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Humidity —

Part 1: Terms, definitions and formulae

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Committees responsible for this British Standard

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British Compressed Gases Association

Institution of Chemical Engineers

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Contents

Foreword

This British Standard has been prepared by Technical Committee CPI/29, Humidity and temperature conditioning requirements. It supersedes BS 1339:1965 (which was concerned solely with the humidity of the air), and extends the consideration of humidity to that of any gas. BS 1339:1965 is now withdrawn.

It is based partly upon *A Guide to the Measurement of Humidity* [1] published by the Institute of Measurement and Control under Crown Copyright.

This is part 1 of a series of parts of BS 1339 on humidity as follows:

— *Part 1: Terms, definitions and formulae*;

— *Part 2: Humidity calculation and tables*;

— *Part 3: Guide to the measurement of humidity*.

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Summary of pages

This document comprises a front cover, an inside front cover, pages i and ii, pages 1 to 23 and a back cover.

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1 Scope

This part of BS 1339 gives terms, definitions, symbols, units, formulae and constants associated with humidity and its measurement.

2 Terms and definitions

NOTE Some alternative and obsolescent terms and definitions used in considering humidity and its measurement are discussed in part 3 of this British Standard.

2.1 Definitions of general terms

2.1.1

absorption

retention of a substance, e.g. water or **water vapour**, by penetration into the bulk of a material

2.1.2

adsorption

retention of a substance, e.g. water or **water vapour**, as a layer on the surface of a material or within a material

2.1.3

absolute humidity

deprecated term used loosely to describe either **mixing ratio** (**2.1.29**), **specific humidity** (**2.1.41**) or **volumetric humidity** (**2.1.49**)

2.1.4

adiabatic saturation temperature

final temperature reached by a small quantity of **vapour/gas** mixture into which water is evaporating

2.1.5

condensate

condensed substance, e.g. liquid water or ice

NOTE Technically, if vapour condenses directly to a solid without passing through a liquid phase, it is termed a sublimate. In this Standard, condensate is used as a general term for any liquid or solid produced by condensation of vapour.

2.1.6

condensation temperature

temperature at which **condensate** forms as liquid or solid on cooling a **humid gas**

2.1.7

desiccant

substance which exerts a drying action by **adsorption** or **absorption** of, or chemical reaction with, **water vapour**

2.1.8

desorption

release of a substance which has been retained by **absorption** or **adsorption**

2.1.9

dew point

temperature at which the **vapour pressure** of the **vapour in a humid gas** is equal to the **saturation vapour pressure** over pure liquid and at which **condensate** forms as liquid on cooling the **gas**

NOTE Below freezing point **dew point** is usually used to mean **frost point**. When referring to the **supercooled liquid dew point** (**2.1.42**) it is normal to state this explicitly.

2.1.10

dry-bulb temperature

measured air temperature, usually paired with a **wet-bulb temperature** to derive a value for **relative humidity**

2.1.11

dry gas

non-condensable **gas** or gas mixture containing no **vapour**, e.g. dry air at zero humidity

2.1.12

enhancement factor

water vapour enhancement factor

factor by which a value of pure **saturation vapour pressure** is multiplied to obtain the actual **saturation vapour pressure** which takes into account the effect of the presence and overall pressure of air or other **gases**.

NOTE The enhancement factor also applies to unsaturated **humid gas**, where it modifies the pure **vapour pressure** to the actual **vapour pressure**.

2.1.13

enthalpy (of humid gas)

measure of the total energy in a **humid gas**, being the nominal sum of the enthalpies of the **dry gas** (**sensible heat**) and of the **vapour** (**sensible heat** and **latent heat**)

2.1.14

equilibrium relative humidity (of a substance)

value of the **relative humidity** of a **humid gas** at which there is no net exchange of **moisture** with a given substance

NOTE *Equilibrium relative humidity* is a property of the substance and is used for indirectly indicating or controlling the condition of moisture-sensitive substances such as paper. It is normally measured in an enclosed space.

2.1.15

frost point

temperature at which the **vapour pressure** of the **vapour** in a **humid gas** is equal to the **saturation vapour pressure** over ice (frozen solid) and at which **condensate** forms as frost on cooling the **gas**

2.1.16

gas

fluid in which molecules move freely and can expand indefinitely to occupy the total volume in which it is contained

NOTE The term **gas** is used especially for substances which do not become liquid or solid at normal ambient conditions, e.g. air. If this is not the case, the term **vapour** is generally used.

2.1.17

gas density

mass of **humid gas** present in a unit volume of **humid gas**

2.1.18

humidity

presence of **vapour**, e.g. **water vapour**, in air or other **gas**

NOTE **Humidity** is often used to mean only **relative humidity** although, strictly speaking, **humidity** refers to all kinds of absolute indications of **humidity**; for very low humidities, other more specific terms tend to be used.

2.1.19

humidity ratio

deprecated term for **mixing ratio** (**2.1.29**)

2.1.20

humid gas

mixture containing one or more non-condensable **gases** and one or more **vapours**, e.g. a mixture of air and **water vapour**

2.1.21

humid heat

heat required to raise the temperature of a unit mass of **dry gas** and accompanying **vapour** by 1 K at constant pressure; the specific heat capacity of a gas/vapour mixture

2.1.22

humid volume

volume occupied by **humid gas** containing unit mass of **dry gas**

2.1.23

hygrometry

humidity measurement

2.1.24

hygroscopic

tending to absorb **water vapour**

2.1.25

ice-bulb temperature

steady state temperature reached by a small quantity of ice evaporating into a large quantity of unsaturated **water vapour/gas** mixture

2.1.26

ideal gas

gas to which the laws of Boyle, Gay-Lussac and Avogadro are applicable

2.1.27

latent heat

heat energy associated with a change of phase at constant temperature

2.1.28

mass fraction

ratio of the mass of a component in a mixture to the total mass of substance present

NOTE For vapour in gases this is the **specific humidity** and for low humidities becomes approximately equal to the **mixing ratio**.

2.1.29

mixing ratio

mass ratio

humidity ratio (deprecated)

mass of **vapour** per unit mass of **dry gas** with which it is associated; it is a dimensionless ratio although often expressed in units of mass per mass

NOTE The so-called "mixing ratio by volume" is a deprecated term for **mole ratio** or volume ratio.

2.1.30

moisture

water in any form

NOTE Moisture is also used specifically for water that is **absorbed** or **adsorbed** or bound into any material.

