Welcome

Vaisala Humidity 101 – Humidity Theory, Terms & Definitions

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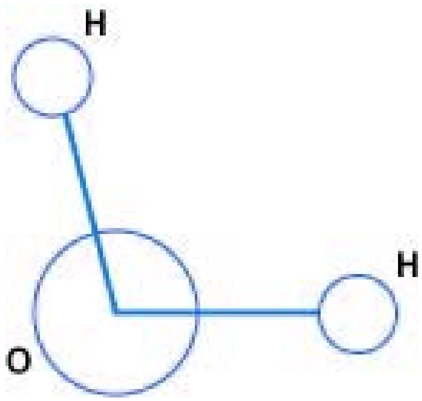
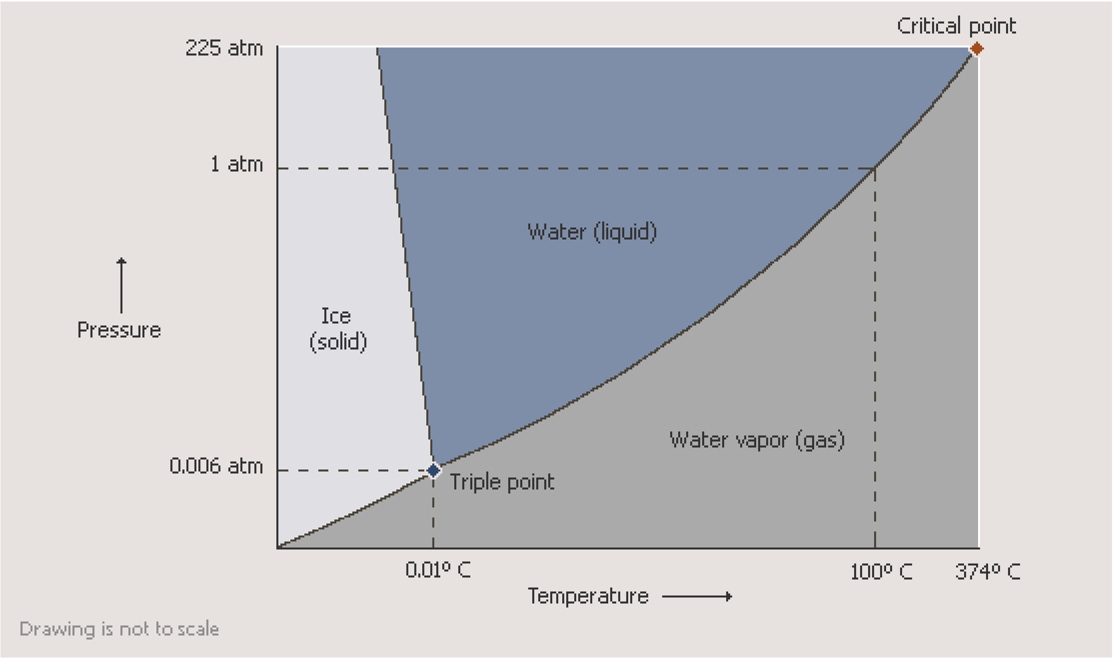
Agenda

1. Why does it help to understand humidity?
2. Dalton’s Law
3. Vapor pressures
4. Relative humidity
5. Td, x, ppm, Tw, h

Water Vapor Theory - H_2O





- Exists in the three phases
- Which phase depends on the amount of thermal energy that is present

American Meteorological Society Glossary   Hu-mid-i-ty

Humidity

1. Generally, some measure of the water vapor content of air.

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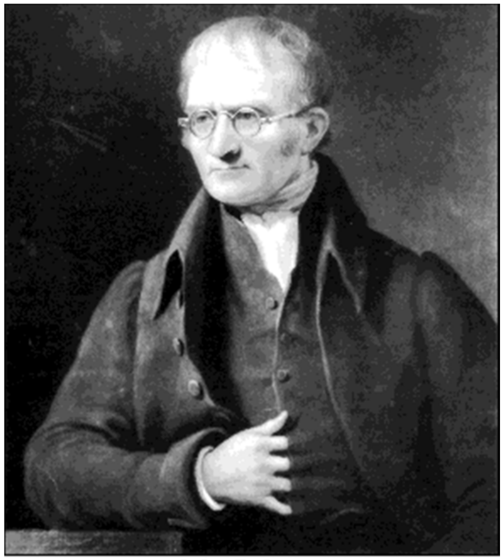
Dalton's Law

