Goals for today: Begin Part II – Water in the Atmosphere 5 Oct., 2011

• what does "relative humidity" mean? Why do we speak of the "dewpoint" of air, as well? How are these related? How do these relate to the mass of water per cubic meter, i.e. "absolute humidity"? We'll cover the most useful humidity variables, their inter-relationship, how to calculate one from another

• what is the difference between "saturated" air and "supersaturated air"?

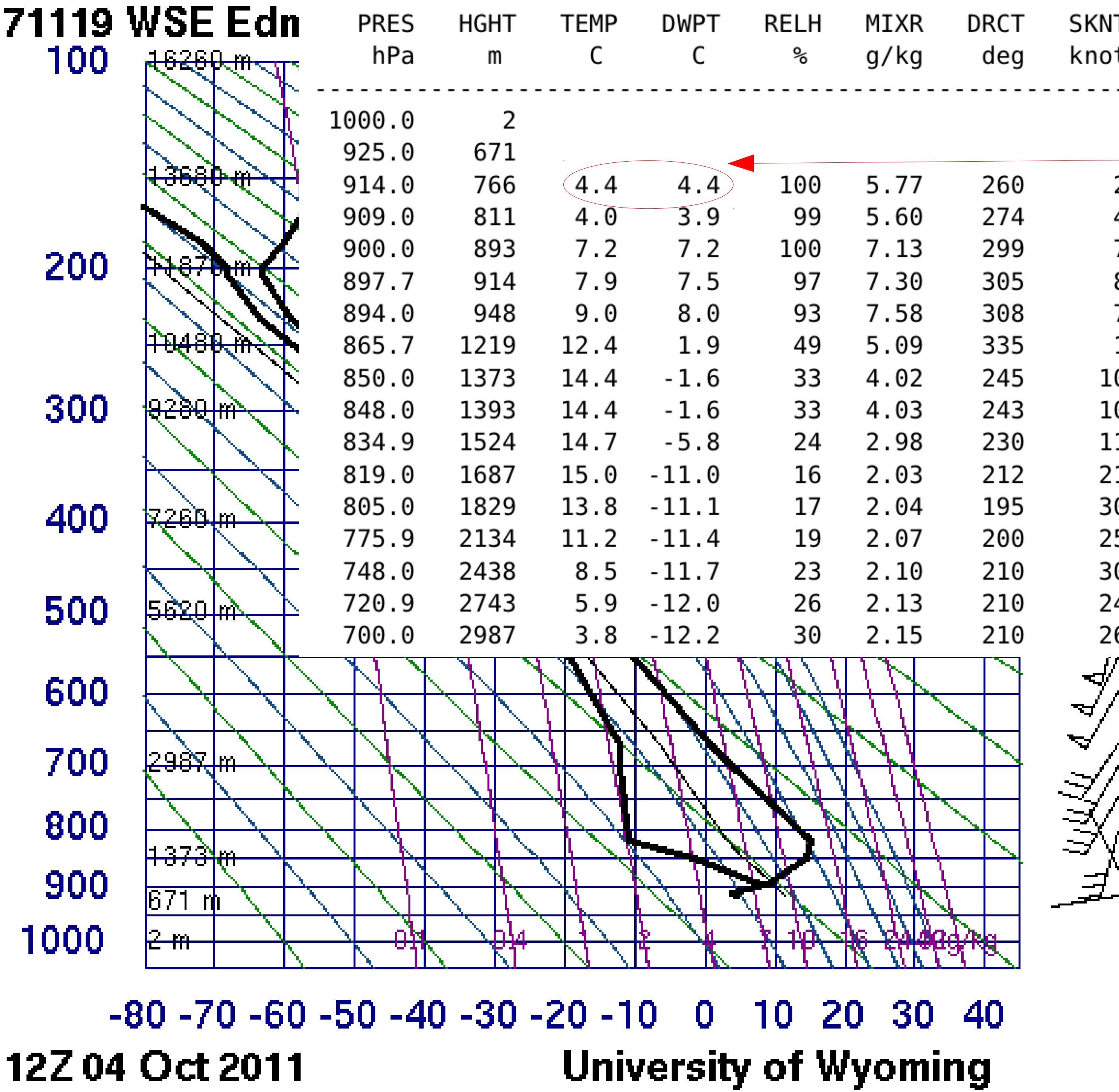
• how can cloud droplets be liquid, yet have a temperature far below 0°C?

