

**Good Practice Guide No. 124**

**The Beginner's Guide to Humidity Measurement**

Stephanie Bell





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## **The Beginner's Guide to Humidity**

Stephanie Bell

National Physical Laboratory

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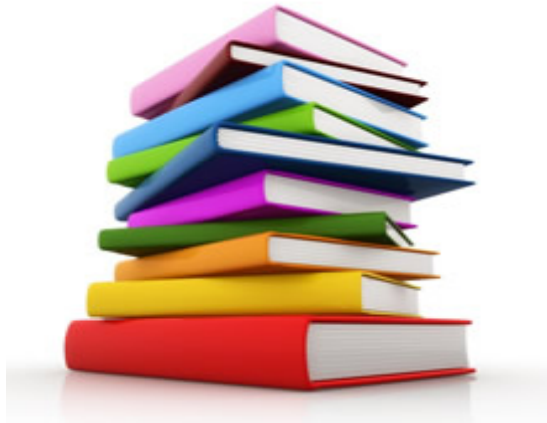
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## NPL Measurement Good Practice Guides



This is one of a series of NPL guides about measurement. These guides are aimed at everyone who has an interest in measurement, whether in a laboratory, factory, hospital, university, college or in any other walk of life.

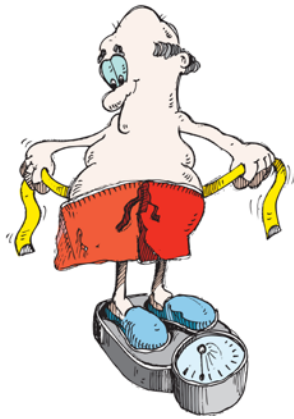
The series includes beginner's guides, which introduce measurement concepts, methods and practices at a basic level. More specialised guides cater for measurement professionals and practicing scientists and engineers who want to go more deeply into an area of measurement. References to additional guides or reading are given where appropriate.

All these guides aim to promote good practice in measurement, and are produced with technical input from specialists in the particular subject covered.

NPL is the UK's national measurement institute. It aims to deliver the highest economic and social benefits through world-leading and responsive science and knowledge services. This series of NPL Good Practice Guides provides one way to transfer knowledge to people who need to make better measurements.

For more information or help with measurement problems visit [www.npl.co.uk/contact-us](http://www.npl.co.uk/contact-us).

## Introduction to measurement



Measurement underpins science, technology and industry. It enables processes to be run efficiently, and innovative and competitive products to be made. It impacts strongly on the welfare of a modern society and touches almost every aspect of daily life.

A measurement tells us about a property of something. It might tell us how heavy an object is, or how hot, or how long it is. A measurement gives a number to that property, expressed in the appropriate unit.

The units of measurement are standardised. The International System of Units (SI) is used worldwide so that measurements can be consistent everywhere.

Measurements are only ever estimates. Every measurement is subject to some uncertainty. Perfect measurements cannot be made and so the true value is never known exactly. The uncertainty of a measurement expresses how good the estimate is thought to be.

A measurement result is incomplete without a statement of uncertainty. It is therefore in three parts: a number, a unit of measurement, and an uncertainty. For example, a length may be measured as  $2.3 \text{ cm} \pm 0.1 \text{ cm}$ .

The uncertainty of a measurement should suit the need: a school clock need not have atomic accuracy.

Measuring equipment should be calibrated by comparison against a suitable reference which itself has been calibrated. An unbroken chain of calibrations linking back to a national standards body such as the National Physical Laboratory (NPL) is known as measurement traceability.

Good measurement practice can reduce uncertainty and so improve the quality of processes and products.

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## **0 About this guide**

This is a guide to humidity measurement for beginners. It introduces the concept of humidity, and the basics of making a reliable humidity measurement.

## **1 Introduction**

### **1.1 What is humidity?**

Humidity is the presence of water vapour in air (or any other gas). In normal room air there is typically about 1 % water vapour, but it is widely present in greater or lesser amounts. High humidity makes hot days feel even hotter. Low humidity can give people a feeling of a dry throat, or sensations of “static” when touching things. Humidity is measured using a hygrometer.