"The total pressure of a gas is equal to the sum of the different gases' partial pressures"

$$P_t = P_1 + P_2 + \ldots P_n$$



John Dalton

English chemist, meteorologist, physicist

(1766 – 1844)

<u>air around us</u>

$$P_t = P_{N2} + P_{O2} + \mathbf{P_w} + P_{misc.}$$

Practical Example of Dalton's Law

Nitrogen.................... 77%
Oxygen 21%
Water vapor 1%
Other gases 1%

1000 mbar = 770mbar + 210mbar + 10mbar + 10mbar

How does this change in Denver?

	840 x 77%	840 x 21%	840 x 1%	840 x 1%
P_t = **840 mbar**	**647** N2 +	**177** O2 +	**8** Pw +	**8** Other

$$P_t = P_w + P_{dry}$$

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Definitions

Psychrometry

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Partial Pressure of Water Vapor (psi,mbar,hPa,inhg…)

$$P_w$$

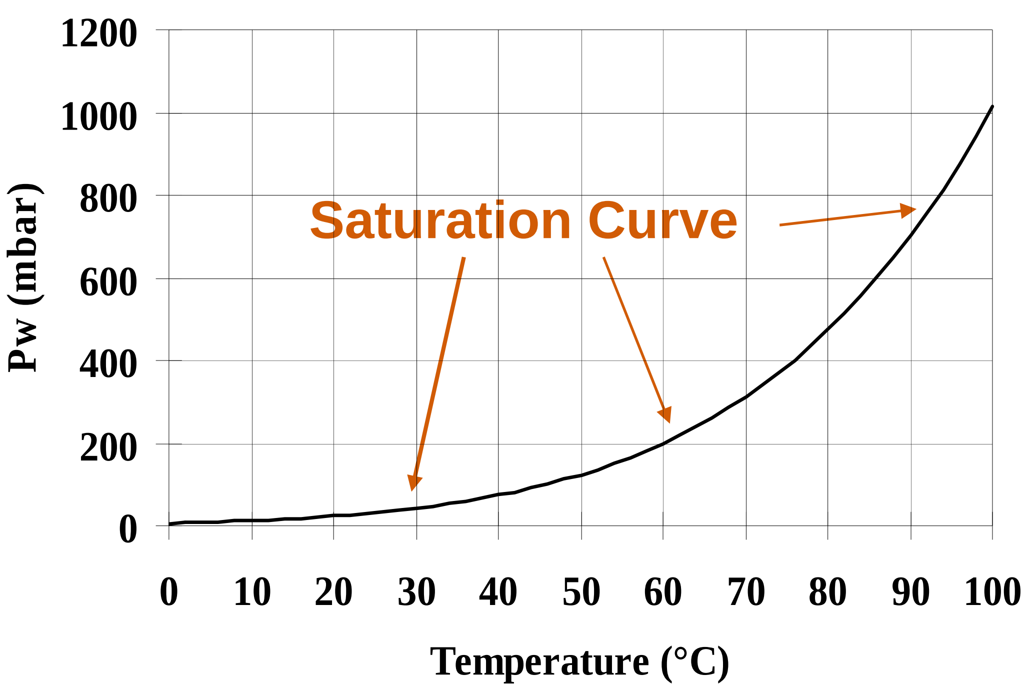
"The key parameter that affects all other humidity parameters"

Note: The only two properties that can affect a change in P_w

- adding or removing water vapor
- changes in system pressure

Saturation Vapor Pressure (psi,mbar,hPa,in hg…)

P_{ws}



On the saturation curve

- evaporation and condensation are in equilibrium and occur at the same rate
- $P_w = P_{ws}$
- dewpoint = temperature
- wet bulb = dry bulb
- RH = 100%