Edmonton Int'l Airport
Past 24 Hour Conditions

Imperial Units

Date / Time (MDT)	Conditions	Temp (°C)	Humidity (%)	Dew Point (°C)
4 October 2011				
8:00	Fog	5	100	5
7:00	Fog	4	100	4
6:00	Fog	4	100	4
5:00	Fog	3	100	3
4:00	Fog	3	99	3
3:00	Cloudy	5	99	4
2:00	Cloudy	3	97	2

71119 WSE Edmonton Stony Plain Observations at 12Z 04 Oct 2011



PRES hPa	HGHT m	TEMP C	DWPT C	RELH %	MIXR g/kg	DRCT deg	SKNT knot	THTA K	THTE K	THTV K
1000.0	2									
925.0	671									
914.0	766	4.4	4.4	100	5.77	260	2			
909.0	811	4.0	3.9	99	5.60	274	4			
900.0	893	7.2	7.2	100	7.13	299	7			
897.7	914	7.9	7.5	97	7.30	305	8			
894.0	948	9.0	8.0	93	7.58	308	7			
865.7	1219	12.4	1.9	49	5.09	335	1			
850.0	1373	14.4	-1.6	33	4.02	245	10			
848.0	1393	14.4	-1.6	33	4.03	243	10			
834.9	1524	14.7	-5.8	24	2.98	230	11			
819.0	1687	15.0	-11.0	16	2.03	212	21			
805.0	1829	13.8	-11.1	17	2.04	195	30			
775.9	2134	11.2	-11.4	19	2.07	200	25			
748.0	2438	8.5	-11.7	23	2.10	210	30			
720.9	2743	5.9	-12.0	26	2.13	210	24			
700.0	2987	3.8	-12.2	30	2.15	210	26			

After today's class you'll be able to check consistency of cited humidity figures – by computing RELH & MIXR from TEMP, DWPT

- nocturnal radiation inversion
- shallow saturated layer
- light wind

Chapter 5 “Atmospheric Moisture” introduces the water vapour variables

- absolute humidity $\rho_v \quad [\mathrm{kg\ m^{-3}}]$
- vapour pressure (partial pressure of water vapour) $e \quad [\mathrm{Pa}]$
- specific humidity $$q = \frac{m_v}{m_v + m_d} = \frac{\rho_v}{\rho} \approx r = \frac{m_v}{m_d}$$

Mixing ratio

q, r do not change when parcel of air expands or contracts without condensation/evaporation; nor do they change if parcel warms/cools

- relative humidity $$\mathrm{RH} = 100 \, \frac{e}{e_s(T)}$$

Denominator is a “benchmark value” for the vapour pressure

- dewpoint temperature T_d

How are these inter-related – and why do we need so many?

Ideal gas law for water vapor

$$e = \rho_v R_v T$$

e , vapor pressure [Pa]

ρ_v , absolute humidity [kg m^{-3}]

R_v = 462 [J kg^{-1} K^{-1}] , specific gas const. for water vapor

T , temperature [K]

Form is identical to the ideal gas law giving relationship between total pressure, total density, and temperature:

$$p = \rho R T$$

Concept of “equilibrium” (or “saturation”) vapour pressure

- A thought experiment… container and contents held at fixed temperature T
- The unique equilibrium value e_s depends only on T, so we write $e = e_s(T)$
- And $e_s(T)$ serves as a “benchmark” against which we may compare the actual vapour pressure of any sample of air

