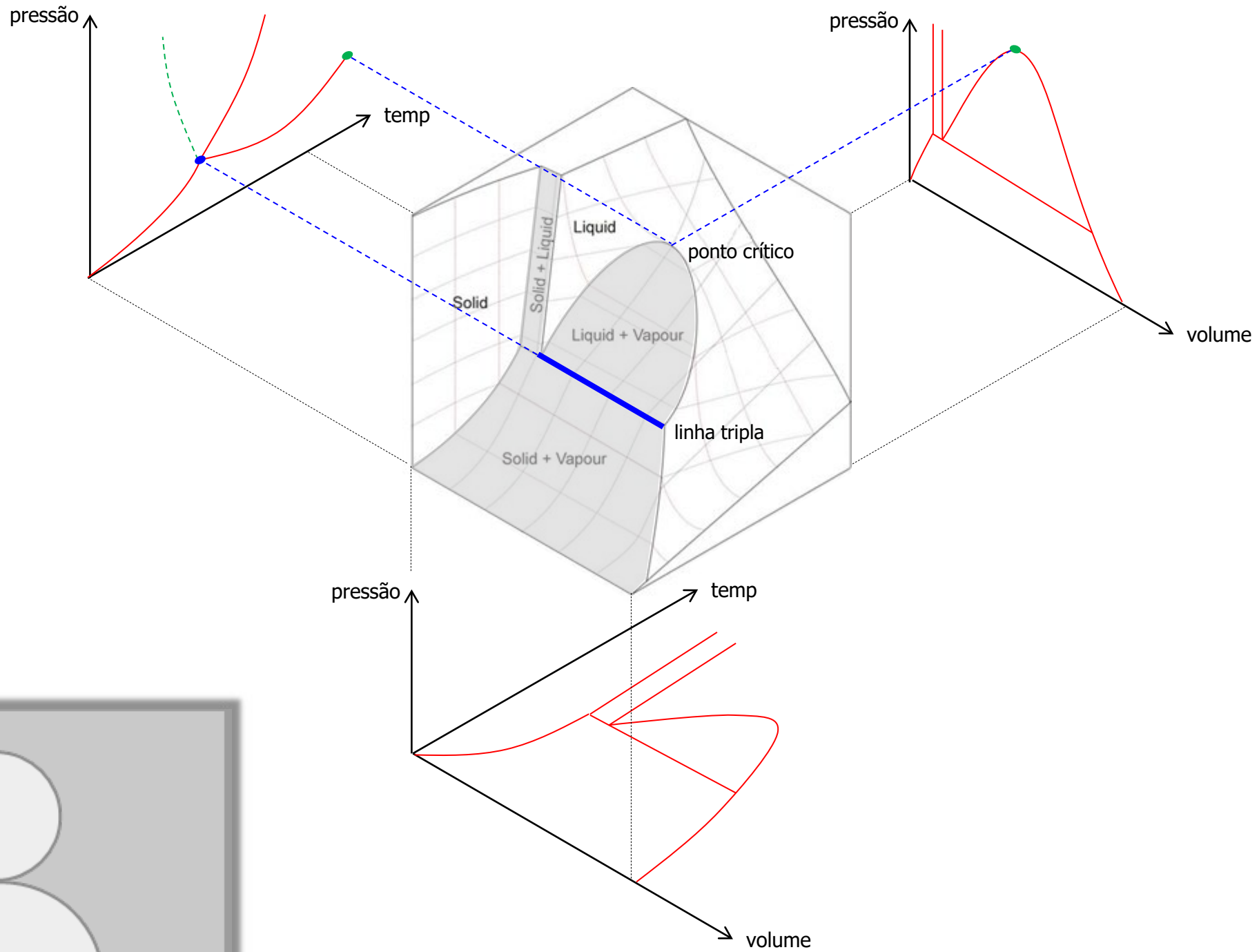
Snowball Earth Theory



Superfície $P \times v \times T$







Detalhamento do diagrama $P \times T \dots$



Diagrama Pressão × Temperatura

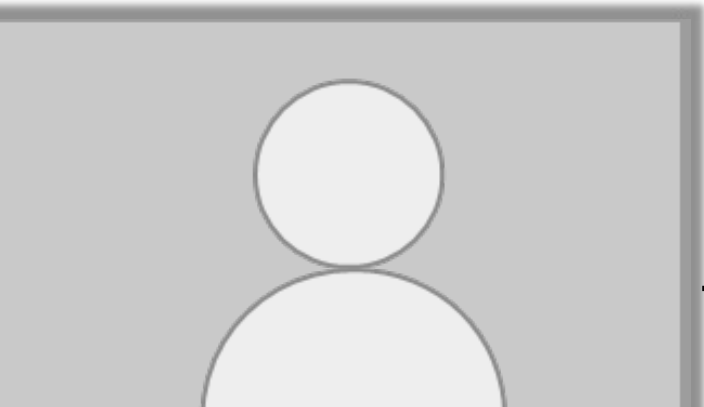
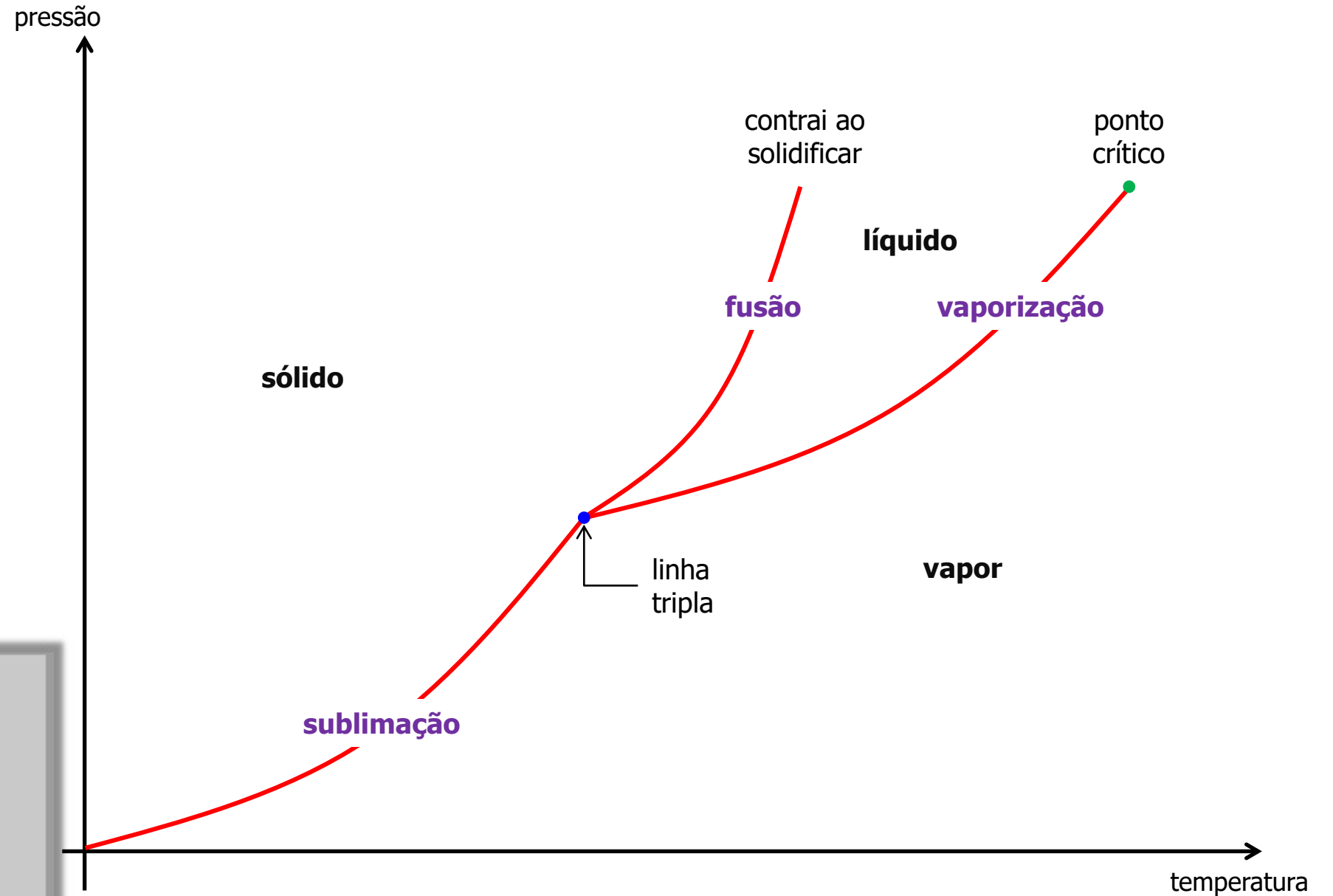


Diagrama Pressão × Temperatura

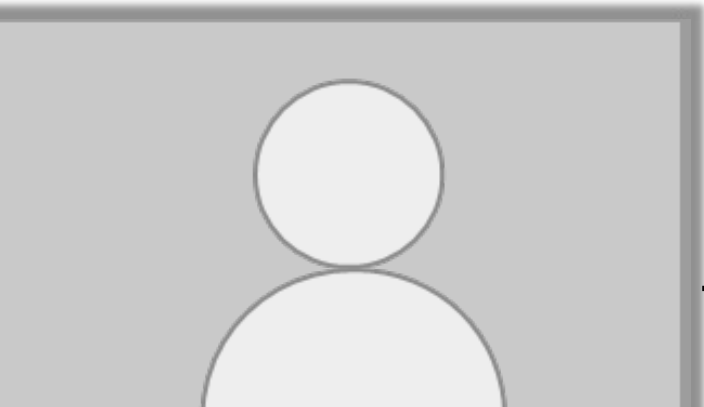
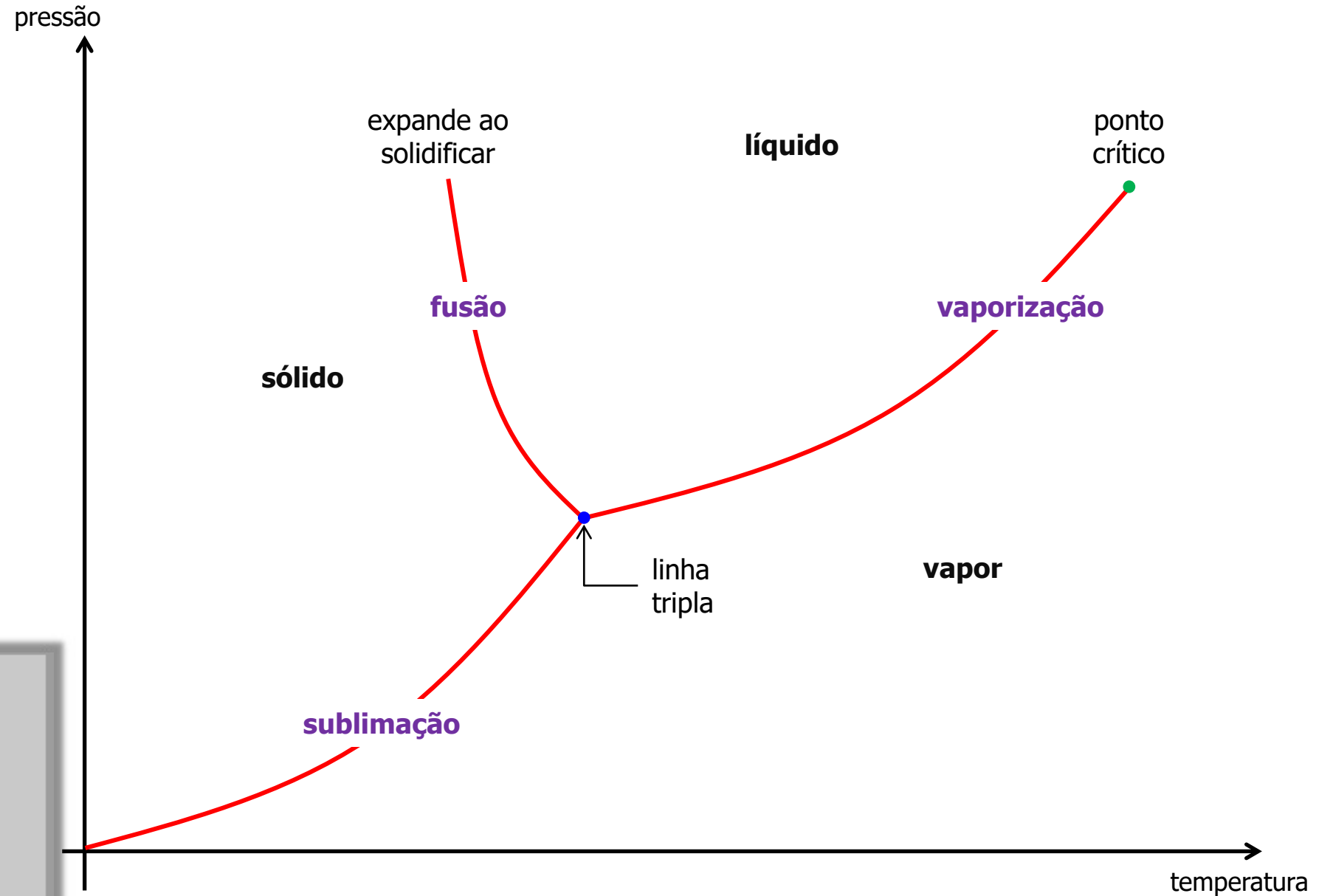


