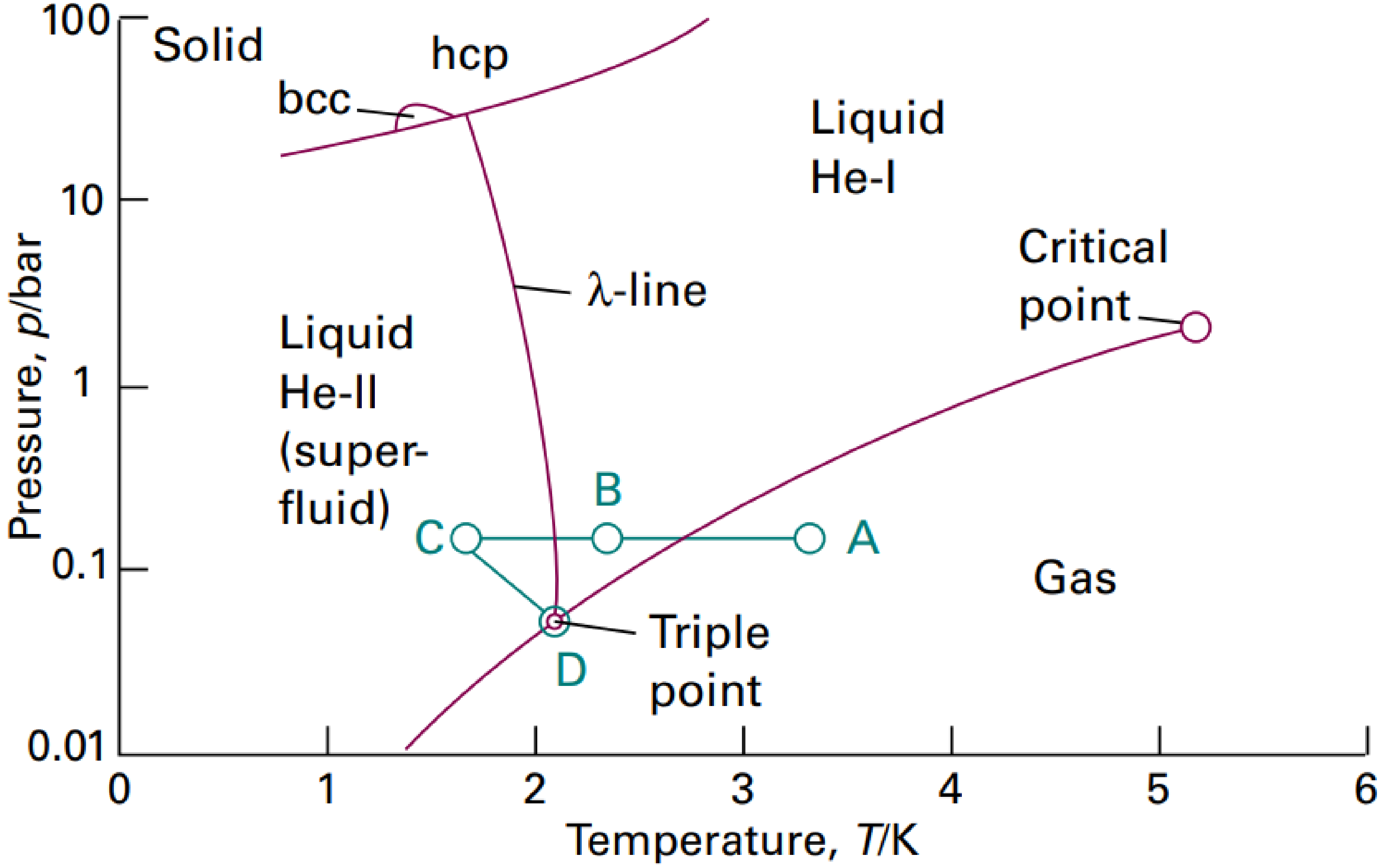
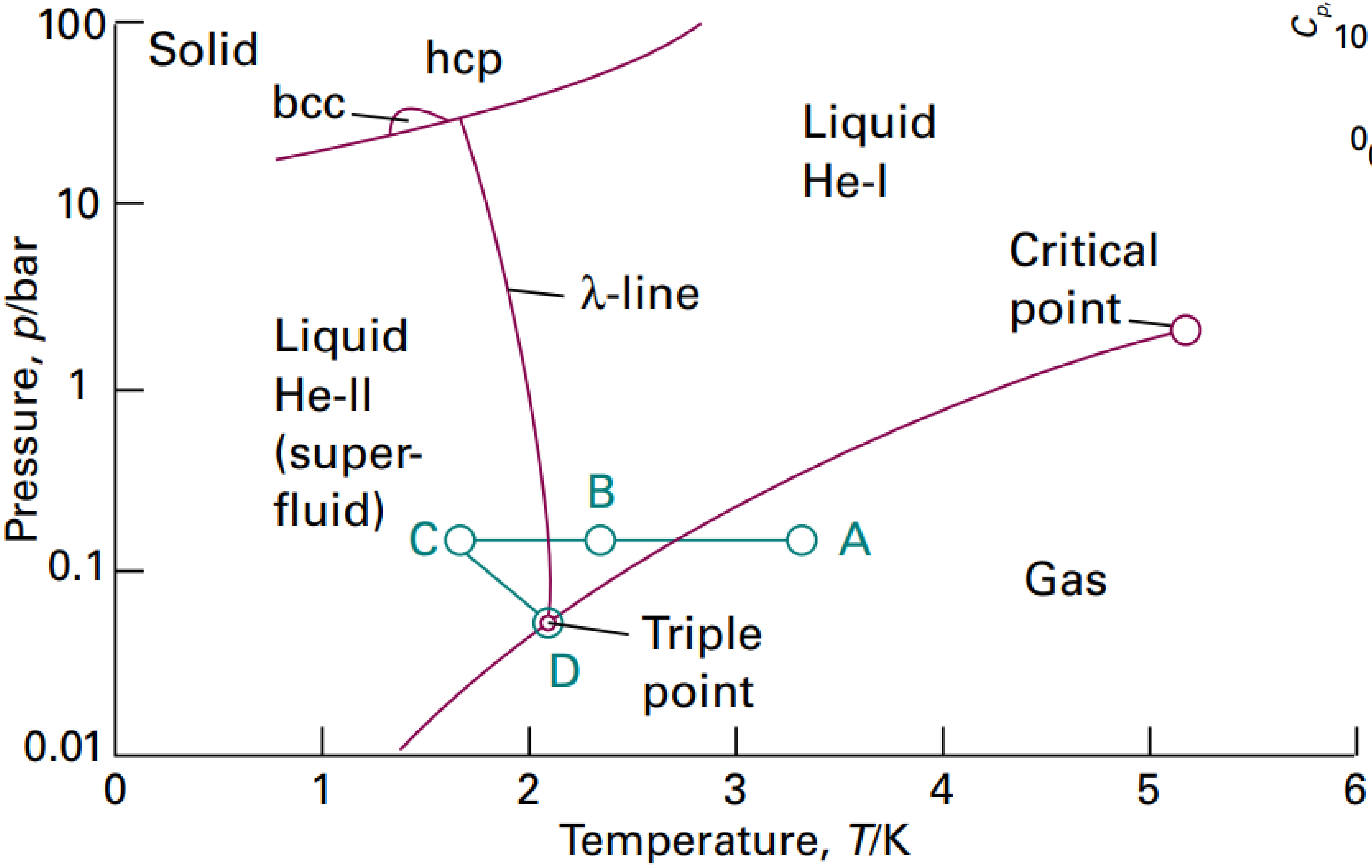
Helium



