HYGROMETRIC DEFINITIONS AND RELATIONSHIPS

- Humidity is the measure of water vapour present in air or other gases.

- The measurement of humidity is called hygrometry derived from the Greek term 'hygros' meaning moist.

- Earth is a very wet planet - Over 70% of the its surface is covered by water.

- Water vapour is present in atmospheric air -
  - Approximately 1% by volume in colder/drier climates
    Up to 2% in warmer/wetter regions.

- **All** industrial and process gases contain moisture -
  - From trace levels for high purity special gases and cryogenic liquefaction processes,
  - Up to high percentages >50% by volume for some product drying processes and humidity conditioning environments.

Water Vapour Pressure (*e*)

That part of the total gas pressure which is contributed by water vapour. Also referred to as the partial pressure of water vapour. This is the fundamental measure of humidity.

Saturation Water Vapour Pressure (e_s)

The maximum attainable water vapour pressure of a gas at a given temperature and pressure.

Water vapour in a gas can be considered as a gas itself in accordance with **Dalton's law** for a mixture of gases.

The total pressure (P_{TOTAL}) of a gas is composed of the partial pressure of the dry gas ($P_{DRY\ GAS}$) plus the partial pressure of water vapour (P_{WATER}).

$P_T = P_{DRY\ GAS} + P_{WATER}$

For atmospheric air,

$P_{TOTAL} = P_{NITROGEN} + P_{OXYGEN} + P_{ARGON} + \mathbf{P_{WATER}} + P_{TRACE\ ELEMENTS}$

Partial pressures of typical atmospheric air the component gases:

$P_{NITROGEN}$ = 78 KPa
P_{OXYGEN} = 21 KPa
P_{ARGON} = 1 KPa
***P_{WATER}** = 1 KPa*
P_{TRACE} = 0.3 KPa
P_{TOTAL} = 101.3 KPa

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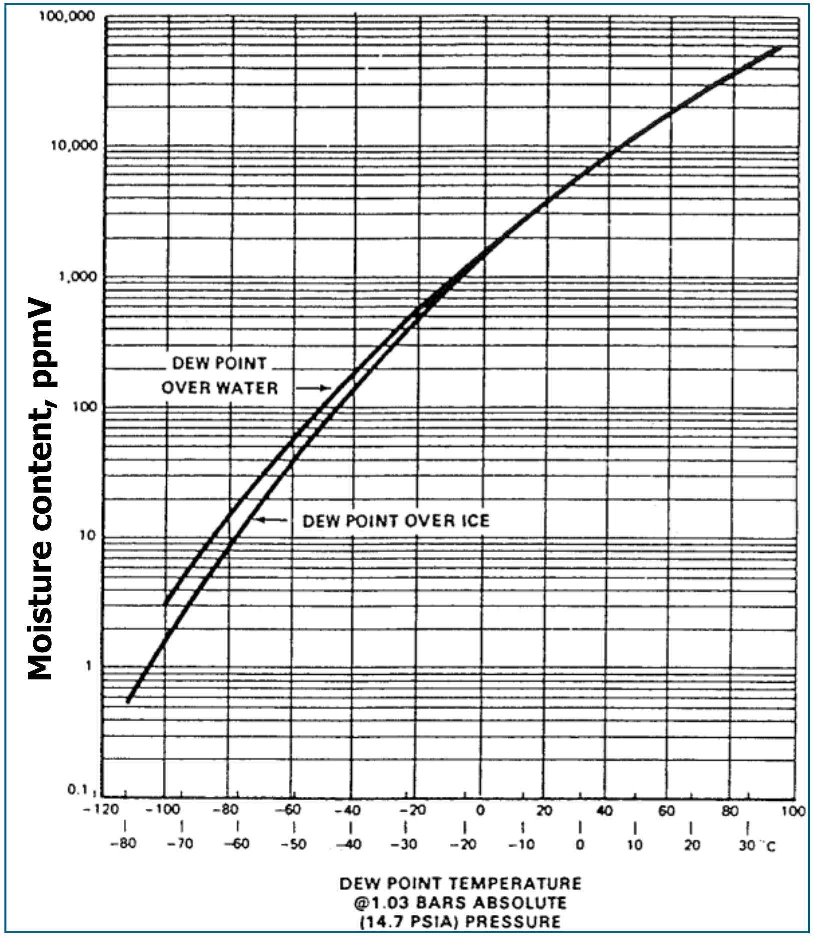
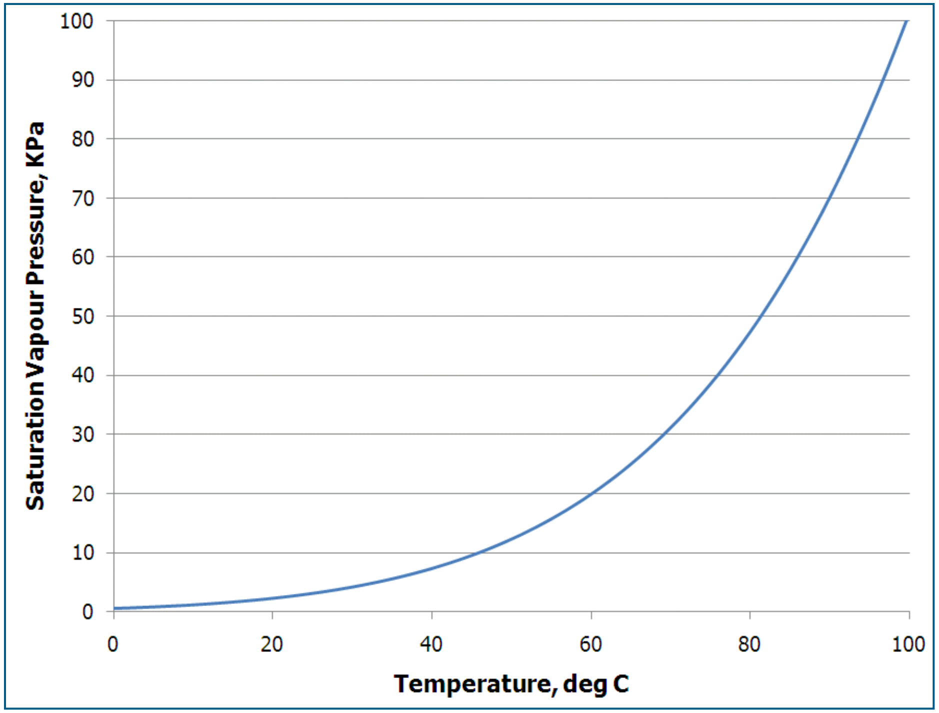
Saturation Water Vapour Pressure Tables