### **1.2 Why is humidity important?**

Humidity affects many properties of air, and of materials in contact with air. Water vapour is key agent in both weather and climate, and it is an important atmospheric greenhouse gas. A huge variety of manufacturing, storage and testing process are humidity-critical. Humidity measurements are used wherever there is a need to prevent condensation, corrosion, mould, warping or other spoilage of products. This is highly relevant for foods, pharmaceuticals, chemicals, fuels, wood, paper, and many other products.

Air-conditioning systems in buildings often control humidity, and significant energy may go into cooling the air to remove water vapour. Humidity measurements contribute both to achieving correct environmental conditions and to minimising the energy cost of this.



Source: NPL

**One of nature’s hygrometers:  
pine cones open at low humidity  
to release their spores.**

## 2 Some humidity concepts

Some main concepts are outlined below, and there is a list of keywords and definitions at the end of this Guide.

### 2.1 What qualities does water vapour have?

Water vapour is normally invisible, and behaves like a gas, except when it condenses to form water or ice. Even without condensing, water vapour can react with surfaces and penetrate materials. The capacity of a gas (or a space) to hold water vapour depends on its temperature: the higher the temperature, the more water vapour it can contain.

### 2.2 How do we quantify humidity?

Humidity is expressed in several different ways (see also the keywords at the end of this Guide).

**Relative humidity** – how saturated a gas (or a space) is with water vapour. This is the most commonly used measure of humidity. Usually expressed as a percentage, with the symbol “%rh”, for example “The humidity is 51 %rh”. The term “relative humidity” is commonly abbreviated to RH (note this is different from the unit symbol: %rh).

Interaction of water vapour with materials is often in proportion to relative humidity.

**Dew point (or dew-point temperature)** - the temperature at which condensation (dew) would occur if a gas were cooled. Dew point is a useful measure for two reasons:

- The dew point tells us what temperature to keep a gas, to prevent condensation
- Dew point is an absolute measure of the gas humidity (at any temperature) and relates directly to the amount of water vapour present (partial pressure of water vapour).

Dew point is expressed in temperature units, for example “Today the dew point in my office is 10 °C.” If the condensation would be ice (below 0°C) then the term **frost point** is used.

**Fraction or ratio** – the proportion of water vapour in a gas. This can be given in terms of mass, volume or amount of substance (moles).

**Concentration** – the amount or mass of water vapour per unit volume, for example room air might typically contain about 10 grams of water vapour per cubic metre.

## 2.3 Other important humidity concepts

**Saturation** – When a gas (or a space) holds the maximum water vapour possible at a given temperature, it is said to be saturated. If extra water is added to a saturated gas, or if its temperature is reduced, some of the water vapour will condense.

**Partial pressure** – A gas mixture such as air is made up of several pure gas components (such as oxygen, nitrogen and others). The total pressure of the gas is said to be the sum of partial pressures of the component gases. In room air, the partial pressure of water vapour might be around 1000 pascals (Pa). (Compare this to typical atmospheric pressure, which is around 100 000 Pa.)

**Saturation vapour pressure (SVP)** – the maximum partial pressure of water vapour that can occur. At any given temperature, there is an upper limit to how much water vapour a gas (or space) can contain. For example, at 20 °C, the saturation vapour pressure of water is around 2500 Pa.

**Supercooled water** – liquid water below the normal freezing temperature. Occasionally dew occurs as supercooled water below 0 °C (freezing to ice eventually).



Dew, or condensation.

Source: NPL

## 3 Humidity-measuring instruments - hygrometers

### 3.1 Hygrometer types

Because so many things are influenced by humidity, it follows that there are very many effects that can be used to measure it. Some main methods are as follows:

**Relative humidity sensor (electrical impedance)** - hygrometer based on an electronic component that absorbs water vapour according to air humidity, and changes electrical impedance (resistance or capacitance). The instrument is usually in the form of a “probe” attached directly, or by a cable, to electronics unit to display the relative humidity reading.

**Condensation principle hygrometer** - hygrometer using cooling to induce controlled condensation. The stable temperature at which this occurs is measured and reported as dew point or frost point. A usual format is a cooled mirror with optical detection of condensation used as feedback to control the mirror temperature.

**“Dew-point” probe** - hygrometer based on an electronic sensor changing electrical capacitance on absorbing water, capable of measuring trace levels of water vapour in very dry gases. Often scaled in units of dew point (or frost point) – hence the instrument name – but readings can be displayed in other terms.