100
10
1
0.1
0.01
Pressure, p/bar
Solid
hcp
bcc
Liquid
He-I
λ-line
Critical
point
Liquid
He-II
(super-
fluid)
B
C
A
Gas
D
Triple
point
0
1
2
3
4
5
6
Temperature, T/K

Helium



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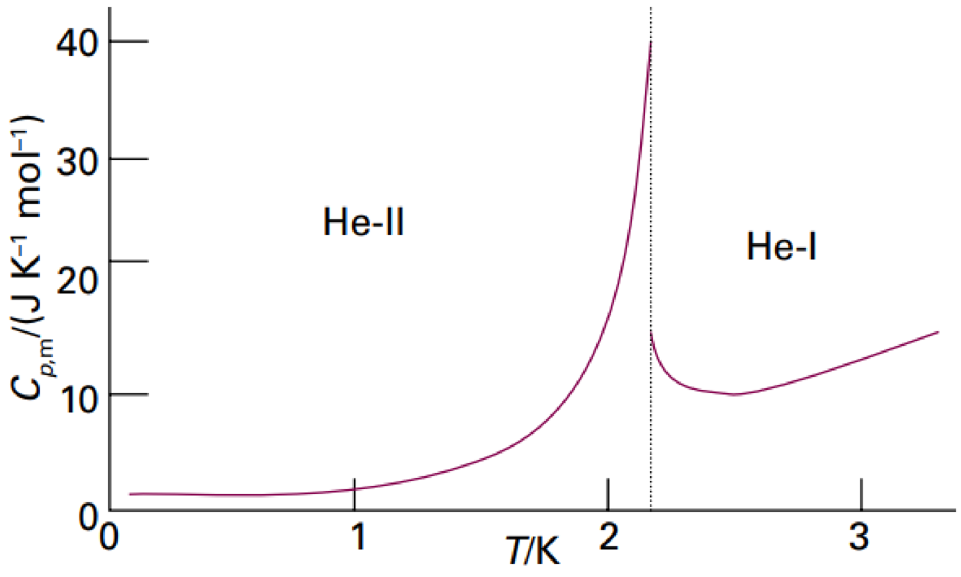

$C_{p,m}/(J\ K^{-1}\ mol^{-1})$
40
30
20
10
0
He-II
He-I
0
1
2
3
T/K

Letters to the Editor

The Editor does not hold himself responsible for opinions expressed by his correspondents. He cannot undertake to return, or to correspond with the writers of, rejected manuscripts intended for this or any other part of NATURE. *No notice is taken of anonymous communications.*

NOTES ON POINTS IN SOME OF THIS WEEK'S LETTERS APPEAR ON P. 83.

CORRESPONDENTS ARE INVITED TO ATTACH SIMILAR SUMMARIES TO THEIR COMMUNICATIONS.

Viscosity of Liquid Helium below the λ-Point

THE abnormally high heat conductivity of helium II below the λ-point, as first observed by Keesom, suggested to me the possibility of an explanation in terms of convection currents. This explanation would require helium II to have an abnormally low viscosity; at present, the only viscosity measurements on liquid helium have been made in Toronto[1], and showed that there is a drop in viscosity below the λ-point by a factor of 3 compared with liquid helium at normal pressure, and by a factor of 8 compared with the value just above the λ-point. In these experiments, however, no check was made to ensure that the motion was laminar, and not turbulent.

The important fact that liquid helium has a specific density ρ of about 0·15, not very different from that of an ordinary fluid, while its viscosity μ is very small comparable to that of a gas, makes its

tube 3 could be set above or below the level (5) of the liquid in the surrounding Dewar flask. The amount of flow and the pressure were deduced from the difference of the two levels, which was measured by cathetometer.

The results of the measurements were rather striking. When there were no distance pieces between the disks, and the plates 1 and 2 were brought into contact (by observation of optical fringes, their separation was estimated to be about half a micron), the flow of liquid above the λ-point could be only just detected over several minutes, while below the λ-point the liquid helium flowed quite easily, and the level in the tube 3 settled down in a few seconds. From the measurements we can conclude that the viscosity of helium II is at least 1,500 times smaller than that of helium I at normal pressure.

The experiments also showed that in the case of helium II, the pressure drop across the gap was

Nobel Prize in Physics 1996

Photo from the Nobel Foundation archive.

David M. Lee

Prize share: 1/3

Photo from the Nobel Foundation archive.

Douglas D. Osheroff

Prize share: 1/3

Photo from the Nobel Foundation archive.