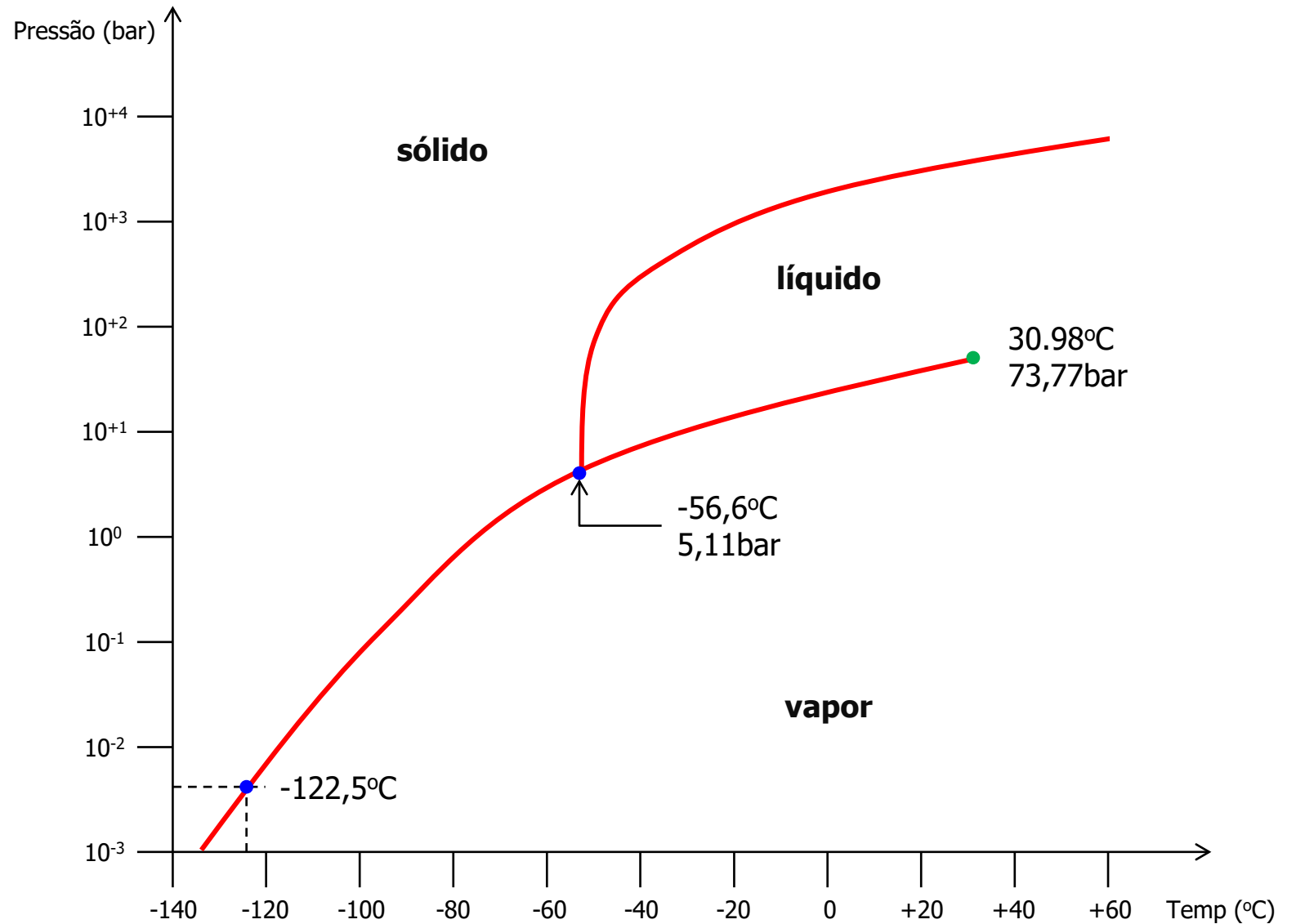
Diagrama Pressão × Temperatura: dióxido de carbono

atmosfera da terra

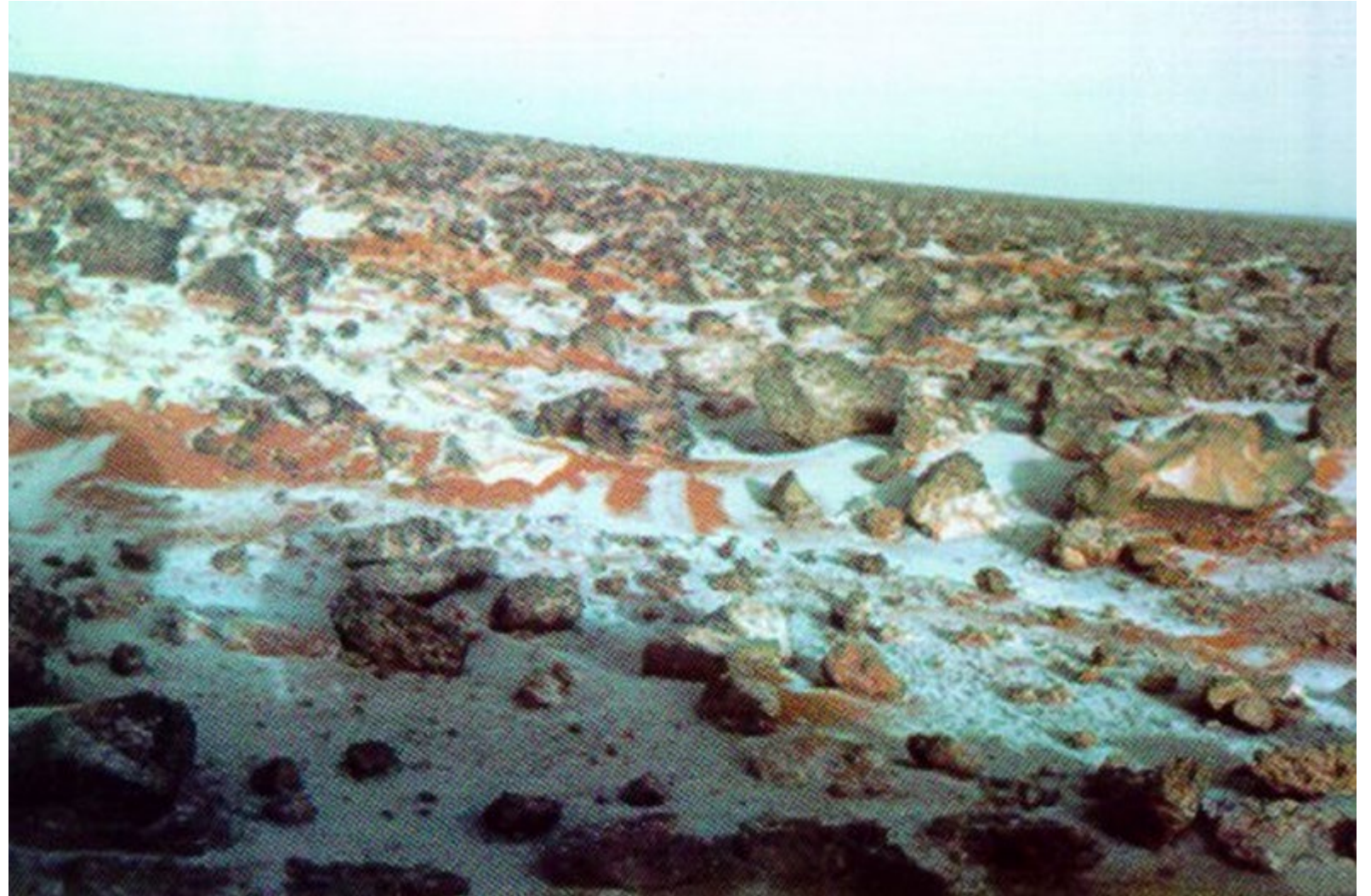
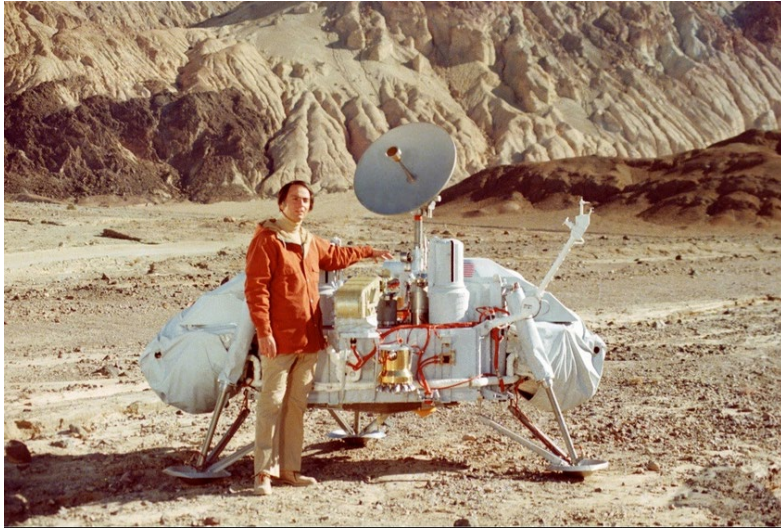
Nitrogen	78,08%
Oxygen	20,94%
Argon	0,934%
Carbon Dioxide	0,04%
Neon	0,002%

atmosfera marciana

Carbon Dioxide	96,0%
Argon	1,90%
Nitrogen	1,90%
Oxygen	0,145%
C. Monoxide	0,006%



Formação de neve de dióxido de carbono em Marte



Heavy Frost, or Snow, Deposit at Viking Lander 2 Site (Viking Lander Image 211093)

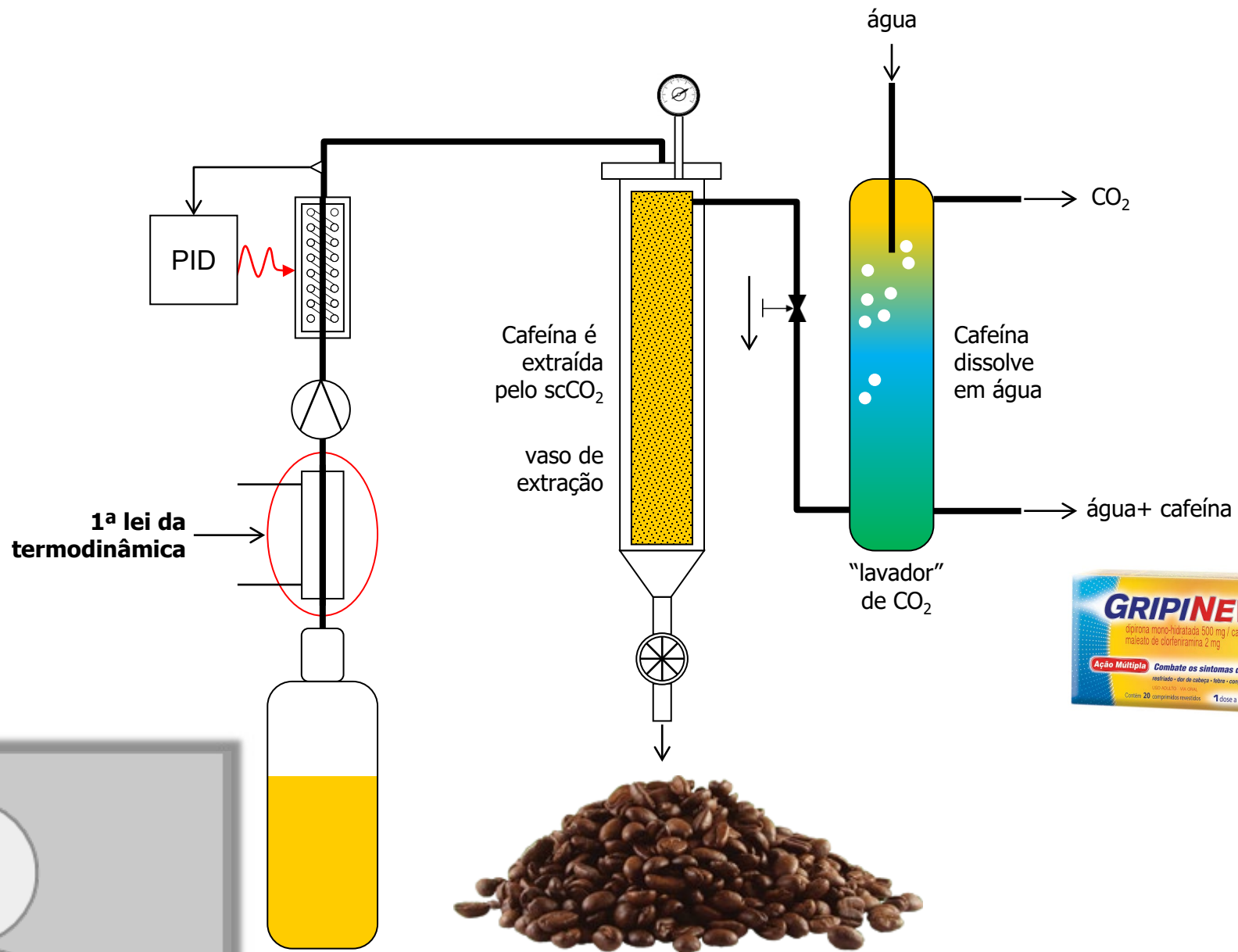


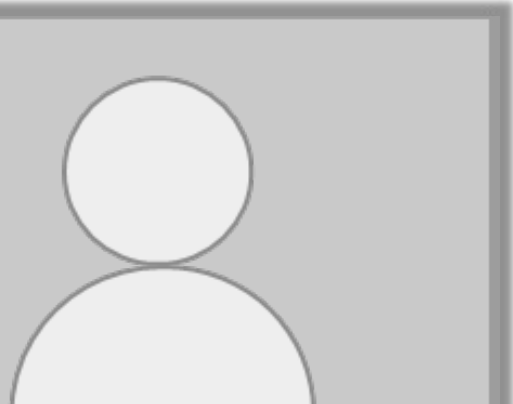
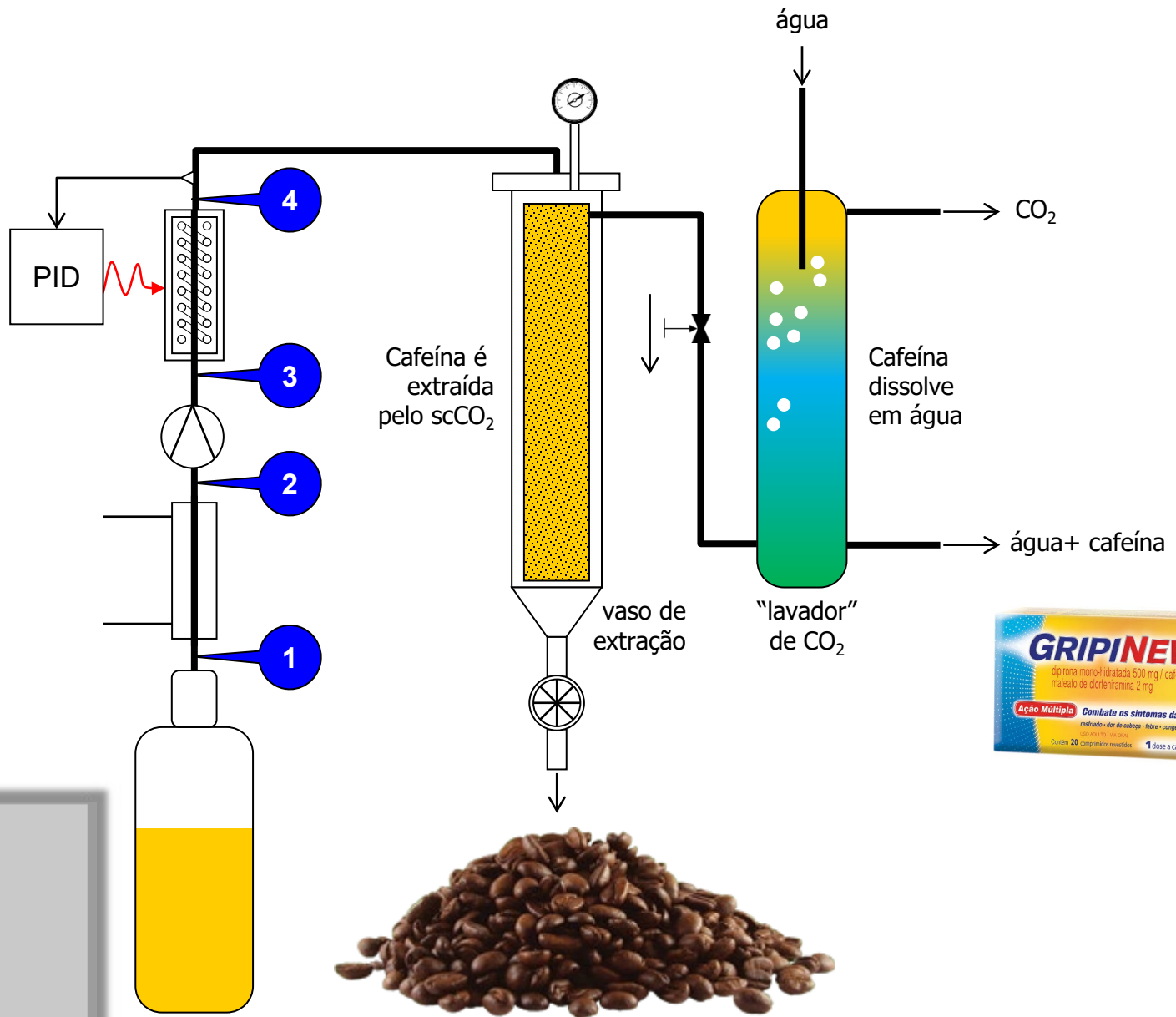
Exemplo de análise de um processo...