**Psychrometer (wet- and dry-bulb hygrometer)** - Hygrometer using evaporative cooling as a measure of humidity. A dry thermometer is compared against one sheathed in a wet wick, in moving air. The paired temperature values can be used to find the humidity using tables or by calculation (sometimes internally calculated and displayed directly by modern psychrometers).

**Mechanical hygrometer** - hygrometer using change in length of hair (hair hygrometer) or other organic material to measure humidity. Some types record on a chart driven by clockwork or batteries. Very basic types are not powered at all. Electronic sensor-based hygrometers are usually preferred now, but many mechanical hygrometers remain in use for room monitoring.

## A wide variety of other humidity sensing principles are used ...

| Hygrometer type                      | Sensing principle   |
|--------------------------------------|---|
| Absorption spectrometer              | Infrared light absorption by water vapour   |
| Acoustic                             | Humidity-dependent acoustical transmission or resonance   |
| Adiabatic expansion                  | “Cloud” formation in chamber on expansion cooling of sample gas   |
| Cavity ring-down spectrometer        | Decay time of absorbed, multiply-reflected infrared light   |
| Colour change                        | Crystals or inks using cobalt chloride or other chemicals changing colour with hydration  |
| Condensation                         | Temperature of formation of water or ice, on cooling humid air  |
| Electrical impedance                 | Relative humidity sensor – electrical change on absorption of water vapour into (typically) polymer film<br>“Dew-point” probe – electrical change on absorption of water vapour into (typically) porous metal oxide film. |
| Electrolytic (phosphorous pentoxide) | Electric current proportional to dissociation of water into hydrogen and oxygen   |
| Gravimetric                          | By weighing - mass of water gained or lost by humid air sample  |
| Mechanical                           | Dimensional change of humidity sensitive material (hair, polymer, paper ...)  |
| Optical fibre                        | Change in reflected or transmitted light, using hygroscopic coating, or optical grating   |
| Quartz crystal resonator             | Change in resonant frequency due to mass of surface-adsorbed water  |
| Saturated lithium chloride           | Conductivity of hygroscopic salt  |
| Wet- and dry-bulb (psychrometer)     | Humidity-dependent evaporative cooling of wetted surface  |
| Zirconia                             | Humidity derived from oxygen content of gas   |

### 3.2 Air temperature measurement

Air temperature is a key measurement alongside relative humidity. This is because the “relative” aspect is effectively “relative to temperature” (how saturated the gas is at its current temperature). For a given air sample, a rise in temperature means a fall in relative humidity. For example, at a humidity of 50 %rh, a temperature rise from 20 °C to 21 °C will cause relative humidity to fall by about 3 %rh. Because of this (and because temperature is usually of interest anyway) relative humidity instruments generally have integral temperature sensors.

## 4 How to measure humidity

### 4.1 Selection of an instrument

Consider:

- What you want to measure – is it relative humidity, dew point, or something else? Many instruments display results converted into several alternative units but the measurement will be intrinsically just one of these.
- What humidity range, and what temperature range. Must it survive extreme conditions – very dry, hot or wet?
- Instrument performance needed (resolution, short-term stability, long-term drift, speed of response, non-linearity, hysteresis, temperature coefficient, uncertainty of calibration)
- Configuration – a hygrometer probe measuring in free space, or will humid gas be supplied through tubing to flow through the instrument? Hand-held, bench-top, or surface mounted. Any space constraint?
- Power – battery, mains electricity or even unpowered.
- Data output format - display, analogue voltage or current, digitally-read output (RS232 ...) or data logged and stored, to be downloaded later. Some instruments can record on paper charts. An instrument that gives an electrical output (analogue or digital) but no displayed result is sometimes called a “transmitter”.
- Are any “alarms” needed if humidity passes any limit?
- Is sensor output to be used to automatically control something?
- Compatibility with any unusual gases
- Contamination such as dust or chemicals
- Use in hazardous areas (may require special design and certification)
- Robustness
- Cost and upkeep
- Calibration
- Versatility
- Interchangeability
- Ease of use or level of skill required

... and possibly others!



## 4.2 Other points to consider

Once you have your hygrometer, some other actions follow:

- Operating procedures, and staff training if needed
- Maintenance (if any)
- Initial calibration, and repeat calibrations at intervals
- Other checks in between calibrations. This is particularly important when a hygrometer has been exposed to extreme conditions, or mistreated, or whenever there is doubt about whether it is reading correctly.