Robert C. Richardson

Prize share: 1/3

The Nobel Prize in Physics 1996 was awarded jointly to David M. Lee, Douglas D. Osheroff and Robert C. Richardson "for their discovery of superfluidity in helium-3"

LAW: Superfluids climb up the walls of their container due to a phenomenon called the Rollin film effect. Explain the effect briefly.

Focus 4: Physical transformation of pure substances

Phase diagrams of pure substances

Thermodynamic aspects of phase transitions

Variation of chemical potential with T and P

Variation of chemical potential with T and P

$$\mu = G_m$$

Variation of chemical potential with T and P

$$\mu = G_{\mathrm{m}}$$

$dG = -SdT$ at constant pressure;

$dG = Vdp$ at constant temperature

Variation of chemical potential with T and P

$$\mu = G_{\mathrm{m}}$$

$\mathrm{d}G = -S\mathrm{d}T$ at constant pressure;
$\mathrm{d}G = V\mathrm{d}p$ at constant temperature

$$\left(\frac{\partial \mu}{\partial T}\right)_p = -S_{\mathrm{m}}$$

$$\left(\frac{\partial \mu}{\partial p}\right)_T = V_{\mathrm{m}}$$

Temperature dependence of phase stability

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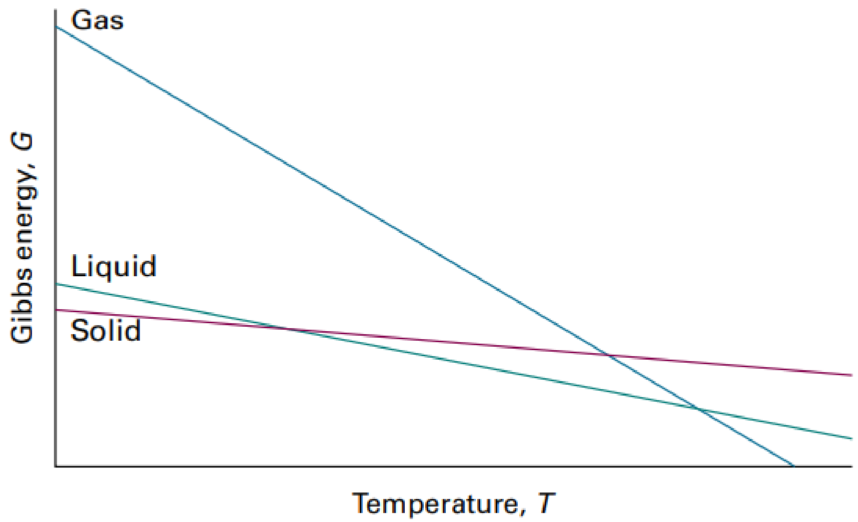
Temperature dependence of phase stability



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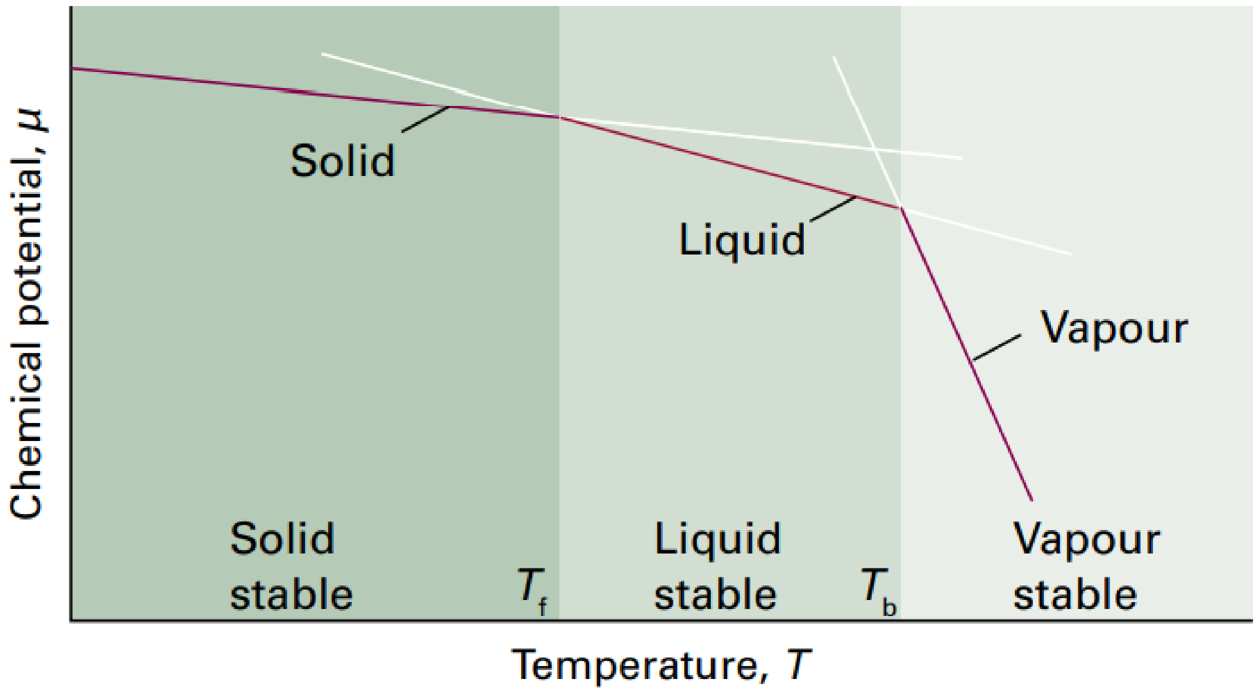
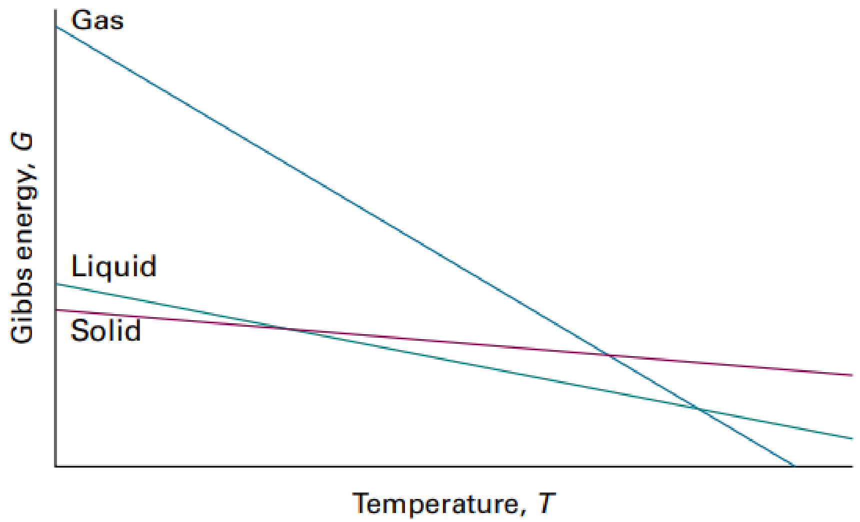
Temperature dependence of phase stability