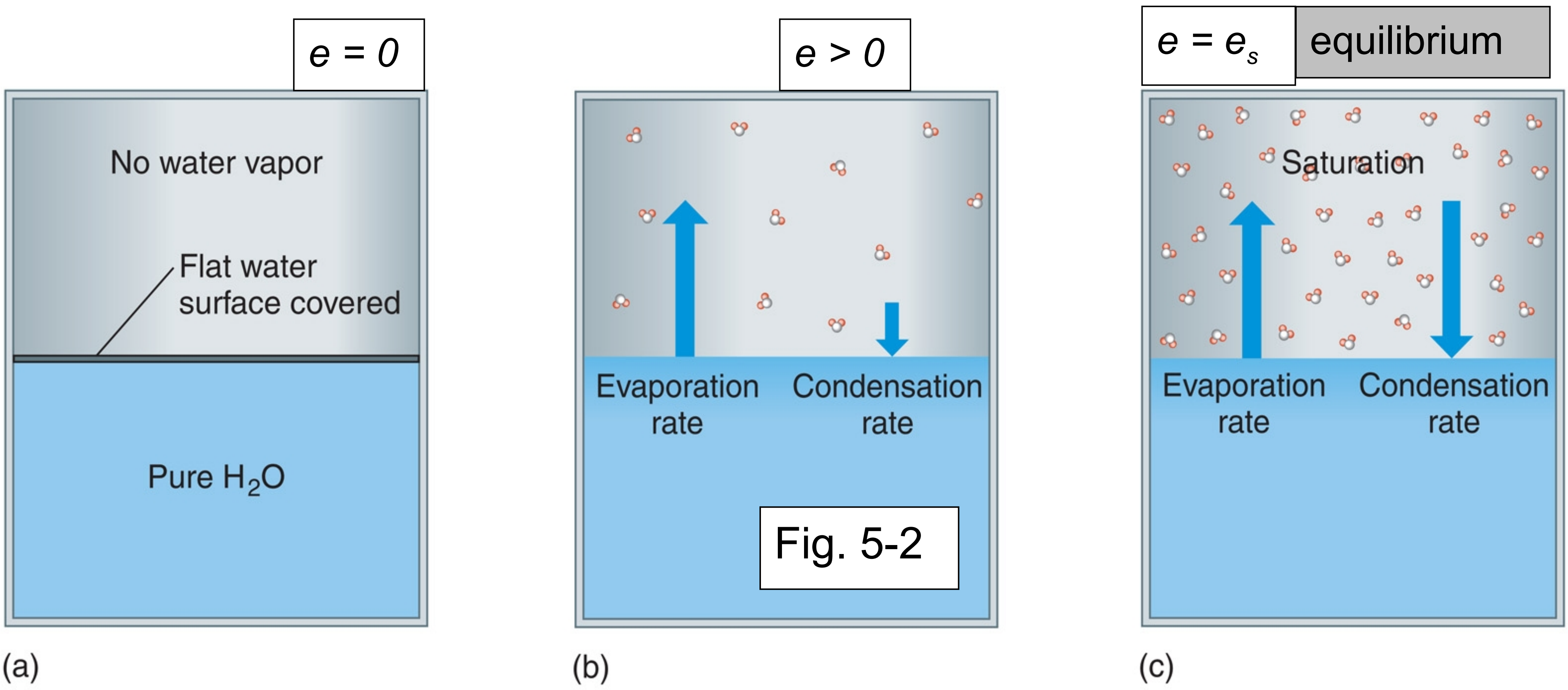


Fig. 5-2

Nature of the "equilibrium"

• The warmer the "system" the higher the average kinetic energy of the molecules in the liquid layer and the more likely their ability to "bust the bonds" (of electrical attraction – water being a polar molecule) retaining them in the liquid layer

