Focus 1: Properties of gases

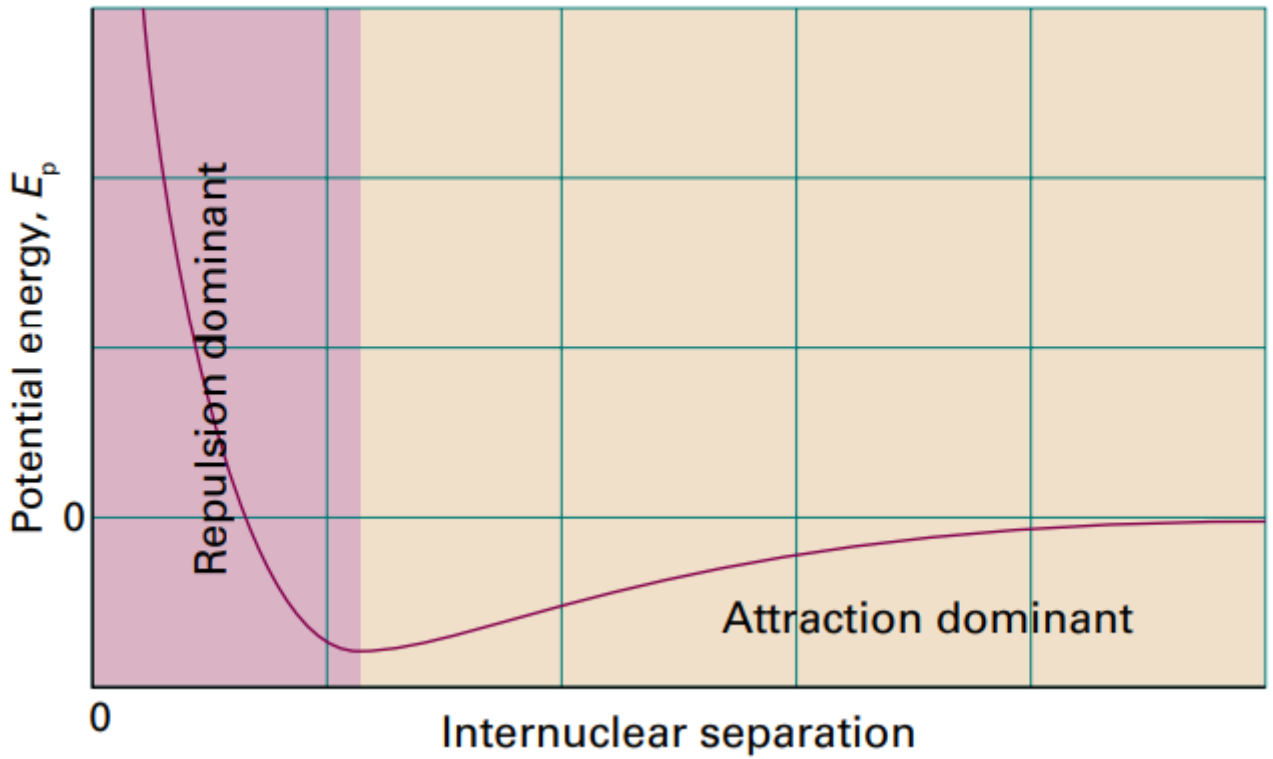
Perfect gas

Kinetic model

Real gases

Real gases

Interactions!



0
At large separations

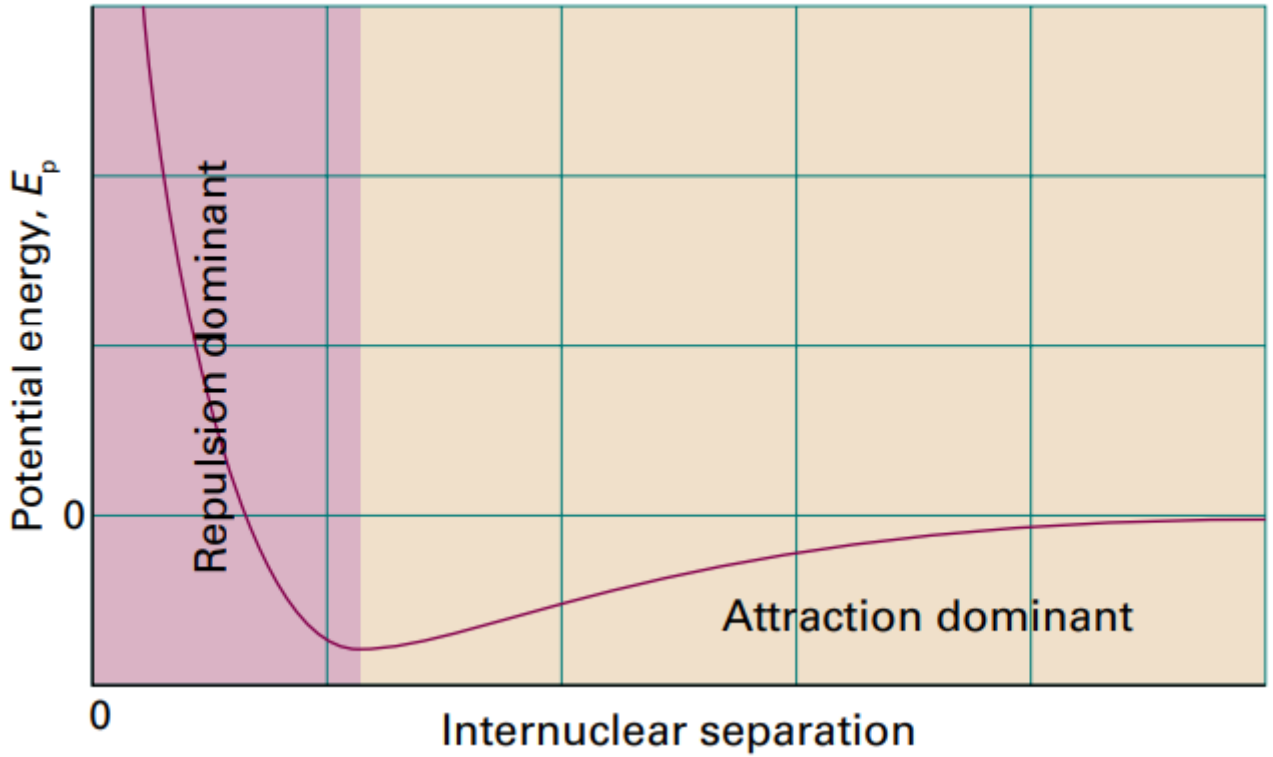
Small separations

Intermediate separations

Real gases

At high P, low T: Interactions are stronger

Interactions!



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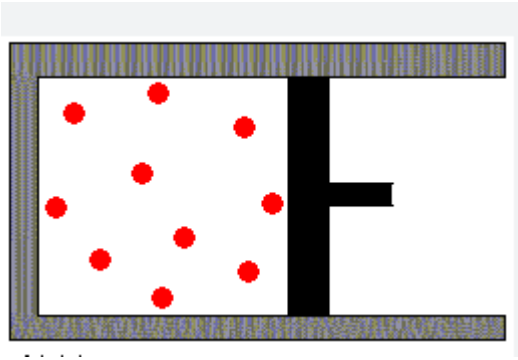
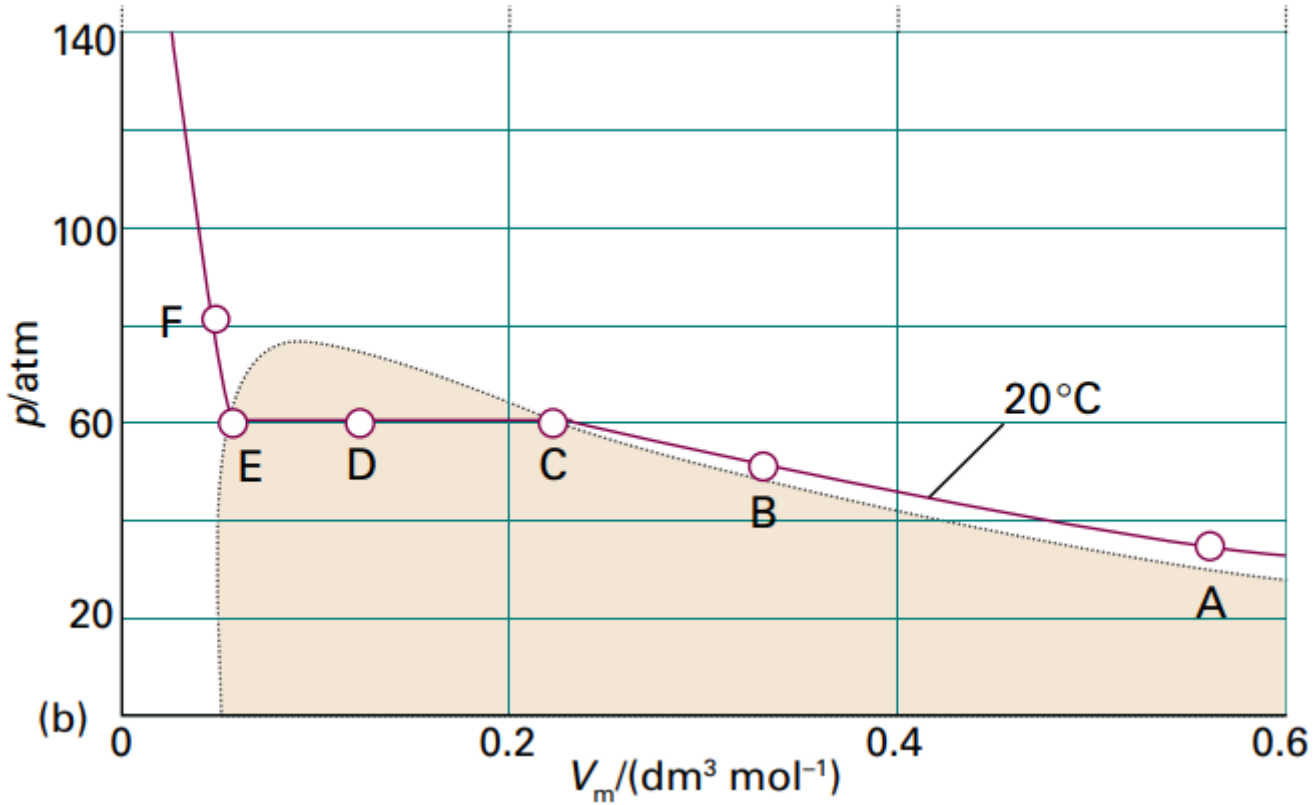
Compression

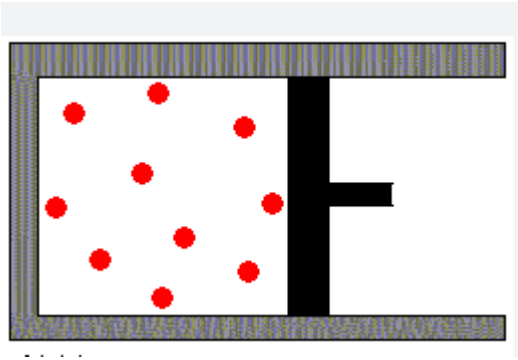


At constant T



Compression

Isothermal or adiabatic?



