

۱ ترمودینامیک

استاد:

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۱۳۹۹



بورگناک - زونتاگ - (ون وایلن)

ویرایش ہفتم

چاپ سی و ششم

مبانی ترمودینامیک



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solid states, the liquid P - v - T surface for lower temperatures is fairly steep and flat, so this region also describes an incompressible substance with a specific volume that is only a weak function of T , which we can write

$$v \approx v(T) = v_f \quad (2.3)$$

where the saturated liquid specific volume v_f at T is found in the Appendix B tables as the first part of the tables for each substance. A few other entries are found as density ($1/v$) for some common liquids in Tables A.3 and F.2.

In-Text Concept Questions

- a. If the pressure is smaller than the smallest P_{sat} at a given T , what is the phase?
- b. An external water tap has the valve activated by a long spindle, so the closing mechanism is located well inside the wall. Why?
- c. What is the lowest temperature (approximately) at which water can be liquid?

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.

- Ammonia 30°C , 1000 kPa
- R-134a 200 kPa, $0.125\text{ m}^3/\text{kg}$

Solution

- 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 .

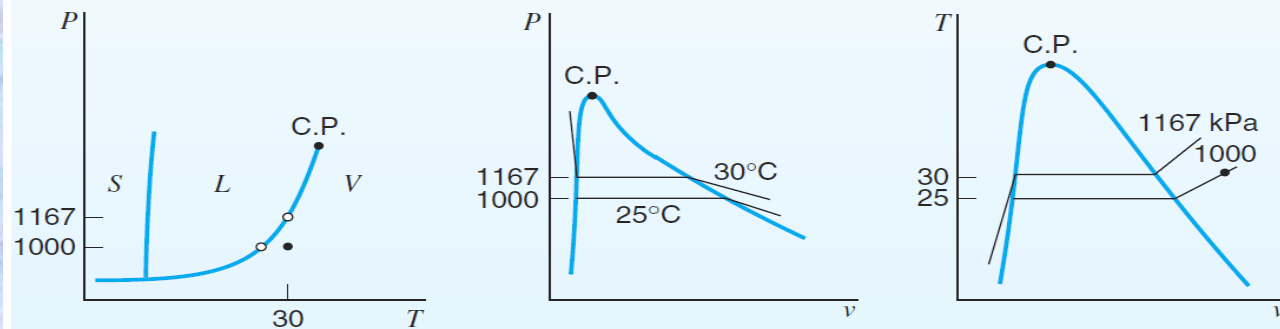


FIGURE 2.13 Diagram for Example 2.3a.

- 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 .

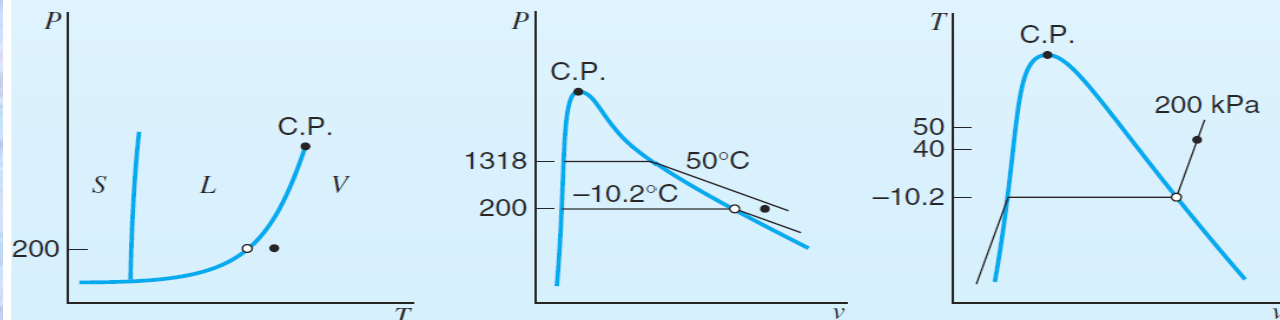


FIGURE 2.14 Diagram for Example 2.3b.

Example 2.4

A rigid vessel contains saturated ammonia vapor at 20°C. Heat is transferred to the system until the temperature reaches 40°C. What is the final pressure?