• Mechanism of evaporation? A near surface molecule gets "bumped" by another and escapes – evaporation systematically removes molecules having more energy than average, which is why energy must be supplied to maintain the evaporating surface at constant temperature

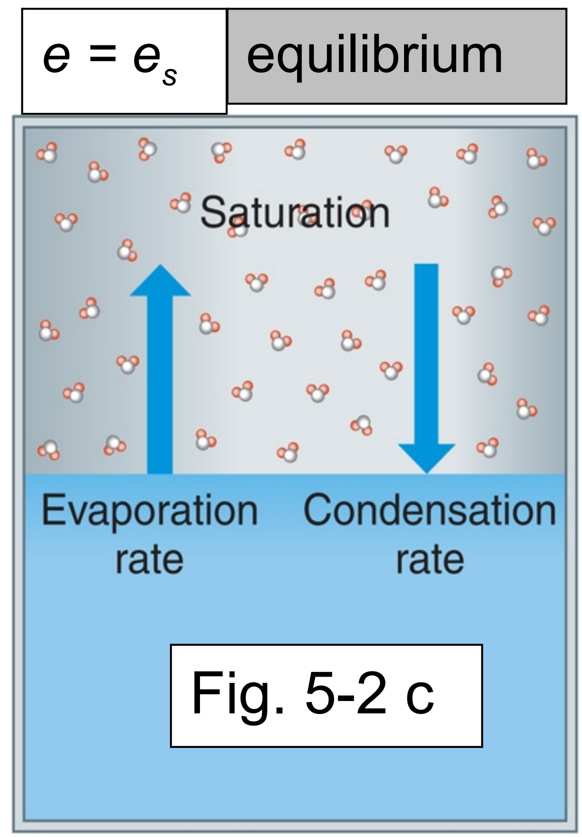
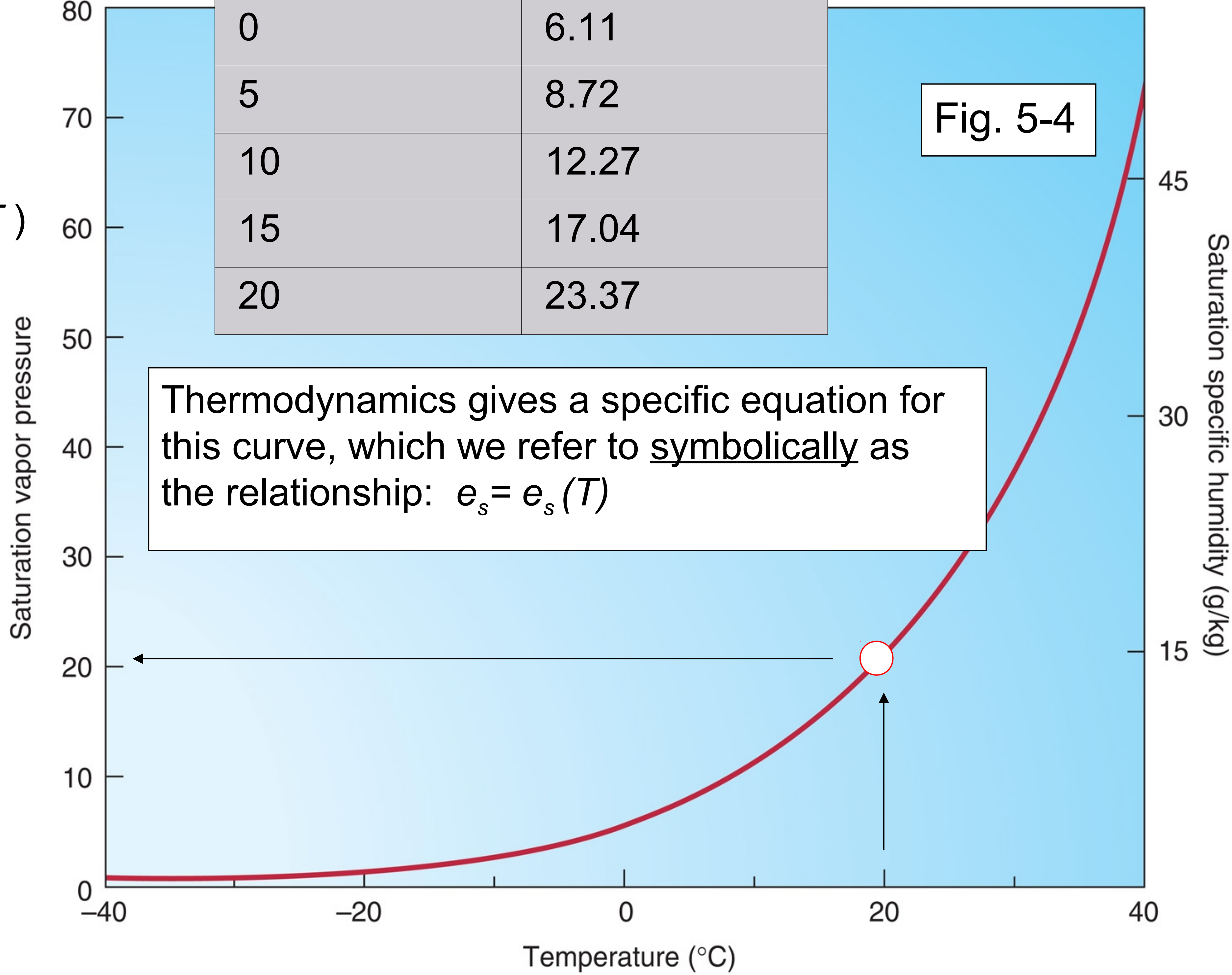