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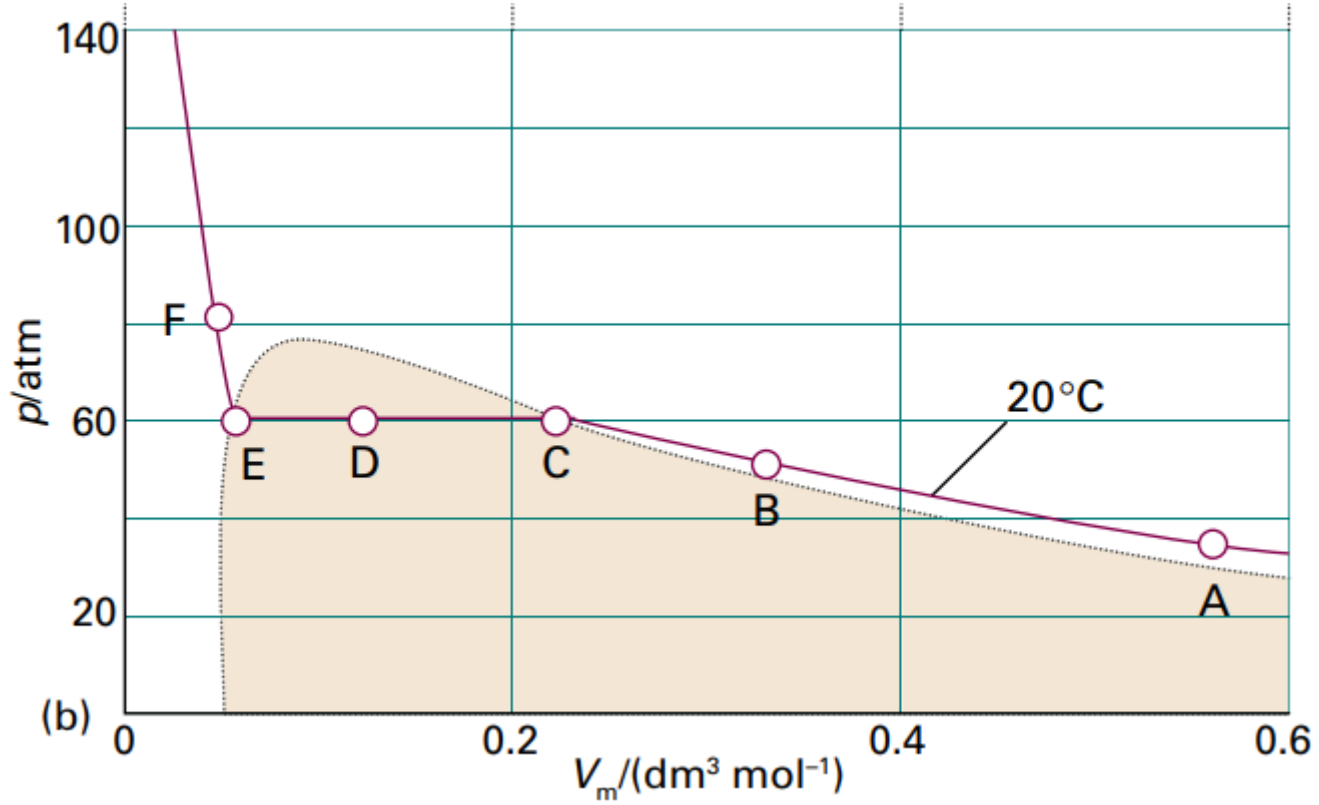
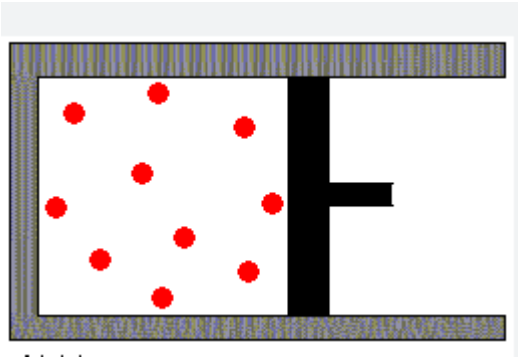


Compression

Heat transfer: Heat is exchanged with the surroundings to keep the temperature constant (isothermal)
Work Done: The work done on the gas is completely transferred as heat to the surroundings.



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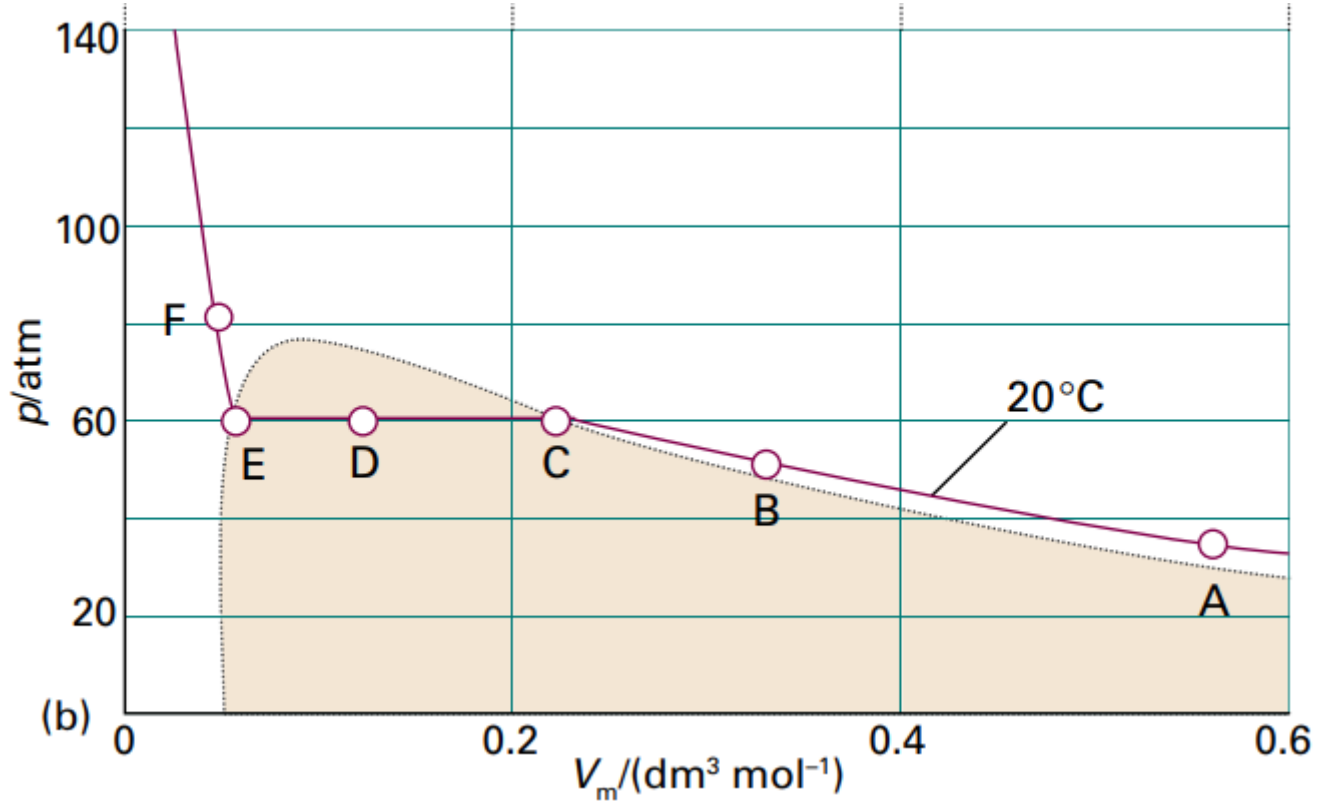

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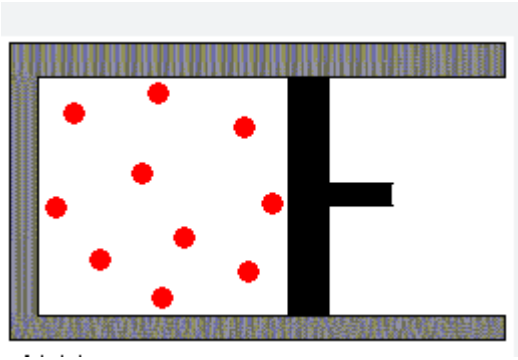