Solution

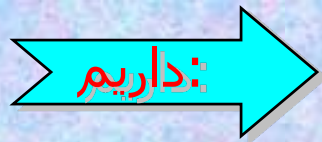
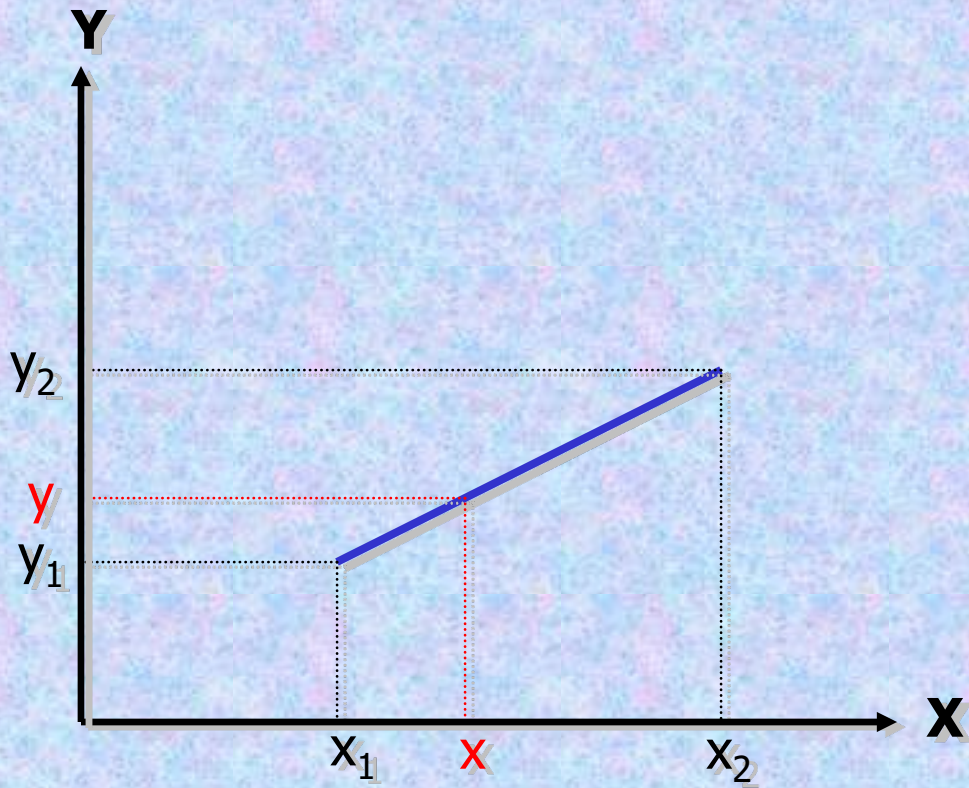
Since the volume does not change during this process, the specific volume also remains constant. From the ammonia tables, Table B.2.1, we have

$$v_1 = v_2 = 0.14922 \text{ m}^3/\text{kg}$$

Since v_g at 40°C is less than 0.14922 m³/kg, it is evident that in the final state the ammonia is superheated vapor. By interpolating between the 800- and 1000-kPa columns of Table B.2.2, we find that

$$P_2 = 945 \text{ kPa}$$

فرمول درون یابی :



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

Example 2.5

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

Solution

Start in Table B.1.1 with 200°C and note that $\nu > \nu_g = 0.12736 \text{ m}^3/\text{kg}$, so we have superheated vapor. Proceed to Table B.1.3 at any subsection with 200°C ; suppose we start at 200 kPa. There $\nu = 1.08034$, which is too large, so the pressure must be higher. For 500 kPa, $\nu = 0.42492$, and for 600 kPa, $\nu = 0.35202$, so it is bracketed. This is shown in Fig. 2.15.

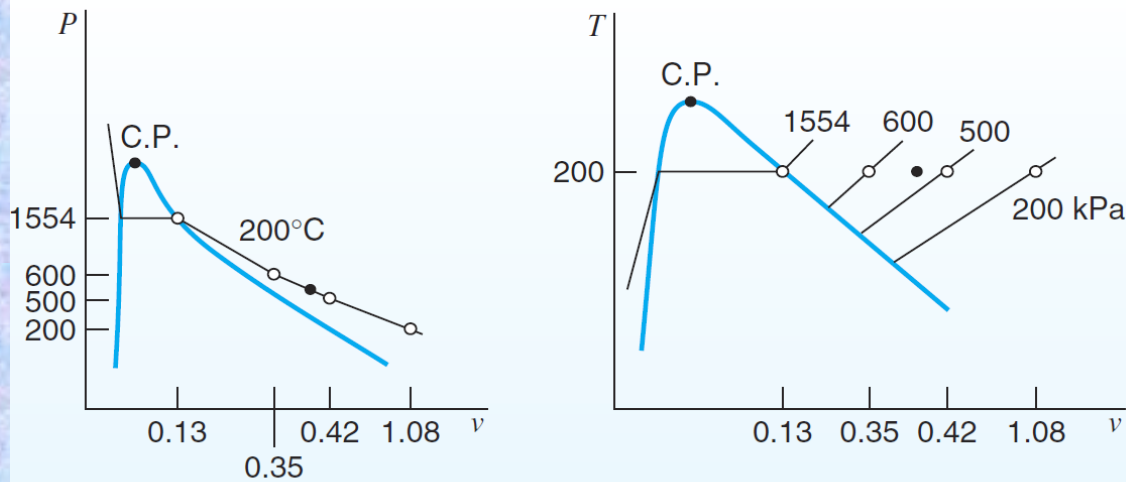
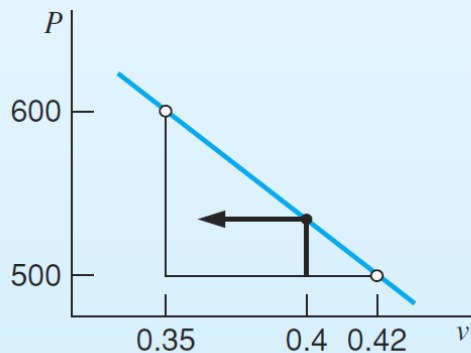