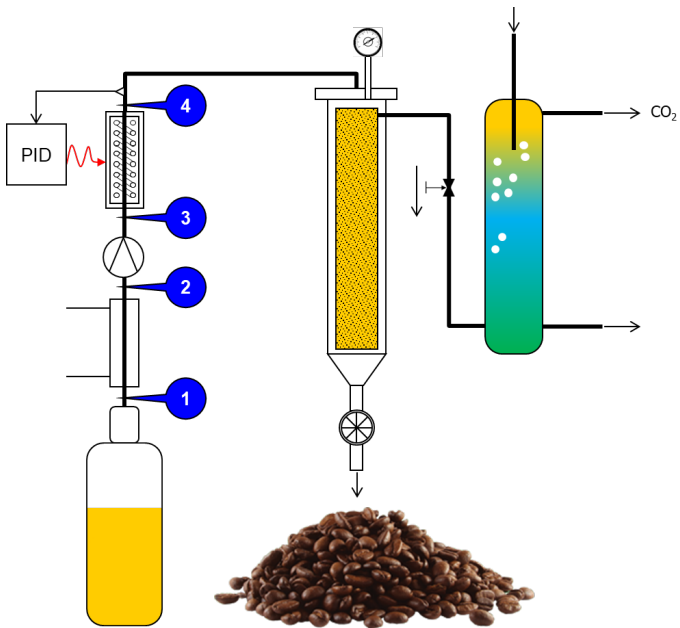


Análise Termodinâmica: visualização das transformações em um diagrama de equilíbrio

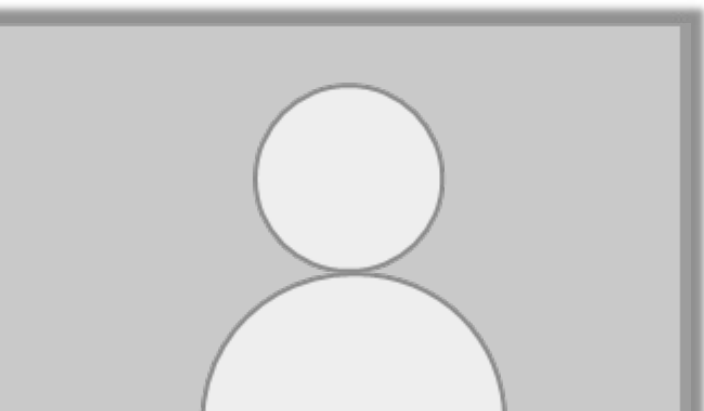
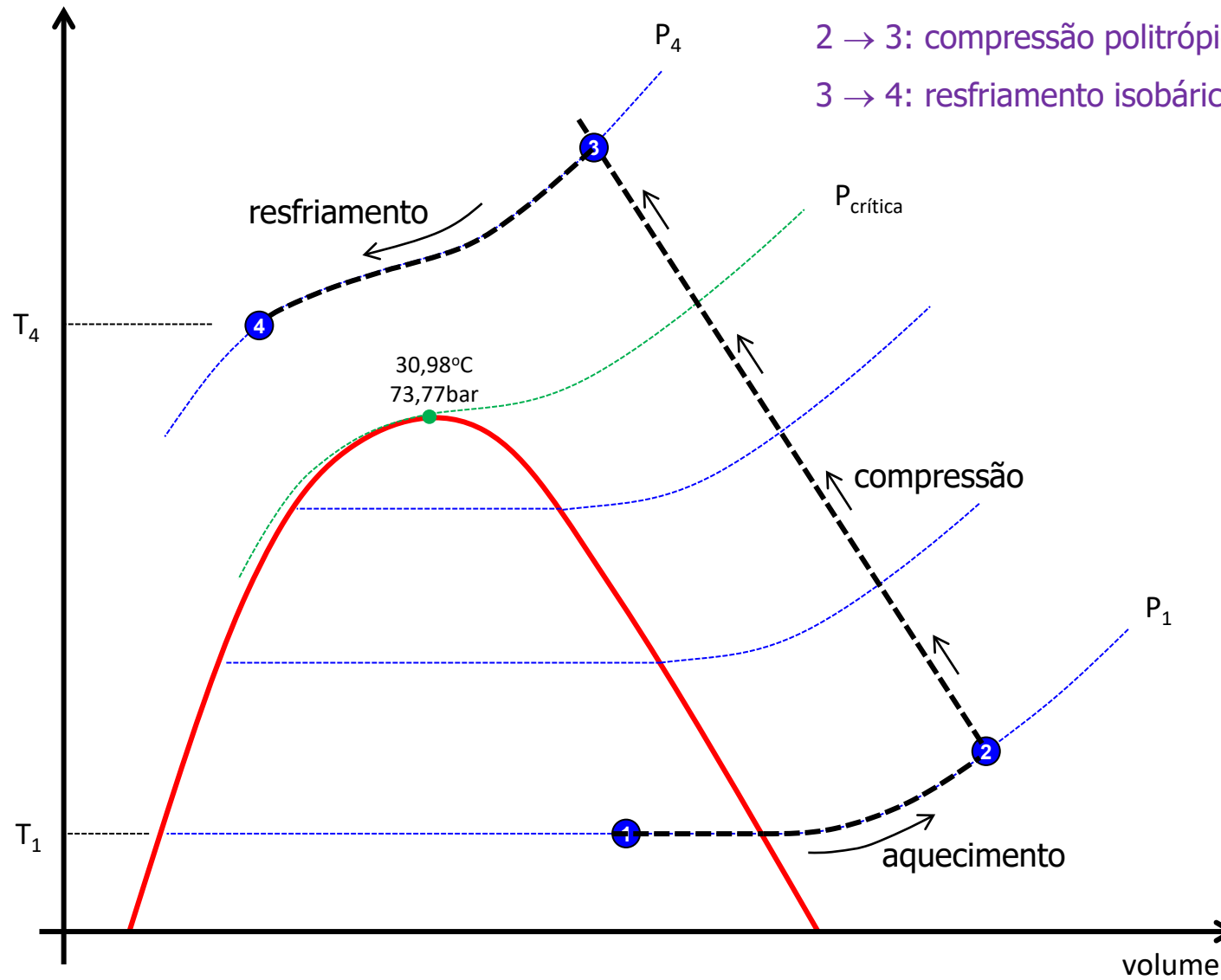








temperatura

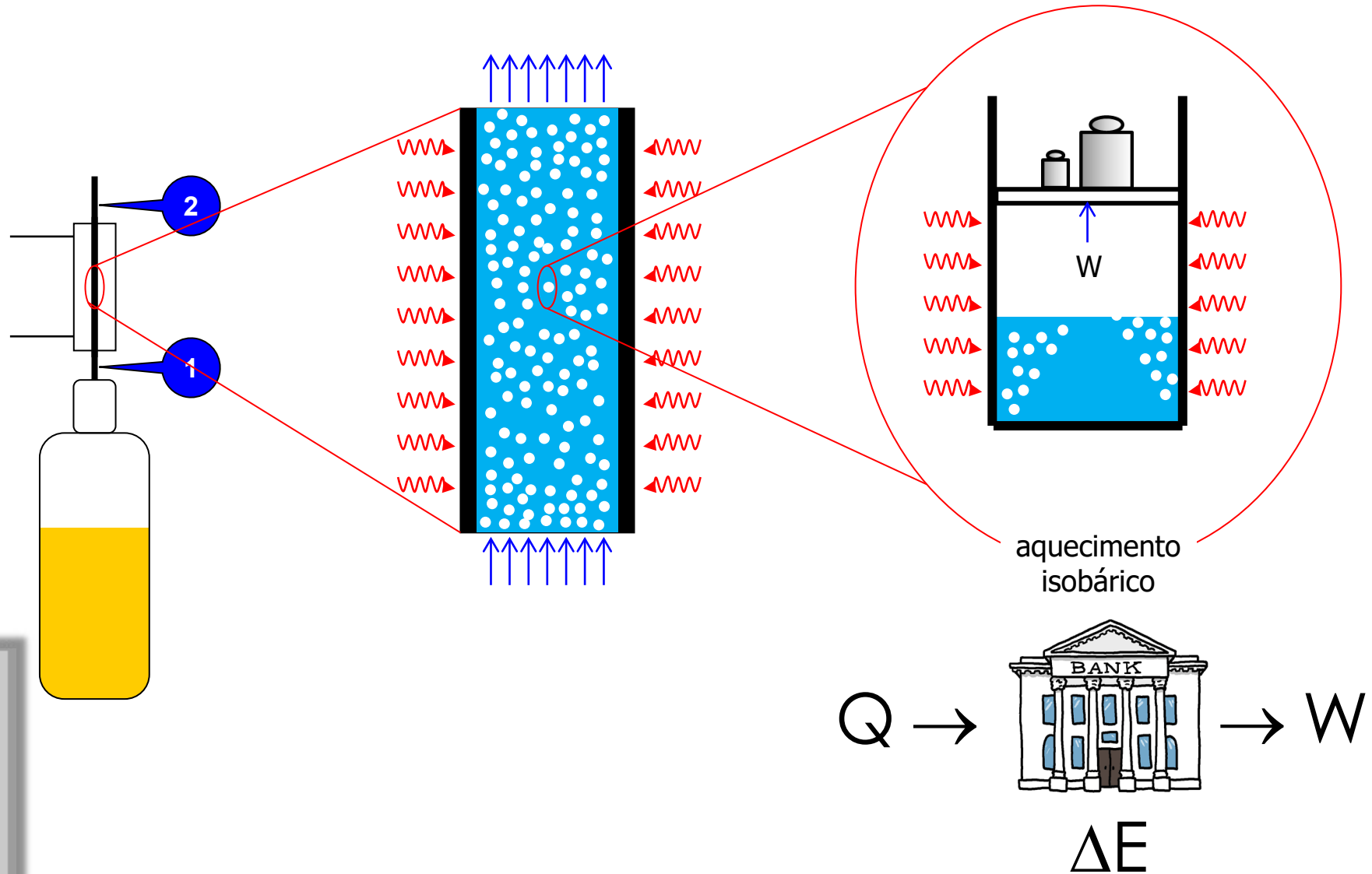


Propriedade Termodinâmica: entalpia – calor trocado @ $P = \text{cte}$

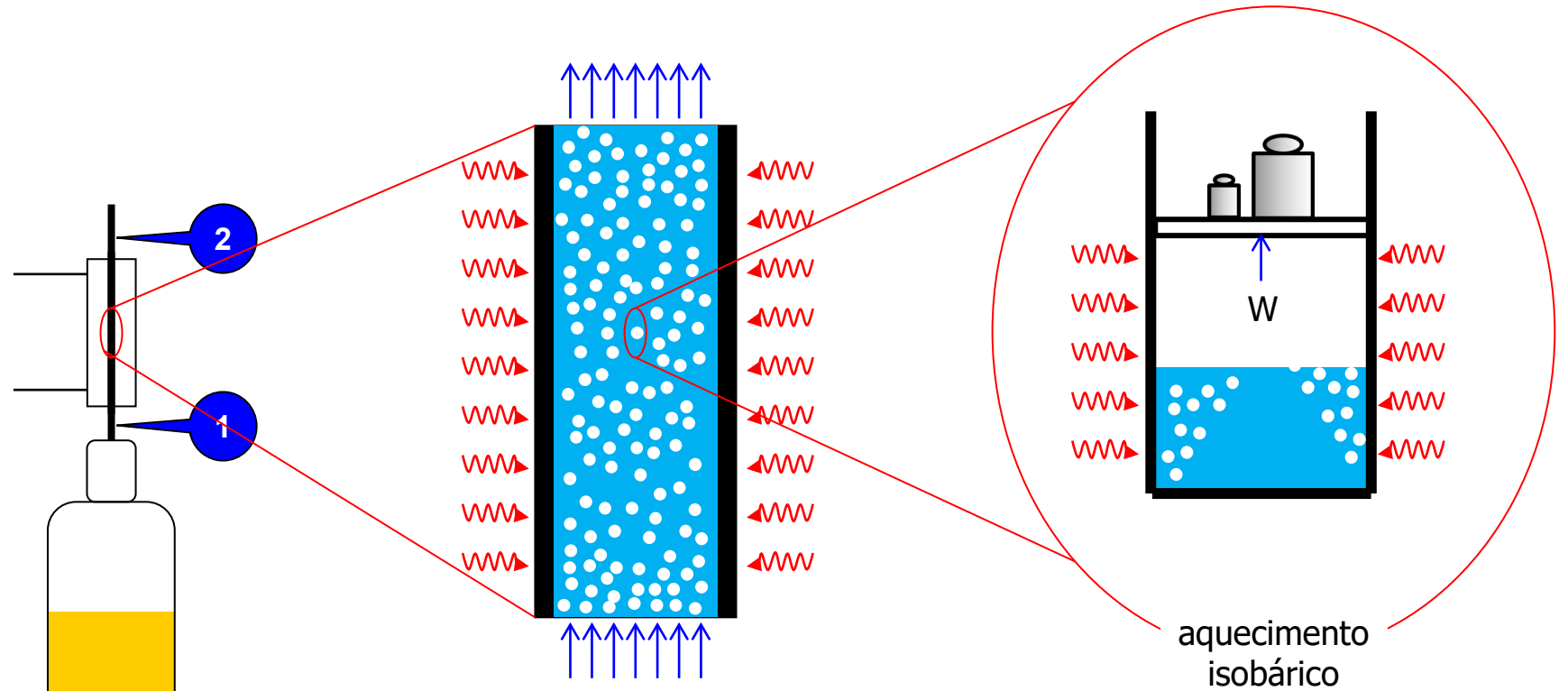
1º lei x diag. equilíbrio



Aplicação da 1ª lei da termodinâmica



Aplicação da 1ª lei da termodinâmica



$$\Delta E = Q - W$$

$$U_2 - U_1 = Q_{12} - W_{12}$$

Definição de uma nova propriedade
termodinâmica...