Note: The only property that affects P_{ws} is <u>temperature</u>

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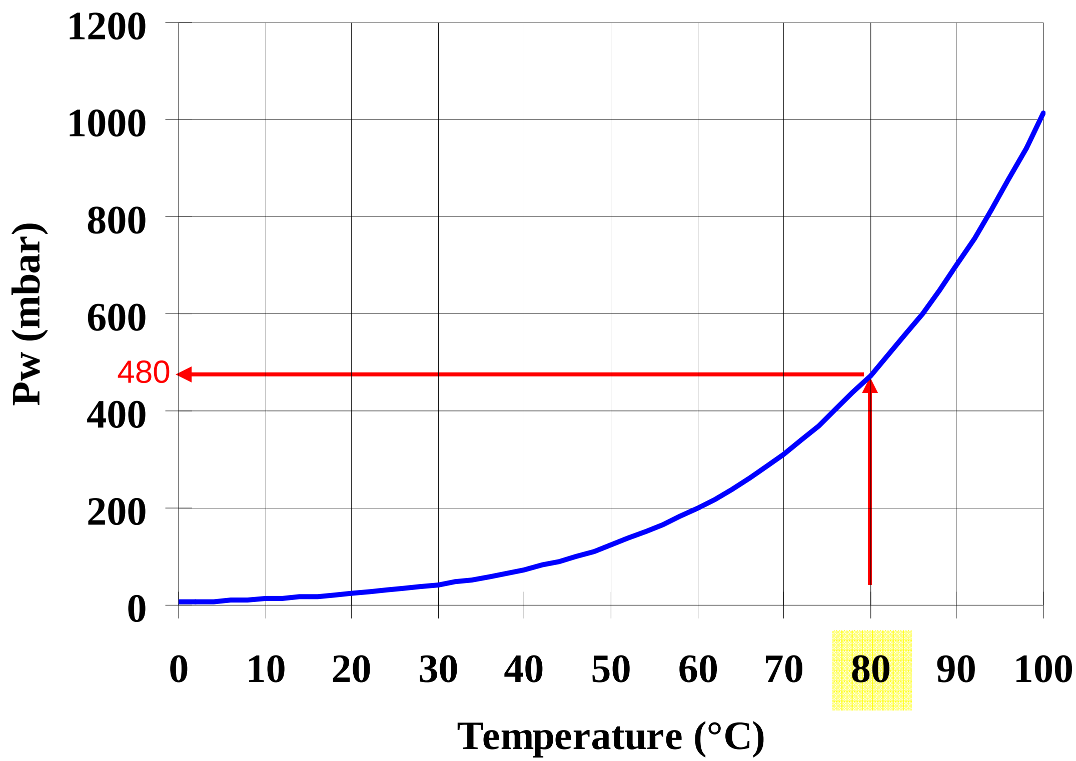
P_{ws} Saturation Vapor Pressure

P_{ws} - maximum vapor pressure or amount of water vapor that can exist at a given temperature. Expressed in units of pressure.

Pws = 480 mbar



Relative Humidity (%)

RH

Relative humidity is the ratio of water vapor partial pressure present in a gas (P_w) to the saturation vapor pressure of water at that temperature [$P_{ws}(t)$]

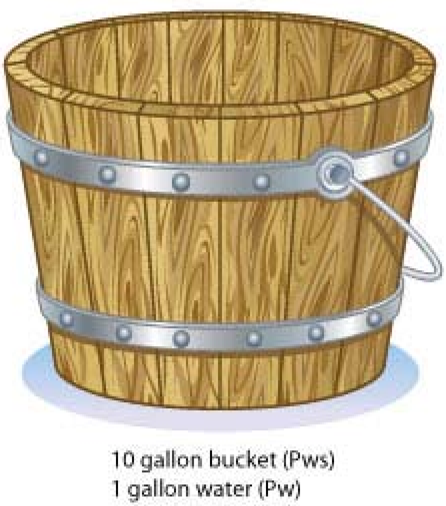
or

The amount of water vapor present in air (gas) expressed as a percentage of the amount needed for saturation at the same temperature.