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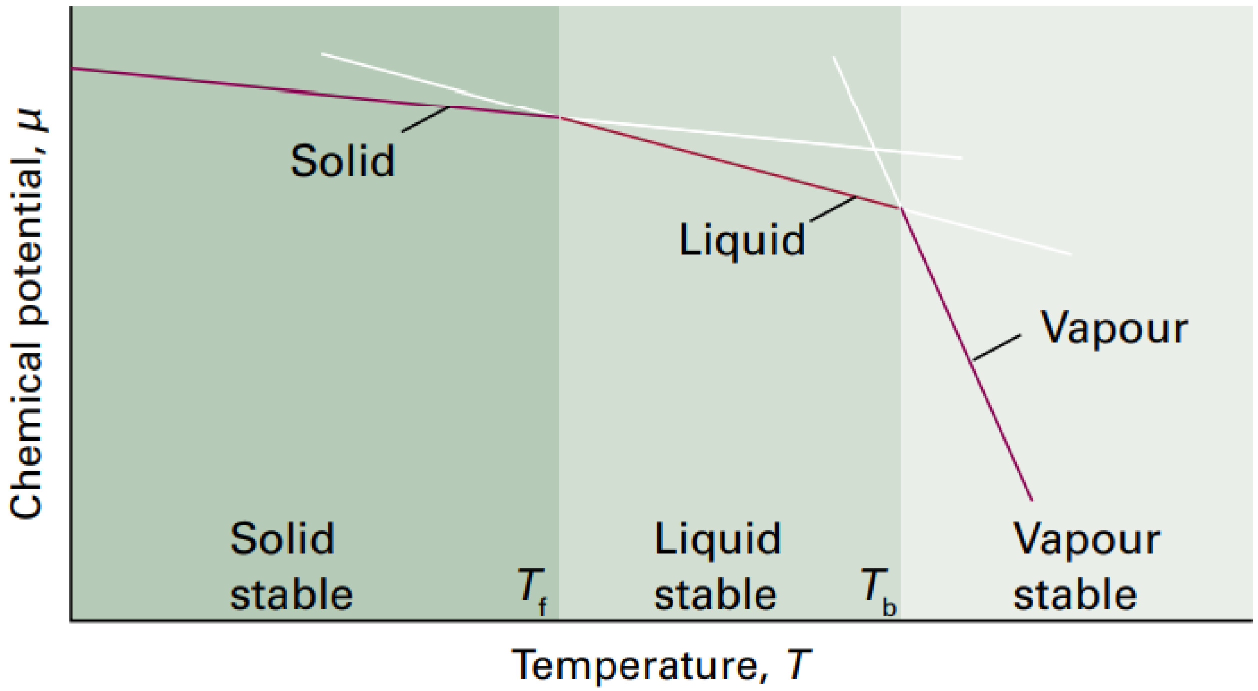

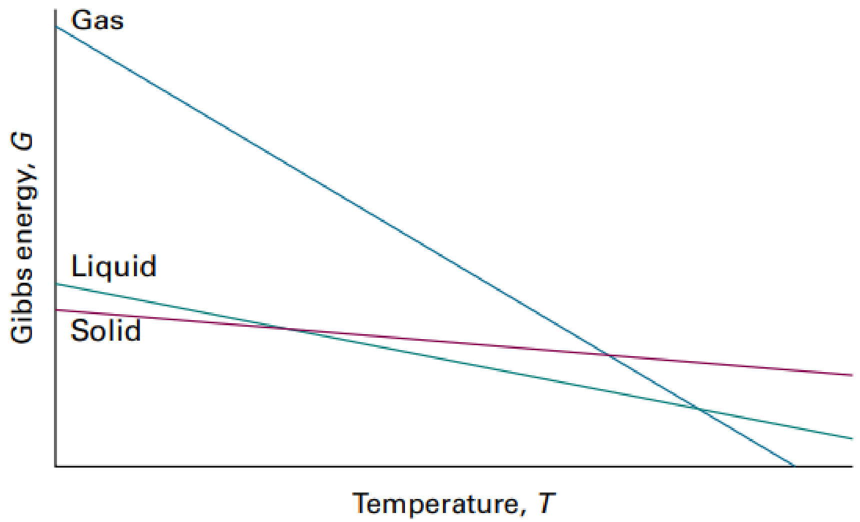

$$\left(\frac{\partial \mu}{\partial T}\right)_p = -S_m$$

The phase with the lowest chemical potential at a specified temperature is the most stable one at that temperature!