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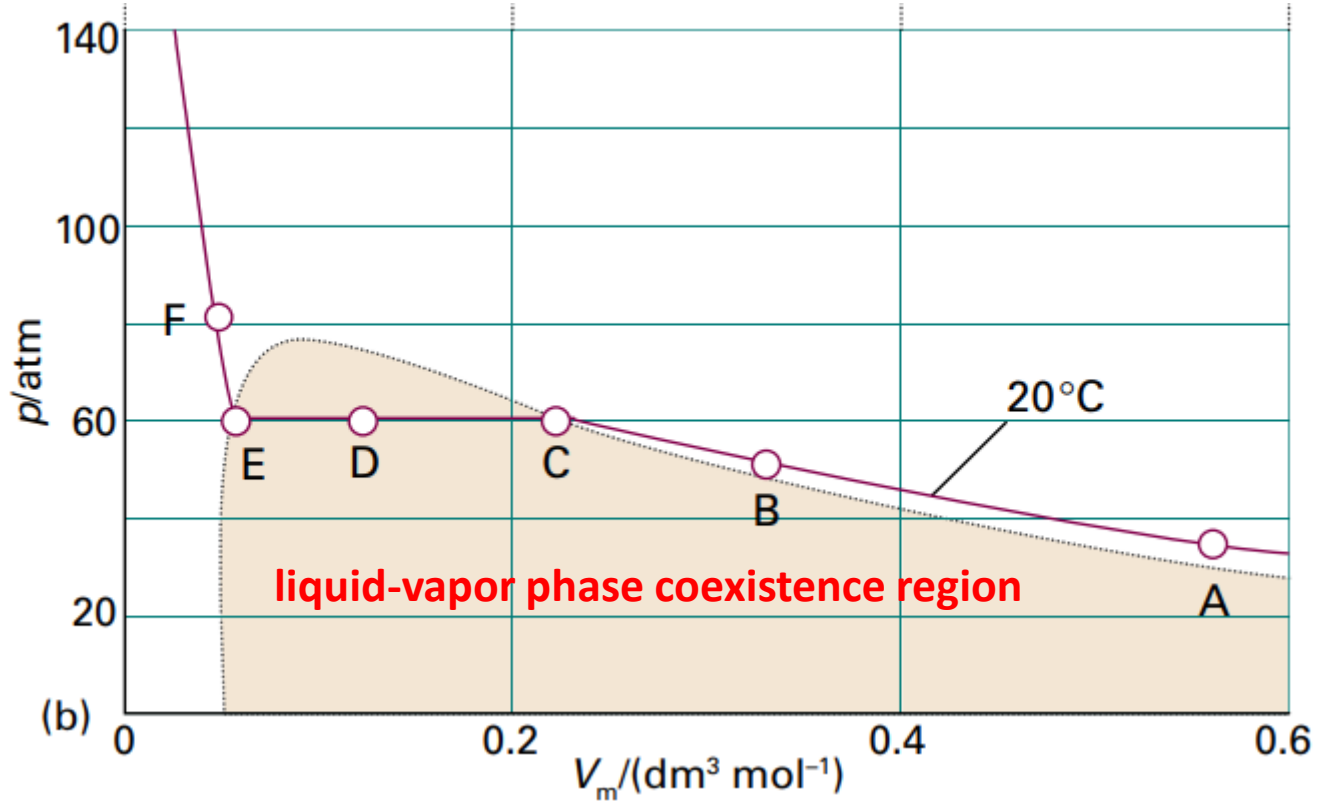
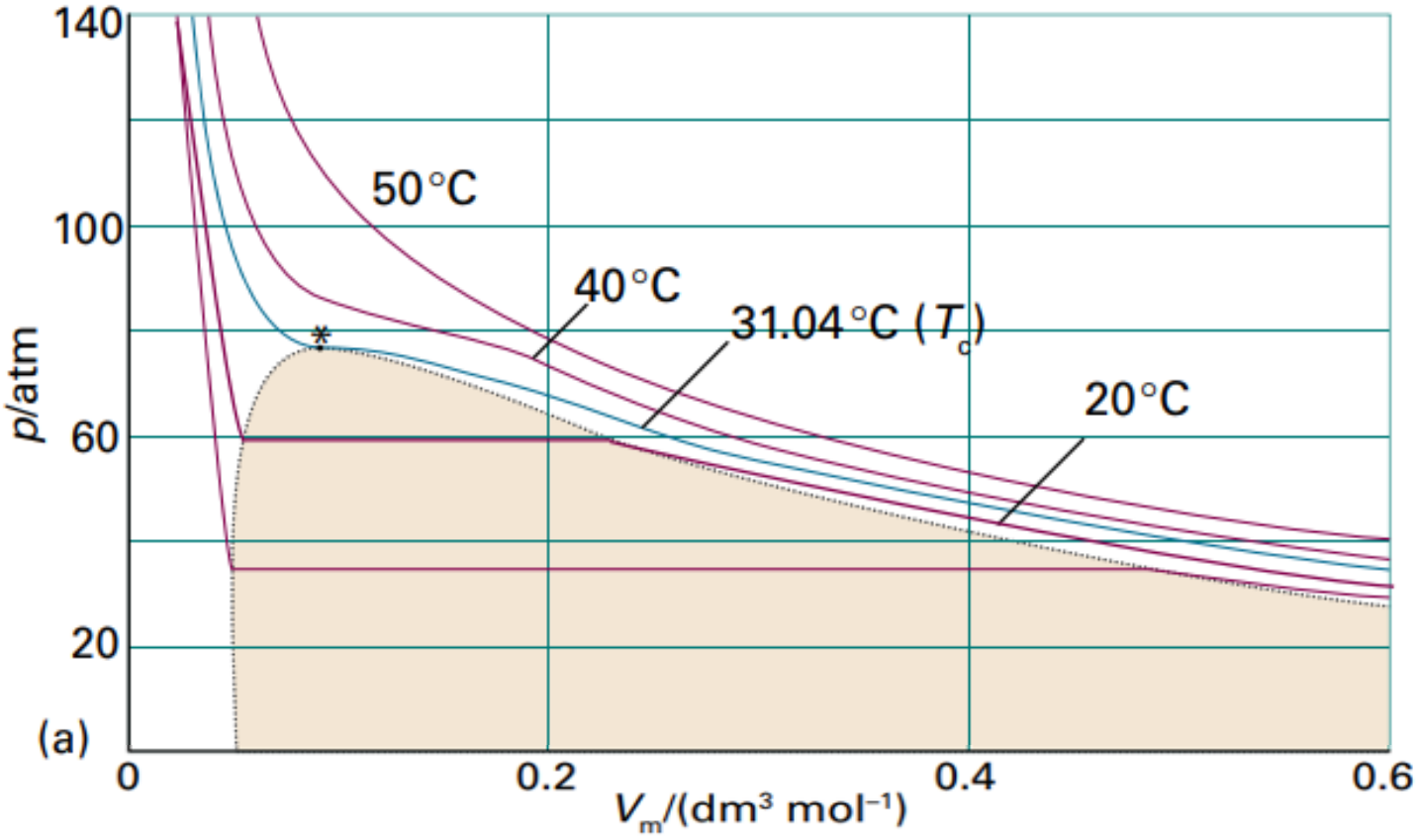


Compression – Different isotherms



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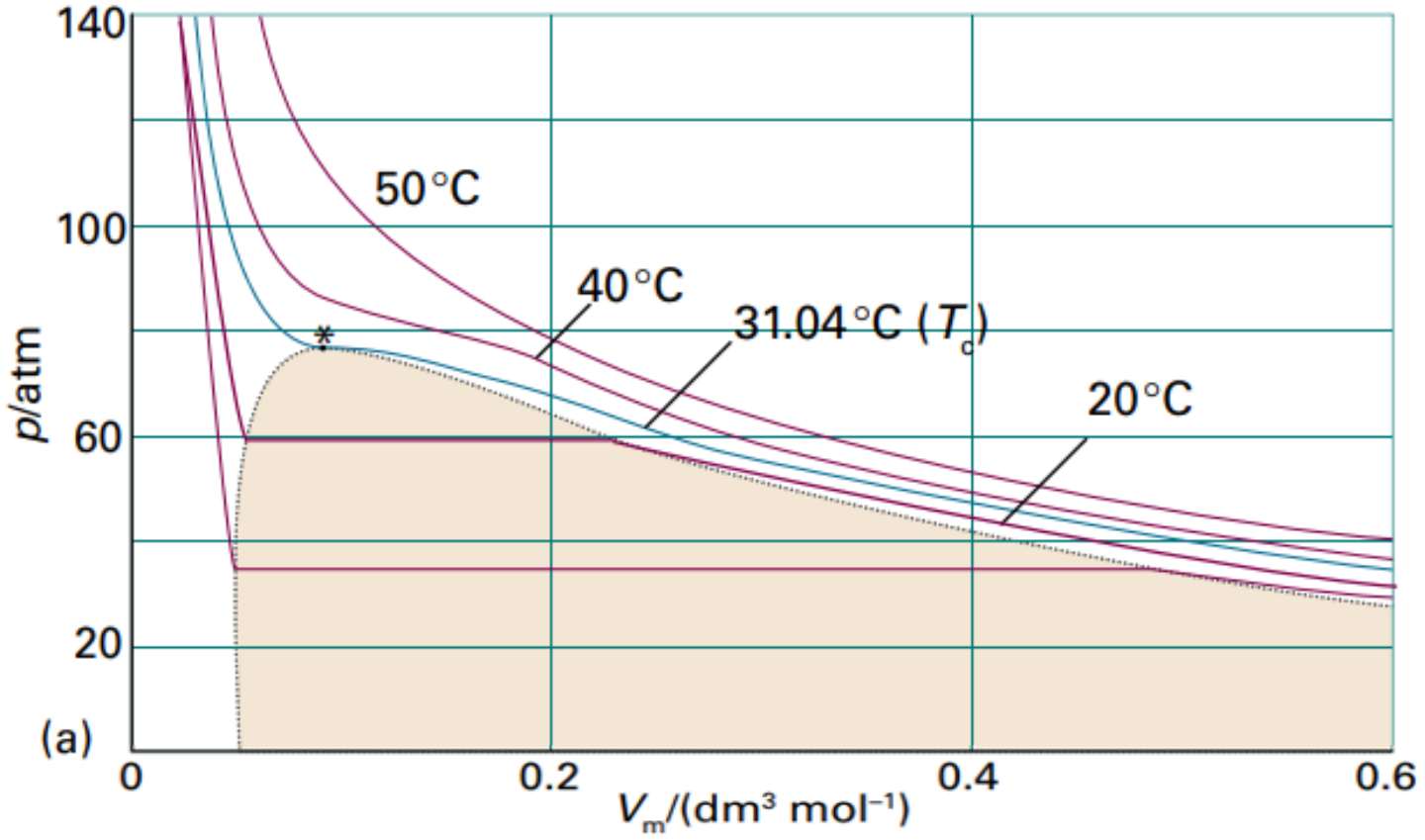

Critical Temperature (C_T)
Above this temperature, a gas cannot be liquefied by pressure alone