FIGURE 2.15 Diagram for Example 2.5.

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

$$P = 500 + (600 - 500) \frac{0.4 - 0.42492}{0.35202 - 0.42492} = 534.2 \text{ kPa}$$

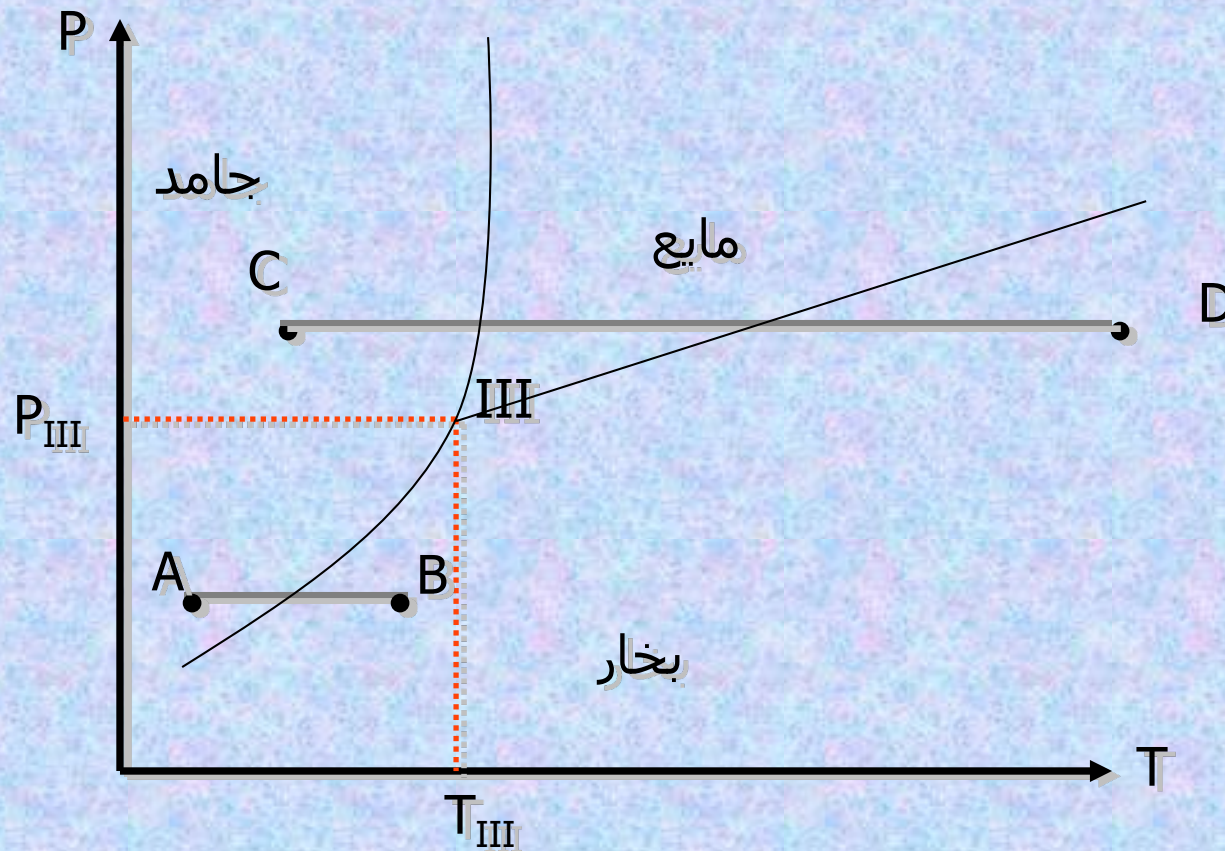


The real constant-T curve is slightly curved and not linear, but for manual interpolation we assume a linear variation.