Fig. 5-2 c

• At a higher system temperature T there is a greater flux of escaping molecules – and to balance the escape flux we need an increased return flux, which is achieved by having more molecules of vapour above the liquid surface. More (and more energetic) molecules of vapour in the gas volume results in a higher vapour pressure e

T [°C]	e_s(T) [hPa]
0	6.11
5	8.72
10	12.27
15	17.04
20	23.37

Fig. 5-4



Thermodynamics gives a specific equation for this curve, which we refer to symbolically as the relationship: $e_s = e_s(T)$

The "benchmark" changes with changing air temperature, so RH does not depend on humidity alone!

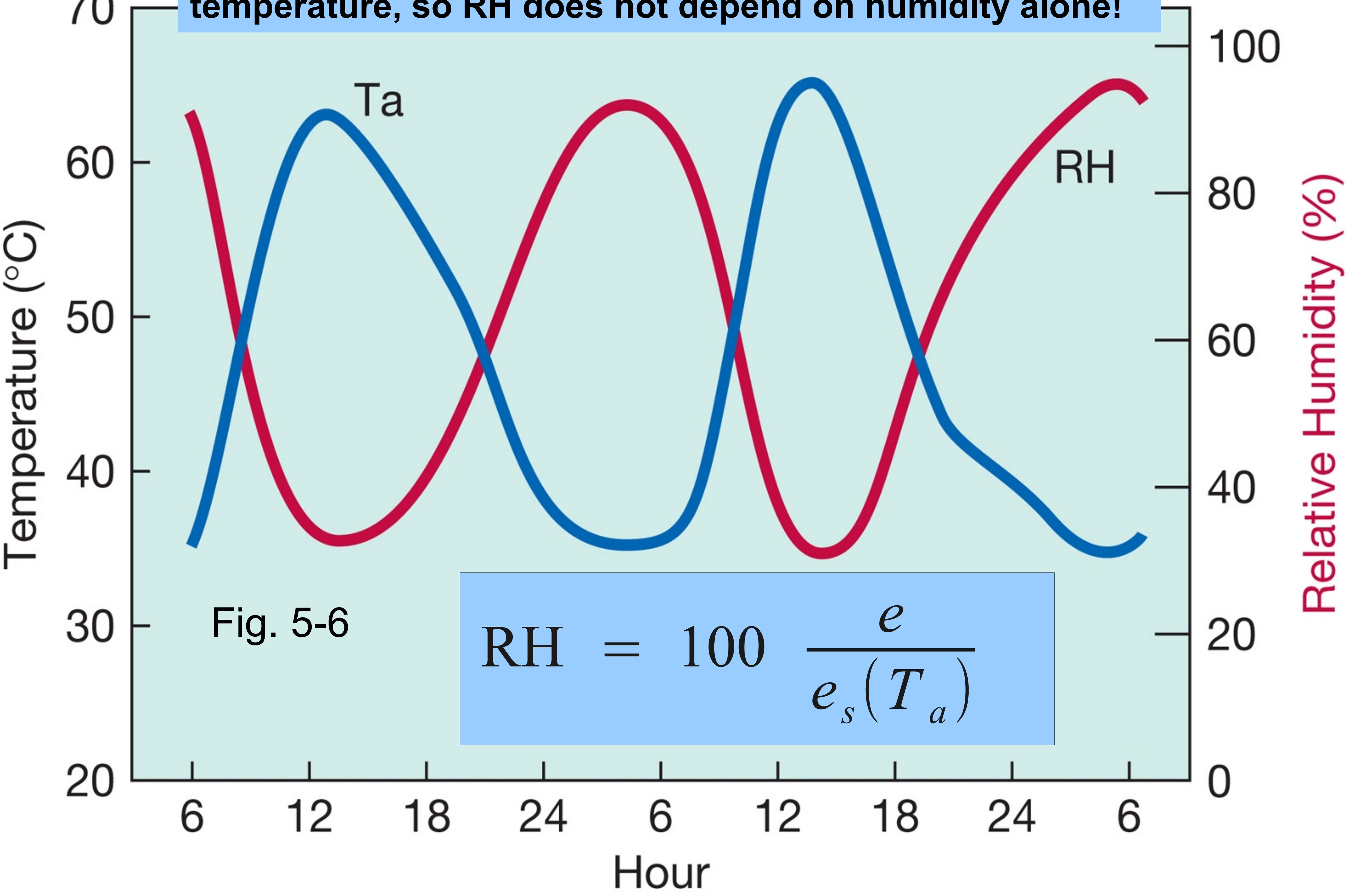
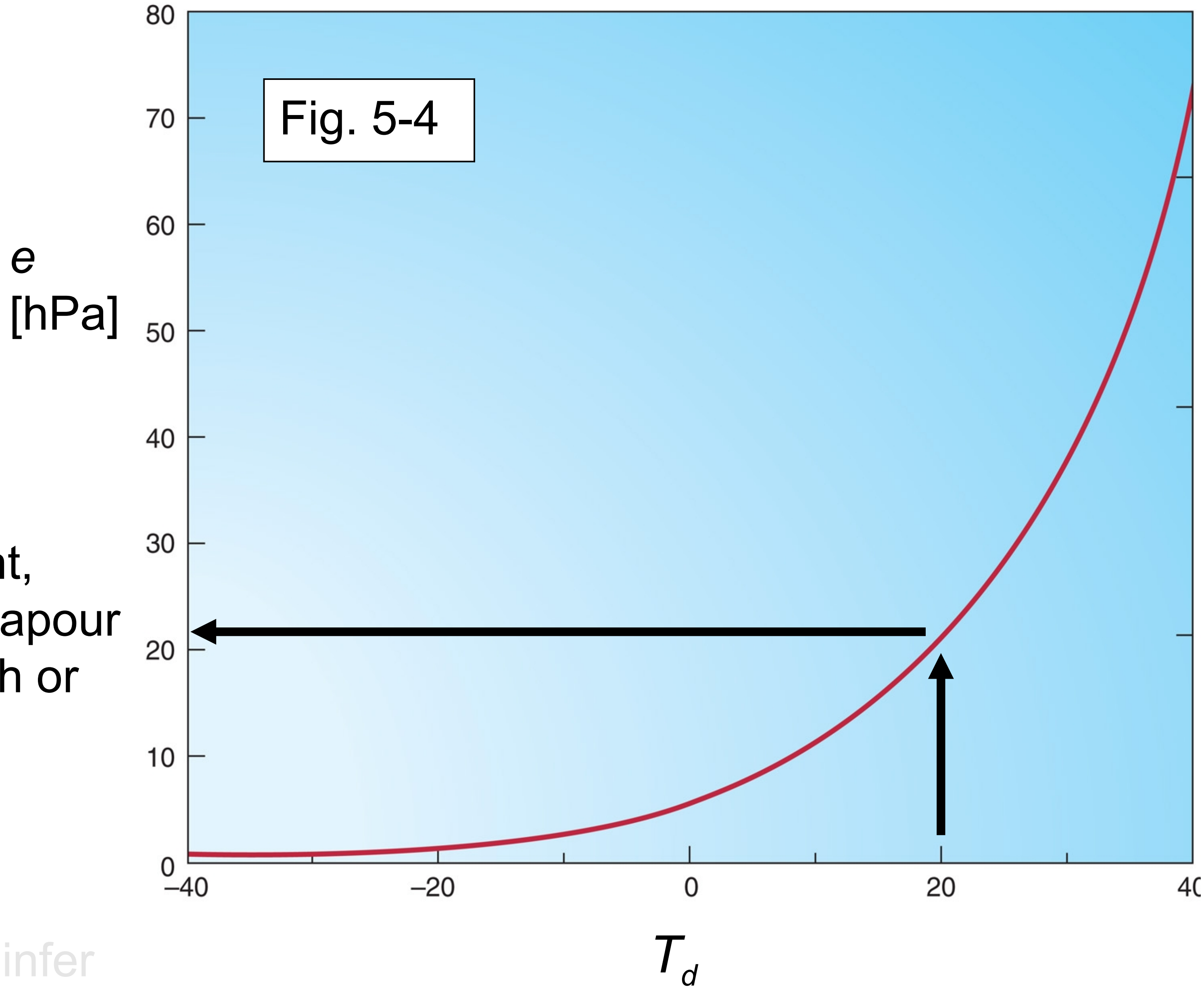