Compression factor

To describe the behavior of a real gas compared to an ideal gas under the same conditions of temperature and pressure

$$Z = \frac{V_m}{V_m^\circ}$$

Molar volume ratio: real gas/perfect gas

Compression factor

$$Z = \frac{V_m}{V_m^\circ}$$

$\downarrow$

RT/p

Molar volume ratio: real gas/perfect gas

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$$RT/p$$

$$Z = pV_m/RT$$

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Perfect gas: Z =1

Can use to quantitate the deviation from perfect gas behavior

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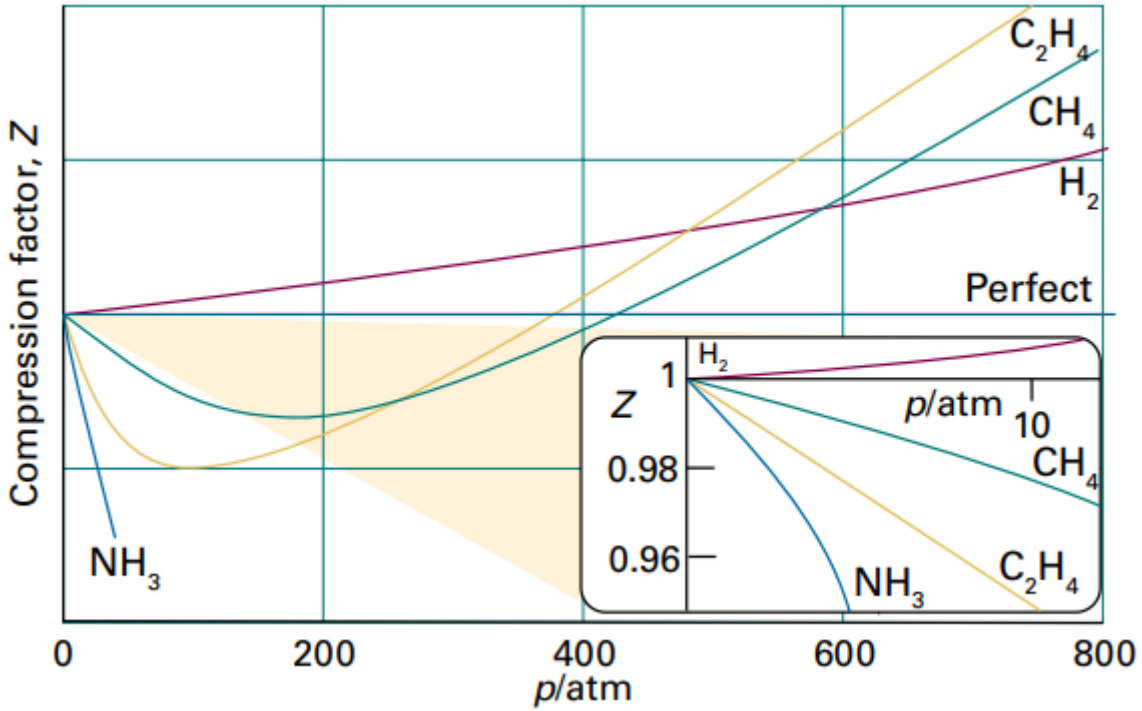

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Perfect gas: Z =1

Can use to quantitate the deviation from perfect gas behavior

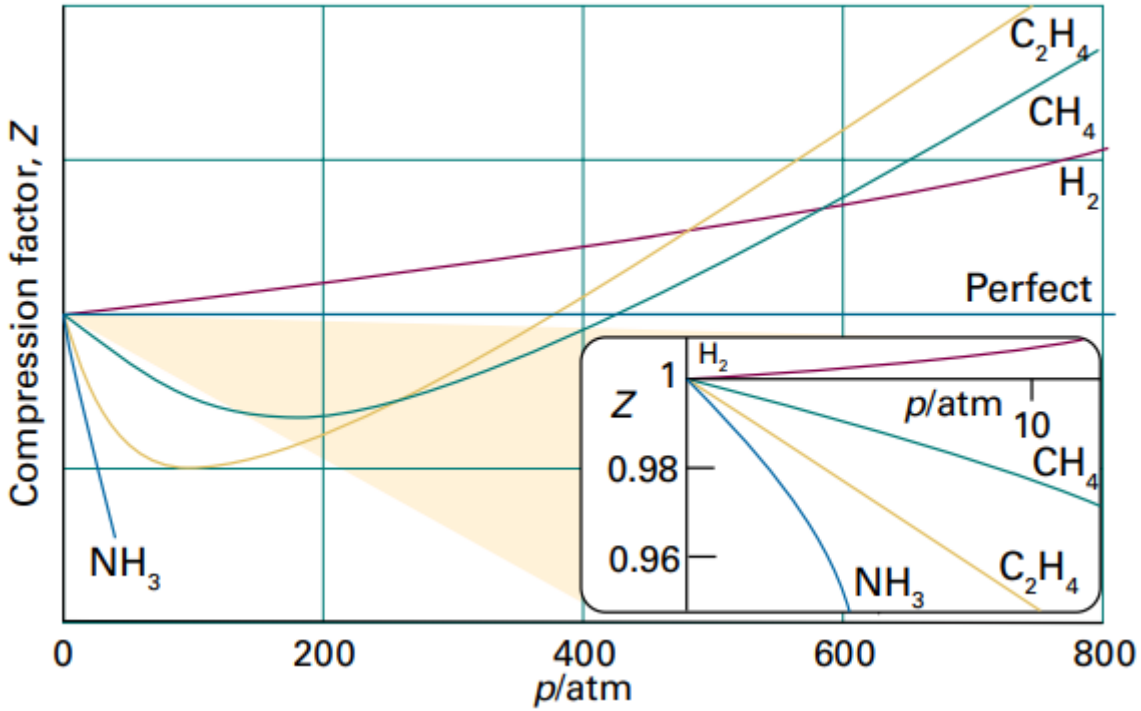
Compression factor

Hydrogen a "restless" molecule, even at low temperatures, due to its high zero-point energy!

$$Z = \frac{V_m}{V_m^\circ}$$

$$\downarrow$$

$$RT/p$$



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Virial equation of state

$$pV_m = RT(1 + B'p + C'p^2 + \cdots)$$

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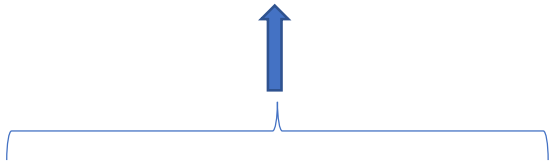

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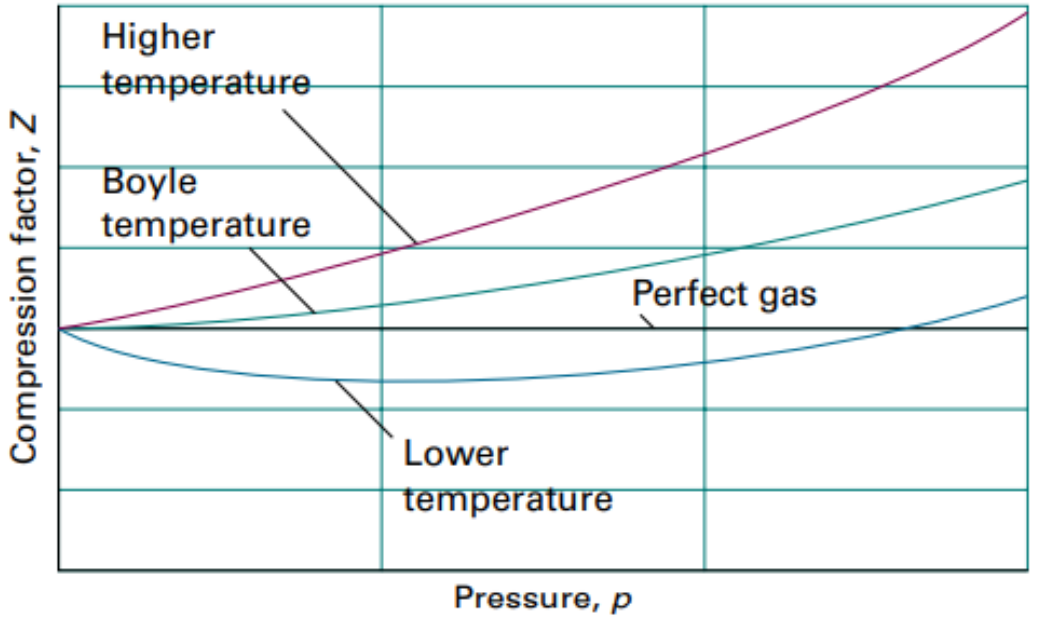
Table 1C.1 Second virial coefficients, $B/(\mathrm{cm^3\ mol^{-1}})$*

	Temperature	
	273 K	600 K
Ar	−21.7	11.9
CO_2	−149.7	−12.4
N_2	−10.5	21.7
Xe	−153.7	−19.6

* More values are given in the *Resource section*.

Virial equation of state

Virial coefficients



For real gases: The compression factor, Z, approaches 1 at low pressures, but does so with different slopes!

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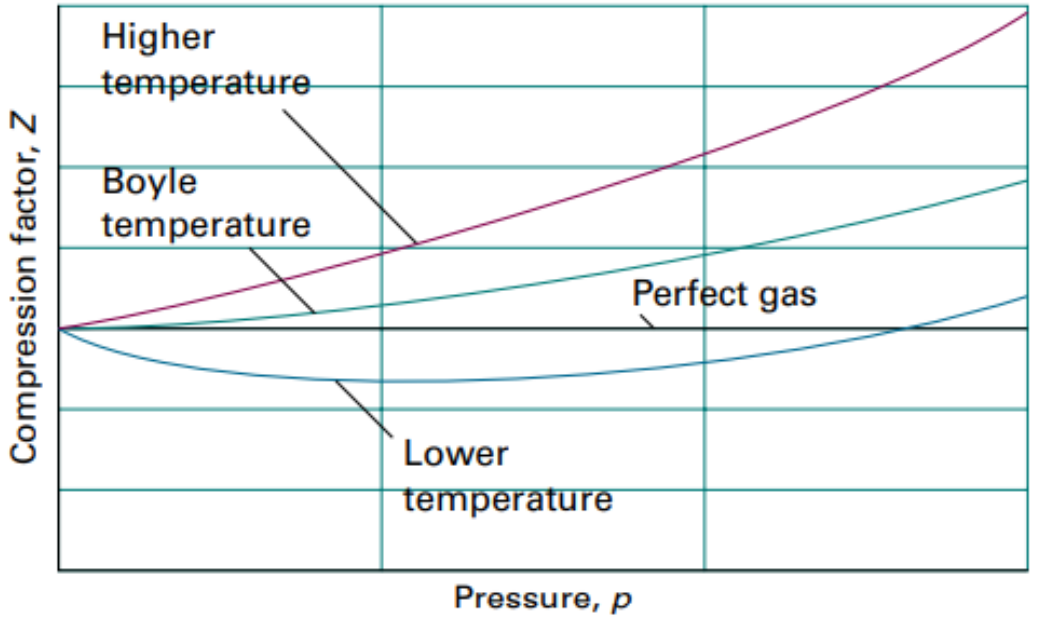