FIGURE 2.16 Linear interpolation for Example 2.5.

نقطه سه گانه:

حالتی است که در آن هر سه فاز جامد، مایع و گاز می‌توانند در تعادل با یکدیگر باشند. به عنوان مثال برای آب در فشار 611.3 pa و دمای 0.01°C هر سه حالت ماده وجود دارند.



* با توجه به نمودار قبل می‌توان مشاهده کرد که چگونه فازهای مختلف با یکدیگر در حال تعادل هستند. همچنین می‌توان در مورد تغییر فرایندهای مختلف با توجه به اینکه فشار کمتر از فشار نقطه سه‌گانه یا بیشتر از آن باشد، صحبت کرد. (فرایند AB و CD)

بخار $\xrightarrow{\text{طی (AB) جامد}}$: با افزایش دما ، $P < P_{III}$

بخار $\xrightarrow{\text{طی (CD) مایع}}$ جامد $\xrightarrow{\text{طی (CD) مایع}}$: با افزایش دما ، $P > P_{III}$

نکته: برای تشخیص حالت ماده نیاز به در دست داشتن دو مشخصه آن است مثل فشار و دما اما اگر حالت اشباع باشد نیاز به داشتن دو مشخصه مستقل از هم می‌باشد. فشار و دما در حالت اشباع مستقل از هم نیستند. پس به عنوان مثال فشار و حجم ویژه یا عیار و دما را باید داشته باشیم.

TABLE 2.1

Some Solid–Liquid–Vapor Triple-Point Data

	Temperature, °C	Pressure, kPa
Hydrogen (normal)	−259	7.194
Oxygen	−219	0.15
Nitrogen	−210	12.53
Carbon dioxide	−56.4	520.8
Mercury	−39	0.000 000 13
Water	0.01	0.6113
Zinc	419	5.066
Silver	961	0.01
Copper	1083	0.000 079

معادله حالت گاز ایده‌آل:

P [kpa]

V[m³]

M[kg]

$$* \quad R = \frac{\bar{R}}{M}, \quad PV = mRT \quad \bar{R} = 8.3144 \left[\frac{kJ}{kmol.k} \right]$$

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

همچنین
داریم \rightarrow

$$* \quad \frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2}$$

R ثابت عمومی گازها، \bar{R} ثابت جهانی گازها، M جرم مولکولی $\left[\frac{KJ}{Kmol} \right]$

TABLE A.5

Properties of Various Ideal Gases at 25°C, 100 kPa* (SI Units)

Gas	Chemical Formula	Molecular Mass (kg/kmol)	R (kJ/kg-K)	ρ (kg/m ³)	C_{p0} (kJ/kg-K)	C_{v0} (kJ/kg-K)	$k = \frac{C_p}{C_v}$
Steam	H ₂ O	18.015	0.4615	0.0231	1.872	1.410	1.327
Acetylene	C ₂ H ₂	26.038	0.3193	1.05	1.699	1.380	1.231
Air	—	28.97	0.287	1.169	1.004	0.717	1.400
Ammonia	NH ₃	17.031	0.4882	0.694	2.130	1.642	1.297
Argon	Ar	39.948	0.2081	1.613	0.520	0.312	1.667
Butane	C ₄ H ₁₀	58.124	0.1430	2.407	1.716	1.573	1.091
Carbon dioxide	CO ₂	44.01	0.1889	1.775	0.842	0.653	1.289
Carbon monoxide	CO	28.01	0.2968	1.13	1.041	0.744	1.399
Ethane	C ₂ H ₆	30.07	0.2765	1.222	1.766	1.490	1.186
Ethanol	C ₂ H ₅ OH	46.069	0.1805	1.883	1.427	1.246	1.145
Ethylene	C ₂ H ₄	28.054	0.2964	1.138	1.548	1.252	1.237
Helium	He	4.003	2.0771	0.1615	5.193	3.116	1.667
Hydrogen	H ₂	2.016	4.1243	0.0813	14.209	10.085	1.409
Methane	CH ₄	16.043	0.5183	0.648	2.254	1.736	1.299
Methanol	CH ₃ OH	32.042	0.2595	1.31	1.405	1.146	1.227
Neon	Ne	20.183	0.4120	0.814	1.03	0.618	1.667
Nitric oxide	NO	30.006	0.2771	1.21	0.993	0.716	1.387
Nitrogen	N ₂	28.013	0.2968	1.13	1.042	0.745	1.400
Nitrous oxide	N ₂ O	44.013	0.1889	1.775	0.879	0.690	1.274
<i>n</i> -Octane	C ₈ H ₁₈	114.23	0.07279	0.092	1.711	1.638	1.044
Oxygen	O ₂	31.999	0.2598	1.292	0.922	0.662	1.393
Propane	C ₃ H ₈	44.094	0.1886	1.808	1.679	1.490	1.126
R-12	CCl ₂ F ₂	120.914	0.06876	4.98	0.616	0.547	1.126
R-22	CHClF ₂	86.469	0.09616	3.54	0.658	0.562	1.171
R-32	CF ₂ H ₂	52.024	0.1598	2.125	0.822	0.662	1.242
R-125	CHF ₂ CF ₃	120.022	0.06927	4.918	0.791	0.722	1.097
R-134a	CF ₃ CH ₂ F	102.03	0.08149	4.20	0.852	0.771	1.106
R-410a	—	72.585	0.11455	2.967	0.809	0.694	1.165
Sulfur dioxide	SO ₂	64.059	0.1298	2.618	0.624	0.494	1.263
Sulfur trioxide	SO ₃	80.053	0.10386	3.272	0.635	0.531	1.196