Temperature dependence of phase stability

The standard molar entropy of liquid water at 100 °C is 86.8 J K^{-1} mol^{-1} and that of water vapour at the same temperature is 195.98 J K^{-1} mol^{-1}. It follows that when the temperature is raised by 1.0 K the changes in chemical potential are

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$$\Delta\mu(\mathrm{g}) \approx -S_{\mathrm{m}}(\mathrm{g})\Delta T$$

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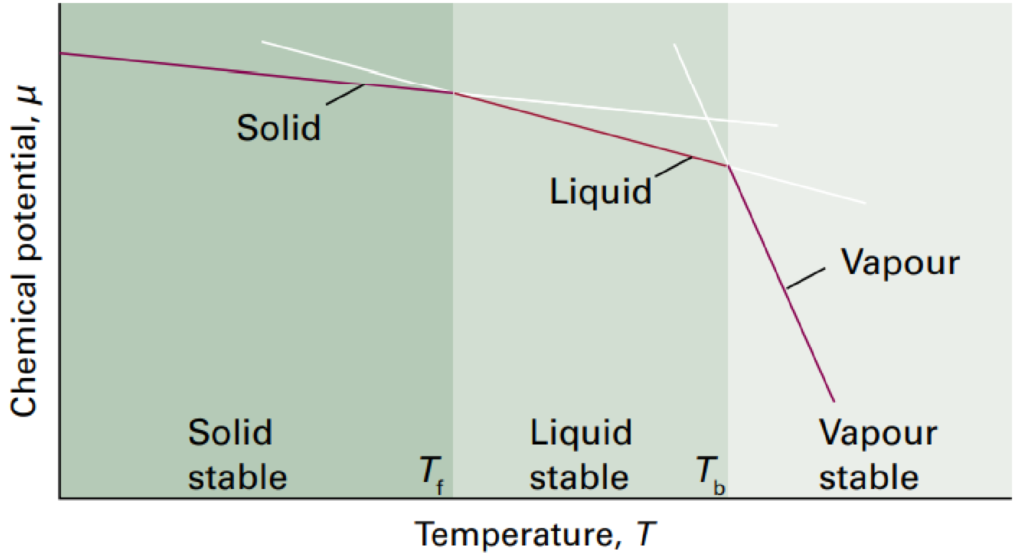
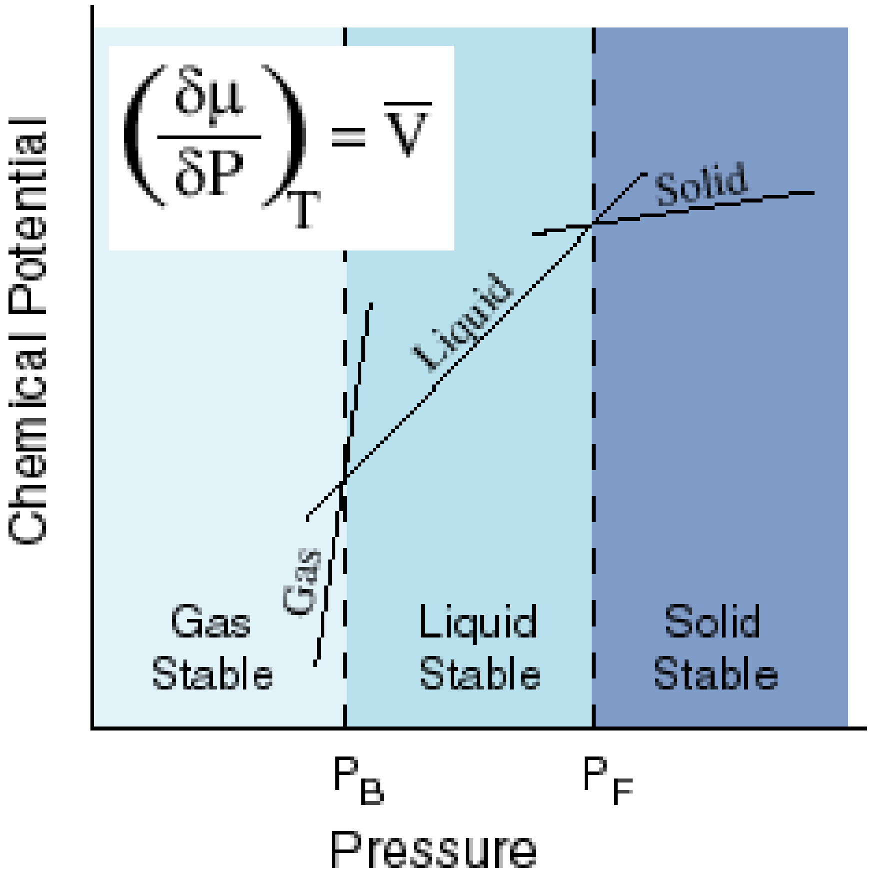


Pressure dependence of phase stability

$$\left(\frac{\partial \mu}{\partial p}\right)_T = V_{\mathrm{m}}$$

Pressure dependence of phase stability



$$\left(\frac{\partial \mu}{\partial p}\right)_T = V_m$$

LAW: The response of melting to applied pressure

Calculate the change in chemical potentials of ice and water when the pressure is increased from 1.00 bar to 2.00 bar at 0 °C.
The mass density of ice is 0.917 g cm^{-3} and that of liquid water is 0.999 g cm^{-3} under these conditions.

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$$\Delta\mu(\text{ice}) = \frac{(1.802\times10^{-2}\,\text{kg}\,\text{mol}^{-1})\times(1.00\times10^{5}\,\text{Pa})}{917\,\text{kg}\,\text{m}^{-3}}$$

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$$\Delta\mu(\text{water}) = \frac{(1.802\times10^{-2}\,\text{kg}\,\text{mol}^{-1})\times(1.00\times10^{5}\,\text{Pa})}{999\,\text{kg}\,\text{m}^{-3}} = +1.80\,\text{J}\,\text{mol}^{-1}$$