2.1.31

mole fraction

volume fraction

ratio of the number of moles of a component in a **humid gas** to the total number of moles of **humid gas** present

2.1.32

mole ratio

molal ratio

volume ratio

mixing ratio by volume (deprecated)

ratio of the number of moles of a component in a **humid gas** to the amount of **dry gas** present

2.1.33

partial pressure (of vapour)

that part of the overall pressure exerted by the **vapour** component in a **humid gas**

2.1.34

percentage saturation

ratio of the actual **mixing ratio** to the **saturation mixing ratio** at the same temperature and pressure, expressed as a percentage (%)

NOTE Under ordinary climatic conditions, **percentage saturation** is almost identical to **relative humidity**.

2.1.35

ppm$_v$

PPM$_V$

mole ratio, expressed as parts per million (10^{-6})

NOTE This may also be termed ppm$_v$ (dry basis). At low humidities it is almost identical to ppm$_v$ (wet basis), which is the **mole fraction** expressed as parts per million. Mole ratio may also be expressed in parts per billion (10^{-9}), ppb$_v$.

2.1.36

ppm$_w$

PPM$_W$

mixing ratio, expressed as parts per million (10^{-6})

NOTE This may also be termed ppm$_w$ (dry basis). At low humidities it is almost identical to ppm$_w$ (wet basis), which is the **specific humidity** (**mass fraction**) expressed as parts per million. Mixing ratio may also be expressed in parts per billion (10^{-9}), ppb$_w$.

2.1.37

relative humidity

ratio of the actual **vapour pressure** to the **saturation vapour pressure** over a plane liquid water surface at the same temperature, expressed as a percentage

NOTE 1 **Relative humidity** is commonly abbreviated to rh, although this is not a recognized abbreviation.

NOTE 2 Values of **relative humidity** are usually expressed in units of percentage **relative humidity**, % rh. “% rh” is not an agreed SI unit. However, the use of the symbol “%” alone to denote units of relative humidity is generally not advisable, since there is a risk of confusion between value of relative humidity and fraction of value.

2.1.38

saturation mixing ratio

mixing ratio of **humid gas** in equilibrium with a plane surface of water or ice at the same temperature containing the equilibrium quantity of dissolved gas

NOTE This is the highest **mixing ratio** which non-supersaturated **humid gas** can attain at the given temperature, and corresponds to a **relative humidity** of 100 %.

2.1.39

saturation vapour pressure

maximum pressure of **vapour** that can exist at a given temperature

NOTE Pure saturation vapour pressure is the pressure exerted by vapour with no other gases present, i.e. in a partial vacuum. Actual saturation vapour pressure of a **vapour** in a **humid gas** is slightly different; the difference is quantified by the **enhancement factor**.

2.1.40

sensible heat

component of the **enthalpy** of a substance that varies according to temperature

2.1.41

specific humidity

mass of **vapour** per unit mass of **humid gas**

2.1.42

supercooled liquid dew point

supercooled water dew point

dew point with respect to liquid (e.g. water) below the normal freezing point

2.1.43

thermodynamic wet-bulb temperature

deprecated term for **adiabatic saturation temperature (2.1.4)**

NOTE For the air–water system at atmospheric pressure between 0 °C and 100 °C, with water vapour contents of less than 0.1 $\text{kg}\cdot\text{kg}^{-1}$, the thermodynamic wet-bulb temperature is within 1 °C of the **wet-bulb temperature**. For vapours other than water vapour, the thermodynamic wet-bulb temperature may be markedly different to the wet-bulb temperature.

2.1.44

vapour

substance in the gaseous state which may be liquefied by increasing the pressure without altering the temperature

NOTE This is a **gas** below its critical temperature.

2.1.45

vapour density

deprecated term used either for **gas density** (**2.1.17**) or **volumetric humidity** (**2.1.49**)

2.1.46

vapour pressure (of water)

partial pressure

that part of the total pressure contributed by the **vapour**

NOTE Pure vapour pressure is the pressure exerted by vapour with no other gases present, i.e. in a partial vacuum. Actual vapour pressure of a **vapour** in a **humid gas** is slightly greater; the difference is quantified by the **enhancement factor**.

2.1.47

vapour pressure deficit

vapour pressure difference

difference between actual **vapour pressure** and **saturation vapour pressure** at air temperature (usually given symbol of D or δp)

2.1.48

volume fraction

ratio of the volume nominally occupied by a component of a mixture to the total volume

NOTE This is numerically identical to **mole fraction** for an **ideal gas**.

2.1.49

volumetric humidity

mass of **vapour** present in a unit volume of **humid gas**

2.1.50

water activity (of a substance)

equilibrium relative humidity, expressed on a scale of 0 to 1 (dimensionless units) instead of 0 % to 100 %

2.1.51

water vapour

water in gaseous form below its critical temperature

2.1.52

wet-bulb temperature

temperature indicated by a thermometer sheathed in wet wicking, and influenced by the rate of evaporation from the wicking. The steady state temperature reached by a small quantity of liquid evaporating into a large quantity of unsaturated **vapour/gas** mixture is the **wet-bulb temperature** of a perfect **psychrometer**

NOTE 1 This is usually paired with a **dry-bulb temperature** to derive a value for **relative humidity**.

NOTE 2 See also **thermodynamic wet-bulb temperature** (**2.1.43**) and **psychrometer** (**2.2.22**).

NOTE 3 For the air–water system at atmospheric pressure between 0 °C and 100 °C, with water vapour contents of less than 0.1 $\text{kg}\cdot\text{kg}^{-1}$, the wet-bulb temperature is within 1 °C of the **adiabatic saturation temperature**.

2.2 Measurement terms

2.2.1

acoustic humidity sensor

acoustic sensor

sensor utilizing the transmission of sound in a **humid gas** to indicate its **humidity**

2.2.2

adiabatic expansion hygrometer

hygrometer in which the cooling on expansion of **humid gas** produces a cloud if the **dew point** is reached

2.2.3

aspirated psychrometer

psychrometer with provision for a forced flow of **humid gas** over the **sensors**

2.2.4

capacitive hygrometer

capacitance hygrometer

electrical impedance hygrometer or **dew-point sensor**

2.2.5

colour change hygrometer

hygrometer indicating changes in **humidity** by the change in colour of a material occurring as a result of its reaction to **moisture**

2.2.6

condensation hygrometer

hygrometer in which the **dew-point temperature** is measured by cooling a sample of **humid gas** until **condensate** in the form of dew or frost appears, and observing the temperature at which this happens

2.2.7

dew-point sensor

sensor in which the measured electrical property changes in a way more nearly related to the **dew point** or **vapour pressure** rather than the **relative humidity**

NOTE Commonly the impedance change of an aluminium oxide capacitor as moisture penetrates the pore structure.

2.2.8

electrical impedance hygrometer

resistive or capacitive hygrometer

hygrometer in which the **sensor** consists of a **hygroscopic** material, the electrical properties of which alter according to the **absorption** or **desorption** of water molecules

NOTE Many sensors are constructed using thin film technology, or other means and the **sensor** may exhibit changes in resistance, capacitance or some combination of the two.