Bucket Analogy

P_{ws} = bucket size or max amount of water

P_w = amount of water in the bucket



Relative fill = 1/10
10%

Relative fill = 1/5
20%

Relative fill = 1/1
100%

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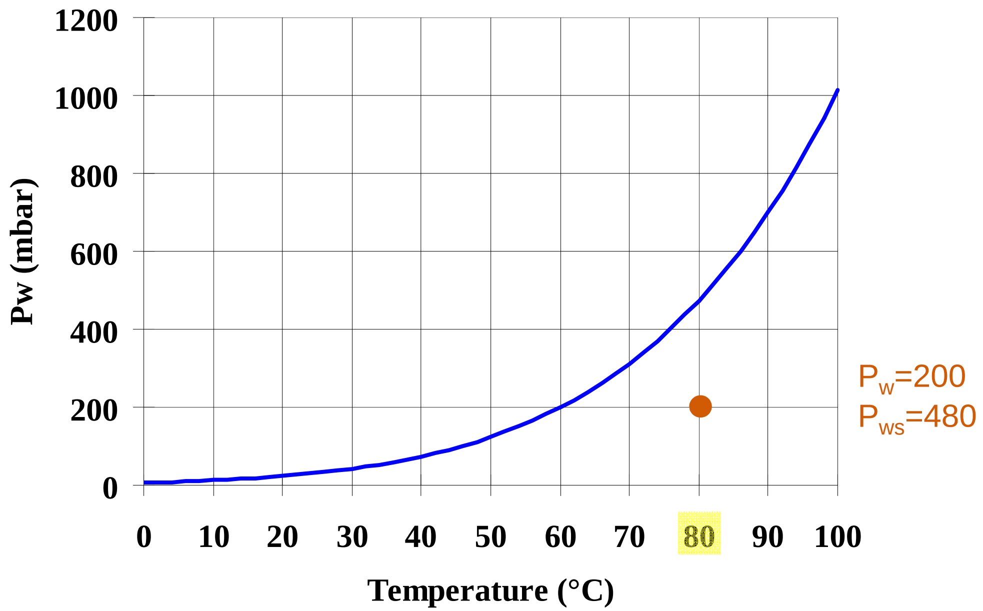
Relative humidity

$$\%RH = 100 \times \frac{P_w}{P_{ws}(t)}$$

$$\%RH = 100 \times \frac{200}{480_{(t=80)}} = 42\%$$



Note: Relative humidity is strongly proportional to temperature and **its measurement is very sensitive to temperature differences.**

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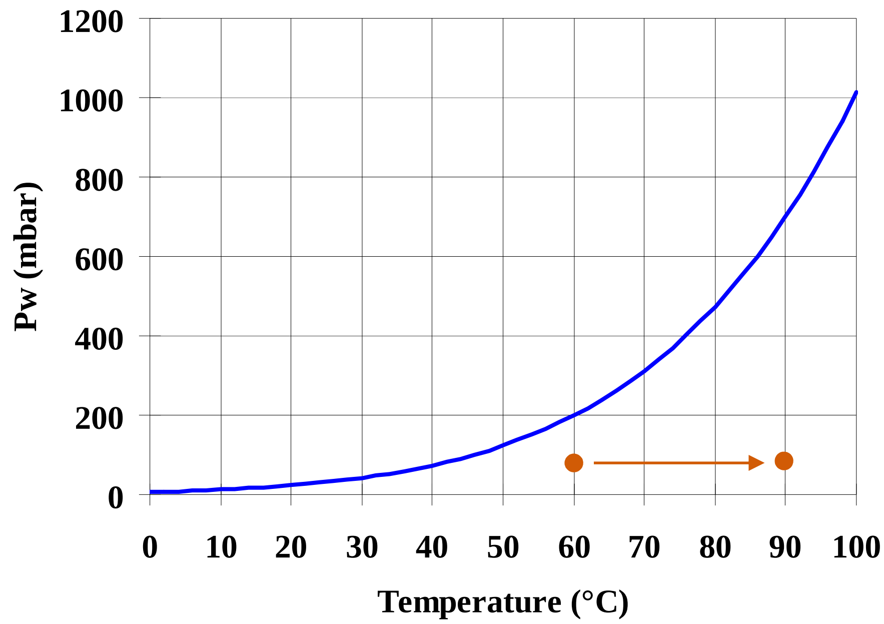
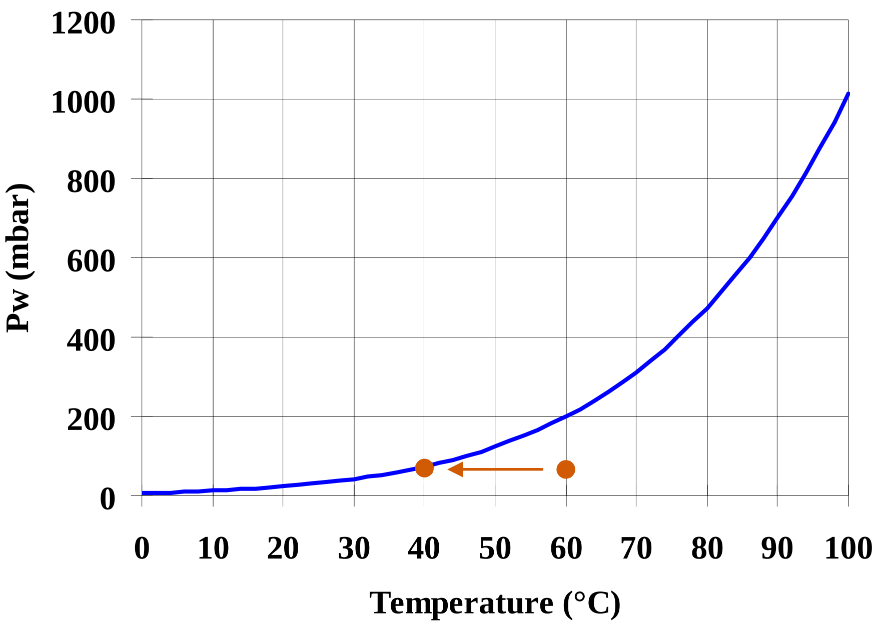
Temperature and Relative Humidity