Fig. 5-6

$$RH = 100\,\frac{e}{e_s(T_a)}$$

True vapour pressure e and dewpoint T_d are in 1:1 relationship

$$e \equiv e_s(T_d)$$



• given the dewpoint, one may infer the vapour pressure from graph or table

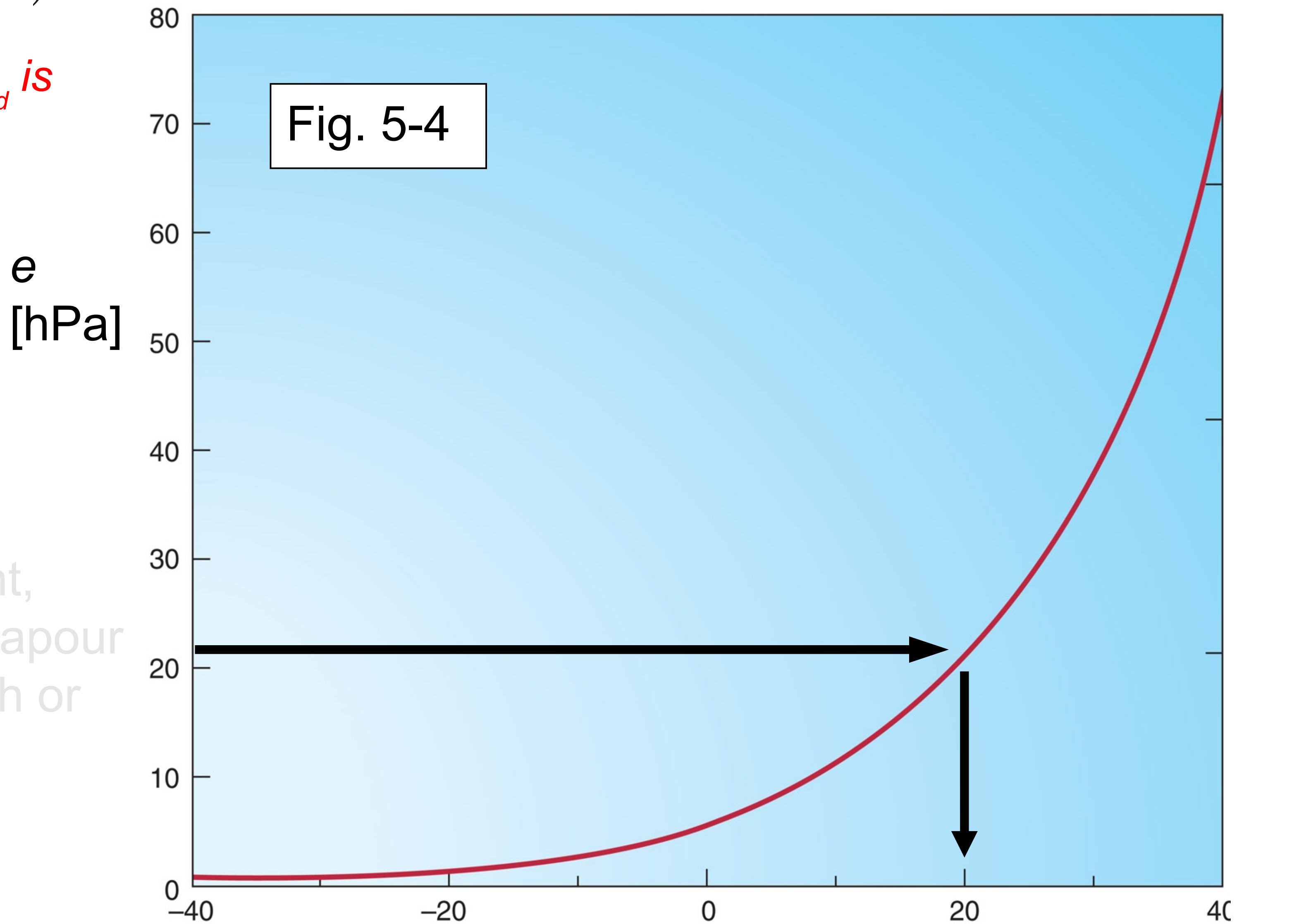
or

• given the vapour pressure, one may infer the dewpoint

True vapour pressure e and dewpoint T_d are in 1:1 relationship

$$T_d \equiv e_s^{-1}(e)$$

Notation indicates T_d is the inverse of e



• given the dewpoint, one may infer the vapour pressure from graph or table

<u>or</u>

• given the vapour pressure, one may infer the dewpoint

T=15°C, T_d=10°C ⟷ T =15°C, e =1227 Pa

Same information

$$e = e_s(T_d)$$

$$\mathrm{RH} = \frac{e}{e_s(T)} = \frac{12.27}{17.04} = 0.72 \quad \text{or } 72\,\%$$

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Why call the equilibrium** vapour pressure a "benchmark"?...