2.2.9

electrolytic hygrometer

phosphorus pentoxide hygrometer

hygrometer in which **humidity** is measured by the electrolysis of the water taken up by a sensor consisting of a film of the **desiccant** phosphorus pentoxide (P_2O_5)

2.2.10

electrolytic impedance hygrometer

type of **hygrometer** using electrolysis as the sensing mechanism

NOTE **Electrolytic impedance hygrometers** should not be confused with electrolytic phosphorus pentoxide hygrometers, or with **electrical impedance hygrometers**.

2.2.11

gravimetric hygrometer

hygrometer utilizing the weight of absorbed **moisture** as a measure of **humidity**

2.2.12

hygrometer

instrument for measuring **humidity**

2.2.13

infrared absorbance hygrometer

spectroscopic hygrometer utilizing the principle that water attenuates infrared radiation

2.2.14

Lyman-alpha hygrometer

spectroscopic hygrometer utilizing the absorption and emission of ultra-violet light by a **humid gas**

2.2.15

mechanical hygrometer

hygrometer exploiting the expansion and contraction of organic materials with changes in **humidity**

NOTE The **sensor** may be hair, catgut, goldbeater's skin (cow's intestine), paper, textile or plastic or other material.

2.2.16

optical dew-point hygrometer

condensation hygrometer in which **condensate** is sensed optically

2.2.17

optical fibre hygrometer

hygrometer utilizing the loss, or reflection, of light by coatings on an optical fibre to indicate changes in **humidity**

2.2.18

optical refractive index hygrometer

hygrometer utilizing the principle that the speed of light in a **gas** depends upon its composition, including **water vapour**

2.2.19

piezoelectric hygrometer

hygrometer utilizing the resonating frequency of a quartz crystal to indicate the mass of water it has absorbed from the **humid gas**

2.2.20

pneumatic bridge hygrometer

hygrometer in which the **water vapour** pressure is found from the change in overall pressure occurring after **water vapour** has been removed from a **humid gas**.

2.2.21

probe

part of a **hygrometer** housing a **sensor** external to the main body of the instrument, e.g. at the end of a connecting electrical lead

NOTE The probe may be fixed to the main body of the instrument or connected by means of a cable.

2.2.22

psychrometer

wet- and dry-bulb hygrometer

hygrometer in which **humid gas** is drawn over two matched temperature **sensors**, one of which is maintained wet

2.2.23

relative humidity (rh) sensor

sensor that measures relative humidity.

NOTE Commonly this term is used for electrical impedance hygrometer.

2.2.24

saturated lithium chloride hygrometer

lithium chloride hygrometer

hygrometer in which the **sensor** is a **hygroscopic** salt absorbing water from the **humid gas**

NOTE 1 This may be lithium chloride or another salt, sometimes held in a gel or matrix of some kind.

NOTE 2 An electrical voltage is applied across the salt and current passes according to the amount of **water vapour** that has been absorbed; this current also heats the salt. Eventually a balance is achieved between **absorption** and heating; the temperature at which this occurs is related to the **water vapour** pressure.

2.2.25

sensor

active or sensing part of a **hygrometer**

NOTE In some cases a complete **hygrometer** may be referred to as a **sensor**.

2.2.26

spectroscopic hygrometer

hygrometer in which the **water vapour** content of a **humid gas** mixture is measured by analysing how its constituents absorb or emit light of particular wavelengths

NOTE Specific examples of spectroscopic hygrometers are **infrared absorbance hygrometer** (**2.2.13**) and **Lyman-alpha hygrometer** (**2.2.14**); spectroscopic measurement by these techniques can be used to measure the concentrations of other constituents of the mixture, as well as that of the **water vapour**.

2.2.27

thermal conductivity hygrometer

hygrometer utilizing the principle that the heat loss from a hot wire is affected by the **water vapour** in a **humid gas** as well as by the other constituent **gases**

2.2.28

thermal rise hygrometer

hygrometer utilizing the heat of **adsorption** or **desorption** of water from a **desiccant** as a measure of **humidity**

2.2.29

transmitter

hygrometer which gives an analogue or digital electrical output

NOTE The **sensor** may be an integral part of the transmitter or may be in a probe connected via an external cable.

2.2.30

zirconia hygrometer

hygrometer in which **water vapour** is detected by measuring the oxygen content of a **humid gas** and comparing this with the amount of oxygen due to the **dry gas** alone

2.3 Symbols and units

2.3.1

A

psychrometer coefficient expressed per kelvin (K^{-1})

2.3.2

a_w

water activity expressed as a scale of 0 to1 dimensionless units

2.3.3

C_{pg}

specific heat capacity at constant pressure of **dry gas** expressed as kilojoules per kilogram per kelvin ($kJ \cdot kg^{-1} \cdot K^{-1}$)

2.3.4

C_{pv}

specific heat capacity at constant pressure of **vapour** expressed as kilojoules per kilogram per kelvin ($kJ \cdot kg^{-1} \cdot K^{-1}$)

2.3.5

C_s

humid heat expressed as kilojoules per kilogram of **dry gas** per kelvin ($kJ \cdot kg^{-1} \cdot K^{-1}$)

2.3.6

d_v

volumetric humidity expressed as kilograms of **vapour** per cubic metre of **humid gas** ($kg \cdot m^{-3}$)

2.3.7

f

(water vapour) **enhancement factor** expressed as dimensionless units

2.3.8

h

enthalpy expressed as kilojoules per kilogram ($kJ \cdot kg^{-1}$)

2.3.9

h_g

enthalpy of **dry gas** (relative to gas at datum temperature, usually 0 °C) expressed as kilojoules per kilogram of **dry gas** ($kJ \cdot kg^{-1}$)

2.3.10

h_s

sensible heat expressed as kilojoules per kilogram ($kJ \cdot kg^{-1}$)

2.3.11

h_v

enthalpy of pure **vapour** (relative to liquid at datum temperature, usually 0 °C) expressed as kilojoules per kilogram of **vapour** ($kJ \cdot kg^{-1}$)

2.3.12

k_y

mass transfer coefficient for vapour-phase transport expressed as kilograms per square metre per second ($kg \cdot m^{-2} \cdot s^{-1}$)

2.3.13

M_g

molal mass (molecular weight) of **dry gas** expressed as kilograms per mole ($kg \cdot mol^{-1}$)

2.3.14

M_v

molal mass (molecular weight) of **vapour** expressed as kilograms per mole ($kg \cdot mol^{-1}$)

2.3.15

m

mass expressed as kilograms (kg)

2.3.16

n

amount of substance expressed as moles (mol)