$$\%RH = 100 \times \frac{P_w}{P_{ws}(t)}$$



Temperature and Relative Humidity

$$\%RH = 100 \times \frac{P_w}{P_{ws}(t)}$$



Temperature and Relative Humidity – Rule of Thumb #1

Rule of Thumb #1*

-As temperature increases, air becomes drier (RH decreases)

-As temperature decreases, air becomes wetter (RH increases)

• drier and wetter are relative terms; applies to a closed system where pressure and water vapor content do not change

What about pressure and Relative Humidity?

Recall Dalton's Law of Partial Pressures $P_t = P_w + P_{dry}$

If double total pressure;

then $2(P_t) = 2(P_w + P_{dry}) = 2P_w + 2P_{dry}$

so P_w changes proportionately to overall pressure changes

remember that Pws remains unchanged because T is unchanged

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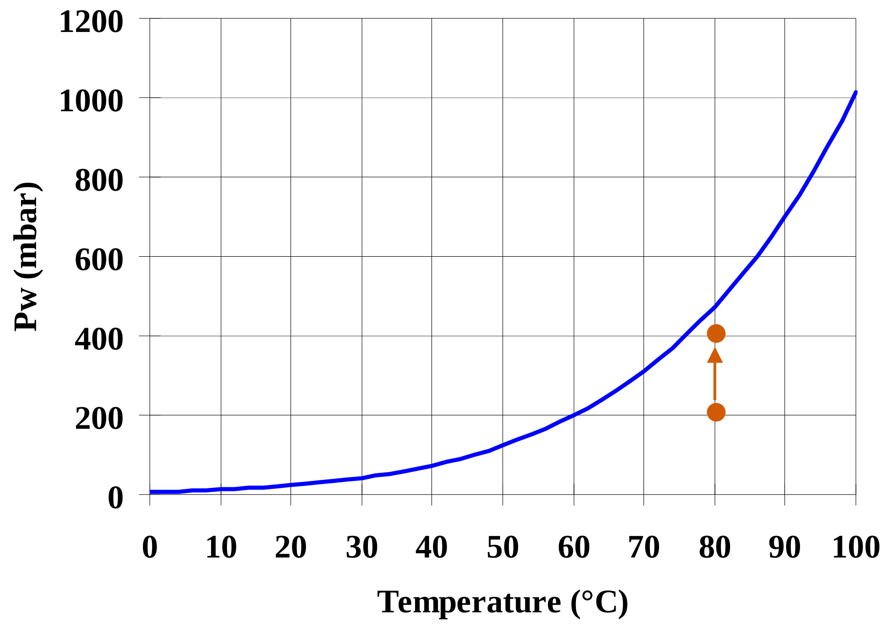
Pressure and Relative Humidity

P_t = 1000 mbar

We double the total pressure

so P_t = 2000 mbar

What happens to Pw? Pws?



Pressure and Relative Humidity – Rule of Thumb #2

Rule of Thumb #2*

-As pressure decreases, air becomes drier (RH goes down)

-As pressure increases, air becomes wetter (RH goes up)

* drier and wetter are relative terms; applies to a closed system where temperature and water vapor content do not change

Relative Humidity Application Example

Relative humidity is the common parameter in HVAC applications where comfort balanced with efficiency is the main concern.