- air does not "have" saturation vapour pressure, but has an ACTUAL vapour pressure e

- normally e is less than or equal to the "holding capacity at equilibrium" or "benchmark," e_s

Analogy: your bank account allows an overdraft of $1000. Designate that overdraft limit by the symbol "OL." Different people, or the same person at different times, have different numerical values for the variable whose symbol is OL.

You carry a certain amount of cash ("c", [$]). Perhaps at noon you have c=1.5 and since you wish to buy a book, you go to an ATM and withdraw $20, so now c=21.5, until you buy the book. You do not "have" or "carry about" an amount of money OL. OL is, as far as your every day behaviour is concerned, only an idea. The reality in your pocket is the actual amount of cash, c. And OL is only relevant to c in as much as, potentially, you can augment c by drawing on your account, until such time as your account is overdrawn by amount OL.

** The term "equilibrium" v.p. is clearer than "saturation" v.p.

Humidity calculations

Suppose the surface analysis for 12Z (0600 MDT) indicates that $(T, T_d) = (8, 4)$ °C. What was the relative humidity outside?

- If outside air was drawn into your house and mixed well inside without addition of water vapour, and if inside temperature was +21 °C, what was the relative humidity inside your house?
- What was the vapour density (ie. absolute humidity, ρ_v) of this inside air?

T °C	$e_s(T)$ [hPa]
4	8.13
8	10.72
21	24.86

First, establish the “benchmark” outside, $e_s(T)=e_s(8)=10.72$ hPa

Now, establish the actual vapour pressure outside, $e= e_s(4)=8.13$ hPa

Then, RH outside was RH=100 e / benchmark = 100   8.13/10.72 = 76%

Inside, the benchmark is $e_s(T)=e_s(21) = 24.5$ hPa.

But the actual vapour pressure is just that of the outside air, e=8.13 hPa.

So, the RH of the air in the house is RH = 100   8.13/24.86 = 33%

And, the absolute humidity, from the Gas Law, is:

$$\rho_v = e / R_v\, T = 813 / (462*(273+21)) = 6.0 \times 10^{-3}\ \mathrm{kg\ m^{-3}} = 6\ \mathrm{g\ m^{-3}}$$

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Our common measures of humidity…

1) $$\mathrm{RH} = 100\,\frac{e}{e_s(T)}$$

2) Vapour pressure deficit (V.P.D.) $e_s(T) - e$

3) Temperature-dewpoint spread $T - T_d$

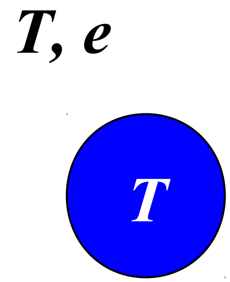
… all relate back to this "benchmark," whose definition appeals to a plane surface of liquid water. But in the atmosphere, where is this plane surface of free water?... Absent!

Condensation in the atmosphere does not necessarily occur at RH=100%

Condensation may commence at RH < 100% onto tiny "hygroscopic" (water-seeking) particles, e.g. sea-salt ("condensation nuclei")

… or, condensation in a very clean atmosphere might not commence until RH > 100% ("supersaturation")

Necessary relative humidity of air to cause formation of liquid water droplets in atmos - the curvature effect



Assume a pure droplet of radius *R* which is at same temperature *T* as air around it. What is the numerical value of the vapour pressure *e* around the droplet necessary to ensure equilibrium? Is it equal to $e_s(T)$?

No.

Equilibrium can only occur if $e > e_s(T)$, a condition called “supersaturation”. The smaller the drop radius, the larger the supersaturation necessary to ensure equilibrium (Fig 5-12).

“If the atmosphere were devoid of aerosols, condensation would occur only by ***homogeneous nucleation***, in which droplets form by chance collision” - such droplets are initially small, and so only possible with a high level of supersaturation (p147)