2.3.17

P

total atmospheric pressure expressed as newtons per square metre ($\text{N}\cdot\text{m}^{-2}$) or pascals (Pa)

2.3.18

p

pure **vapour pressure** expressed as newtons per square metre ($\text{N}\cdot\text{m}^{-2}$) or pascals (Pa)

2.3.19

p'

actual **vapour pressure** expressed as newtons per square metre ($\text{N}\cdot\text{m}^{-2}$) or pascals (Pa)

2.3.20

p_s

pure **saturation vapour pressure** expressed as newtons per square metre ($\text{N}\cdot\text{m}^{-2}$) or pascals (Pa)

2.3.21

p_s'

actual **saturation vapour pressure** expressed as newtons per square metre ($\text{N}\cdot\text{m}^{-2}$) or pascals (Pa)

2.3.22

p_wb

saturation vapour pressure at the **wet-bulb temperature** expressed as newtons per square metre ($\text{N}\cdot\text{m}^{-2}$) or pascals (Pa)

2.3.23

$\textbf{ppm}_\text{v}$

mole ratio expressed as parts per million of **dry gas** by volume

2.3.24

$\textbf{ppm}_\text{w}$

mixing ratio expressed as parts per million of **dry gas** by mass

2.3.25

R

universal gas constant expressed as joules per mole of air per kelvin ($\text{J}\cdot\text{mol}^{-1}\cdot\text{K}^{-1}$)

2.3.26

R'

universal gas constant expressed as joules per kilogram of air per kelvin ($\text{J}\cdot\text{kg}^{-1}\cdot\text{K}^{-1}$)

2.3.27

S

percentage saturation (%)

2.3.28

T

absolute temperature expressed as kelvins (K)

2.3.29

t

dry-bulb temperature expressed as degrees Celsius (°C)

2.3.30

t_{as}

adiabatic saturation temperature expressed as degrees Celsius (°C)

2.3.31

t_{dp}

dew point expressed as degrees Celsius (°C)

2.3.32

t_f

freezing point of liquid expressed as degrees Celsius (°C)

2.3.33

t_{fp}

frost point expressed as degrees Celsius (°C)

2.3.34

t_{wb}

wet-bulb temperature expressed as degrees Celsius (°C)

2.3.35

v

humid volume expressed as cubic metres per kilogram of **dry gas** ($m^3 \cdot kg^{-1}$)

2.3.36

Y

mixing ratio expressed as kilograms of **vapour** per kilogram of **dry gas** ($kg \cdot kg^{-1}$)

2.3.37

Y_{as}

mixing ratio at the **adiabatic saturation temperature** expressed as kilograms of **vapour** per kilogram of **dry gas** ($kg \cdot kg^{-1}$)

2.3.38

Y_W

specific humidity expressed as kilograms of **vapour** per kilogram of **humid gas** ($kg \cdot kg^{-1}$)

2.3.39

Y_{wb}

mixing ratio at the **wet-bulb temperature** expressed as kilograms of **vapour** per kilogram of **dry gas** ($kg \cdot kg^{-1}$)

2.3.40

y

mole fraction of **vapour** expressed as moles of **vapour** per mole of **humid gas** ($mol \cdot mol^{-1}$)

2.3.41

$1-y$

mole fraction of **dry gas** expressed as moles of **dry gas** per mole of **humid gas** ($\mathrm{mol \cdot mol^{-1}}$)

2.3.42

z

mole ratio of **vapour** expressed as moles of **vapour** per mole of **dry gas** ($\mathrm{mol \cdot mol^{-1}}$)

2.3.43

α

heat transfer coefficient from gas to wet bulb expressed as kilojoules per second per square metre per kelvin ($\mathrm{kJ \cdot s^{-1} \cdot m^{-2} \cdot K^{-1}}$)

2.3.44

β

psychrometric ratio expressed in dimensionless units

2.3.45

λ

latent heat of evaporation expressed as kilojoules per kilogram ($\mathrm{kJ \cdot kg^{-1}}$)

2.3.46

$\lambda_{\mathbf{as}}$

latent heat of evaporation at the **adiabatic saturation temperature** expressed as kilojoules per kilogram ($\mathrm{kJ \cdot kg^{-1}}$)

2.3.47

$\lambda_{\mathbf{wb}}$

latent heat of evaporation at the **wet-bulb temperature** expressed as kilojoules per kilogram ($\mathrm{kJ \cdot kg^{-1}}$)

2.3.48

$\lambda_{\mathbf{0}}$

latent heat of evaporation at the enthalpy-datum temperature (usually 0 °C) expressed as kilojoules per kilogram ($\mathrm{kJ \cdot kg^{-1}}$)

2.3.49

$\rho_{\mathbf{g}}$

gas (vapour) density expressed as kilograms of **humid gas** per cubic metre of **humid gas** ($\mathrm{kg \cdot m^{-3}}$)

2.3.50

Ψ

relative humidity expressed as percentage relative humidity (% rh)

3 Formulae and constants

3.1 Constants

Universal gas constant, R	8.314 5 $\text{J}\cdot\text{mol}^{-1}\cdot\text{K}^{-1}$	(8 314.5 $\text{J}\cdot\text{kmol}^{-1}\cdot\text{K}^{-1}$)
Molal mass of dry air	0.028 964 5 $\text{kg}\cdot\text{mol}^{-1}$	(28.964 5 $\text{kg}\cdot\text{kmol}^{-1}$)
Molal mass of water	0.018 015 28 $\text{kg}\cdot\text{mol}^{-1}$	(18.015 28 $\text{kg}\cdot\text{kmol}^{-1}$)
International standard atmosphere		101 325 Pa

These constants are listed and referenced by Sonntag [2].

3.2 Formulae

3.2.1 *Main symbols*

In addition to the constants in **3.1**, the following are the main symbols used in the formulae (others are defined locally in the text):