T_d Dewpoint (ºC,ºF,ºK)

T_d

The temperature to which a given portion of air must be cooled at constant pressure and constant water vapor content in order for saturation to occur

The temperature at which a moist gas is saturated with respect to a plane surface of pure liquid water

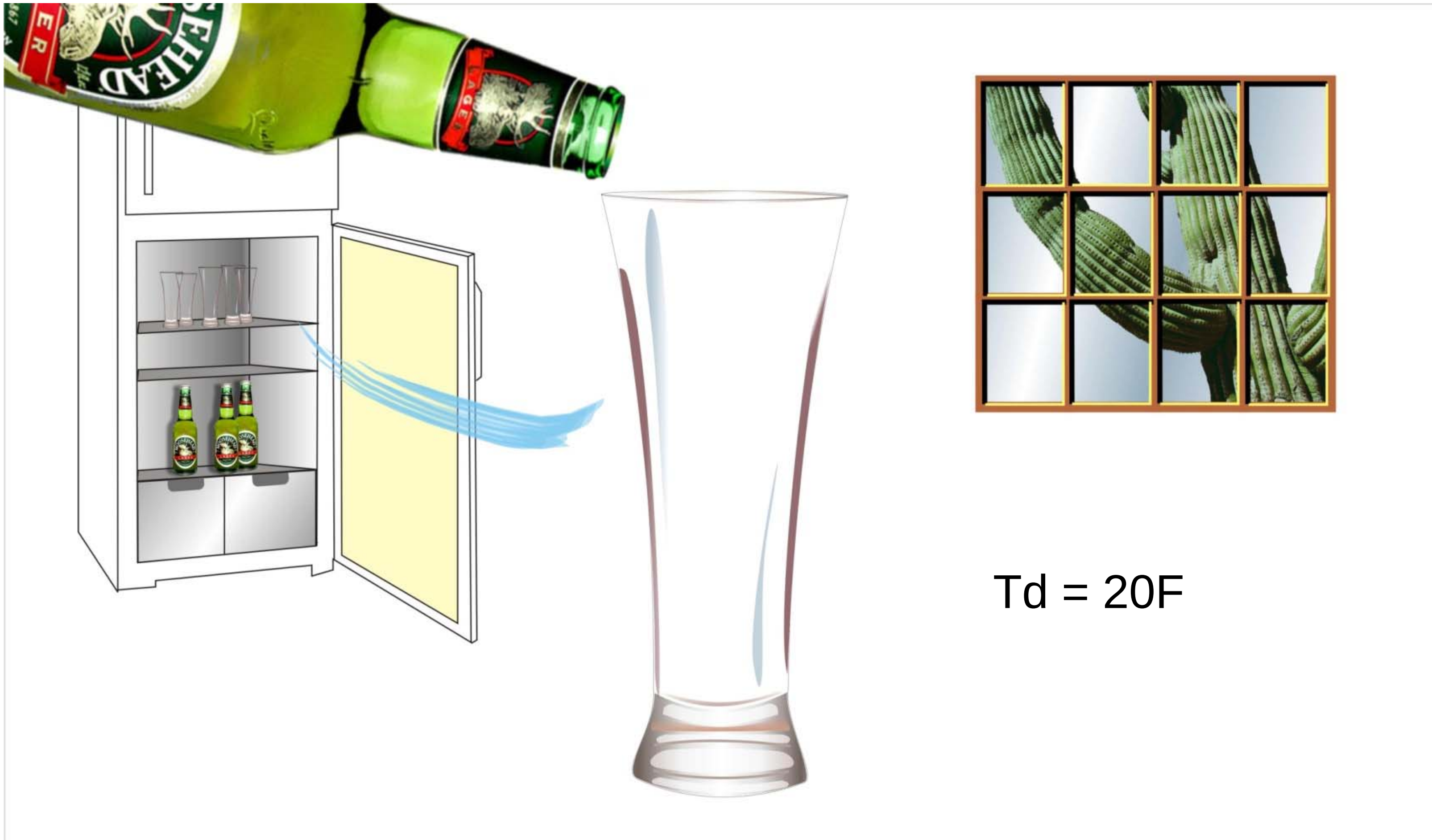
Dewpoint

$$T_d = \frac{T_n}{\frac{m}{\log\left(\frac{P_w}{A}\right)} - 1}$$

- changes with water vapor
- changes with pressure

Note: Dewpoint is not a temperature dependent parameter

Beer temperature = 38F



Td = 20F

Glass temperature above the dewpoint – no condensation

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Beer temperature = 38F

Glass temperature below the dewpoint – condensation appears

Dewpoint & Pressure Rule of Thumb

Rule of Thumb

-As pressure increases, dewpoint temperature rises, air becomes more moist (RH increases)