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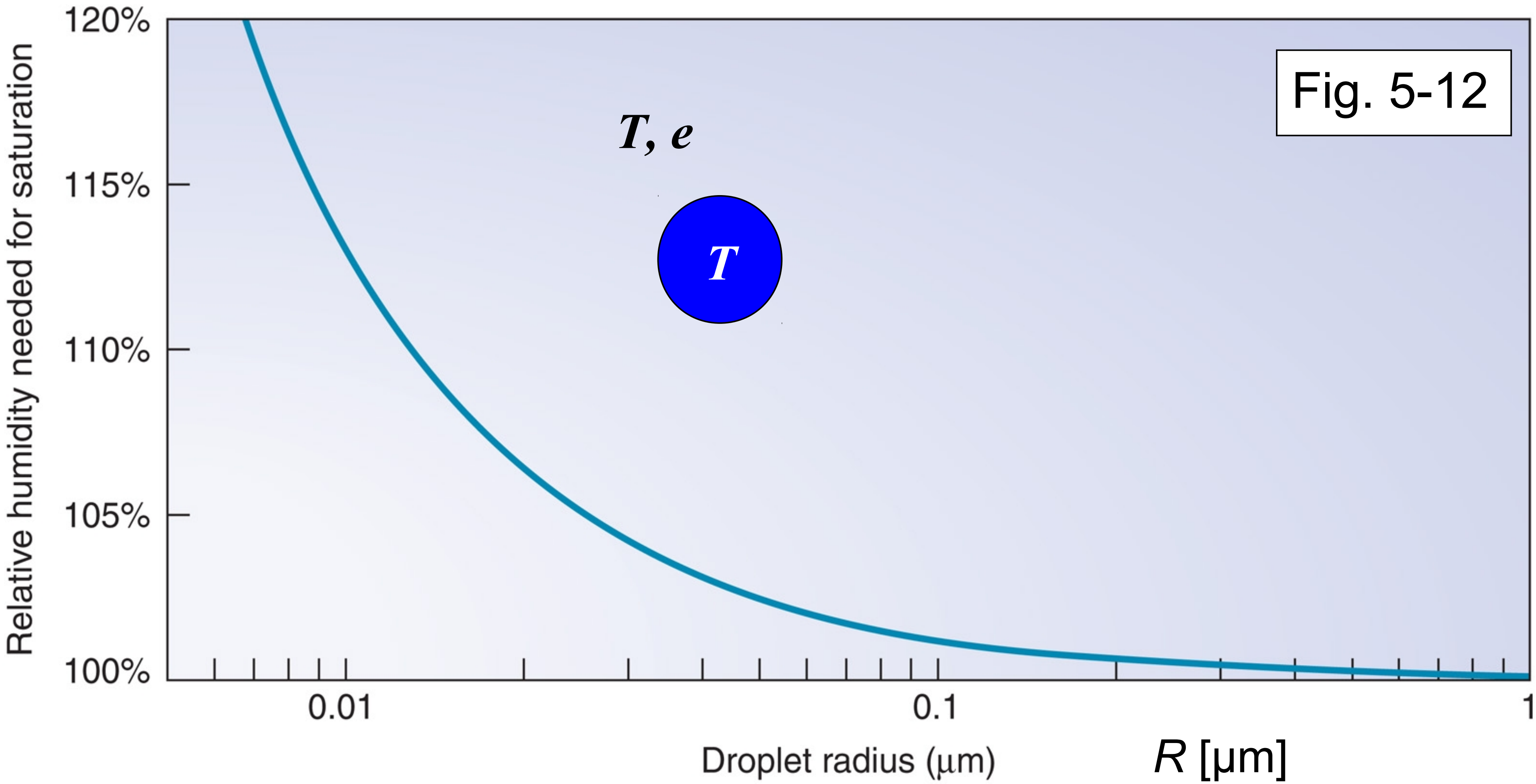
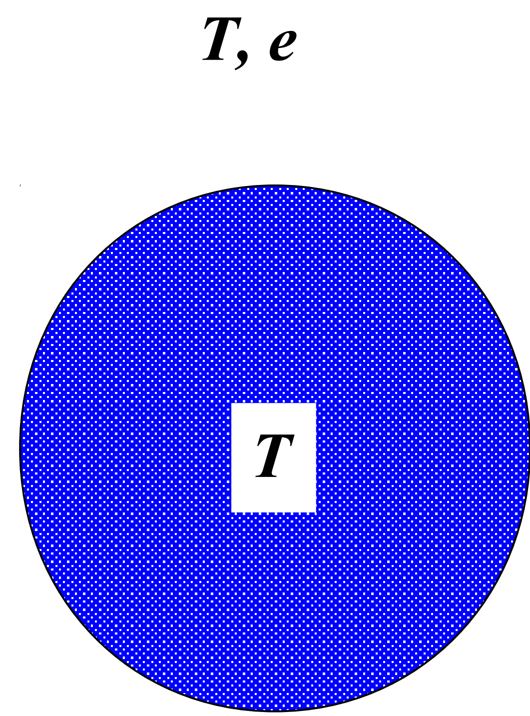


Explanation? The surface area ($4\pi R^2$) to volume ($4/3\ \pi R^3$) ratio of a spherical particle is ***3/R*** and so goes to infinity as radius ***R*** becomes small… so very easy for liquid water to escape from small droplets

Necessary relative humidity of air to cause formation of liquid water droplets in atmos - the solute effect



Now assume an impure droplet of sufficiently large radius *R* that the curvature effect can be neglected. Again, let it be at same temperature *T* as air around it.

What is the numerical value of the vapour pressure ***e*** around the droplet necessary to ensure equilibrium?

Equilibrium occurs at $e < e_s(T)$. Solutions require less vapour above the surface to maintain equilibrium.

Explanation? The solute molecules substitute for water molecules, so there are fewer water molecules adjacent to the surface and able to escape.

"under most circumstances" (p147-8) the solute effect and curvature effect approximately cancel, and condensation *normally* occurs at RH slightly below 100%