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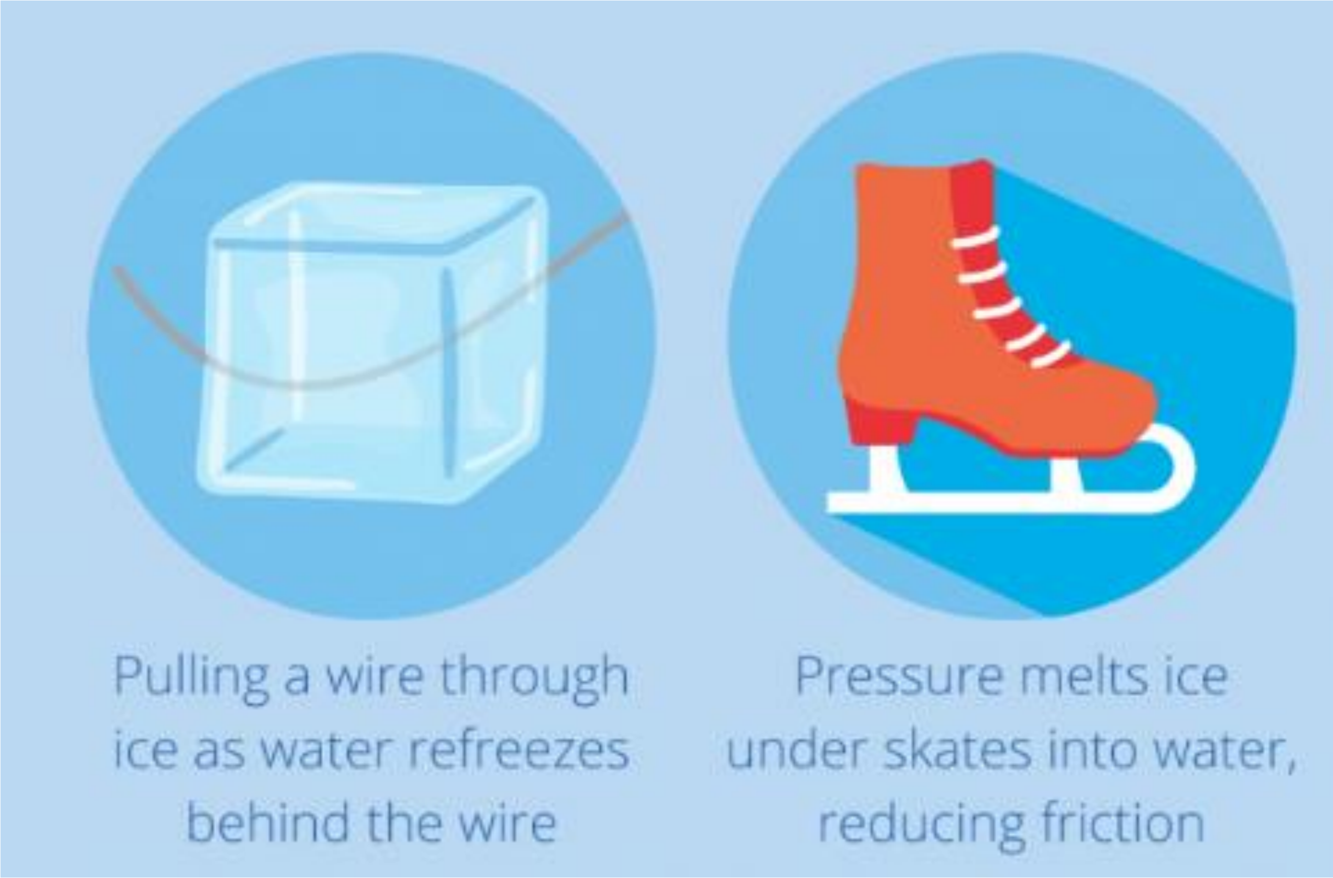
Thus, ice -> water with increased pressure (under above conditions)

Ice melting under pressure

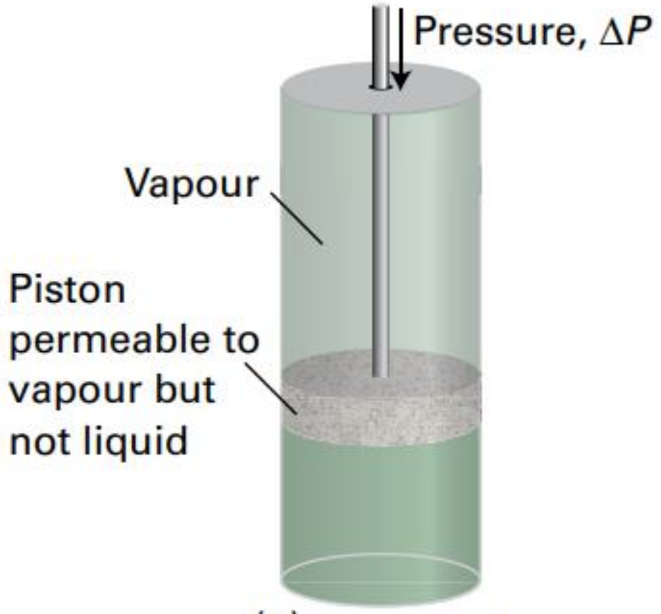
Pulling a wire through ice as water refreezes behind the wire