-1	531.822	535.760	539.724	543.714	547.730	551.7
0	572.384	576.587	580.818	585.076	589.362	593.6
	0.0	**0.1**	**0.2**	**0.3**	**0.4**	**0.5**
°C	**Pa**	**Pa**	**Pa**	**Pa**	**Pa**	**Pa**
0	611.213	615.668	620.152	624.665	629.207	633.7
1	657.080	661.830	666.611	671.423	676.265	681.1
2	705.972	711.034	716.129	721.255	726.414	731.6
3	758.060	763.451	768.876	774.335	779.829	785.3
4	813.520	819.259	825.033	830.843	836.690	842.5
5	872.540	878.645	884.788	890.968	897.187	903.4
6	935.313	941.804	948.335	954.907	961.518	968.1
7	1002.04	1008.94	1015.88	1022.86	1029.89	1036.
8	1072.94	1080.27	1087.64	1095.05	1102.52	1110.
9	1148.23	1156.01	1163.83	1171.70	1179.62	1187.
10	1228.13	1236.39	1244.69	1253.04	1261.44	1269.

Charts showing Dew Point to Moisture Content & Saturation Vapour Pressure





Absolute Humidity

A measure of the amount of water vapor present in the system

Dew-Point Temperature

Frost-Point Temperature

Parts Per Million/Billion

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DEW-POINT TEMPERATURE

The temperature to which a gas must be cooled to be saturated with water vapor.

\- or -

The temperature to which a gas must be cooled where the first molecule of water vapor changes to the liquid phase.

For a given partial pressure of water, there is only one corresponding dew point.

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Dew Point (°Cdp, °Fdp)

• The dew point is the temperature at which condensation occurs if a gas is cooled (at constant pressure). At the dew-point temperature a gas is saturated in equilibrium with water vapour.

• The dew point is therefore the temperature at which saturation water vapour pressure would occur if a gas were to be cooled (at constant pressure).

• In the operation of a cooled mirror dew-point hygrometer, a mirror surface is cooled to the temperature at which condensation occurs - *By definition this is the dew-point temperature*.