*Or saturation pressure if it is less than 100 kPa.

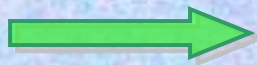
$$24 \frac{Kj}{Kmol}$$

Quiz: مخزني به حجم 1 m^3 داراي 20 Kg گاز ايده آل به وزن مولكولي در دماي 25°C است. فشار را بدست آوريد.

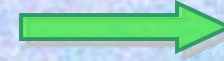
$$m=20 \text{ Kg}$$

$$T=273+25^\circ\text{C}=298^\circ\text{K}$$

$$PV=mRT$$



$$P \times 1 = 20 \times 298 \times \frac{8.3144}{24}$$



$$P=2064.74 \text{ KPa}$$

2.9 THE COMPRESSIBILITY FACTOR

A more quantitative study of the question of the ideal gas approximation can be conducted by introducing the **compressibility factor** Z , defined as

$$Z = \frac{Pv}{RT}$$

or

$$Pv = ZRT \quad (2.12)$$

Note that for an ideal gas $Z = 1$, and the deviation of Z from unity is a measure of the deviation of the actual relation from the ideal gas equation of state.

Figure 2.20 shows a skeleton compressibility chart for nitrogen. From this chart we make three observations. The first is that at all temperatures $Z \rightarrow 1$ as $P \rightarrow 0$. That is,

as the pressure approaches zero, the P - v - T behavior closely approaches that predicted by the ideal gas equation of state. Second, at temperatures of 300 K and above (that is, room temperature and above), the compressibility factor is near unity up to a pressure of about 10 MPa. This means that the ideal gas equation of state can be used for nitrogen (and, as it happens, air) over this range with considerable accuracy.

Third, at lower temperatures or at very high pressures, the compressibility factor deviates significantly from the ideal gas value. Moderate-density forces of attraction tend to pull molecules together, resulting in a value of $Z < 1$, whereas very-high-density forces of repulsion tend to have the opposite effect.