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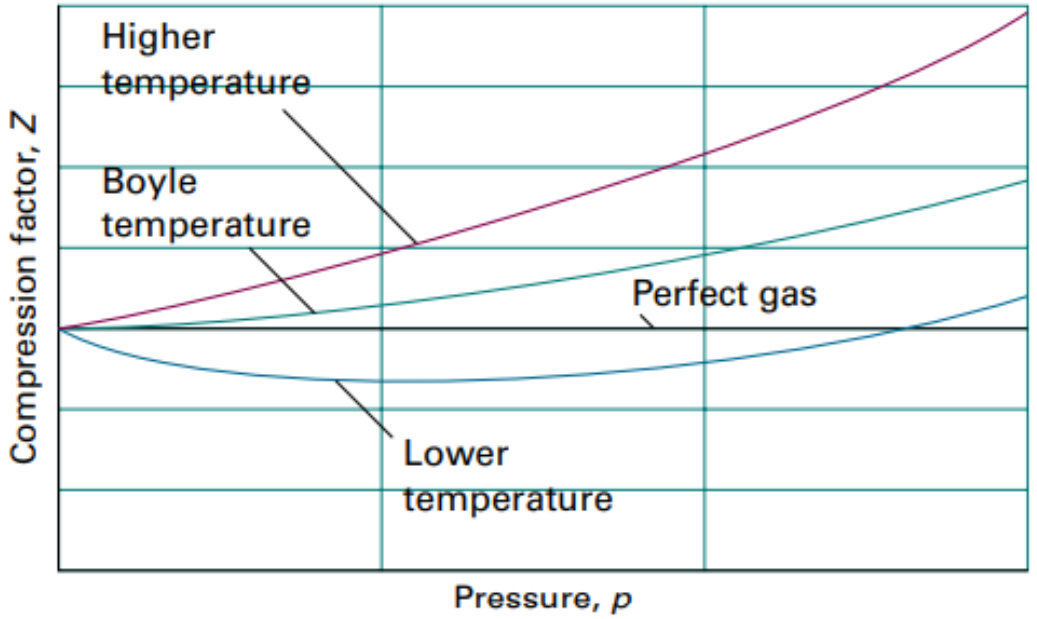

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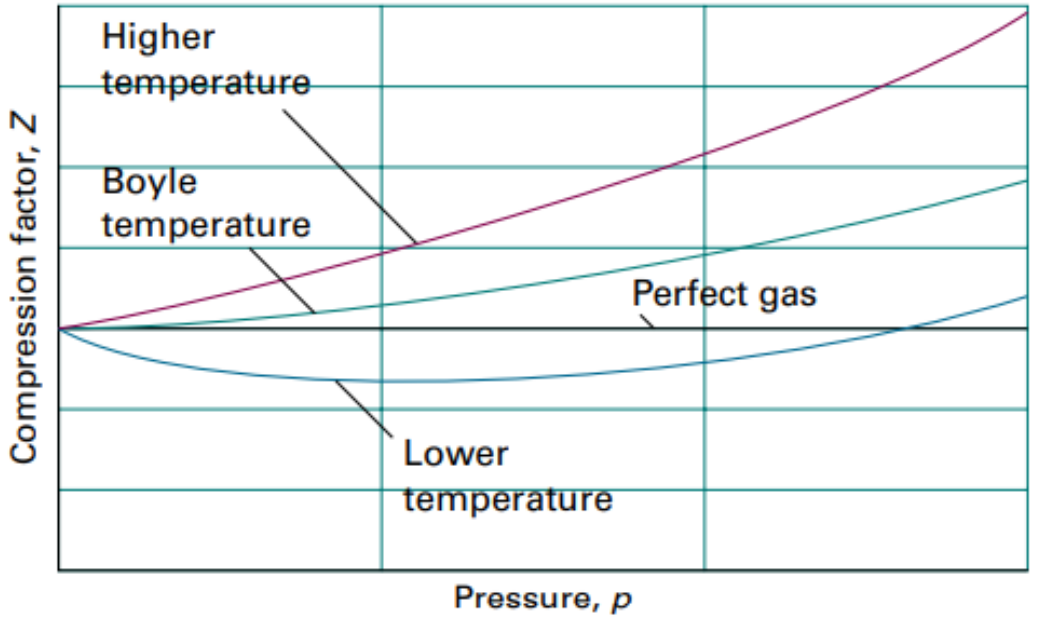

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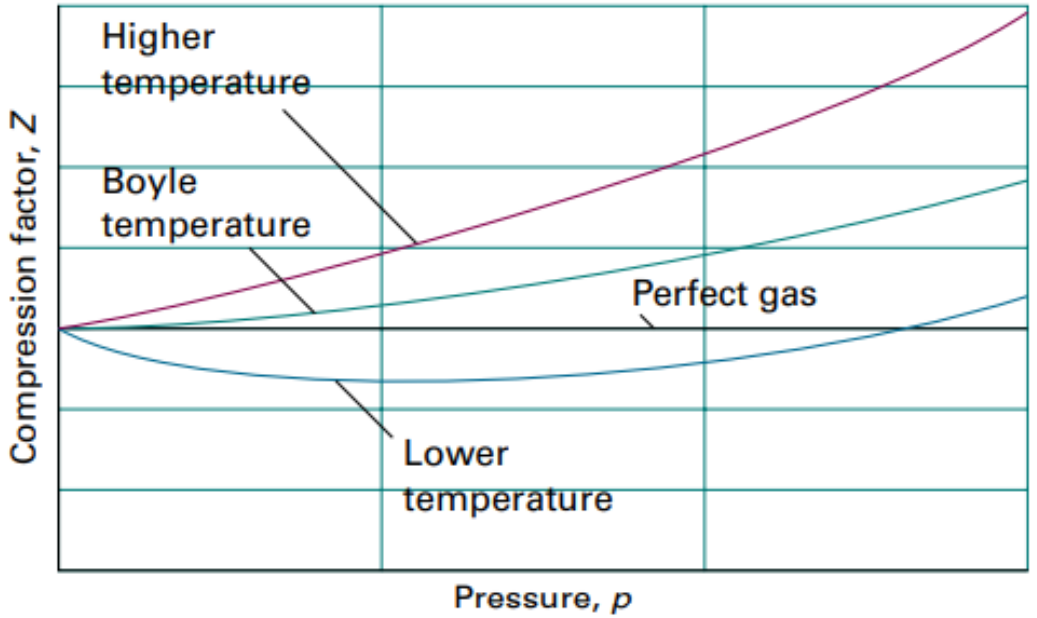

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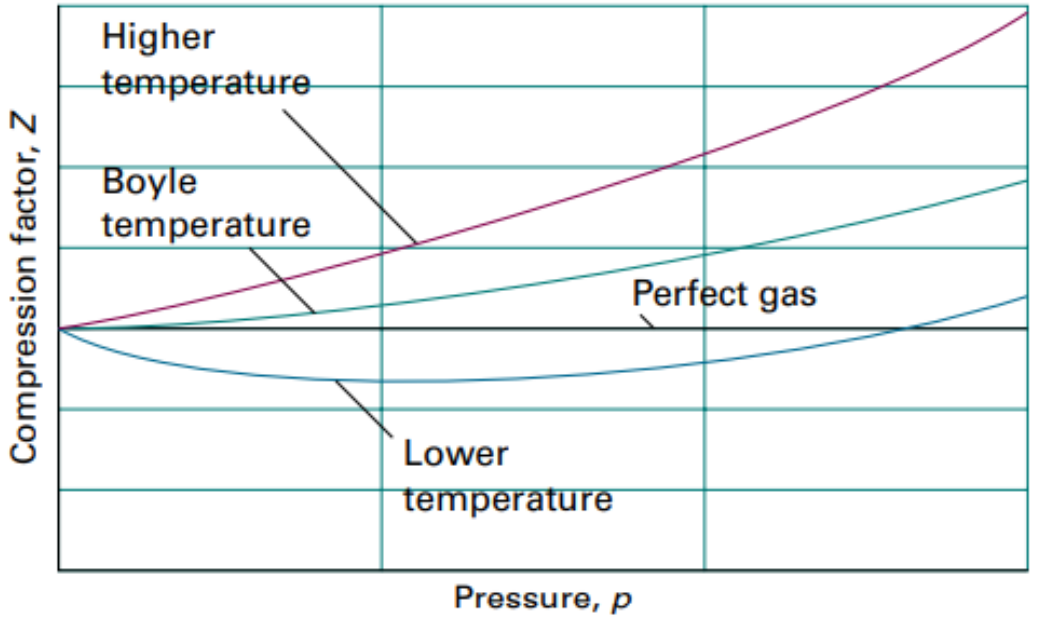

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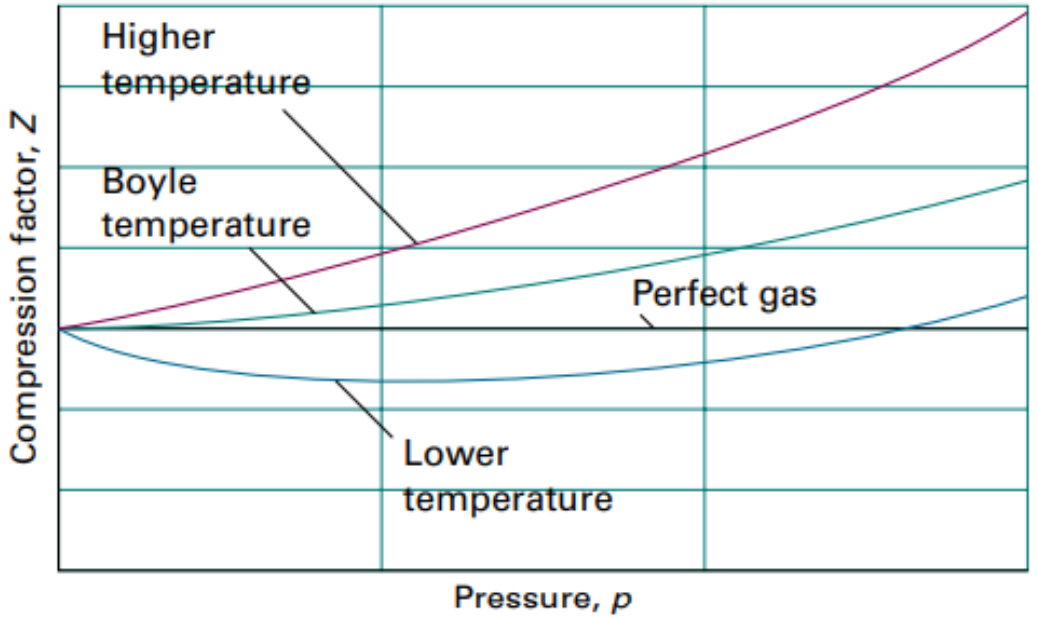