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Frost-Point

- When a gas is saturated with respect to ice the appropriate term is ‘frost point’ although the convention has developed of using the term ‘dew point’ irrespective of temperature.

FROST-POINT TEMPERATURE

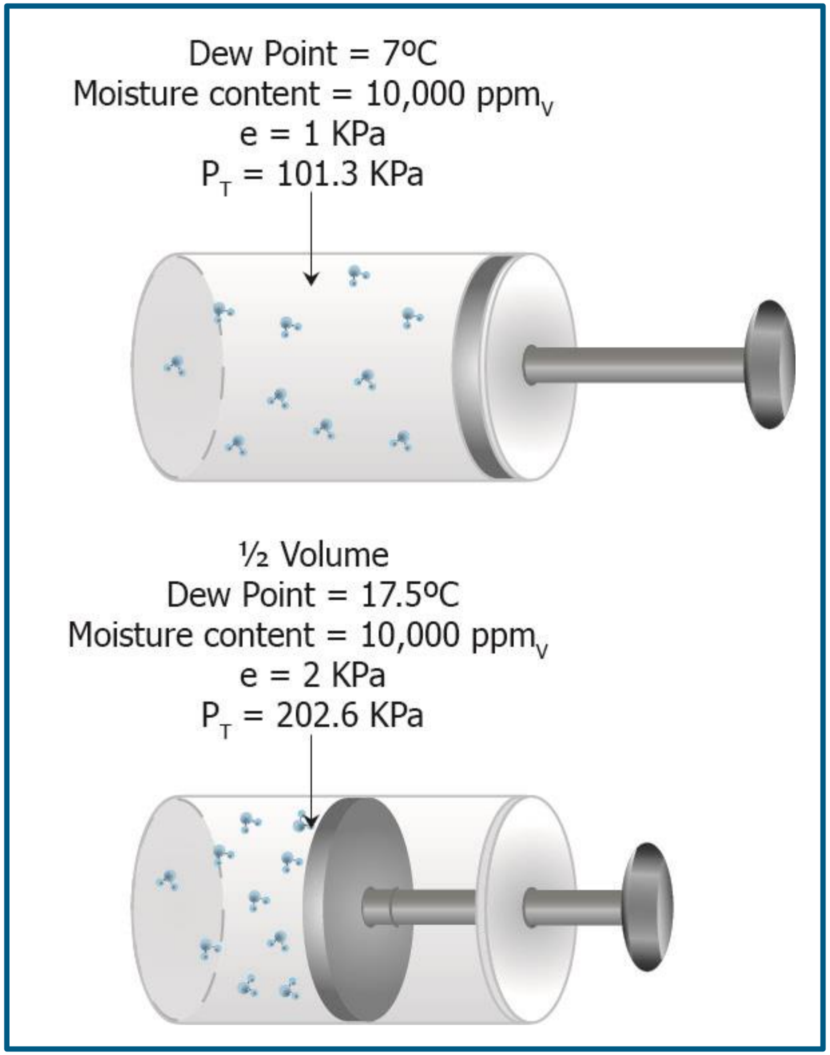
The temperature to which a gas must be cooled to be saturated with respect to ice (solid water).

- or -

The temperature to which a gas must be cooled where the first molecule of water vapor changes to the solid phase.

For a given partial pressure of water, there is only one corresponding frost point.