Ice melting under pressure



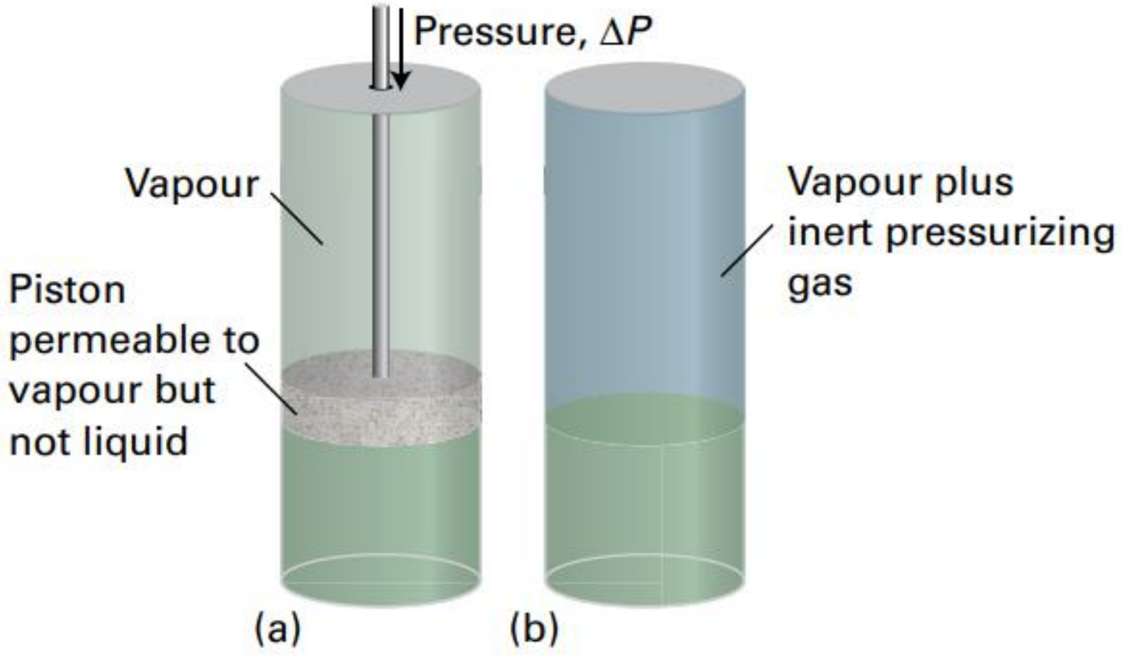
Ice melting under pressure

Vapor pressure of a pressurized liquid



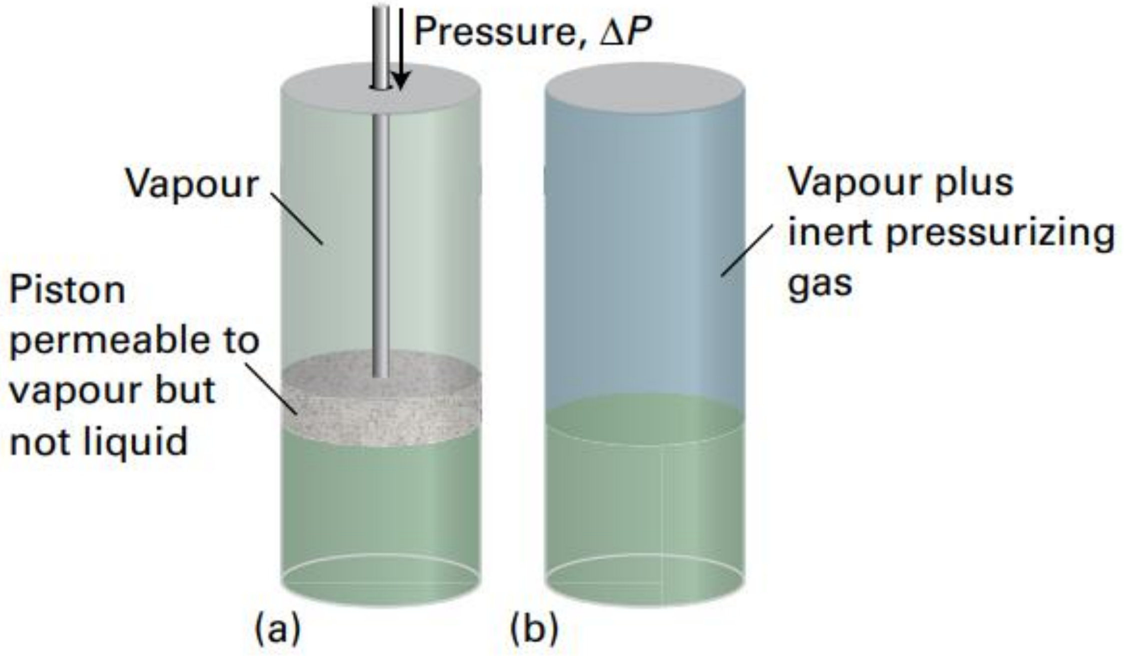
(a)

Vapor pressure of a pressurized liquid



Vapor pressure of a pressurized liquid

$$p = p^{*} e^{V_m(\mathrm{l})\Delta P/RT}$$



P = total pressure and p= partial vapor pressure

Vapor pressure of a pressurized liquid

partial vapor pressure

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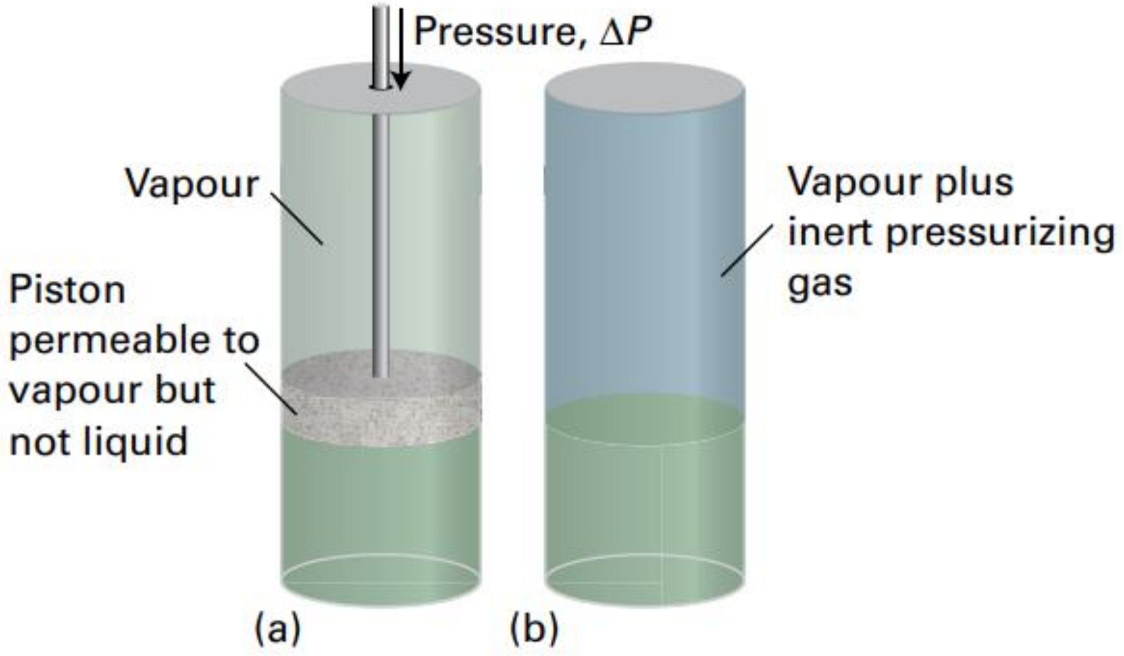