Aplicação da 1ª lei da termodinâmica

$$W = F \cdot \Delta x$$

$$U_2 - U_1 = Q_{12} - W_{12}$$

$$U_2 - U_1 = Q_{12} - \int_1^2 P \cdot dV = Q_{12} - P \cdot \int_1^2 dV$$

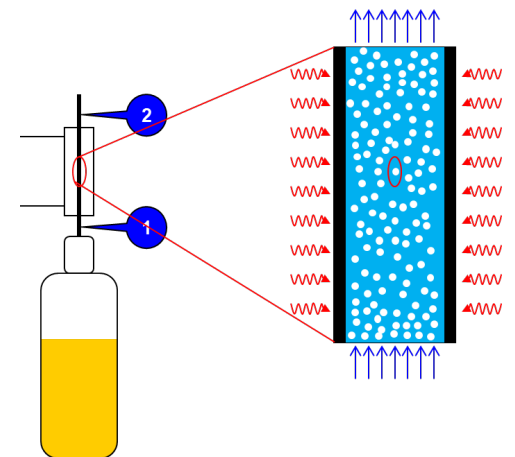
$$U_2 - U_1 = Q_{12} - P \cdot (V_2 - V_1)$$

$$U_2 - U_1 = Q_{12} - P_2 V_2 + P_1 V_1$$

$$Q_{12} = (U_2 + P_2 V_2) - (U_1 + P_1 V_1)$$

entpia 2

entpia 1



Aplicação da 1ª lei da termodinâmica

$$W = F \cdot \Delta x$$

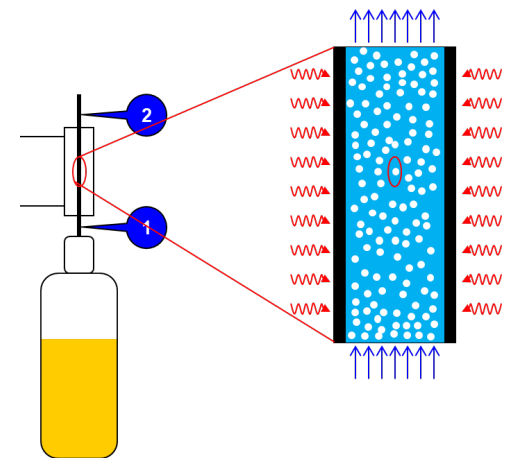
$$H \stackrel{\text{def}}{=} U + PV$$

$$Q_{12} = (U_2 + P_2 V_2) - (U_1 + P_1 V_1)$$

$$Q_{12} = H_2 - H_1$$

$$Q_{12} = m \cdot (h_2 - h_1)$$

A entalpia pode ser interpretada como a quantidade de calor transferido a pressão constante



Exemplo de aplicação da entalpia...



Diagrama $P \times h$ do CO_2

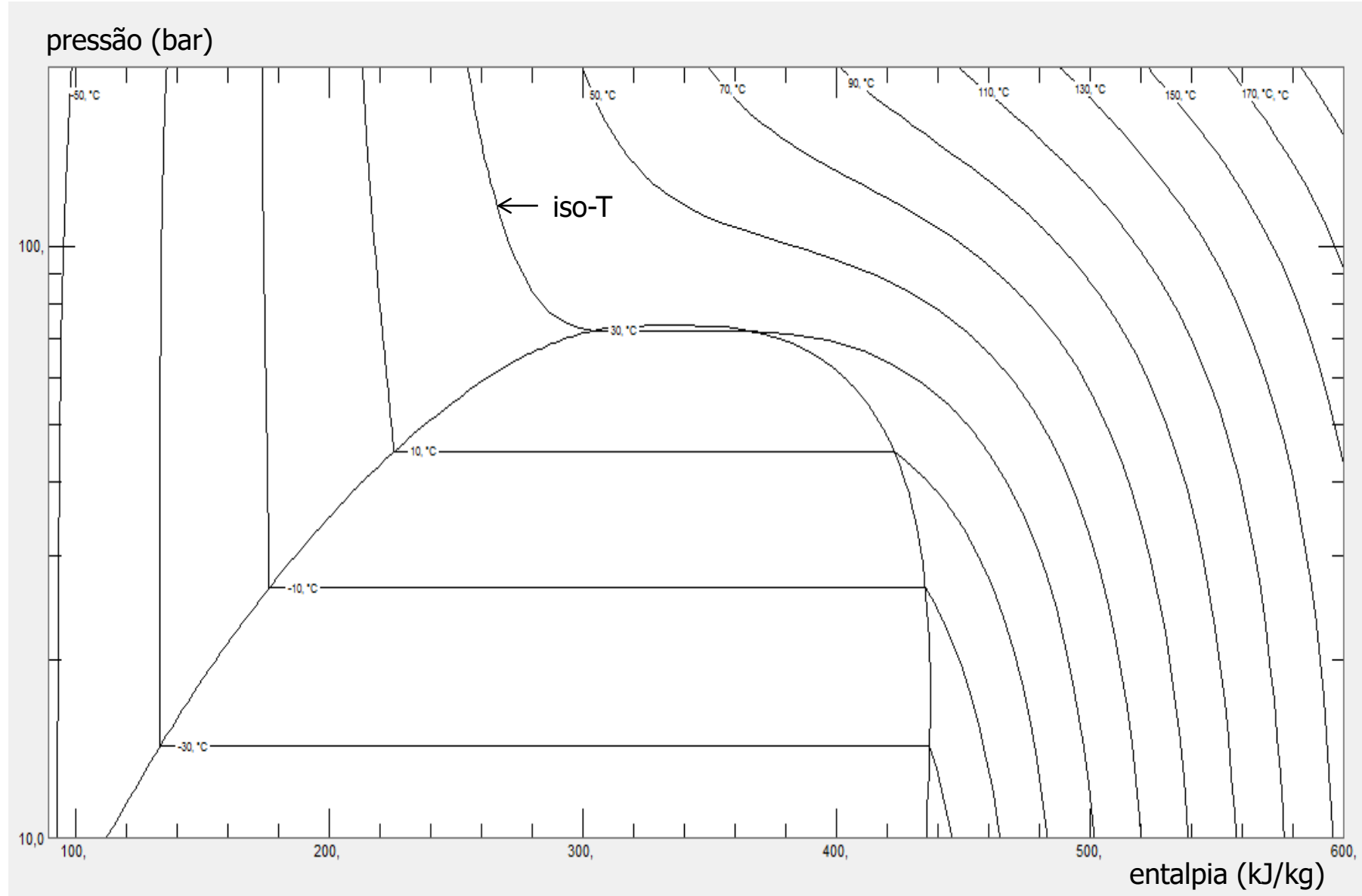
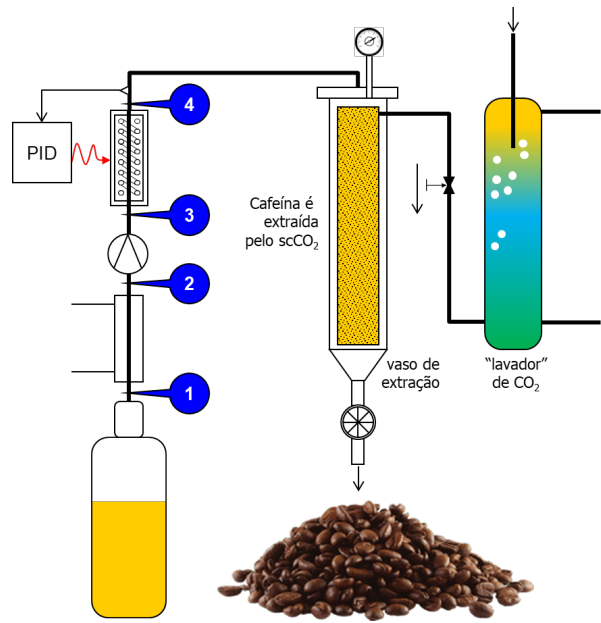
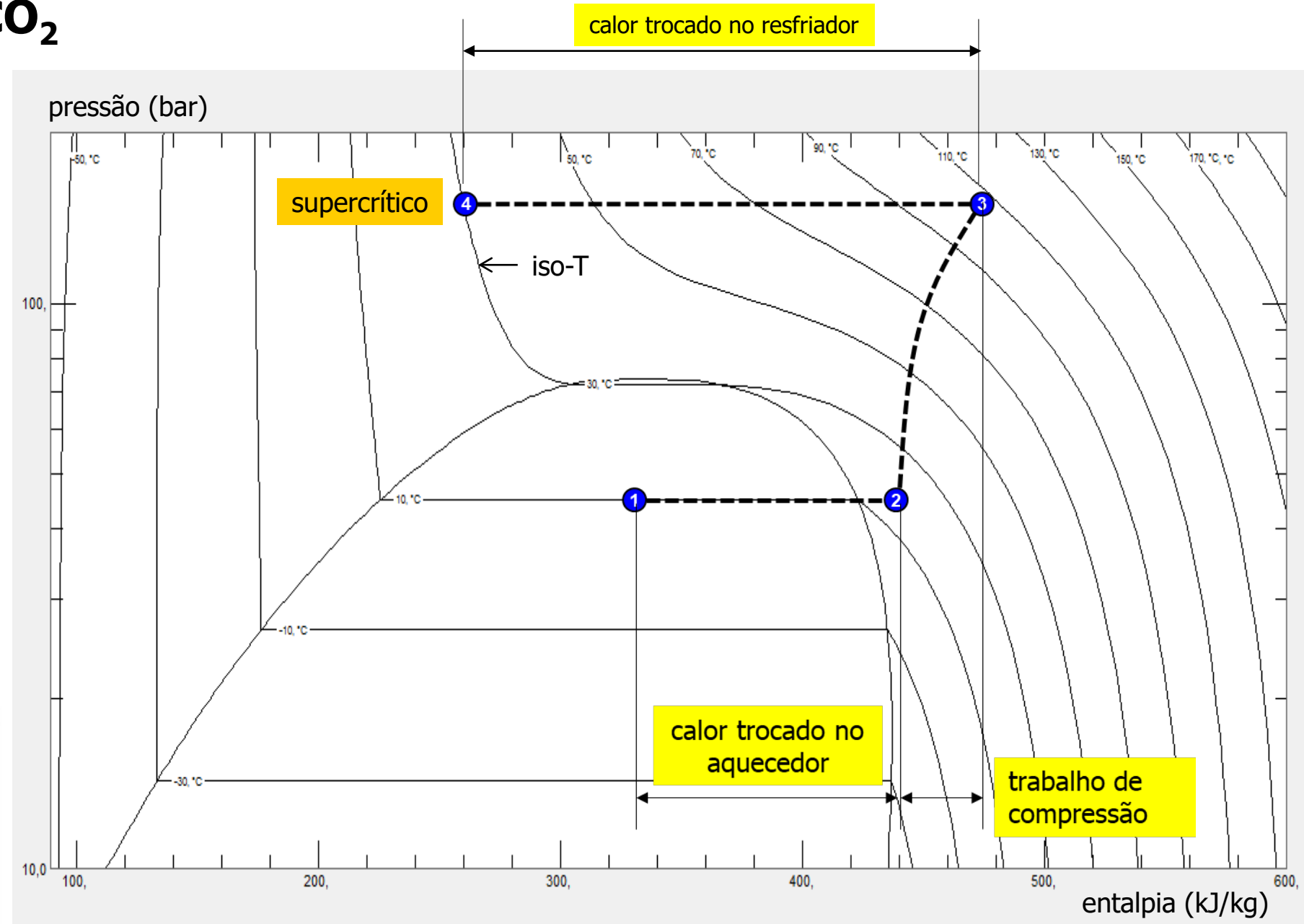
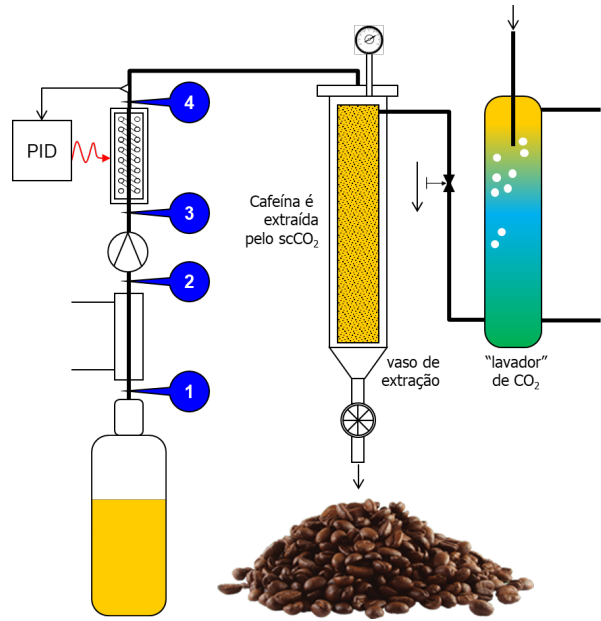


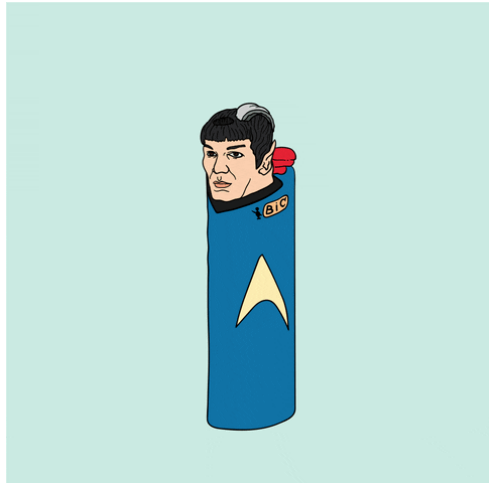
Diagrama $P \times h$ do CO_2



Exercício resolvido: tutorial REFPROP



Exercício resolvido: determine a pressão interna num isqueiro de bolso contendo butano. Construa um gráfico mostrando a variação da pressão com a temperatura.