A = psychrometer coefficient (K^{-1})
C_p = specific heat capacity of pure gas (C_pg) or vapour (C_pv) ($\text{kJ}\cdot\text{kg}^{-1}\cdot\text{K}^{-1}$)
C_s = specific heat capacity of gas–vapour mixture (humid heat) ($\text{kJ}\cdot\text{kg}^{-1}\cdot\text{K}^{-1}$)
d_v = volumetric humidity ($\text{kg}\cdot\text{m}^{-3}$)
f = (water vapour) enhancement factor (-)
h = enthalpy of humid gas, per unit mass of dry gas ($\text{kJ}\cdot\text{kg}^{-1}$)
k = coverage factor (statistical term)
k_y = mass transfer coefficient based on humidity driving force ($\text{kg}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$)
M_g = molal mass (molecular weight) of dry gas ($\text{kg}\cdot\text{mol}^{-1}$)
M_v = molal mass (molecular weight) of vapour ($\text{kg}\cdot\text{mol}^{-1}$)
m_g = mass of dry gas (kg)
m_v = mass of vapour (kg)
n_g = number of moles of dry gas (mol)
n_v = number of moles of vapour (mol)
p = pure vapour pressure (partial pressure) of component in $\text{N}\cdot\text{m}^{-2}$ (Pa)
p' = actual vapour pressure of component in $\text{N}\cdot\text{m}^{-2}$ (Pa)
p_s = pure saturation vapour pressure of component in $\text{N}\cdot\text{m}^{-2}$ (Pa)
p_s' = actual saturation vapour pressure of component in $\text{N}\cdot\text{m}^{-2}$ (Pa)
P = total atmospheric pressure in $\text{N}\cdot\text{m}^{-2}$ (Pa)
t = Celsius temperature (dry-bulb temperature unless otherwise stated) (°C)
T = absolute temperature (K)
Y = mixing ratio ($\text{kg}\cdot\text{kg}^{-1}$)
Y_W = specific humidity ($\text{kg}\cdot\text{kg}^{-1}$)
y = mole fraction ($\text{mol}\cdot\text{mol}^{-1}$)
z = mole ratio ($\text{mol}\cdot\text{mol}^{-1}$)
β = psychrometric ratio (-)
λ = latent heat of evaporation ($\text{kJ}\cdot\text{kg}^{-1}$)
ρ_g = density of humid gas ($\text{kg}\cdot\text{m}^{-3}$)
Ψ = relative humidity (% rh)

3.2.2 *Saturation vapour pressure,* $\mathbf{p_s}$

Saturation vapour pressure of water in pascals ($\mathrm{N{\cdot}m^{-2}}$) at absolute temperature T (Sonntag [2]):

$$\ln p_s = -6096.9385T^{-1} + 21.2409642 - 2.711193 \times 10^{-2}T + 1.673952 \times 10^{-5}T^2 + 2.433502 \ln T \qquad (1)$$

and a similar formula applies for saturation vapour pressure over ice:

$$\ln p_s = -6024.5282T^{-1} + 29.32707 + 1.0613868 \times 10^{-2}T - 1.3198825 \times 10^{-5}T^2 - 0.49382577 \ln T \qquad (2)$$

Uncertainty (at a coverage factor approximately k = 2, i.e. a confidence level of approximately 95 %) quoted as:

<0.01 % of value for water from 0 °C to 100 °C.

<0.6 % of value for supercooled water from 0 °C to –50 °C.

<1.0 % of value for ice from 0 °C to –100 °C.

Coverage factors are explained by Bell [3].

NOTE The Sonntag [2] equation is highly accurate for water vapour. Simpler formulae in common use (given in Part 3 of this British Standard) are the Magnus formula and the Antoine equation; for the latter, coefficients are available in the literature for a very wide variety of solvents besides water. See, for example, *The Properties of Gases and Liquids*, (Reid, Prausnitz, Sherwood et al). [4,5].

3.2.3 *Enhancement factor,* **f**

Equations (1) and (2) strictly only apply to water vapour with no other gases present (i.e. in a partial vacuum). In a gas mixture, e.g. water vapour in air, the pure saturation vapour pressure p_s must be multiplied by the enhancement factor f to give the actual vapour pressure p'_s.

$$p'_s = fp_s \qquad (3)$$

The enhancement factor also applies to unsaturated humid gas:

$$p' = fp \qquad (4)$$

Here p' is the actual vapour pressure, which is the pure vapour pressure p multiplied by the enhancement factor f.

The water vapour enhancement factors in air, $f_w\ (P, t_{dp})$, for water, and $f_i\ (P, t_{fp})$, for ice, can be found from the following equations derived by Bögel and quoted by Sonntag [2]. Overall pressure P and vapour pressures $p_w\ (t)$, for water, and $p_i\ (t)$, for ice, are in pascals. In equations (5) and (6) below, t should be taken as the dew point and frost point temperature respectively.

$$f_w\ (P, t_{dp}) = 1 + \frac{10^{-6} p_w(t)}{273 + t}\left[(38 + 173e^{-t/43})\left(1 - \frac{p_w(t)}{P}\right) + (6.39 + 4.28e^{-t/107})\left(\frac{P}{p_w(t)} - 1\right)\right] \qquad (5)$$

$$f_w\ (P, t_{fp}) = 1 + \frac{10^{-7} p_i(t)}{273 + t}\left[(2\,100 - 65t)\left(1 - \frac{p_i(t)}{P}\right) + \left(109 - 0.35t + \frac{t^2}{338}\right)\left(\frac{P}{p_i(t)} - 1\right)\right] \qquad (6)$$

Uncertainty:

In the temperature range –50 °C to +100 °C, the two equations above have an uncertainty of <0.010 % of value (at a coverage factor of approximately $k = 2$), under the following pressure and temperature conditions:

valid for P between 500 Pa (0.5 kPa, 5 hPa, 5 mbar, 0.005 bar) and 110 kPa (1.1×10^5 Pa, 1100 hPa, 1100 mbar, 1.1 bar) at t <0 °C

valid for P between 1 kPa and 110 kPa at t = 10 °C

valid for P between 10 kPa and 110 kPa at t = 50 °C

valid for P between 30 kPa and 110 kPa at t = 70 °C

In the smaller temperature range –50 °C to +70 °C and corresponding pressure ranges to the above, the uncertainty is 0.0026 %.

At near-ambient conditions (approximately 1 atmosphere, 101 325 Pa, between –10 °C and +50 °C) from the above equations, f = 1.004 7 to four decimal places.

Approximate values of f for water vapour in air for total pressure P between 3×10^3 Pa and 1.1×10^5 Pa are given by the simpler direct formula:

$$f = 1.0016 + 3.15 \times 10^{-8} P - 74P^{-1} \tag{7}$$

Uncertainty: <0.08 % of value from –50 °C to 60 °C. P is in pascals.

At higher pressures, the more complex formulae given by Greenspan [6] and updated to the ITS–90 temperature scale by Hardy [7] are recommended.

For most calculations, p' can be assumed equal to p in these and all following equations. For air at near-atmospheric pressure the water vapour enhancement factor does not exceed 1.006 and hence the error in approximating $p' = p$ is less than 0.6 % of result, except for dew points below –50 °C. However, at elevated pressures, this approximation leads to larger errors, e.g. of the order of 5 % at a total pressure of 10 bar.

NOTE Values of the water vapour enhancement factor can be obtained from Part 2 of this British Standard.

3.2.4 *Mixing ratio (mass ratio or humidity ratio), Y*

$$Y = \frac{m_v}{m_g} \tag{8}$$

m_v is the mass of vapour and m_g is the mass of dry gas in the mixture.