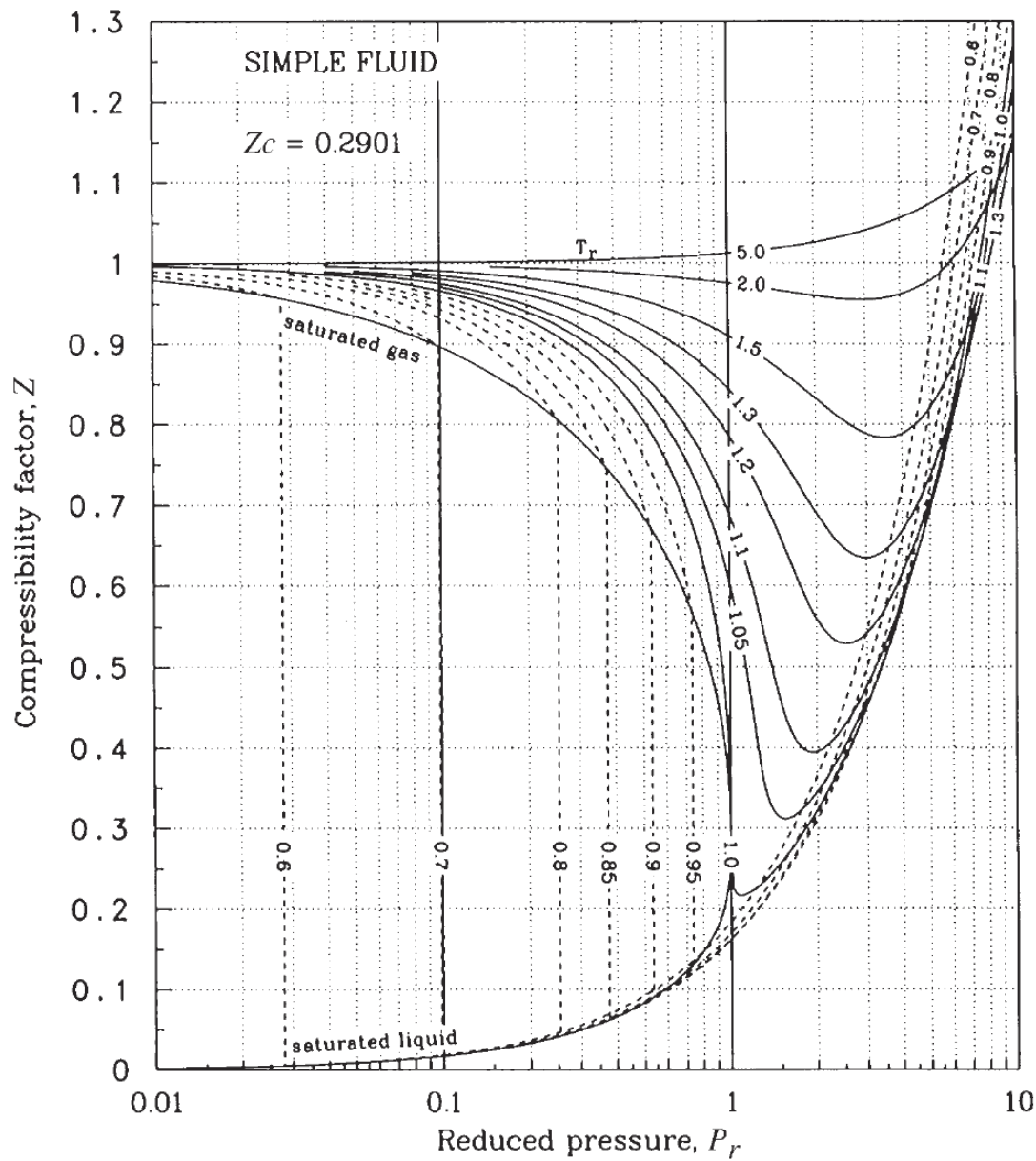


FIGURE D.1 Lee-Kesler simple fluid compressibility factor.

$$\text{reduced pressure} = P_r = \frac{P}{P_c}, \quad P_c = \text{critical pressure}$$

$$\text{reduced temperature} = T_r = \frac{T}{T_c}, \quad T_c = \text{critical temperature} \quad (2.13)$$

Example 2.9

Is it reasonable to assume ideal gas behavior at each of the given states?

- a. Nitrogen at 20°C, 1.0 MPa
- b. Carbon dioxide at 20°C, 1.0 MPa
- c. Ammonia at 20°C, 1.0 MPa

Solution

In each case, it is first necessary to check phase boundary and critical state data.

- a. For nitrogen, the critical properties are, from Table A.2, 126.2 K, 3.39 MPa. Since the given temperature, 293.2 K, is more than twice T_c and the reduced pressure is less than 0.3, ideal gas behavior is a very good assumption.
- b. For carbon dioxide, the critical properties are 304.1 K, 7.38 MPa. Therefore, the reduced properties are 0.96 and 0.136. From Fig. D.1, carbon dioxide is a gas (although $T < T_c$) with a Z of about 0.95, so the ideal gas model is accurate to within about 5% in this case.
- c. The ammonia tables, Table B.2, give the most accurate information. From Table B.2.1 at 20°C, $P_g = 858$ kPa. Since the given pressure of 1 MPa is greater than P_g , this state is a compressed liquid, not a gas.