-As pressure decreases, dewpoint temperature goes lower, air becomes drier (RH decreases)

- drier and wetter are relative terms; applies to a closed system where water vapor content does not change

$T_{d/f}$ Frostpoint (ºC,ºF,ºK)

$T_{d/f}$

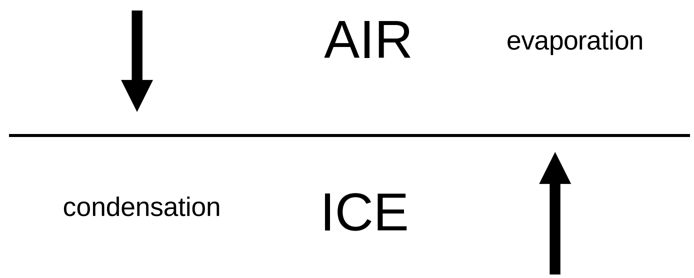
The temperature to which a given portion of air must be cooled at constant pressure and constant water vapor content in order for saturation to occur

The temperature at which a moist gas is saturated with respect to a plane surface of pure ice

Note: $T_{d/f}$ is a Vaisala term which means dewpoint above 32ºF and frostpoint 32ºF and below

Dewpoint versus Frostpoint

Frostpoint	Dewpoint
-0.10° C	-0.11° C
-5.00° C	-5.64° C
-10.00° C	-11.23° C
-20.00° C	-22.25° C
-30.00° C	-33.09° C
-40.00° C	-43.74° C
-50.00° C	-54.24° C
-60.00° C	-64.59° C
-70.00° C	-74.88° C
-80.00° C	-85.29° C
-90.00° C	-96.37° C



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$T_{d/f}$ Frostpoint

T_d or $T_{d/f}$

Td/f – gives you dewpoint at 32 degrees (F) and above and frostpoint below 32 degrees (F)

Td – gives you dewpoint across the entire range of temperatures and assumes supercooled water below 32 degrees (F)

Application Example - compressed air

compressor picture courtesy of Atlas Copco

Dewpoint is the common parameter for measurement in compressed air systems and plastics production feed drying

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X Mixing Ratio or Humidity Ratio (g/kg, gr/lb)

X

– *the ratio of the mass of water vapor per unit mass of dry air to which it is associated*

$X=B*P_w/(P_{tot}-P_w)$

B=621.9907 g/kg

Note: mixing ratio is an absolute measure, not affected by temperature or pressure

Application Example – drying process

Mixing ratio can be used as a measure to help determine drying time where moisture content of a product is important like paper drying or dog biscuit drying.

ppm_v ppm_w

parts per million (volume/weight)

ppm_v

$$PPM_v = \frac{P_w}{(P_{tot} - P_w)} 10^6$$

- volume of water vapor per total volume of dry gas

ppm_w

$$PPM_m = \frac{M_w P_w}{M_d (P_{tot} - P_w)} 10^6$$

- mass of water vapor per total mass of dry gas

Note: ppm is an absolute measure, not affected by temperature or pressure
Mw is molecular mass of water ; Md is molecular mass of dry air

ppm_v and ppm_w

Td/f	PPMw	PPMv
-40.00	14	23
-35.00	24	39
-30.00	42	67
-25.00	69	111
-20.00	113	181
-15.00	181	290
-10.00	284	456
-5.00	439	706

$$PPM_v = \frac{P_w}{(P_{tot} - P_w)} 10^6$$

$$PPM_m = \frac{M_w P_w}{M_d (P_{tot} - P_w)} 10^6$$

Mw/Md = .621980

Application Example – glove box

ppm is sometimes used in dry environments where very precise absolute measurement is required such as in a glove box or clean room

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a Absolute Humidity (g/m^3, gr/ft^3, lbs/MMcf)

a

- *the mass of water vapor per unit volume of moist air*
- *the density of the water vapor*

$A = C * P_W / T$ (g/m^3), where

C=constant 216.679 gK/J
P_W=vapour pressure in hPa
T=temperature i K

Application Example – natural gas

Absolute humidity is the common parameter for measurement of moisture content in natural gas (in the U.S.)