REFPROP (butane) - NIST Reference Fluid Properties (DLL version 9,1)

File Edit Options Substance Calculate Plot Window Help Cautions

Select Fluid

- acetone (propanone)
- ammonia
- argon
- benzene
- butane**
- carbon dioxide
- carbon monoxide
- cyclohexane
- cyclopentane
- decane
- dimethylether (methoxymethane)
- dodecane
- ethane
- ethanol (ethyl alcohol)
- ethylene (ethene)
- helium (helium-4)
- heptane
- hexane
- hydrogen (normal)
- hydrogen sulfide
- isobutane (2-methylpropane)
- isopentane (2-methylbutane)
- krypton
- methane
- methanol

OK

Cancel

Info

All fluids

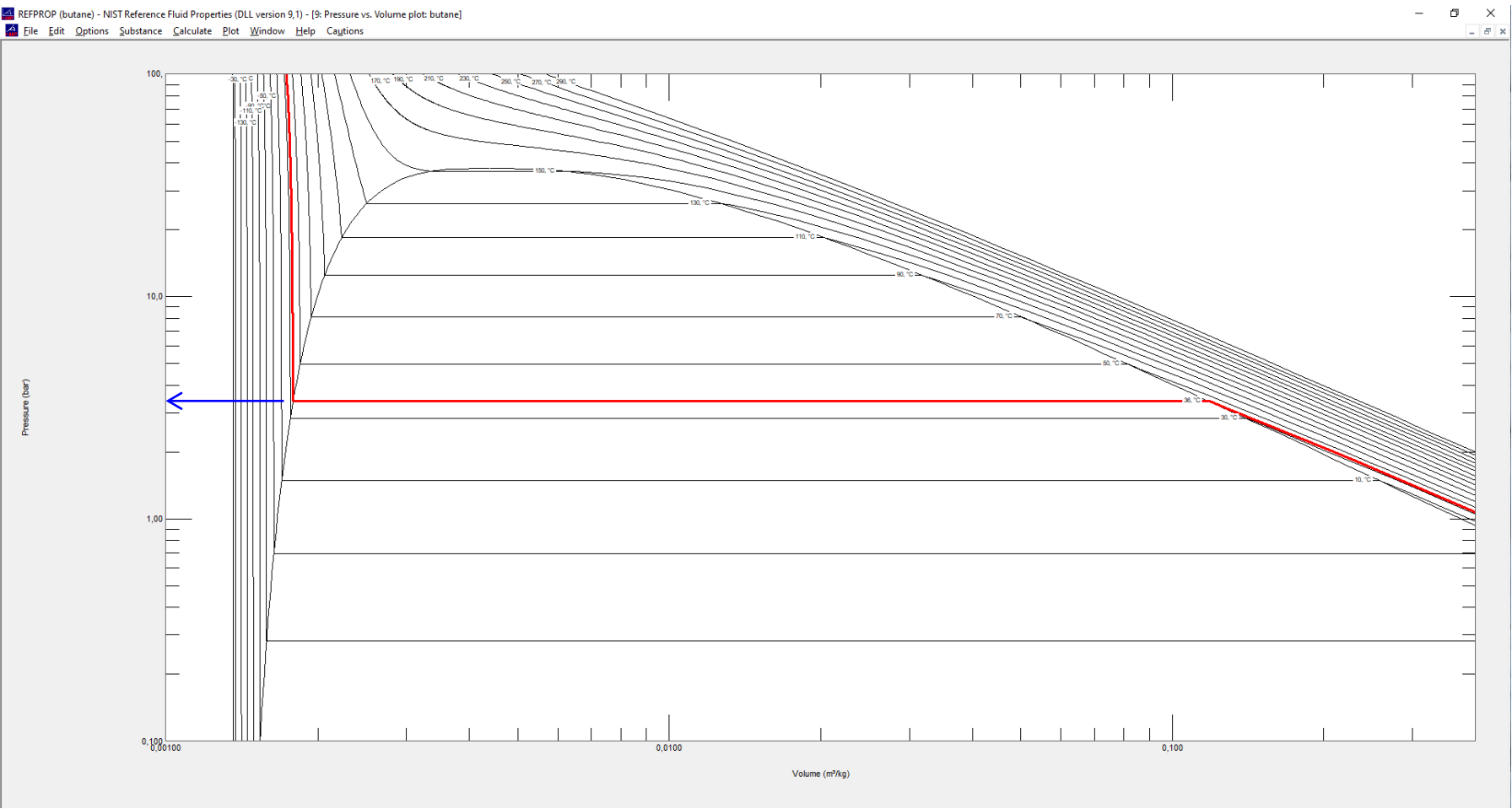
Select fluids

Sort by

- Short name
- Full name
- CAS number
- Chemical formula
- Synonym
- UN Number



Exercício resolvido: determine a pressão interna num isqueiro de bolso contendo butano. Construa um gráfico mostrando a variação da pressão com a temperatura.



Exercício resolvido: determine a pressão interna num isqueiro de bolso contendo butano. Construa um gráfico mostrando a variação da pressão com a temperatura.



REFPROP (butane) - NIST Reference Fluid Properties (DLL version 9,1)
 File Edit Options Substance Calculate Plot Window Help Cautions

10: butane: Saturation points (at equilibrium)

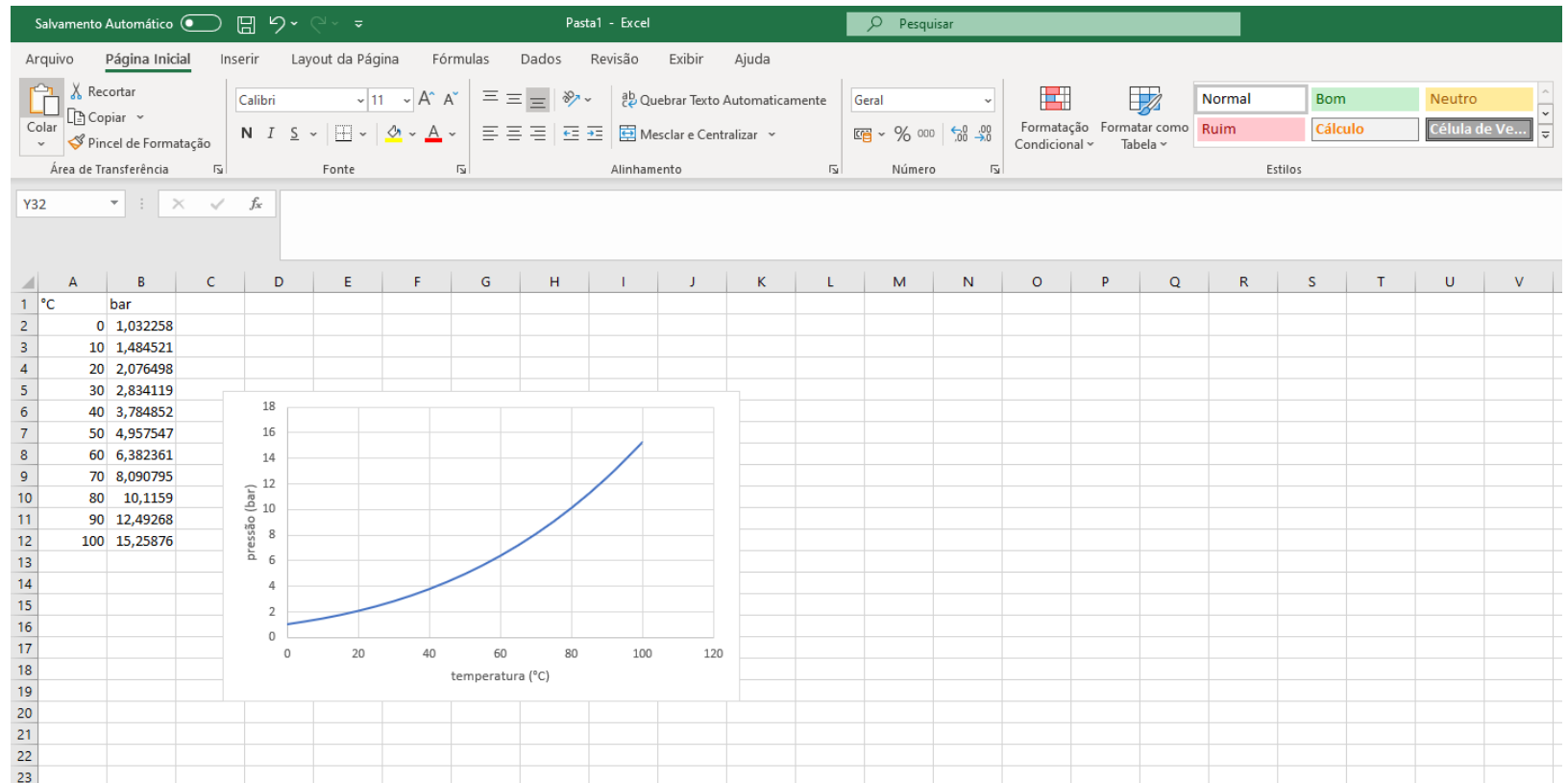
	Temperature (°C)	Pressure (bar)	Liquid Density (kg/m³)	Vapor Density (kg/m³)	Liquid Volume (m³/kg)	Vapor Volume (m³/kg)	Liquid Int. Energy (kJ/kg)	Vapor Int. Energy (kJ/kg)	Liquid Enthalpy (kJ/kg)	Vapor Enthalpy (kJ/kg)	Liquid Entropy (kJ/kg-K)	Vapor Entropy (kJ/kg-K)	Liquid Cp (kJ/kg-K)	Vapor Cp (kJ/kg-K)	Liquid Flow Exergy (kJ/kg)	Vapor Flow Exergy (kJ/kg)
1	36.000000	3.3795681	559.79838	8.4452854	0.0017863574	0.11840926	286.11712	596.57181	286.72084	636.58902	1.2966022	2.4283123	2.5059073	1.8762431	231.90283	244.35164
2																

13: butane: V/L sat. T=0, to 100, °C

	Temperature (°C)	Pressure (bar)	Liquid Density (kg/m³)	Vapor Density (kg/m³)	Liquid Volume (m³/kg)	Vapor Volume (m³/kg)	Liquid Int. Energy (kJ/kg)	Vapor Int. Energy (kJ/kg)	Liquid Enthalpy (kJ/kg)	Vapor Enthalpy (kJ/kg)	Liquid Entropy (kJ/kg-K)	Vapor Entropy (kJ/kg-K)	Liquid Cp (kJ/kg-K)	Vapor Cp (kJ/kg-K)	Liquid Flow Exergy (kJ/kg)	Vapor Flow Exergy (kJ/kg)
1	0.0000000	1.0322579	600.73123	2.7567392	0.0016646380	0.36274740	199.82817	547.82747	200.00000	585.27236	1.0000000	2.4104791	2.3118748	1.6438018	233.61392	198.35195
2	10.000000	1.4845212	589.82546	3.8733997	0.0016954168	0.25817113	223.14355	561.20017	223.39524	599.52622	1.0838409	2.4122215	2.3604080	1.7024224	232.01201	212.08630
3	20.000000	2.0764979	578.59117	5.3125781	0.0017283361	0.18823253	246.94386	574.71739	247.30275	613.80383	1.1664613	2.4166782	2.4128507	1.7653163	231.28624	225.03516
4	30.000000	2.8341186	566.97591	7.1366267	0.0017637434	0.14012222	271.26250	588.35045	271.76237	628.06275	1.2480580	2.4233850	2.4695824	1.8330119	231.41779	237.29442
5	40.000000	3.7848516	554.91713	9.4176228	0.0018020709	0.10618391	296.13496	602.06478	296.81702	642.25382	1.3288165	2.4319198	2.5311739	1.9062861	232.39430	248.94085
6	50.000000	4.9575470	542.33880	12.240646	0.0018438659	0.081695038	321.60015	615.81805	322.51425	656.31875	1.4089167	2.4418875	2.5984763	1.9863101	234.20965	260.03392
7	60.000000	6.3823605	529.14654	15.708826	0.0018898357	0.063658483	347.70223	629.55763	348.90839	670.18677	1.4885401	2.4529057	2.6727646	2.0748236	236.86407	270.61687
8	70.000000	8.0907947	515.21997	19.951342	0.0019409185	0.050121942	374.49346	643.21548	376.06382	683.76811	1.5678786	2.4645835	2.7559860	2.1742474	240.36474	280.71646
9	80.000000	10.115901	500.40067	25.136495	0.0019983986	0.039782793	402.03857	656.69653	404.06013	696.94041	1.6471472	2.4764840	2.8512144	2.2883315	244.72712	290.34064
10	90.000000	12.492679	484.47157	31.493676	0.0020641046	0.031752407	430.42215	669.86226	433.00077	709.52952	1.7266043	2.4880768	2.9635487	2.4246423	249.97763	299.47334
11	100.00000	15.258764	467.11978	39.352181	0.0021407786	0.025411552	459.76206	682.51450	463.02863	721.28938	1.8065872	2.4986970	3.1020673	2.5987614	256.15856	308.06680