Example 2.10

Determine the specific volume for R-134a at 100°C, 3.0 MPa for the following models:

- a. The R-134a tables, Table B.5
- b. Ideal gas
- c. The generalized chart, Fig. D.1

Solution

a. From Table B.5.2 at 100°C, 3 MPa

$$v = 0.006\ 65\ \text{m}^3/\text{kg}\ (\text{most accurate value})$$

b. Assuming ideal gas, we have

$$R = \frac{\bar{R}}{M} = \frac{8.3145}{102.03} = 0.081\ 49\ \frac{\text{kJ}}{\text{kg K}}$$

$$v = \frac{RT}{P} = \frac{0.081\ 49 \times 373.2}{3000} = 0.010\ 14\ \text{m}^3/\text{kg}$$

which is more than 50% too large.

c. Using the generalized chart, Fig. D.1, we obtain

$$T_r = \frac{373.2}{374.2} = 1.0, \quad P_r = \frac{3}{4.06} = 0.74, \quad Z = 0.67$$

$$v = Z \times \frac{RT}{P} = 0.67 \times 0.010\ 14 = 0.006\ 79\ \text{m}^3/\text{kg}$$

which is only 2% too large.

Example 2.11

Propane in a steel bottle of volume 0.1 m³ has a quality of 10% at a temperature of 15°C. Use the generalized compressibility chart to estimate the total propane mass and to find the pressure.

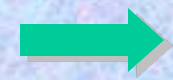
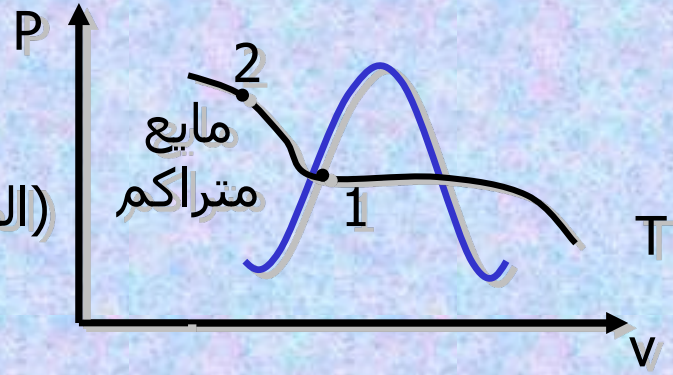
Quiz: برروي يك پيستون بوسيله چند سكه پوشيده شده است. با توجه به اينكه ديواره سيلندر هادي حرارت است و حالت ابتدائي سيستم مايع اشباع مي باشد:



(الف) اگر يك سكه به آن اضافه شود حالت تعادل نهايي چيست؟
(ب) اگر يك سكه از روي پيستون برداريم حالت تعادل نهايي چيست؟

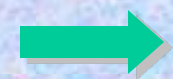
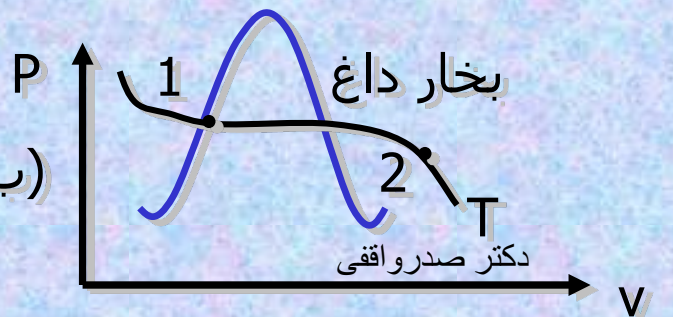
دما \rightleftharpoons دماي محيط \longrightarrow ديواره سيلندر هادي حرارت

(الف) اگر سكه اضافه شود



P افزايش مي يابد
 پس حالت انتهايي
 مايع متراكم است.