Effect of increasing gas pressure on dew point and moisture content



Reference to saturation vapour pressure tables

0	572.384	576.587	580.818	585.076	589.362	593.676	598.018	602.
	0.0	**0.1**	**0.2**	**0.3**	**0.4**	**0.5**	**0.6**	**0.**
°C	**Pa**	**Pa**	**Pa**	**Pa**	**Pa**	**Pa**	**Pa**	**P**
0	611.213	615.668	620.152	624.665	629.207	633.779	638.380	643.
1	657.080	661.830	666.611	671.423	676.265	681.138	686.042	690.
2	705.972	711.034	716.129	721.255	726.414	731.606	736.830	742.
3	758.060	763.451	768.876	774.335	779.829	785.357	790.919	796.
4	813.520	819.259	825.033	830.843	836.690	842.573	848.492	854.
5	872.540	878.645	884.788	890.968	897.187	903.444	909.740	916.
6	935.313	941.804	948.335	954.907	961.518	968.170	974.862	981.
7	1002.04	1008.94	1015.88	1022.86	1029.89	1036.96	1044.07	105
8	1072.94	1080.27	1087.64	1095.05	1102.52	1110.02	1117.57	112
9	1148.23	1156.01	1163.83	1171.70	1179.62	1187.59	1195.60	120
10	1228.13	1236.39	1244.69	1253.04	1261.44	1269.89	1278.39	128
11	1312.90	1321.65	1330.46	1339.31	1348.22	1357.18	1366.19	137
12	1402.77	1412.05	1421.39	1430.77	1440.21	1449.71	1459.26	146
13	1498.02	1507.85	1517.74	1527.68	1537.68	1547.74	1557.86	156
14	1598.91	1609.31	1619.78	1630.31	1640.90	1651.55	1662.26	167
15	1705.71	1716.73	1727.81	1738.95	1750.16	1761.43	1772.76	178
16	1818.74	1830.39	1842.11	1853.90	1865.75	1877.67	1889.66	190
17	1938.28	1950.60	1963.00	1975.46	1987.99	2000.59	2013.27	202
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

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Relative Humidity (%rh)

The ratio of actual water vapour pressure (e) to saturation water vapour pressure (e_s) at a given temperature and expressed as a percentage.

$$rh = \frac{e}{e_s} \times 100\ \%$$

Relative humidity is the humidity present relative to the highest possible humidity at the same temperature.

rh is therefore an expression of degree of saturation expressed as a percentage.

rh is used where degree of moisture saturation is the factor is of significance: Air conditioning systems, food processing and storage environments (warehouses, museums).

For our example of atmospheric air, if we assume normal ambient temperature of 21°C then,

$$rh = \frac{1}{2.5} \times 100\% = 40\%$$

If the ambient temperature is decreased, say to 15°C, then the saturation water vapour pressure will fail and thus the relative humidity will rise,

$$rh = \frac{1}{1.7} \times 100\% = 59\%$$

It is therefore essential, in order to define a measured humidity level in rh, that the prevailing temperature is also stated.

Moisture Content

Units of moisture content are expressions of absolute humidity which will therefore remain constant for a gas of fixed composition irrespective of variations in gas temperature and pressure.

A number of different units are in common usage which are derived as a ratio of volume, mass or as a density.

Care must be taken as some units are expressed as a mixing ratio of moisture to dry gas whilst others are expressed as a specific humidity of moisture to humid gas. The different between the two is almost negligible for trace moisture concentrations but is of significance at higher moisture concentrations.

Parts per million

For low humidity levels, the unit of moisture content in most common usage is **parts per million:** The number of parts of water vapour to one million parts of wet gas expressed either by volume **(ppmV)** or weight **(ppmW)**.

$$ppmV = \frac{e}{P_{TOTAL}} \times 10^6$$

$$ppmW = \frac{\text{grams of water vapour}}{\text{grams of gas}} \times 10^6$$

or simply derived from ppm(V) as follows,

$$ppmW = ppmV \times \frac{\text{molecular weight of water}}{\text{molecular weight of gas}}$$