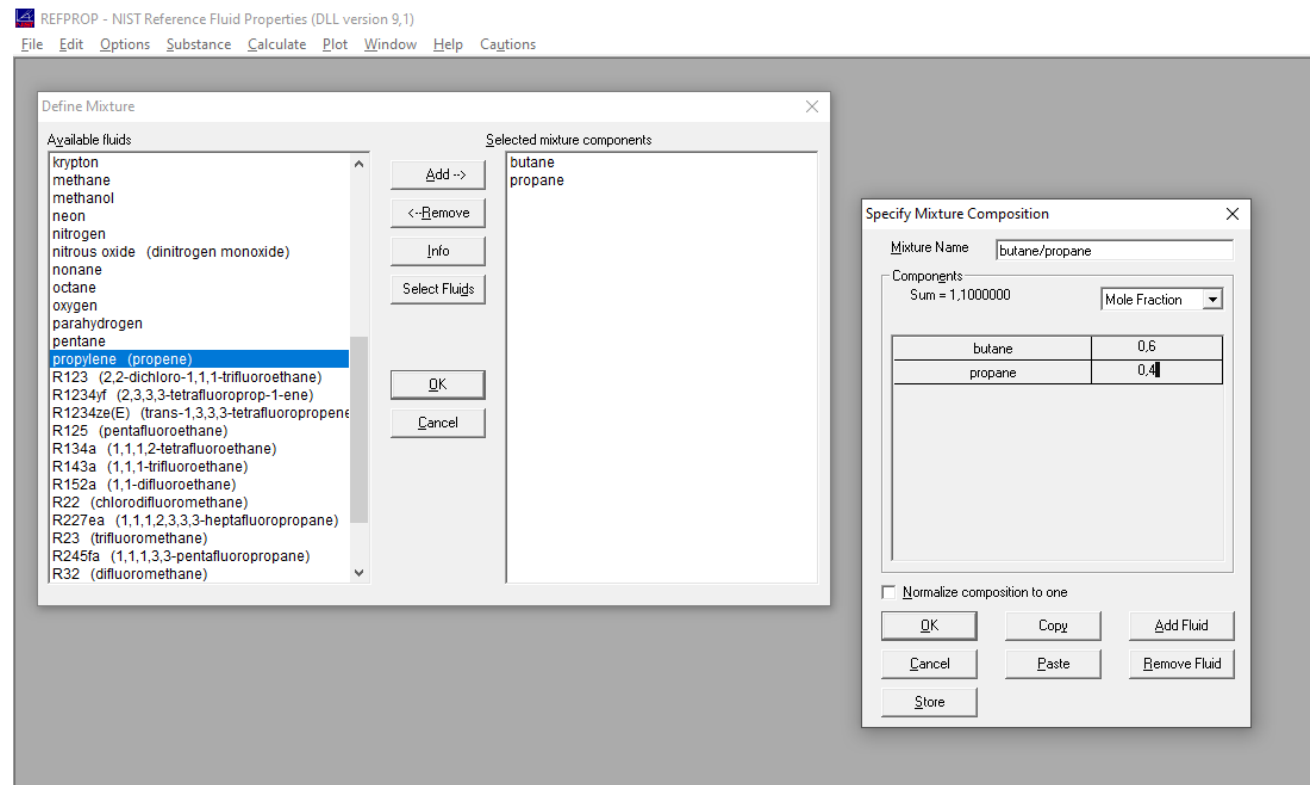
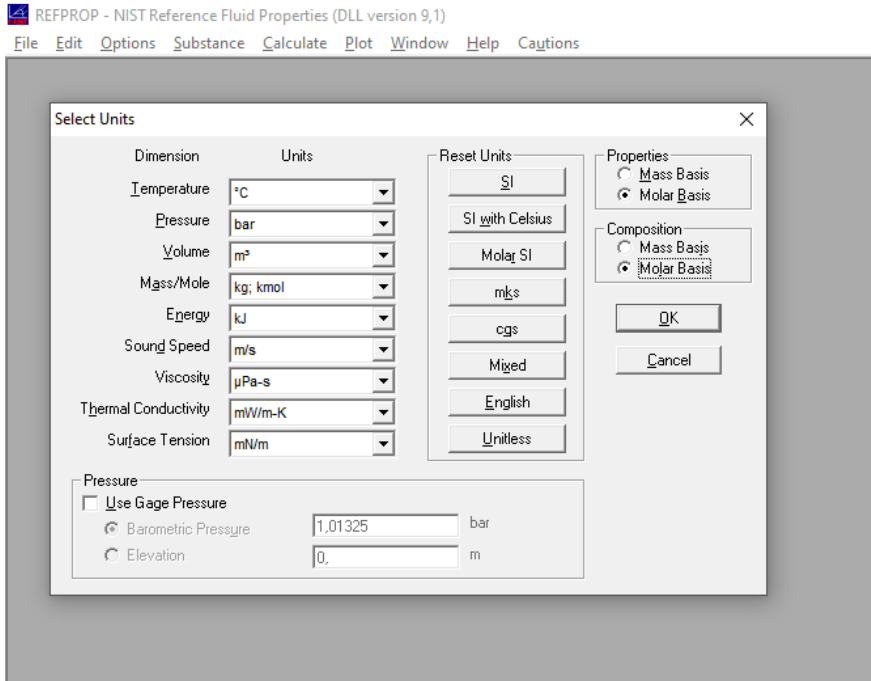
Exercício resolvido: determine a pressão interna num isqueiro de bolso contendo butano. Construa um gráfico mostrando a variação da pressão com a temperatura.



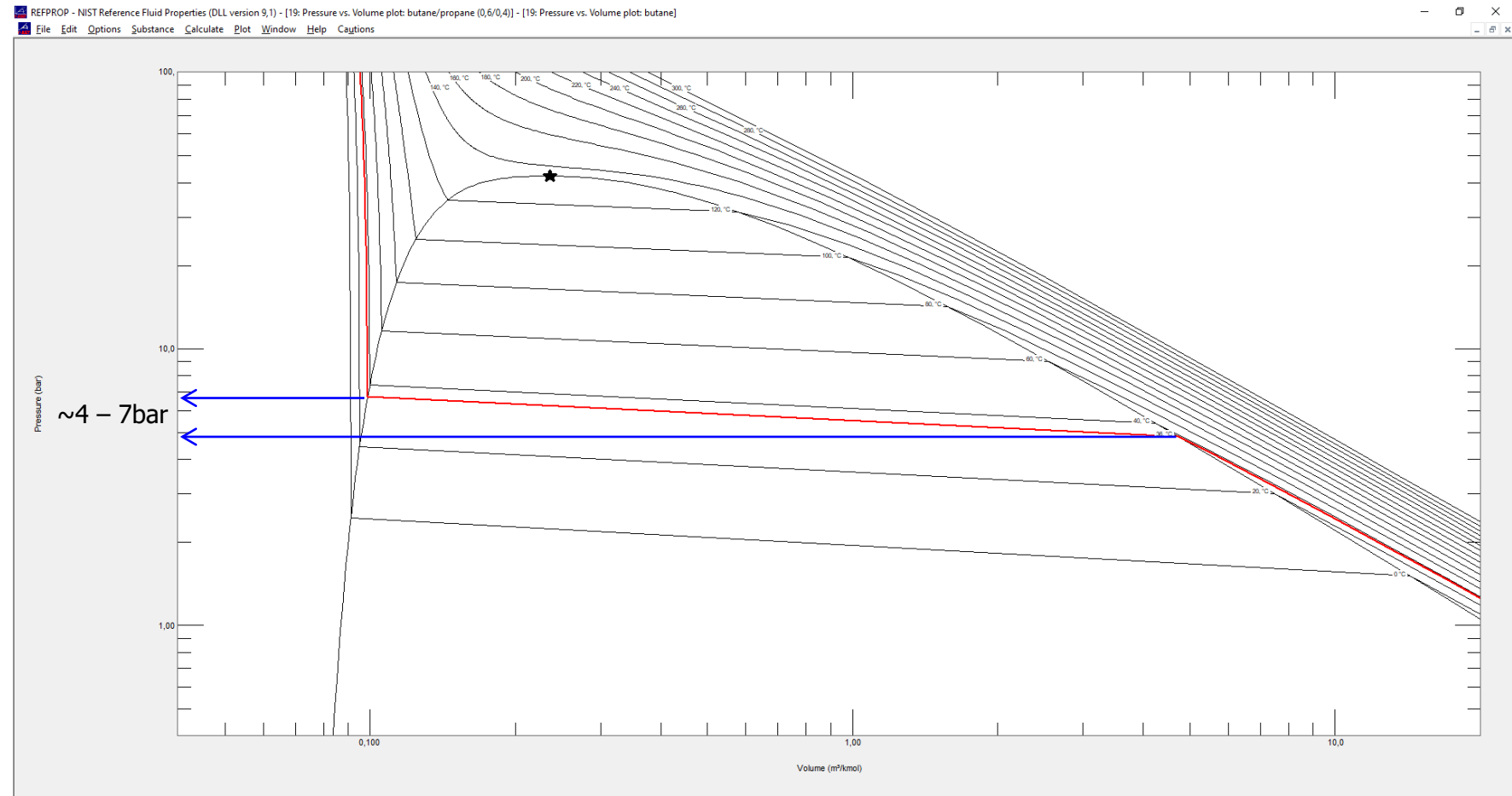
Tópico avançado: termodinâmica de misturas



Exercício resolvido: determine a pressão interna num isqueiro de bolso contendo **uma mistura bifásica de 60% butano e 40% propano (m^3/m^3)**. Construa um gráfico mostrando a variação da composição com a pressão @ T_{cte} . (Obs. o miniRefprop não permite trabalhar com misturas.)



Exercício resolvido: determine a pressão interna num isqueiro de bolso contendo **uma mistura bifásica de 60% butano e 40% propano (m^3/m^3)**. Construa um gráfico mostrando a variação da composição com a pressão @ T_{cte} . (Obs. o miniRefprop não permite trabalhar com misturas.)



Exercício resolvido: determine a pressão interna num isqueiro de bolso contendo **uma mistura bifásica de 60% butano e 40% propano (m^3/m^3)**. Construa um gráfico mostrando a variação da composição com a pressão @ T_{cte} . (Obs. o miniRefprop não permite trabalhar com misturas.)



REFPROP - NIST Reference Fluid Properties (DLL version 9,1) - [19: Pressure vs. Volume plot: butane/propane (0,6/0,4)]

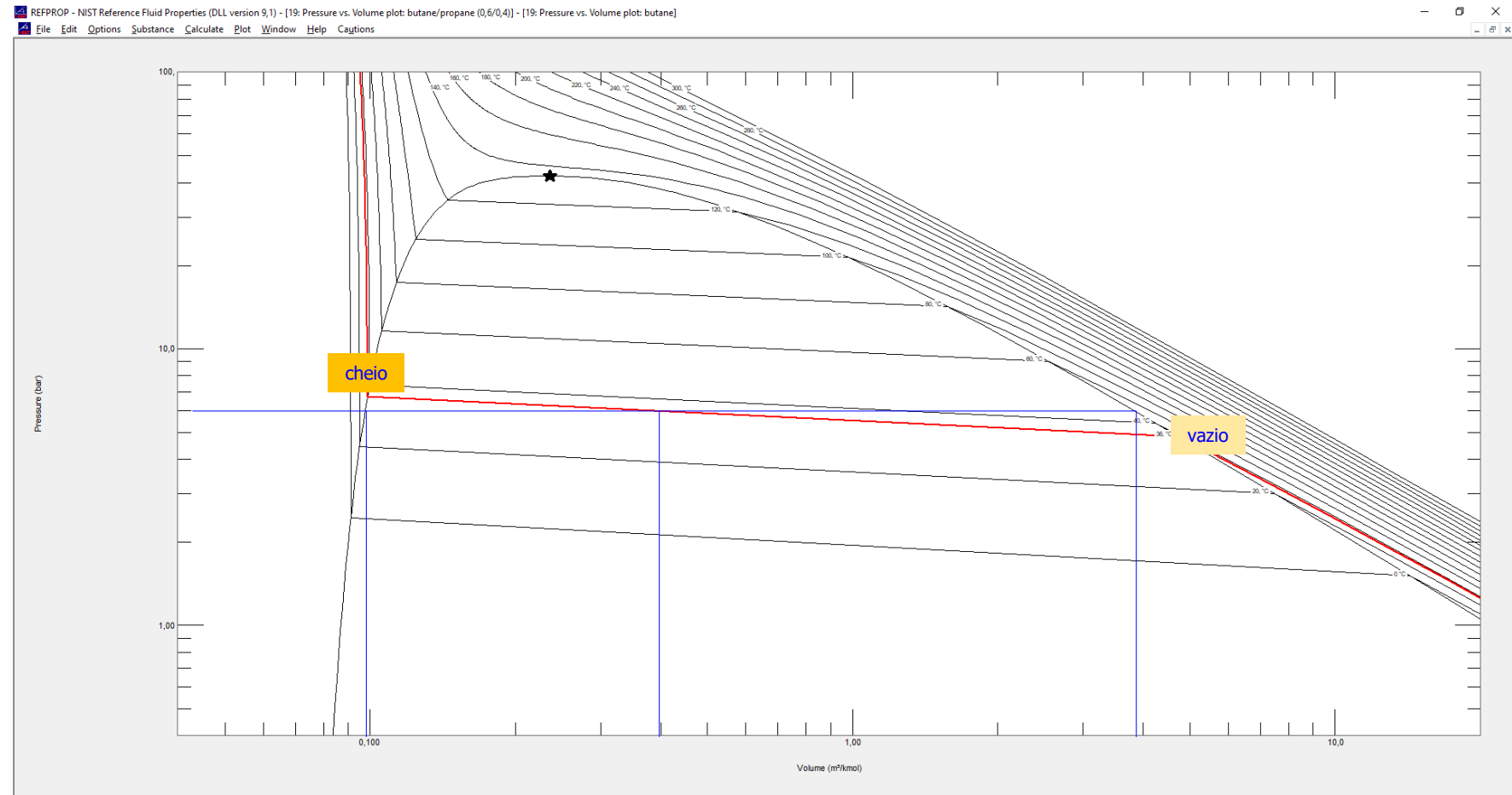
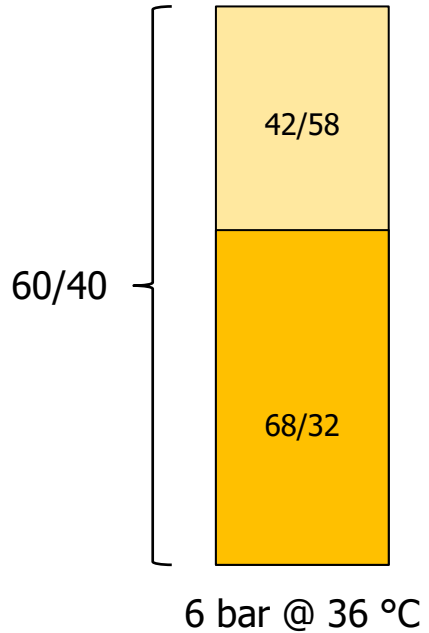
File Edit Options Substance Calculate Plot Window Help Cautions