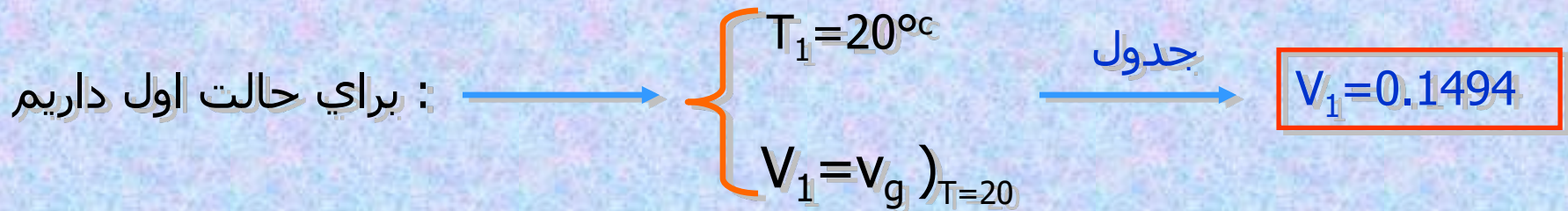
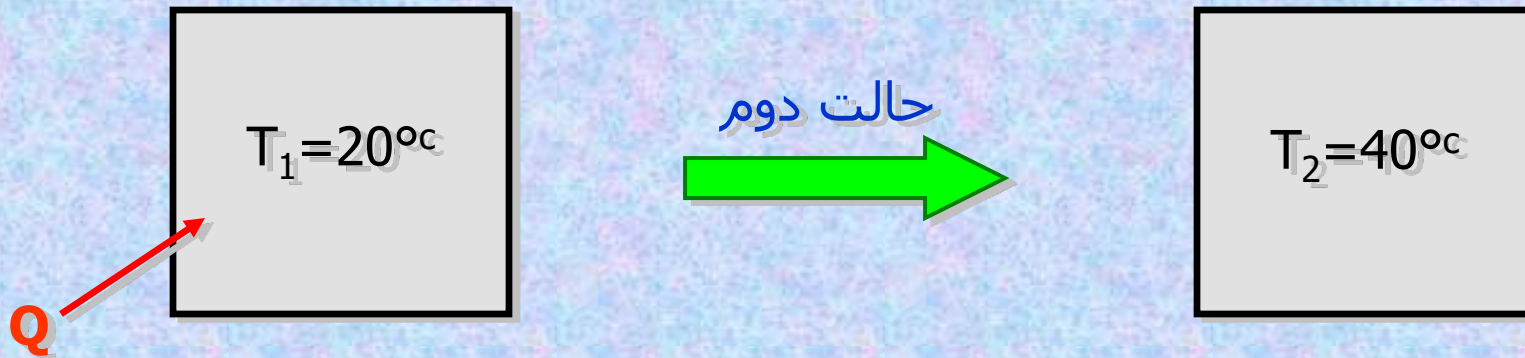
(ب) اگر سكه كم شود



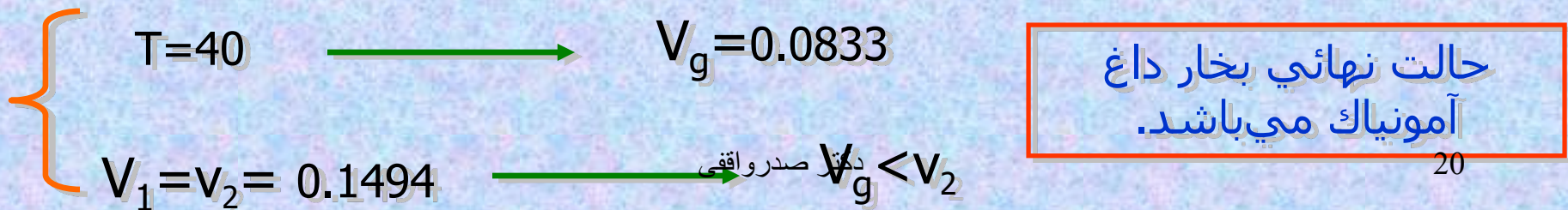
P کاهش مي يابد
 پس حالت انتهايي
 بخار دوف است.

دکتر صدرواقفی

Quiz: به بخار اشباع آمونیاك در دماي 20°C درون يك مخزن صلب حرارت داده مي شود تا دماي آن به 40°C برسد. فشار پاياني چقدر است؟



★ براي تشخيص حالت نهائي سيستم با استفاده از جدول اشباع آمونیاك داريم:



★ به جدول بخار داغ آمونیاك مراجعه مي‌كنيم تا براي دماي 40 درجه و حجم ویژه $v=0.1494$ فشار را بدست آوريم.

از جدول $\longrightarrow T=40, v=0.1494, p=?$

★ حجم ویژه مورد نظر ما در جدول ترموديناميك نيست پس از فرمول درونيابي استفاده مي‌كنيم:

	p	v
1	900	0.1559
	?	0.1494
2	1000	0.1388

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

$$P=938.01$$

تمرین: در ظرفی به حجم 0.4 m^3 , 2 Kg آب مایع و بخار آب در فشار 600 Kpas در حالت تعادل هستند. جرم مایع و جرم بخار را بدست آورید.

$$v = \frac{V}{m} = \frac{0.4}{2} = 0.2 \quad \frac{\text{m}^3}{\text{Kg}}$$

$P=600 \text{ Kpas}$
جدول اشباع \rightarrow $v_f=0.001101$, $v_g=0.3157$

$$v = v_f + v_{fg} \rightarrow 0.2 = 0.001101 + x(0.3157 - 0.001101) \rightarrow x = 0.6322$$

$$x = \frac{m_g}{m_g + m_f} \rightarrow 0.6322 = \frac{m_g}{2} \rightarrow m_g = 1.2644$$

$$m_f + m_g = 2 \rightarrow m_f = 0.7355$$