T_w Wet bulb temperature (ºC,ºF)

T_w

the temperature indicated by a thermometer sheathed in a wet cloth as air is passed over it

Application Example
– evaporative cooler or swamp cooler

By comparing the wet bulb temperature to the dry bulb temperature we can determine cooling capacity of an evaporative cooler.

h Enthalpy (kj/kg; btu/lb)

h

- *Measure of the total energy in a moist gas*
- *heat content*
- *sum of the latent heat + sensible heat*

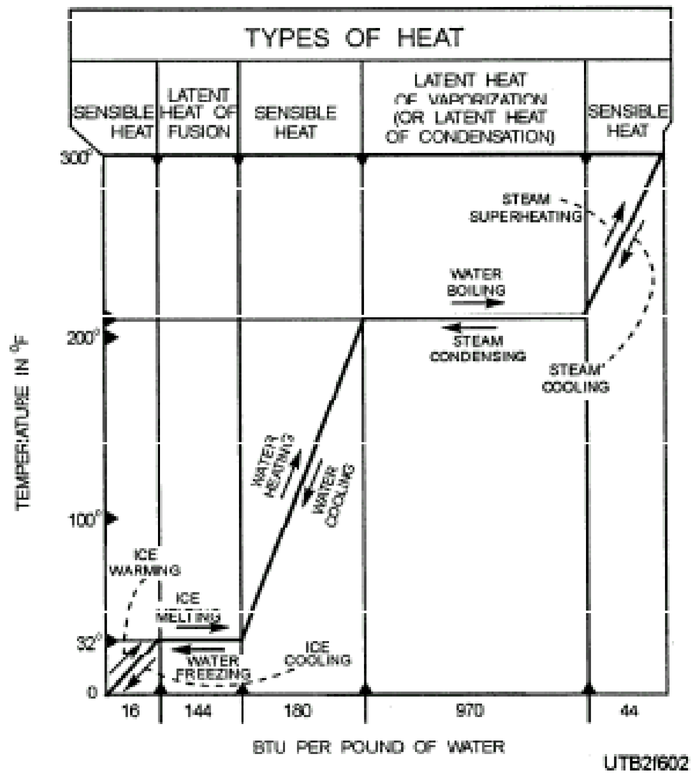

Figure 6-2.—Relationship between temperature and the amount of heat required per pound (for water at atmospheric pressure).

Application Example - HVAC

Enthalpy is a useful measurement for determining HVAC equipment size and efficiency

Psychrometric Terms

– relative humidity	RH	[%RH]
– partial pressure of water vapor	P_w	[mbar; in.Hg, etc.]
– saturation pressure	P_{ws}	[mbar; in.Hg, etc.]
– dewpoint/frostpoint	$T_{d/f}$	[°C; °F]
– absolute humidity	a	[g/m$^{3;}$ gr/ft^3]
– mixing ratio/humidity ratio	x	[g/kg; gr/lb]
– wet bulb temperature	T_w	[°C; °F]
– ppm_v		
– ppm_w		
– enthalpy	h	[kJ/kg; Btu/lb]

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Summary

1. Water vapor theory
2. Dalton's law of partial pressures
3. Pw & Pws
4. RH = Pw/Pws
5. Temperature and RH – Rule of thumb
6. Pressure and RH – Rule of thumb
7. Absolute parameters – x, ppm

Vaisala Humidity Resources

- On-line Humidity Calculator   www.vaisala.com/humiditycalculator
- Slide Rule Calculator to order – http://forms.vaisala.com/forms/RequestSlideRule
- Psychrometric Chart - http://forms.vaisala.com/forms/RequestPsychChart
- Humidity Conversion Formulas - http://forms.vaisala.com/forms/humidity_conversion

For expert assistance with your humidity measurement

Request info: Click here to fill out 'Request Contact' form

Direct telephone: 800-408-9454

Website: www.vaisala.com

Next Webinar – Humidity Sensor Technology - Tutorial

Wednesday, June 26th, 9:30AM MDT

- Humidity Sensor Technology

For full Webinar Schedule info please click here.

Everyone who registered for Humidity Theory will get the invitation for Sensor Technology.

You will receive a follow up email with all of the resource links & link to recording.

Thank you!
This concludes the webinar.

Follow-up email will arrive shortly with the resource links & further contact information.