Mixing ratio can also be expressed as parts per million by weight (mass):

$$\text{ppm}_w = 10^6 Y \tag{9}$$

NOTE A summary table showing the interrelationships between all the standard humidity parameters appears in **3.2.17**.

3.2.5 *Mole ratio (volume ratio), z*

$$z = \frac{n_v}{n_g} \tag{10}$$

n_v is the number of moles of vapour and n_g is the number of moles of dry gas present.

$$z = \frac{M_g Y}{M_v} \tag{11}$$

For the air–water system, $z = \frac{Y}{0.622}$ to three significant figures. (12)

Mole ratio can also be expressed as parts per million by volume:

$$\text{ppm}_v = 10^6 z \tag{13}$$

3.2.6 *Mole fraction, y*

$$y = \frac{n_v}{n_g + n_v} \tag{14}$$

$$y = \frac{Y}{\left(\frac{M_v}{M_g} + Y\right)} \tag{15}$$

For the air–water system, $y = \frac{Y}{0.622 + Y}$ to three significant figures. (16)

3.2.7 *Specific humidity (mass fraction), Y_w*

$$Y_w = \frac{m_v}{m_g + m_v} \tag{17}$$

$$Y_w = \frac{Y}{1 + Y} \tag{18}$$

3.2.8 *Actual vapour pressure (partial pressure), p´*

$$p' = \frac{n_v}{n_g + n_v} P = yP \tag{19}$$

3.2.9 *Relative humidity, Ψ*

$$\Psi = \frac{100pf(P,t)}{p_s f(P,t_{dp})} = \frac{100p'}{p_s{}'} \tag{20}$$

Where $f(P,t)$ is very close to $f(P,t_{dp})$, these two terms may be neglected (given equal to 1) if the utmost accuracy is not required. Equation (20) then simplifies to:

$$\Psi = \frac{100P}{p_s}$$

NOTE Ψ is in %. The pure saturation vapour pressure p_S is over water, even at temperatures and dew/frost points below 0 °C, unless it is specifically stated to be with respect to ice.

Equation (20/21) given above is the one in common use. However, relative humidity is strictly defined as the ratio of mole fraction, y, of water vapour in humid air to the mole fraction, y_s, of water vapour that humid air would have if it were saturated with respect to water or ice at the same pressure and temperature:

$$\psi = \frac{100y}{y_s} \tag{22}$$

For accurate values of f, equation (20) is equivalent to equation (22).

If relative humidity has been measured, actual vapour pressure p' is obtained from:

$$p' = \frac{\Psi p'_s}{100} \tag{23}$$

3.2.10 *Relationships between mixing ratio, mole ratio and vapour pressure*

$$y = \frac{p'}{P} \tag{24}$$

$$z = \frac{p'}{(P-p')} \tag{25}$$

$$Y = \frac{p'M_v}{(P-p')M_g} \tag{26}$$

For the air–water system, $Y = \dfrac{0.622p'}{(P-p')}$ to three significant figures. (27)

$$p' = \frac{PY}{\left(\frac{M_v}{M_g} + Y\right)} \tag{28}$$

For the air–water system, $p' = \dfrac{PY}{0.622 + Y}$ to three significant figures. (29)

$$Y_w = \frac{\frac{M_v}{M_g}p'}{\left(P - p' + \frac{M_v}{M_g}p'\right)} \tag{30}$$

For the air–water system, $Y_w = \dfrac{0.622p'}{(P-0.378p')}$ to three significant figures. (31)

For a complete table of relationships between these quantities, see **3.2.17**.

NOTE The dew point and frost point temperatures are found by calculating the pure vapour pressure p from p', using equations (4), (5) and (6) as necessary, and using equation (1) or (2) respectively to back-calculate the temperature when p_{wb} is set equal to p.

3.2.11 *Density of humid gas ("moist air")*, ρ_g

$$\rho_g = \frac{M_g}{RT}\left(P - p' + \frac{M_v}{M_g}p'\right) \tag{32}$$

Here p' is the partial pressure of the given amount of vapour in the mixture.

For the air–water system, $\rho_g = \dfrac{P - 0.378p'}{287.1T}$ to three significant figures. (33)

NOTE Ideal gas behaviour is assumed. From this formula, density of dry air at 0 °C (273.15 K) and 1 atmosphere is 1.292 kg·m^{-3}. Note that the density of moist air is always lower than that of dry air.

3.2.12 *Volumetric humidity,* d_v

$$d_v = Y_W\rho_g = \frac{Y}{(1 + Y)}\rho_g \tag{34}$$

Here Y_W is specific humidity. In terms of vapour pressure:

$$d_v = \frac{M_v p'}{RT} \tag{35}$$

For the air–water system, $d_v = \dfrac{0.002167p'}{T}$ to three significant figures. (36)

3.2.13 *Humid volume,* v

$$v = \frac{RT}{P}\left(\frac{1}{M_g} + \frac{Y}{M_v}\right) \tag{37}$$

Here v is volume per unit mass of dry air ($\text{m}^3\text{·Kg}^{-1}$). R is in molar units (8.314 $\text{J·mol}^{-1}\text{·K}^{-1}$) if molecular masses are quoted in kg·mol^{-1}. For the air–water system, $M_g \sim 0.02897$ and $M_v \sim 0.01802$, so:

$$v = \frac{461.5T}{P}(0.622 + Y) \text{ to three significant figures.} \tag{38}$$

NOTE Ideal gas behaviour is assumed. This formula gives humid volume at 0 °C (273.15 K) and 1 atmosphere as 0.774 $\text{m}^3\ \text{kg}^{-1}$.

3.2.14 *Specific enthalpy of humid gas ("moist air"),* h

$$h = C_s\,(t - t_f) + \lambda_0 Y \tag{39}$$

where h is in kJ·kg^{-1}, t_f is the freezing point (0 °C for water), C_s is the humid heat of the gas–vapour mixture (mean value over the range t to t_f, in $\text{kJ·kg}^{-1}\text{·K}^{-1}$) and λ_0 is the latent heat of evaporation at t_f. Both h and C_s are stated per kg of dry gas. The humid heat is given by the equation:

$$C_s = (C_{pg} + YC_{pv}) \tag{40}$$

where C_{pg} is the specific heat capacity of gas and C_{pv} the specific heat capacity of vapour. At ambient temperatures (0 °C – to 40 °C), to four significant figures, $C_{pg} = 1.006\ \text{kJ·kg}^{-1}\text{·K}^{-1}$ and $\lambda_0 = 2\,501\ \text{kJ·kg}^{-1}$, while $C_{pv} = 1.82\ \text{kJ·kg}^{-1}\text{·K}^{-1}$ to three significant figures.