For our example of atmospheric air,

$$ppmV = \frac{1}{101.3} \times 10^6$$

$$= 10{,}000$$

$$ppmW = 10{,}000 \times \frac{18}{29}$$

$$= 6{,}207$$

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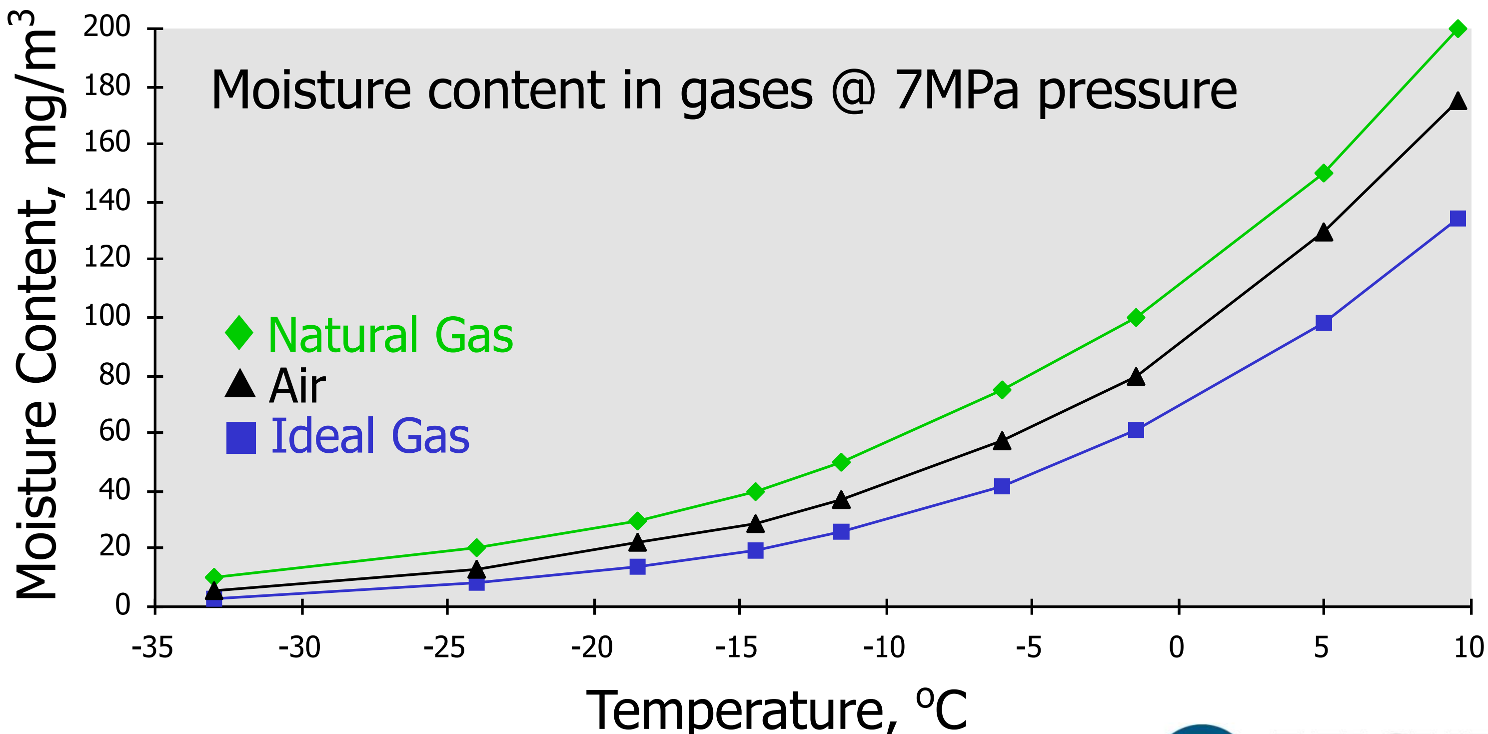
Conversion from Measured Dew Point to Moisture Content



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Absolute Humidity (wet basis)

When moisture content is expressed as a **density**, the most common unit is **mg/m³** which can be calculated from ppmW as follows,

For an ideal gas, 1 mole (grams molecular weight) has a volume of 22.4 litres at s.t.p.
For air, 29 grams has a volume of 22.4 litres at s.t.p. therefore,
10^6 grams of air has a volume = $\frac{10^6}{29} \times 22.4$

$= 772{,}414$ litres

$= 772.4\ m^3$

From previous slide,

$$ppmW = \frac{\text{grams of water vapour}}{\text{grams of wet gas}} \times 10^6$$

Therefore,

$$mg/m^3 = \frac{ppmW}{772.4}$$

For the example of atmospheric air,

$$mg/m^3 = \frac{6{,}207}{772.4}$$

$$= 8.04$$

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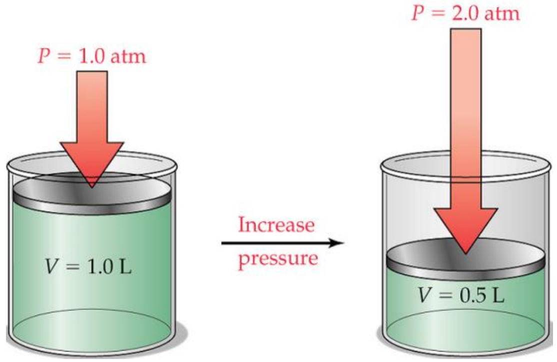
Dew-Point Pressure Relationship



P_{T1} = 1277 mm Hg (10 psig)

P_{W_1} = 0.0966 mm Hg

DP_1 = -40°C

P_{T2} = 5930 mm Hg (100 psig)