37: butane/propane: T = 36, °C (0,6/0,4)

	Temperature (°C)	Pressure (bar)	Volume ($m^3/kmol$)	Liquid Phase Volume ($m^3/kmol$)	Vapor Phase Volume ($m^3/kmol$)	Quality (kmol/kmol)	Mole Frac. (butane)	Mole Frac. (propane)	Liquid Phase Mole Frac. (butane)	Liquid Phase Mole Frac. (propane)	Vapor Phase Mole Frac. (butane)	Vapor Phase Mole Frac. (propane)
1	36,000000	0,00000000	Infinite	Superheated	Infinite	Superheated	0,60000000	0,40000000	Superheated	Superheated	0,60000000	0,40000000
2	36,000000	0,50000000	50,879111	Superheated	50,879111	Superheated	0,60000000	0,40000000	Superheated	Superheated	0,60000000	0,40000000
3	36,000000	1,00000000	25,169549	Superheated	25,169549	Superheated	0,60000000	0,40000000	Superheated	Superheated	0,60000000	0,40000000
4	36,000000	1,50000000	16,595890	Superheated	16,595890	Superheated	0,60000000	0,40000000	Superheated	Superheated	0,60000000	0,40000000
5	36,000000	2,00000000	12,306018	Superheated	12,306018	Superheated	0,60000000	0,40000000	Superheated	Superheated	0,60000000	0,40000000
6	36,000000	2,50000000	9,7294925	Superheated	9,7294925	Superheated	0,60000000	0,40000000	Superheated	Superheated	0,60000000	0,40000000
7	36,000000	3,00000000	8,0094828	Superheated	8,0094828	Superheated	0,60000000	0,40000000	Superheated	Superheated	0,60000000	0,40000000
8	36,000000	3,50000000	6,7787575	Superheated	6,7787575	Superheated	0,60000000	0,40000000	Superheated	Superheated	0,60000000	0,40000000
9	36,000000	4,00000000	5,8536819	Superheated	5,8536819	Superheated	0,60000000	0,40000000	Superheated	Superheated	0,60000000	0,40000000
10	36,000000	4,50000000	5,1322167	Superheated	5,1322167	Superheated	0,60000000	0,40000000	Superheated	Superheated	0,60000000	0,40000000
11	36,000000	4,8369134	4,7290767	0,10149686	4,7290767	1,0000000	0,60000000	0,40000000	0,82077075	0,17922925	0,60000000	0,40000000
									vazio			
12	36,000000	5,00000000	3,9770135	0,10125039	4,5652185	0,86823272	0,60000000	0,40000000	0,80126356	0,19873644	0,56945525	0,43054475
13	36,000000	5,50000000	2,3389699	0,10051163	4,1226293	0,55653724	0,60000011	0,39999989	0,74206243	0,25793757	0,48680131	0,51319869
14	36,000000	6,00000000	1,2486968	0,099797833	3,7528609	0,31450291	0,60000026	0,39999974	0,68372440	0,31627560	0,41751340	0,58248660
15	36,000000	6,50000000	0,42600753	0,099108622	3,4392367	0,097870173	0,60000001	0,39999999	0,62619967	0,37380033	0,35850161	0,64149839
									cheio			
16	36,000000	6,7300119	0,098799789	0,098799789	3,3103953	0,00000000	0,60000000	0,40000000	0,60000000	0,40000000	0,33417191	0,66582809
17	36,000000	7,00000000	0,098787464	0,098787464	Subcooled	Subcooled	0,60000000	0,40000000	0,60000000	0,40000000	Subcooled	Subcooled
18	36,000000	7,50000000	0,098764687	0,098764687	Subcooled	Subcooled	0,60000000	0,40000000	0,60000000	0,40000000	Subcooled	Subcooled
19	36,000000	8,00000000	0,098741973	0,098741973	Subcooled	Subcooled	0,60000000	0,40000000	0,60000000	0,40000000	Subcooled	Subcooled
20	36,000000	8,50000000	0,098719322	0,098719322	Subcooled	Subcooled	0,60000000	0,40000000	0,60000000	0,40000000	Subcooled	Subcooled
21	36,000000	9,00000000	0,098696734	0,098696734	Subcooled	Subcooled	0,60000000	0,40000000	0,60000000	0,40000000	Subcooled	Subcooled
22	36,000000	9,50000000	0,098674207	0,098674207	Subcooled	Subcooled	0,60000000	0,40000000	0,60000000	0,40000000	Subcooled	Subcooled
23	36,000000	10,000000	0,098651742	0,098651742	Subcooled	Subcooled	0,60000000	0,40000000	0,60000000	0,40000000	Subcooled	Subcooled



Exercício resolvido: determine a pressão interna num isqueiro de bolso contendo **uma mistura bifásica de 60% butano e 40% propano (m^3/m^3)**. Construa um gráfico mostrando a variação da composição com a pressão @ T_{cte} . (Obs. o miniRefprop não permite trabalhar com misturas.)



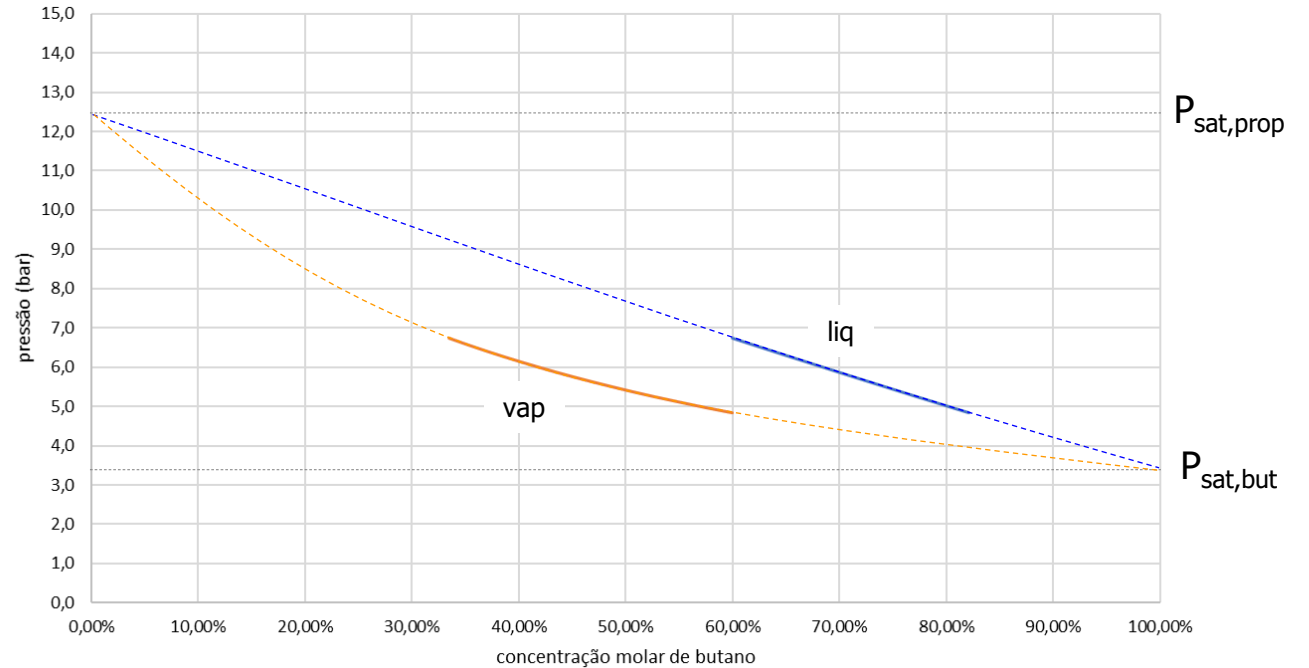
Exercício resolvido: determine a pressão interna num isqueiro de bolso contendo **uma mistura bifásica de 60% butano e 40% propano (m^3/m^3)**. Construa um gráfico mostrando a variação da composição com a pressão @ T_{cte} . (Obs. o miniRefprop não permite trabalhar com misturas.)

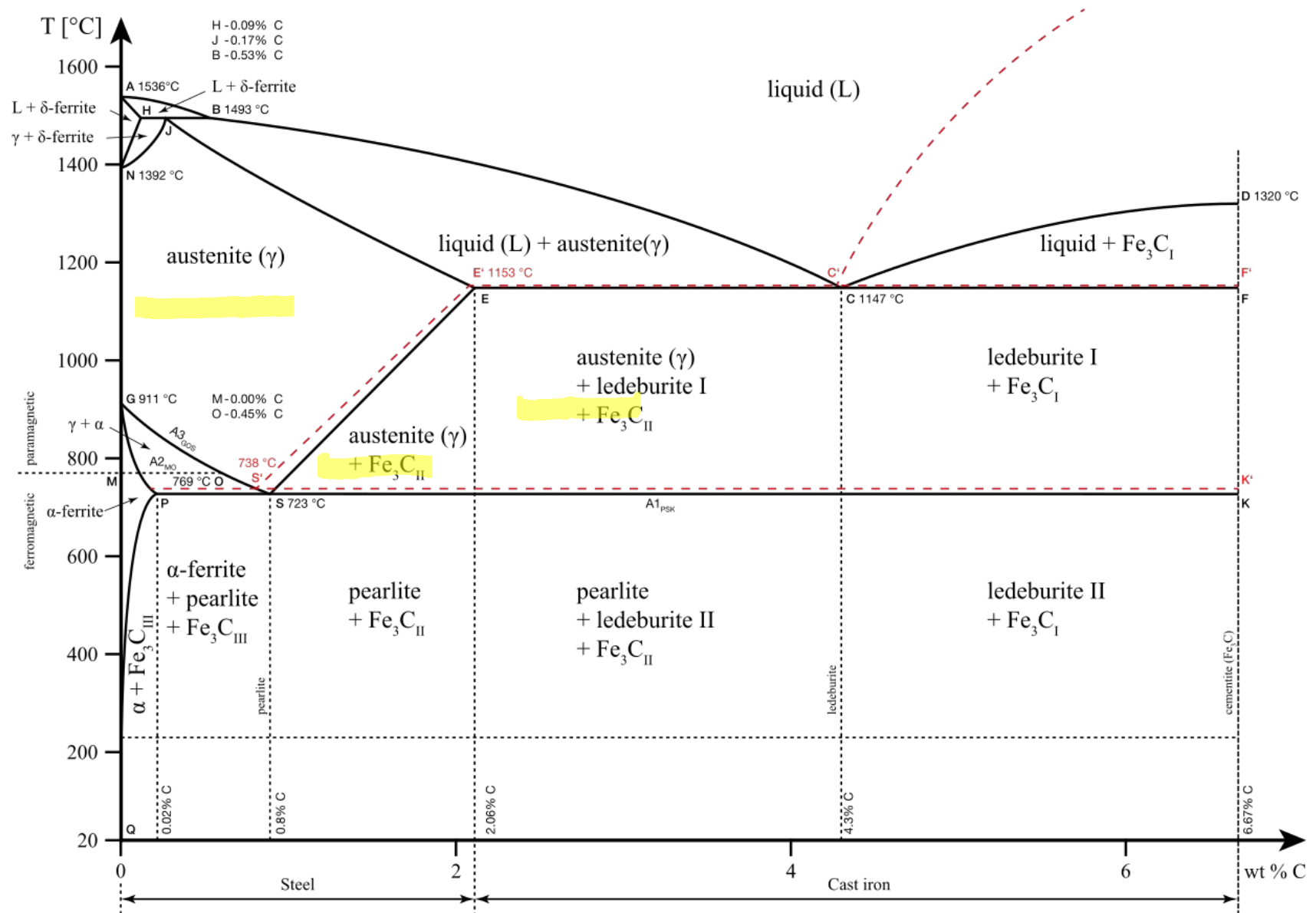
REFPROP - NIST Reference Fluid Properties (DLL version 9.1) - [19: Pressure vs. Volume plot: butane/propane (0,6/0,4)]

File Edit Options Substance Calculate Plot Window Help Cautions

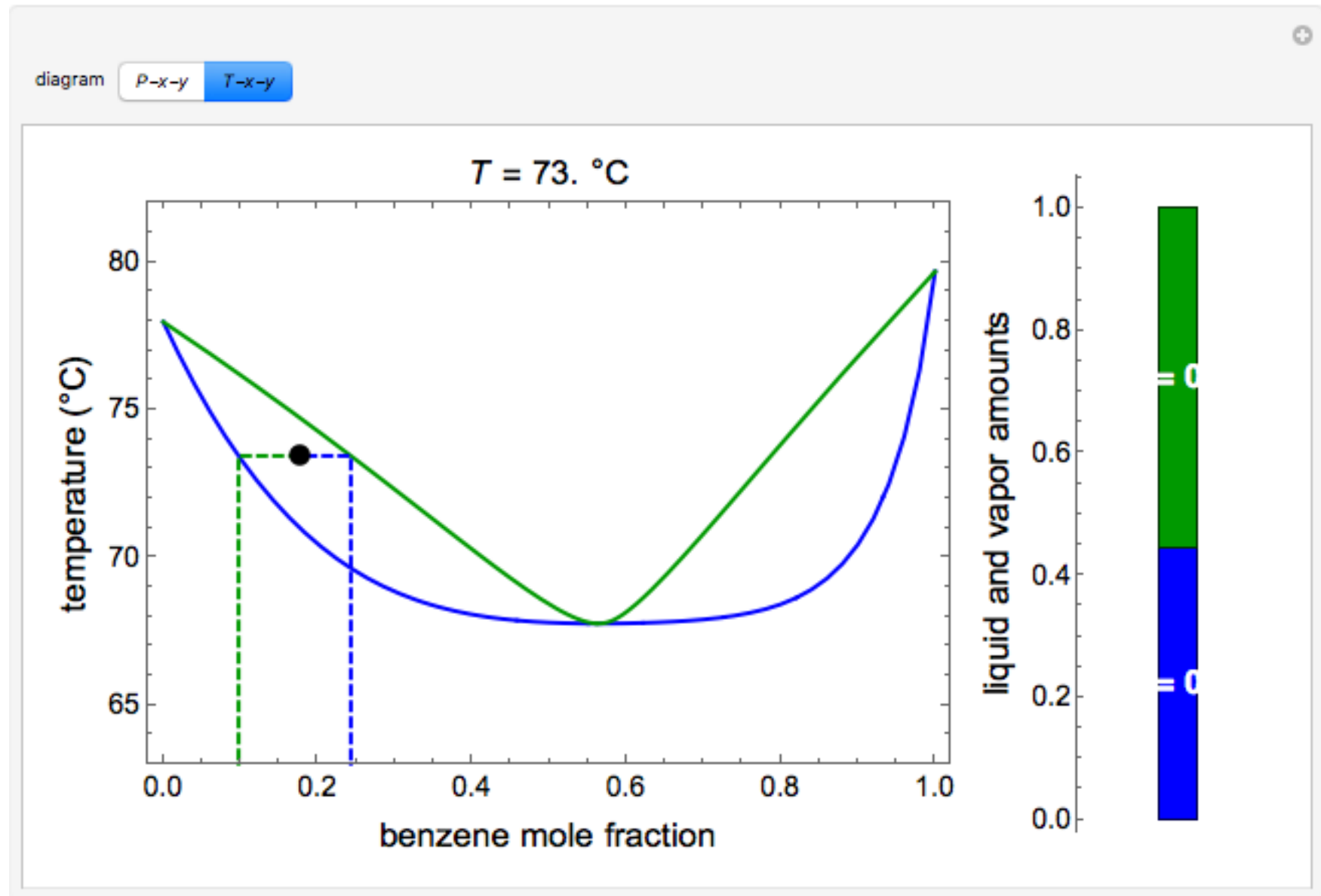
37: butane/propane: T = 36, °C (0,6/0,4)