At higher temperatures and for more accurate calculations, C_{pg} can be found from the following formula based on correlations by Wexler and Hyland [8]:

$$C_{pg} = 1.00579797 + 6.6334639 \times 10^{-6}\,t + 4.54585932 \times 10^{-7}\,t^2 \tag{41}$$

However, because latent heat and specific heat capacities vary with temperature, it is advisable to evaluate enthalpy of the vapour h_v directly, either from steam tables or from the following formula, also from [8]:

$$h_v = (2500.76867 + 1.83864919t - 3.17435306 \times 10^{-4}t^2 - 4.37399356 \times 10^{-6}t^3 - 1.67529532 \times 10^{-8}t^4) \tag{42}$$

Integrating equation (41) gives a corresponding formula for the enthalpy of dry air:

$$h_g = (-5.01700106 \times 10^{-5} + 1.00579797t + 3.31673195 \times 10^{-6}t^2 + 1.51528644 \times 10^{-7}t^3) \tag{43}$$

The overall formula for the enthalpy of humid gas is then:

$$h = h_g + h_v Y \tag{44}$$

Equations (41) to (44) are accurate to within 0.01 % at ambient conditions and within 0.1 % for dry-bulb temperatures from –50 °C to 300 °C. Beyond 350 °C the correlation for air diverges rapidly from experimental values, so other correlations, or data from steam tables, should be used.

3.2.15 *Adiabatic saturation temperature,* t_{as}

$$C_s(t - t_{as}) = \lambda_{as}(Y_{as} - Y) \qquad (45)$$

The adiabatic saturation temperature is given by a heat balance between the initial unsaturated vapour–gas mixture and the final saturated mixture at thermal equilibrium. Equation (45) has to be solved iteratively to obtain t_{as} and Y_{as} (mixing ratio at adiabatic saturation). λ_{as} is the latent heat of evaporation evaluated at the adiabatic saturation temperature. Values for λ at various temperatures may be obtained from steam tables or by the formula:

$$\lambda = 2\,500.8 - 2.33t - 0.001t^2 \qquad (46)$$

Equations (46) is accurate to within 0.01 % (0.3 kJ·kg^{-1}) between 0 °C and 50 °C, and to within 1 kJ·kg^{-1} up to 100 °C. If the process is one of sublimation of ice, the latent heat of evaporation of ice is 333.5 kJ·kg^{-1} greater than the latent heat for water.

For mixing ratios below 0.05 kg·kg^{-1} and the 80–150 °C dry-bulb temperature range, t_{as} (°C) is given directly to within 1 °C by the equation:

$$t_{as} = 3.18\sqrt{t + 2\,400\ Y} \qquad (47)$$

Where t is the dry-bulb temperature expressed in degrees Celsius.

At lower temperatures and humidities, a similar equation can be given for dry-bulb temperatures between 20 and 100 °C and mixing ratio below 0.02 kg·kg^{-1}, again accurate to within 1 °C:

$$t_{as} = 4.2\sqrt{t + 2\,500\ Y} - 11.2$$

3.2.16 *Wet-bulb temperature,* t_{wb}

The wet-bulb temperature is regulated by the rates of vapour-phase heat and mass transfer to and from the wet bulb. Assuming mass transfer is controlled by diffusion effects:

$$\alpha(t - t_{wb}) = k_y\lambda_{wb}(Y_{wb} - Y) \qquad (49)$$

where k_y is the corrected mass transfer coefficient, α is the heat transfer coefficient, Y_{wb} is the saturation mixing ratio at t_{wb} and λ_{wb} is the latent heat evaluated at t_{wb}. This equation must be solved iteratively to obtain t_{wb} and Y_{wb}.

It is often more convenient to obtain wet bulb conditions from adiabatic saturation conditions (which are much easier to calculate) by the following formula:

$$\frac{(t - t_{wb})}{(Y_{wb} - Y)} = \frac{(t - t_{as})}{(Y_{as} - Y)}\beta \qquad (50)$$

where β, the psychrometric ratio = $\overline{C_s}\,k_Y/\alpha$. $\overline{C_s}$ is the mean value of the humid heat over the range from t_{as} to t.

NOTE β is approximately constant over normal ranges of temperature and pressure for any given pair of vapour and gas.

For the air and water system $\beta \sim 1$, and $t_{wb} \approx t_{as}$.

If $\beta < 1$, $t_{wb} > t_{as}$; this is true for most organic vapours. Calculation methods and example values may be found in Keey, 1972 [9] and Kemp et al, 1991 [10].

If $\beta > 1$, $t_{wb} < t_{as}$; this is rare.

For water vapour in air between 0 °C and 100 °C at mixing ratios below 0.1 kg·kg^{-1}, the wet bulb temperature is no more than 1 °C below the adiabatic saturation temperature.

3.2.17 *Psychrometer formula for wet bulb temperature*

The rigorous formulae for wet bulb and adiabatic saturation temperature given above are non-linear, and therefore require an iterative solution based on both humidity and temperature values. A simple linear formula which gives vapour pressure directly, such as the psychrometer equation, is often more convenient:

$$p = p_{\mathrm{wb}} - AP(t - t_{\mathrm{wb}}) \qquad (51)$$

This is equivalent to equation (49). The vapour pressure difference, which is the true driving force, is used instead of mixing ratio, and all the heat and mass transfer coefficients are combined into the psychrometer coefficient A. Quoted values of A range between 6.2×10^{-4} °C^{-1} and 6.8×10^{-4} °C^{-1} for the air–water system at typical ambient temperatures and pressures for various types of psychrometer. A commonly used value has been 6.66×10^{-4} °C^{-1}. Sonntag, 1990 [2] quotes the following formulae for Assmann psychrometers, based on extensive recent experimental data with t_{wb} up to 25 °C, and recommends their use up to $t = 50$ °C.

$$A = 6.53 \times 10^{-4}\,(1 + 0.000944 t_{\mathrm{wb}}) \qquad (52)$$

Note that enhancement factor is applied to p and p_{wb} to give p' and p_{wb}'.

Equation (51) can also be used for ice-bulb conditions, for which the ice-bulb psychrometer coefficient is given by:

$$A_{\mathrm{i}} = 5.75 \times 10^{-4} \qquad (53)$$

if enhancement factor has been applied to give p_{i}' and p_{ib}'.

An approximate relationship for A for any vapour–gas system can be used at low humidities if the appropriate values of molecular weight, humid heat, psychrometric ratio and latent heat of evaporation are substituted:

$$A = \frac{M_{\mathrm{g}} C_{\mathrm{s}}}{M_{\mathrm{v}} \beta \lambda_{\mathrm{wb}}} \qquad (54)$$

Equations (52), (53) and (54) are likely to become very inaccurate as the wet bulb temperature approaches the boiling point. However, large changes in A have little effect on calculated t_{wb} in this region.