P_{W_2} = 0.4486 mm Hg

DP_2 = -25.6°C

Dalton's Law

$$P_T = P_1 + P_2 + \dots P_i$$

$$P_T (\uparrow) = P_1 (\uparrow) + P_2 (\uparrow) + \dots P_i (\uparrow)$$

Pressure Increases (↑) ⇒ Water Partial Pressure Increases (↑)

Water Partial Pressure Increases (↑) ⇒ Dew Point Increases (↑)

PARTS PER MILLION BY VOLUME (PPM_V)

1 minute in 1.9 years = one PPM

$$PPM_V = (P_W / P_T) \times (10^6)$$

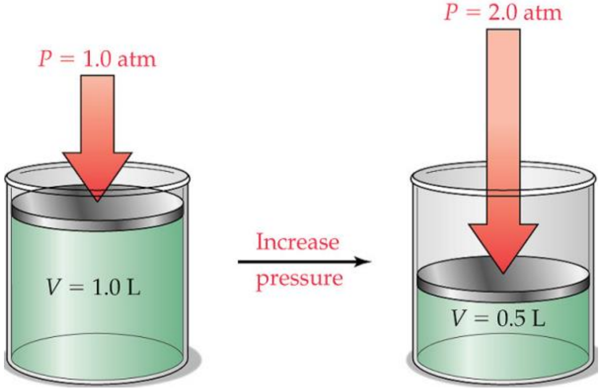
P_W = Partial Pressure of Water

P_T = Total Pressure of the System

PPM_v is most commonly used when measuring moisture in gases.

PPM_V/Pressure Relationship

$$P_1V_1 = P_2V_2$$



P_1 = 1277 mm Hg (10 psig) P_2 = 5930 mm Hg (100 psig)

P_{W_1} = 0.0966 mm Hg P_{W_2} = 0.4486 mm Hg

PPM_{V_1} = 75.6 PPM_{V_2} = 75.6

Dalton's Law $P_T (\uparrow) = P_1 (\uparrow) + P_2 (\uparrow) + \ldots P_i (\uparrow)$

$$PPM_V = (P_{W_1} / P_{T_1}) \times (10^6) = (P_{W_2} / P_{T_2}) \times (10^6)$$

$$(P_{W_1} / P_{T_1}) = (P_{W_2} / P_{T_2})$$

The ratio of water partial pressure to total pressure doesn't change because every component chances proportionally, so $PPM_{V_1} = PPM_{V_2}$

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Influence of Pressure on Moisture content:

Looking again to the effects of doubling the pressure of typical atmospheric air, as the proportion of moisture to carrier gas remains constant, then the moisture content remains constant irrespective of pressure variations:

$$ppm(V) = \frac{2}{202.6} \times 10^6$$

$$= 10{,}000$$

Conclusion: Moisture Content is independent of pressure.

Influence of P and T on Relative Humidity:

Pressure: Changes the partial pressure of water vapour (e),

Temperature: Alters the saturation vapour pressure (e_s) .

Conclusion: %rh is influenced by both temperature and pressure.

Summary:	Dew point	Moisture content	Relative humidity
Increase pressure	↑	0	↑
Decrease pressure	↓	0	↓
Increase temperature	0	0	↓
Decrease temperature	0	0	↑

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Parts Per Million By Weight (PPM_W) In Liquids

Application of Henry's Law

The mass of gas dissolved by a given volume of solvent, at a constant temperature, is directly proportional to the pressure of gas with which it is in equilibrium

$$C = KP$$

C = concentration of the gas

K = Henry's Law constant

P = pressure of the gas

Parts Per Million By Weight (*PPM_W*) In Liquids

Application of Henry's Law

The concentration of water in an organic liquid is equal to the vapor pressure of the water in the liquid multiplied by a constant.

$$Cw = KPw$$

Cw = concentration of water in the liquid

K = Henry's Law constant

Pw = vapor pressure of water in the liquid

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Application of Henry's Law

…and $Cs = KPs$

Cs = saturation concentration of water in the liquid

K = Henry's Law constant

Ps = saturation water vapor pressure

…eliminating K reveals that percent saturation is simply equal to the ratio of the actual vapor pressure of water (dew point) to its saturation vapor pressure at the same temperature.

$$Cw/Cs = Pw/Ps$$

…and finally determining moisture content

$$Cw = (Cs/Ps)\,Pw$$

Water Solubility Data for Mixtures