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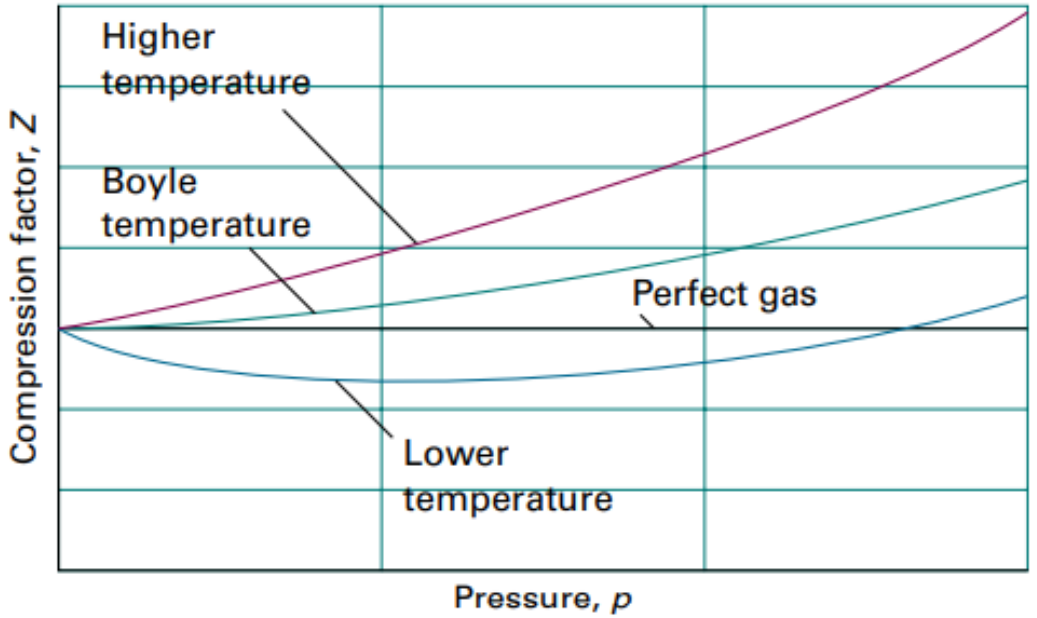

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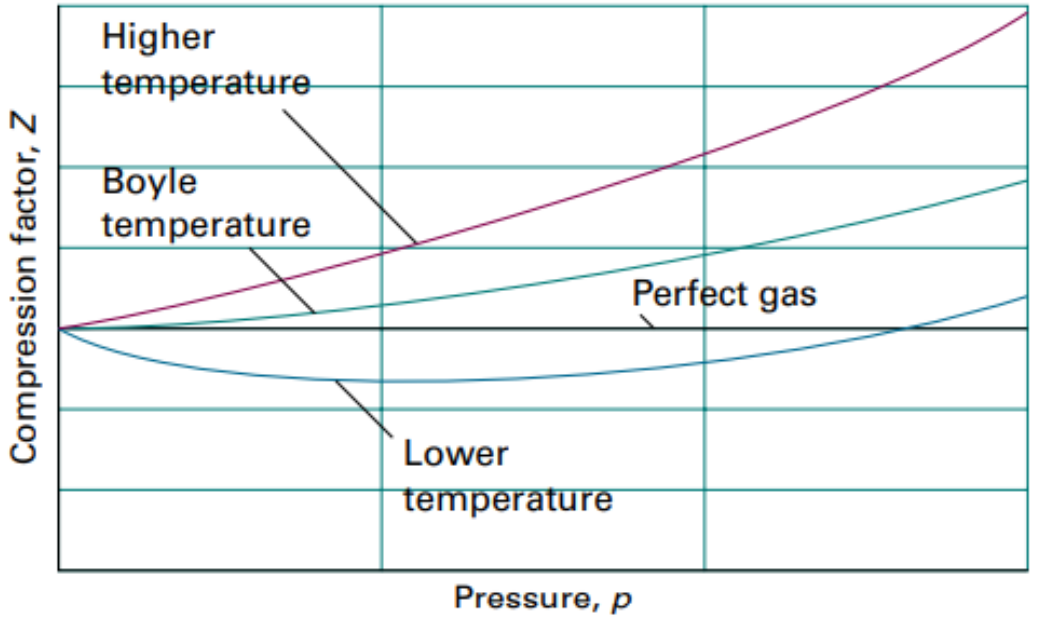

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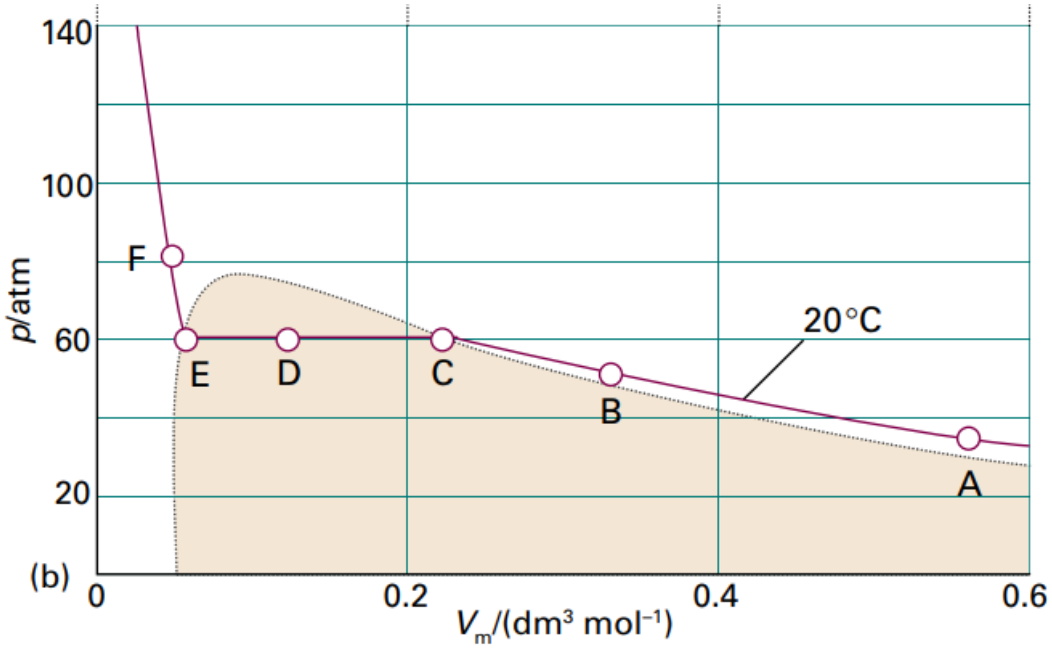
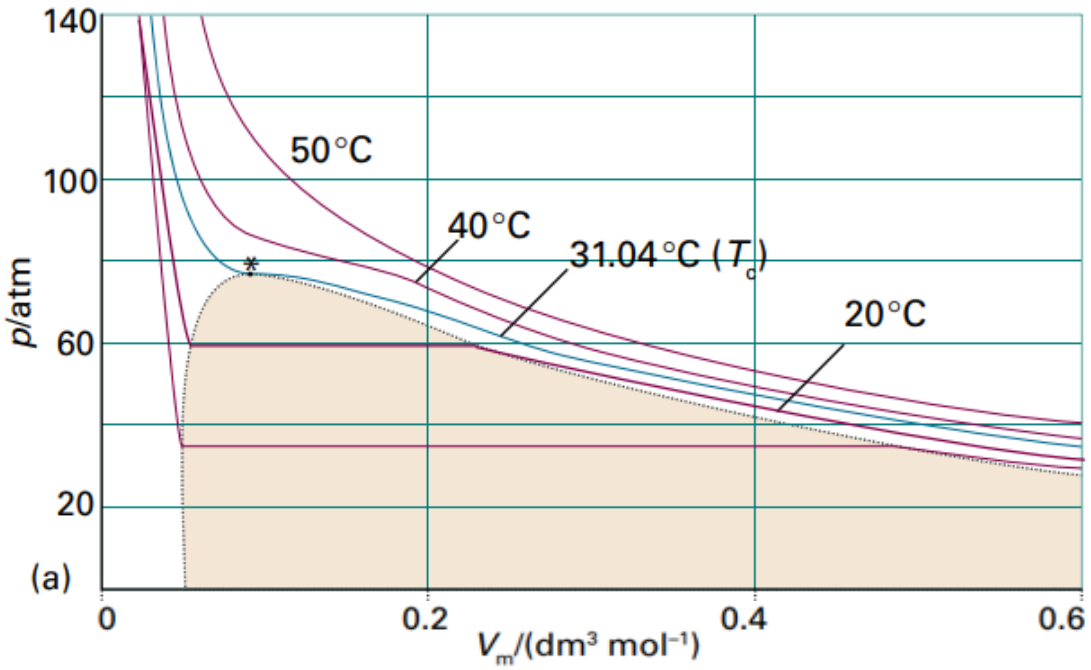
The properties of real gases coincide with those of a perfect gas at T_B for a more extended range of pressures than at other temperatures