	Temperature (°C)	Pressure (bar)	Volume (m³/kmol)	Liquid Phase Volume (m³/kmol)	Vapor Phase Volume (m³/kmol)	Quality (kmol/kmol)	Mole Frac. (butane)	Mole Frac. (propane)	Liquid Phase Mole Frac. (butane)	Liquid Phase Mole Frac. (propane)	Vapor Phase Mole Frac. (butane)	Vapor Phase Mole Frac. (propane)
1	36,000000	0,00000000	Infinite	Superheated	Infinite	Superheated	0,60000000	0,40000000	Superheated	Superheated	0,60000000	0,40000000
2	36,000000	0,50000000	50,879111	Superheated	50,879111	Superheated	0,60000000	0,40000000	Superheated	Superheated	0,60000000	0,40000000
3	36,000000	1,00000000	25,169549	Superheated	25,169549	Superheated	0,60000000	0,40000000	Superheated	Superheated	0,60000000	0,40000000
4	36,000000	1,50000000	16,595990	Superheated	16,595990	Superheated	0,60000000	0,40000000	Superheated	Superheated	0,60000000	0,40000000
5	36,000000	2,00000000	12,306018	Superheated	12,306018	Superheated	0,60000000	0,40000000	Superheated	Superheated	0,60000000	0,40000000
6	36,000000	2,50000000	9,7294925	Superheated	9,7294925	Superheated	0,60000000	0,40000000	Superheated	Superheated	0,60000000	0,40000000
7	36,000000	3,00000000	8,0094828	Superheated	8,0094828	Superheated	0,60000000	0,40000000	Superheated	Superheated	0,60000000	0,40000000
8	36,000000	3,50000000	6,7787575	Superheated	6,7787575	Superheated	0,60000000	0,40000000	Superheated	Superheated	0,60000000	0,40000000
9	36,000000	4,00000000	5,8536819	Superheated	5,8536819	Superheated	0,60000000	0,40000000	Superheated	Superheated	0,60000000	0,40000000
10	36,000000	4,50000000	5,1322167	Superheated	5,1322167	Superheated	0,60000000	0,40000000	Superheated	Superheated	0,60000000	0,40000000
vazio	36,000000	4,8369134	4,7290767	0,10149686	4,7290767	1,00000000	0,60000000	0,40000000	0,62077075	0,17922925	0,60000000	0,40000000
12	36,000000	5,00000000	3,9770135	0,10125039	4,5652185	0,86823272	0,60000000	0,40000000	0,80126356	0,19873644	0,56945525	0,43054475
13	36,000000	5,50000000	2,3389699	0,10051163	4,1226293	0,55853724	0,60000011	0,39999989	0,74206243	0,25793757	0,48680131	0,51319869
14	36,000000	6,00000000	1,2486968	0,099797833	3,7528609	0,31450291	0,60000026	0,39999974	0,68372440	0,31627560	0,41751340	0,58248660
15	36,000000	6,50000000	0,42600753	0,099108622	3,4392367	0,097870173	0,60000001	0,39999999	0,62619967	0,37380033	0,35850161	0,64149839
cheio	36,000000	6,7300119	0,098799789	0,098799789	3,3103953	0,00000000	0,60000000	0,40000000	0,60000000	0,40000000	0,33417191	0,66582809
17	36,000000	7,00000000	0,098787464	0,098787464	Subcooled	Subcooled	0,60000000	0,40000000	0,60000000	0,40000000	Subcooled	Subcooled
18	36,000000	7,50000000	0,098764687	0,098764687	Subcooled	Subcooled	0,60000000	0,40000000	0,60000000	0,40000000	Subcooled	Subcooled
19	36,000000	8,00000000	0,098741973	0,098741973	Subcooled	Subcooled	0,60000000	0,40000000	0,60000000	0,40000000	Subcooled	Subcooled
20	36,000000	8,50000000	0,098719322	0,098719322	Subcooled	Subcooled	0,60000000	0,40000000	0,60000000	0,40000000	Subcooled	Subcooled
21	36,000000	9,00000000	0,098696734	0,098696734	Subcooled	Subcooled	0,60000000	0,40000000	0,60000000	0,40000000	Subcooled	Subcooled
22	36,000000	9,50000000	0,098674207	0,098674207	Subcooled	Subcooled	0,60000000	0,40000000	0,60000000	0,40000000	Subcooled	Subcooled
23	36,000000	10,000000	0,098651742	0,098651742	Subcooled	Subcooled	0,60000000	0,40000000	0,60000000	0,40000000	Subcooled	Subcooled



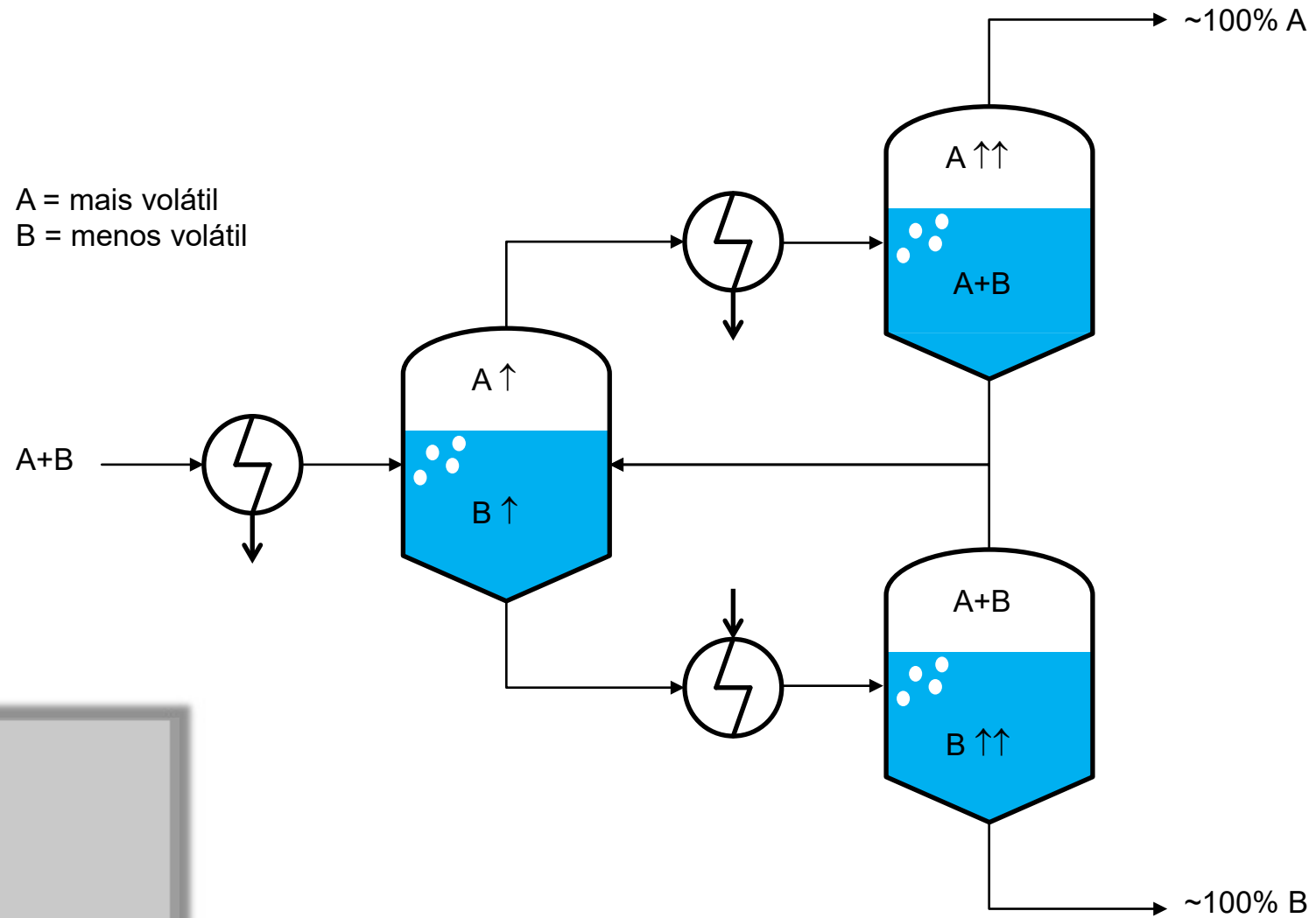


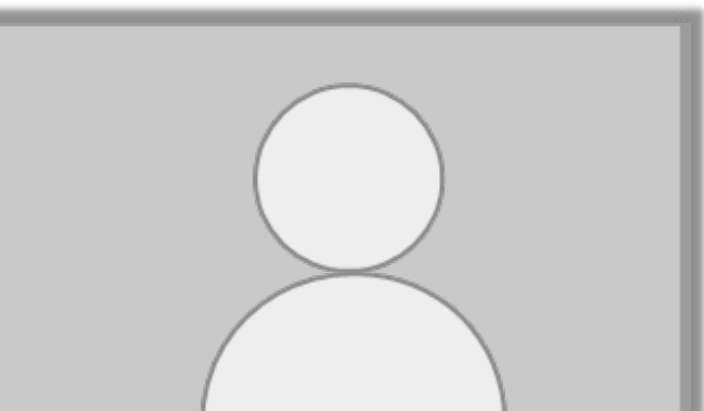
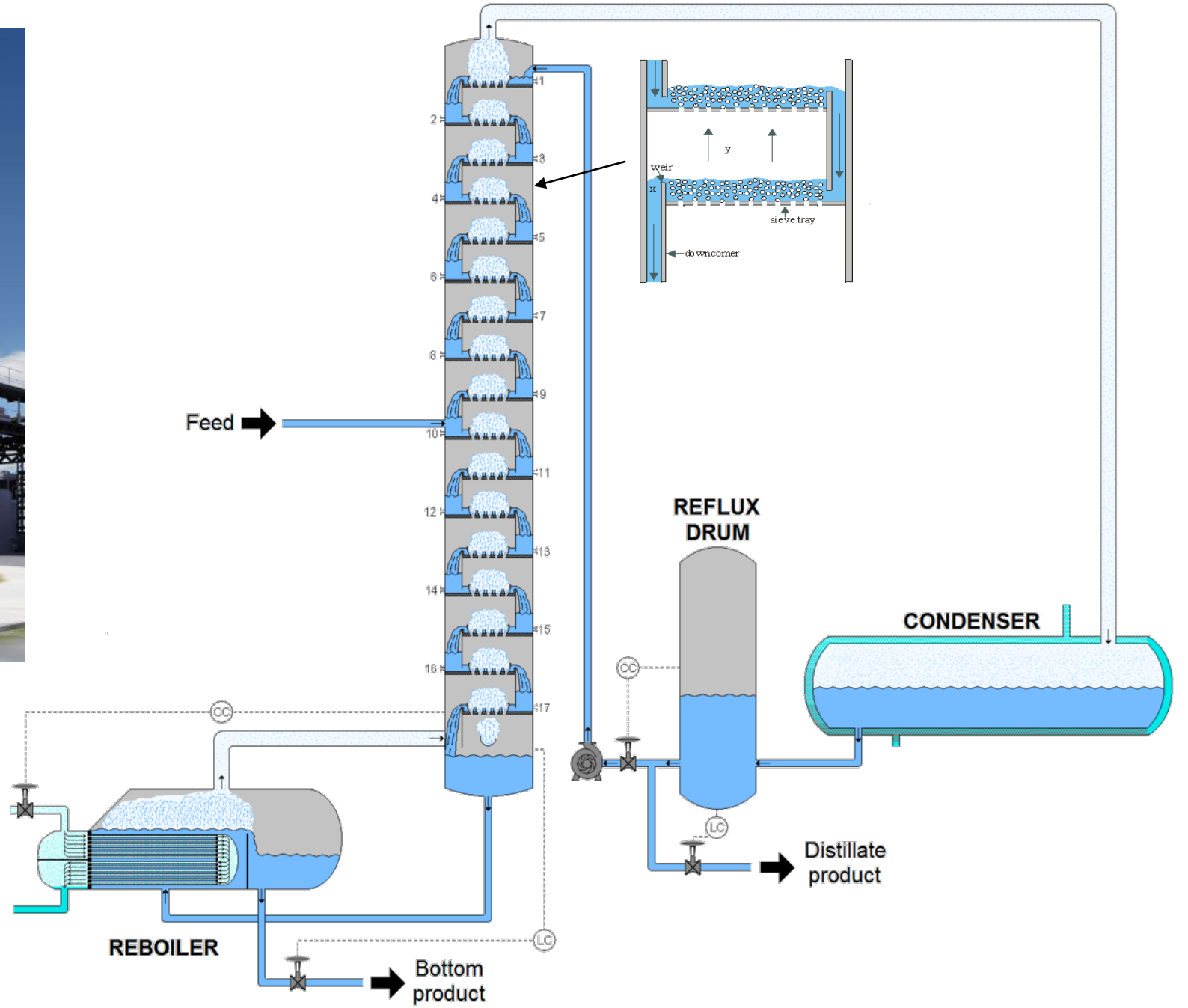
Iron-carbon phase diagram, showing the conditions under which **austenite** (γ) is stable in carbon steel.



Diagrams for vapor-liquid equilibrium (VLE) of a benzene/ethanol mixture (Wolfram)

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