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partial vapor
pressure

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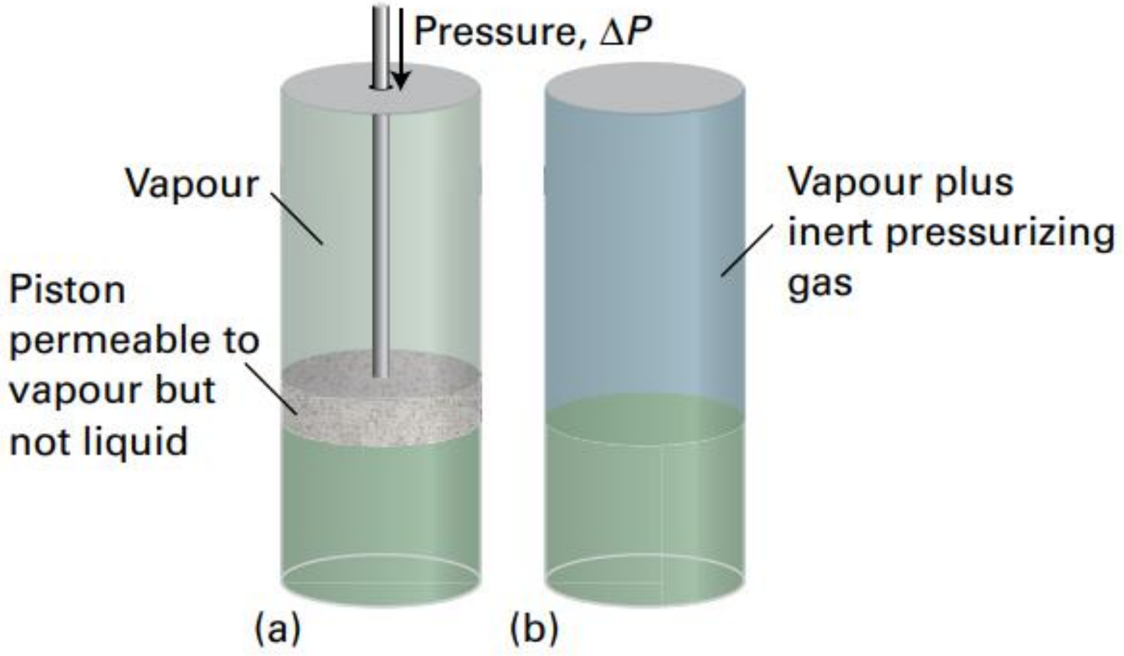
Normal vapor
pressure
(at 1 bar)



P = total pressure and p= partial vapor pressure

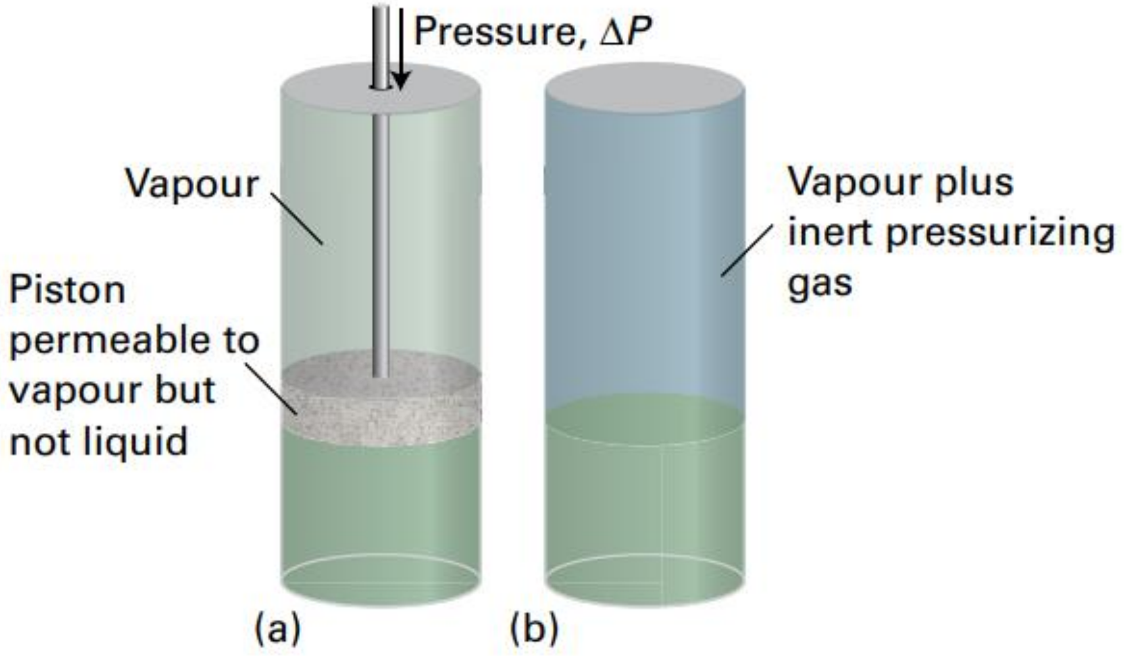
Vapor pressure of a pressurized liquid

partial vapor pressure

applied pressure

$$p = p^* e^{V_m(l)\Delta P/RT}$$

Normal vapor pressure (at 1 bar)



P = total pressure and p= partial vapor pressure

Vapor pressure of a pressurized liquid

For water, which has mass density $0.997\,\mathrm{g\,cm^{-3}}$ at $25\,°\mathrm{C}$ and therefore molar volume $18.1\,\mathrm{cm^3\,mol^{-1}}$, when the applied pressure is increased by $10\,\mathrm{bar}$ (i.e. $\Delta P = 1.0 \times 10^6\,\mathrm{Pa}$)

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p = 1.0073p*

An increase of only 0.73%