Critical constants

CO_2





critical temperature, $\mathbf{T_c}$

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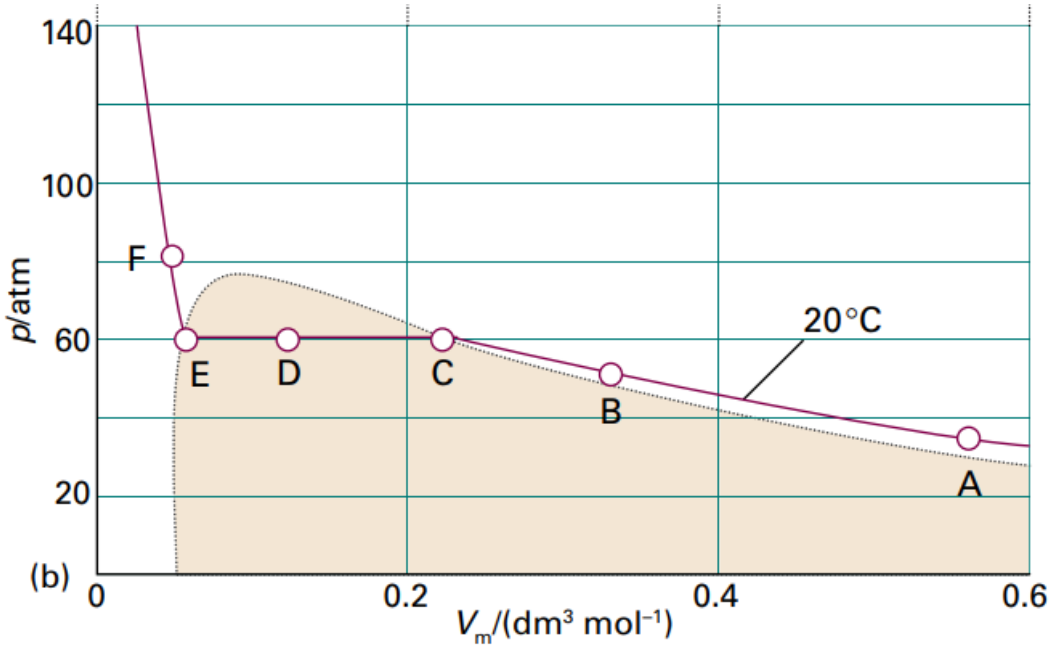

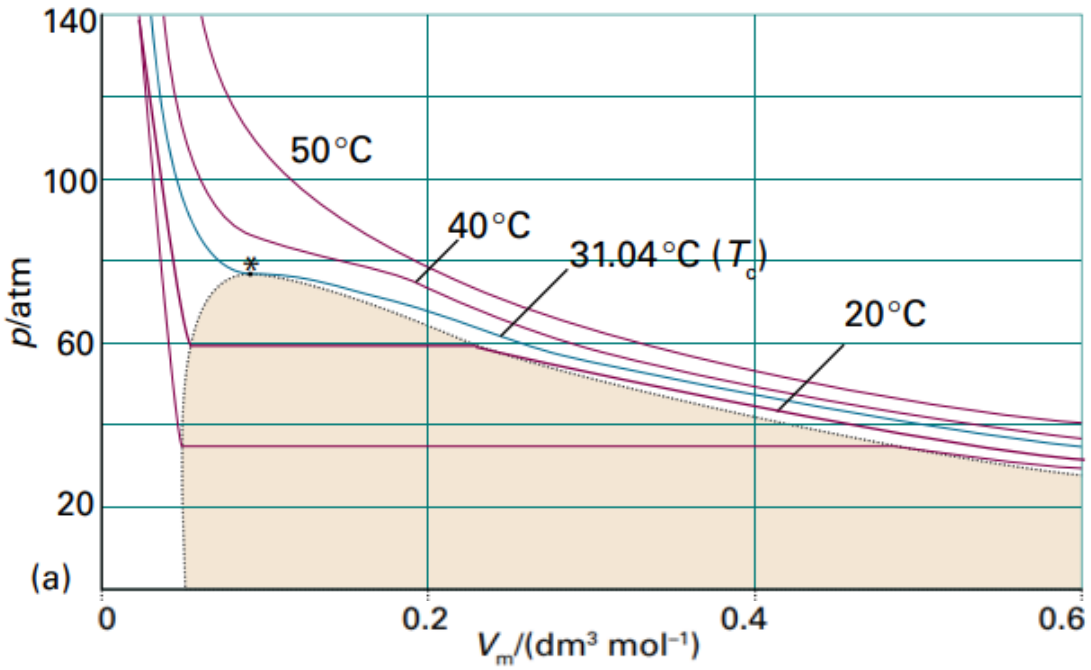

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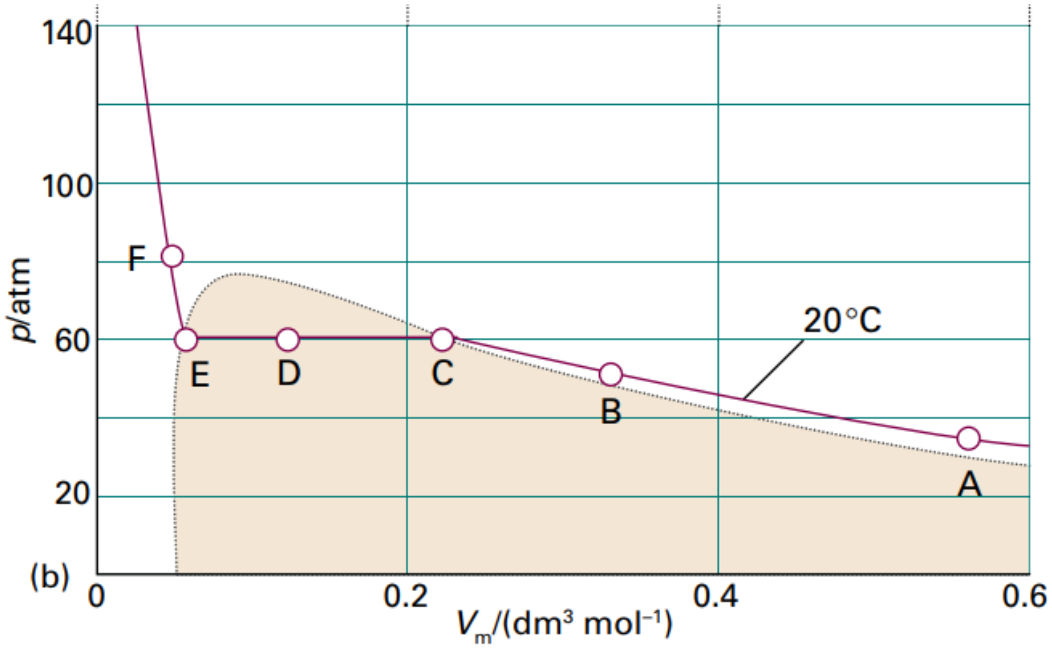

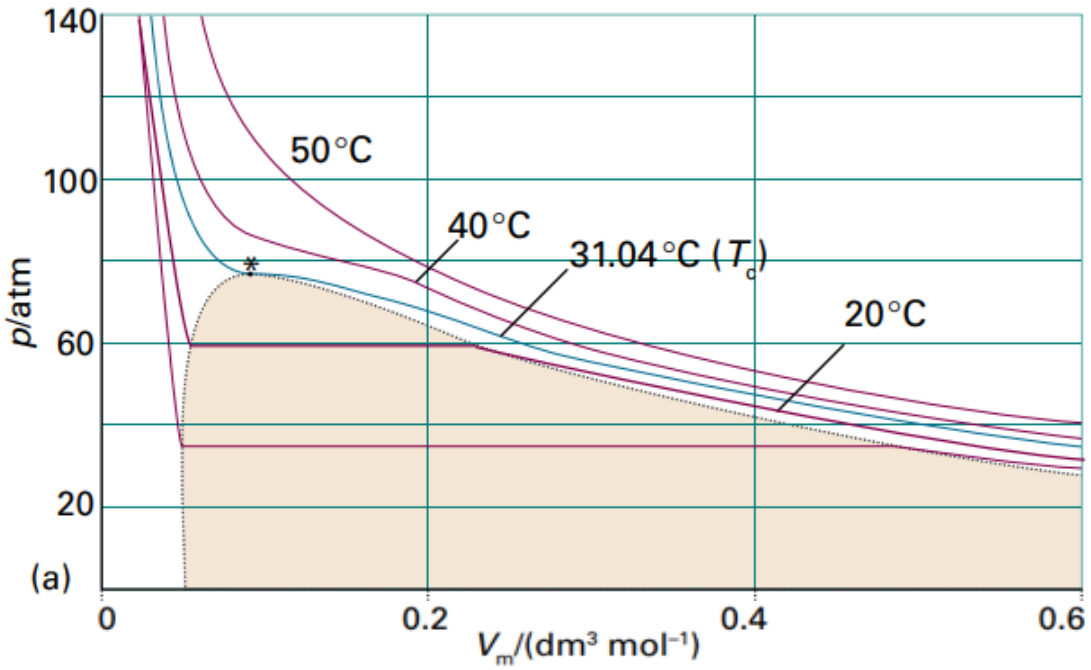

critical constants

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critical molar volume, $\mathbf{V_c}$

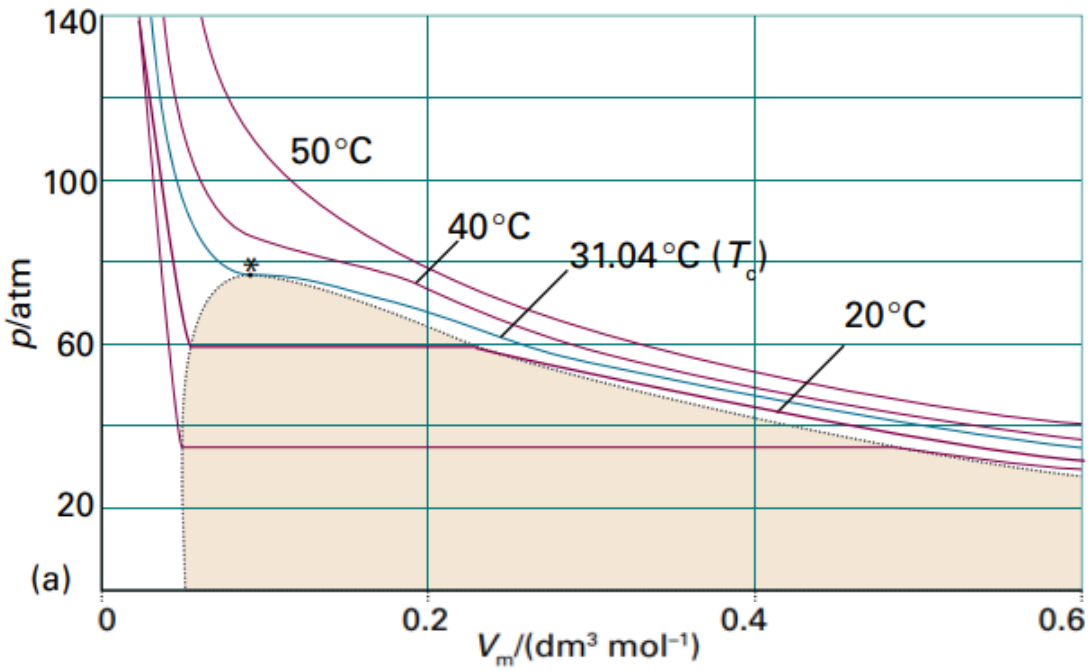
Critical constants

Factors that influence the critical constants:

1. Intermolecular Forces
2. Molecular Size and Molar Mass
3. Molecular Shape
4. Polarity and Dipole Moment
5. Hydrogen Bonding
6. Molecular Symmetry
7. Degree of Unsaturation (Double/Triple Bonds)
8. Compressibility and Molar Density
9. Polarizability

critical constants

CO_2



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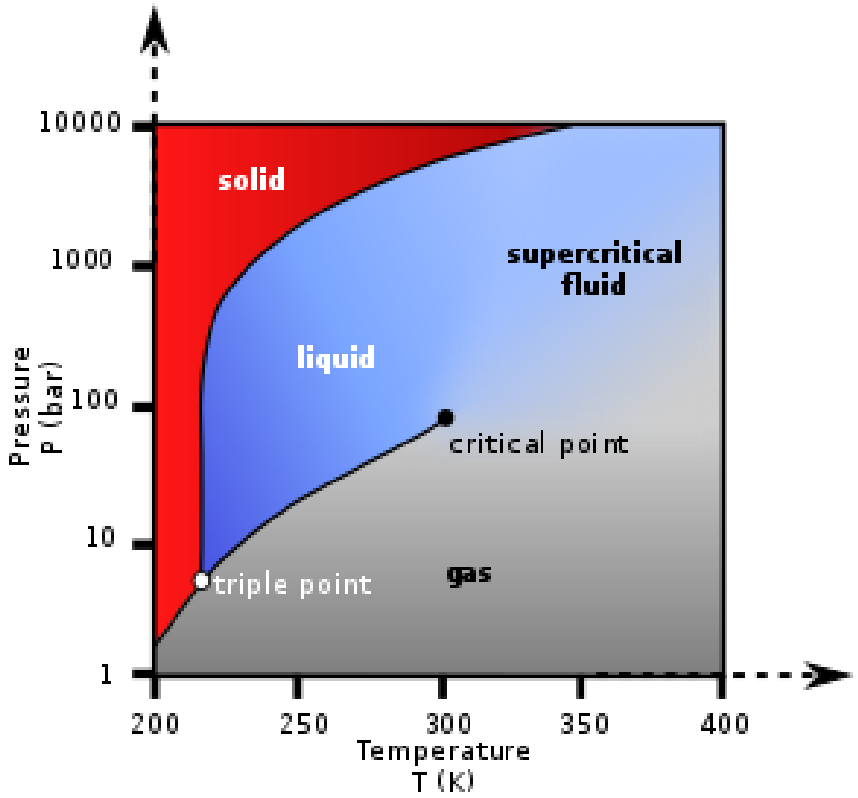

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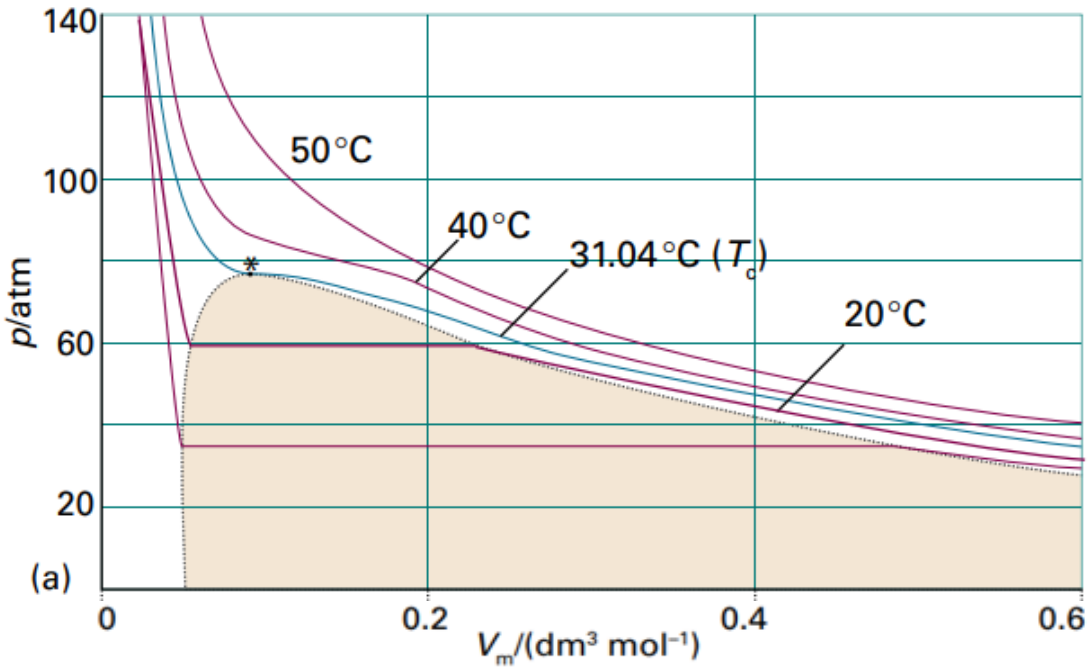
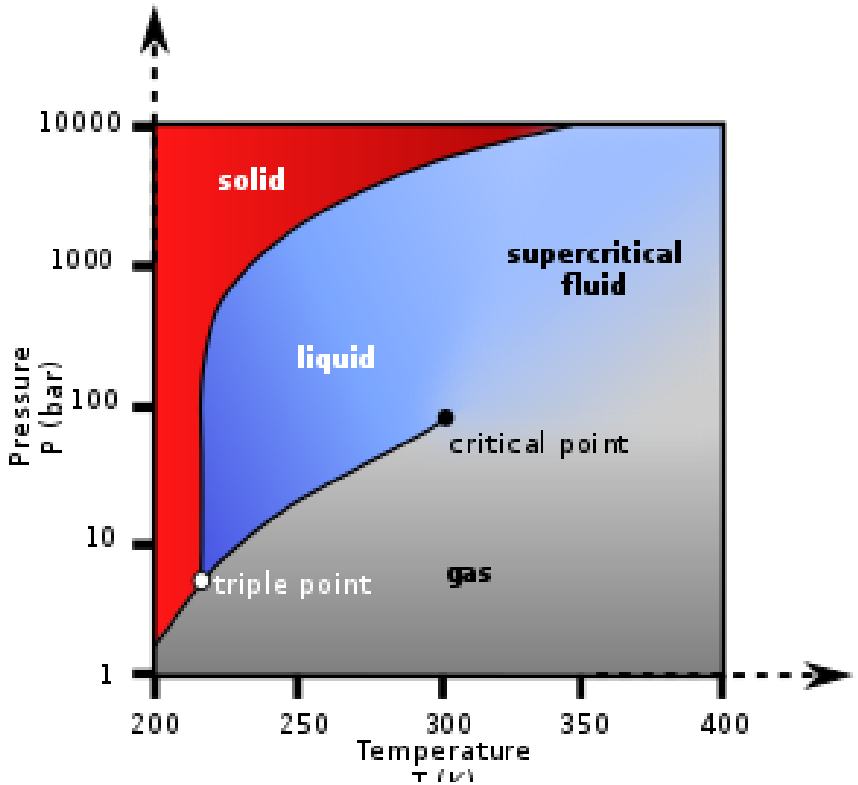
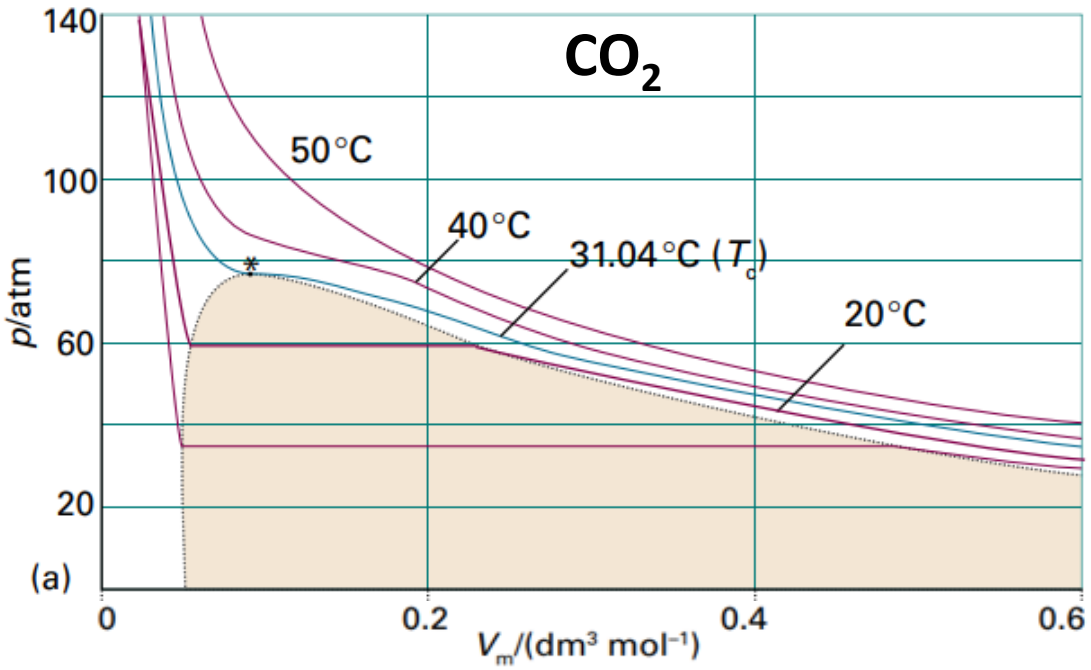


Critical constants are the thermodynamic properties of a substance at its critical point, where the distinction between the liquid and gas phases disappears.

Critical constants





	p_c/atm	V_c/(cm^3 mol^{-1})	T_c/K	Z_c	T_B/K
Ar	48.0	75.3	150.7	0.292	411.5
CO_2	72.9	94.0	304.2	0.274	714.8
He	2.26	57.8	5.2	0.305	22.64
O_2	50.14	78.0	154.8	0.308	405.9

Critical Temperature (T_c)	Boyle's Temperature (T_B)
Maximum temperature for liquefaction of a gas.	Temperature at which a real gas behaves like an ideal gas.