NOTE In practice psychrometers are not “perfect”, because convection is supplemented by conduction and radiation effects, and calibration is always recommended.

The psychrometer formula can also be written in terms of mixing ratio, with a modified psychrometer coefficient A^*;

$$Y = Y_{\mathrm{wb}} - A^*(t - t_{\mathrm{wb}}) \qquad (55)$$

$$A^* = \frac{C_{\mathrm{s}}}{\beta \lambda_{\mathrm{wb}}} = \frac{C_{\mathrm{wb}}}{\beta(\lambda_{\mathrm{wb}} + C_{\mathrm{pv}}(t - t_{\mathrm{wb}}))} \qquad (56)$$

The second form of equation (56) is more convenient in many cases, as C_{wb} does not contain Y.

3.2.18 *Interconversion table for fundamental humidity quantities*

Table 1 is the interconversion table.

Table 1 — Air–water system, to three significant figures

Convert to:	Y (or ppm$_w$)[a]	z (or ppm$_v$)[a]	Y_W	y	p'	d_v
Convert from:						
Mixing ratio[a] Y (kg·kg^{-1})	1	$z = 1.6078Y$	$Y_W = \frac{Y}{1+Y}$	$y = \frac{Y}{(0.622+Y)}$	$p' = \frac{PY}{(0.622+Y)}$	$d_v = \frac{0.002167PY}{(0.622+Y)T}$
Mole ratio[a] z (mol·mol^{-1})	$Y = 0.622\,z$	1	$Y_W = \frac{z}{1.6078+z}$	$y = \frac{z}{1+z}$	$p' = \frac{z}{1+z}P$	$d_v = \frac{0.002167zP}{(1+z)T}$
Specific humidity Y_w (kg·kg^{-1})	$Y = \frac{Y_W}{1-Y_W}$	$z = \frac{1.6078Y_W}{(1-Y_W)}$	1	$y = \frac{Y_W}{(0.622+0.387Y_W)}$	$p' = \frac{PY_W}{(0.622+0.378Y_W)}$	$d_v = \frac{0.002167PY_W}{(0.622+0.378Y_W)T}$
Mole fraction y (mol·mol^{-1})	$Y = \frac{0.622Y}{(1-Y)}$	$z = \frac{y}{1-y}$	$Y_W = \frac{0.622y}{1-0.378y}$	1	$p' = yP$	$d_v = \frac{0.002167yP}{T}$
Vapour pressure p' (Pa)	$Y = \frac{0.622p'}{(P-p')}$	$z = \frac{P'}{(P-p')}$	$Y_W = \frac{0.622p'}{P-0.378p'}$	$y = \frac{p'}{P}$	1	$d_v = \frac{0.002167p'}{T}$
Volumetric humidity d_v (kg·m^{-3})	$Y = \frac{0.622}{\frac{0.002167P}{d_vT}-1}$	$z = \frac{1}{\frac{0.002167P}{d_vT}-1}$	$Y_W = \frac{0.622}{\frac{0.002167P}{d_vT}-0.378}$	$y = \frac{461.5d_vT}{P}$	$p' = 461.5d_vT$	1

[a] Multiply Y by 10^6 to obtain ppm$_w$; multiply z by 10^6 to obtain ppm$_v$
General formulae for any vapour–gas system:

$m_g = n_gM_g$ $m_v = n_vM_v$

Table 1 — Air–water system, to three significant figures *(concluded)*

Convert to:	Y (or ppm$_w$)[a]	z (or ppm$_v$)[a]	Y_W	y	p'	d_v
Definition:	$Y = \frac{m_v}{m_g}$	$z = \frac{n_v}{n_g}$	$Y_W = \frac{m_v}{m_g + m_v}$	$y = \frac{n_v}{n_g + n_v}$	$p' = \frac{n_v}{n_g + n_v} P$	$d_v = \frac{M_v P n_v}{RT(n_g + n_v)}$
Convert from:						
Mixing ratio[a] Y (kg·kg^{-1})	1	$z = \frac{M_g Y}{M_v}$	$Y_W = \frac{Y}{1 + Y}$	$y = \frac{Y}{\left(\frac{M_v}{M_g} + Y\right)}$	$p' = \frac{PY}{\left(\frac{M_v}{M_g} + Y\right)}$	$d_v = \frac{M_v}{RT} \frac{PY}{\left(\frac{M_v}{M_g} + Y\right)}$
Mole ratio[a] z (mol·mol^{-1})	$Y = \frac{M_v z}{M_g}$	1	$Y_W = \frac{z}{\frac{M_g}{M_v} + z}$	$y = \frac{z}{1 + z}$	$p' = \frac{z}{1 + z} P$	$d_v = \frac{M_v z P}{(1 + z) RT}$
Specific humidity Y_W (kg·kg^{-1})	$Y = \frac{Y_W}{1 - Y_W}$	$z = \frac{M_g Y_W}{M_v (1 - Y_W)}$	1	$y = \frac{Y_W}{\left(\frac{M_v}{M_g}(1 - Y_W) + Y_W\right)}$	$p' = \frac{PY_W}{\left(\frac{M_v}{M_g}(1 - Y_W) + Y_W\right)}$	$d_v = \frac{M_v}{RT} \frac{PY_W}{\left(\frac{M_v}{M_g}(1 - Y_W) + Y_W\right)}$
Mole fraction y (mol·mol^{-1})	$Y = \frac{M_v y}{M_g (1 - Y)}$	$z = \frac{y}{1 - y}$	$Y_W = \frac{y}{\frac{M_g}{M_v}(1 - y) + y}$	1	$p' = yP$	$d_v = \frac{M_v y P}{RT}$
Vapour pressure p' (Pa)	$Y = \frac{p' M_v}{(P - p') M_g}$	$z = \frac{P'}{(P - p')}$	$Y_W = \frac{\frac{M_v}{M_g} p'}{\left(P - p' + \frac{M_v}{M_g} p'\right)}$	$y = \frac{p'}{P}$	1	$d_v = \frac{M_v p'}{RT}$
Volumetric humidity d_v (kg·m^{-3})	$Y = \frac{M_v}{M_g \left(\frac{PM_v}{d_v RT} - 1\right)}$	$z = \frac{1}{\frac{PM_v}{d_v RT} - 1}$	$Y_W = \frac{1}{1 + \frac{M_g}{M_v}\left(\frac{PM_v}{d_v RT} - 1\right)}$	$y = \frac{d_v RT}{PM_v}$	$p' = \frac{d_v RT}{M_v}$	1

[a] Multiply Y by 10^6 to obtain ppm$_w$; multiply z by 10^6 to obtain ppm$_v$.

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