## 4.3 Measurement set-up - sampling

Sampling format of a hygrometer can mean its configuration (a probe may sample free air, or a flow of gas is sampled through a tube).

More generally, correct sampling is about making sure the measurement is representative of the condition you want to measure. Avoid water being spuriously added to the measured gas (for example, don't measure near pooled water). Avoid unintended removal of water from sample gas (for example, don't have accidental condensation in tubing upstream of the hygrometer). Wherever there is a risk of condensation, localised heating (such as electrical "trace heating" of sample tubing) protects against this, by keeping the gas above condensation temperature (above the dew point or frost point).

For measuring very dry gases (frost points around  $-40\text{ }^{\circ}\text{C}$ ,  $-50\text{ }^{\circ}\text{C}$ , or below; water vapour fraction around 100 parts per million, or less), sample tubing and all materials in the gas flow path are critical. In this range, even tiny amounts of stray water released from surfaces can significantly add to the gas moisture content, and can give badly misleading results. To avoid this, use clean, moisture-neutral materials; smallest possible volume of pipework; and long flushing times. Sometimes heating is used to drive off traces of surface water. If using a pump – suck, don't blow. Put the pump at the far end (outlet) of a system, to avoid contamination.

For a relative humidity measurement, the temperature must be representative too. Measuring at a "cold spot" in a room can give an over-estimate of the typical relative humidity, even though water vapour might be evenly spread across the space.

If conditions are varying (such as often happens under cycling control of an air conditioning system), take repeated readings over a period of time to get an idea of

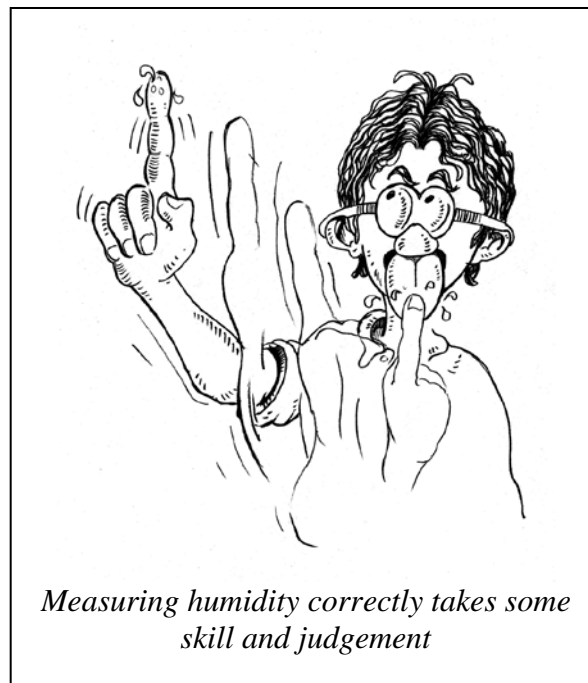
typical range. From repeated readings, you can calculate an average or mean. This can also reduce the uncertainty due to short-term instability of the instrument.

#### 4.4 Recording humidity measurement results

Some hygrometers have internal data logging. In other cases they are read using a computer (by connection, or even wirelessly). Otherwise, records depend on a person reading and writing down results.

Always record the humidity value and units. For relative humidity measurements, temperature is usually essential. Pressure must be known for psychrometers, and sometimes for other cases (such as measurements in compressed air lines – especially if planning to convert to equivalent at atmospheric pressure).

As with all measurements, it is also good practice to record the date, time, place, method, operator, and anything else that allows the measurement to be understood later.





## 5 Some humidity measurement examples

A few basic examples of how instruments might be used in particular applications are as follows:

| Room humidity monitoring   |
|--|
| <b>Requirement:</b> Long-term record of temperature and humidity in a moderate range   |
| <b>Consider:</b> Unsupervised operation? Would data at intervals be enough e.g. hourly? Real-time information needed, or record to view later? |
| <b>Possible solution:</b> Automated “data logger” whose readings can be downloaded easily to a computer.                                       |

| An industrial oven  |
|---|
| <b>Requirement:</b> Humidity measured at high temperatures to show progress of heat treatment such as drying or baking.   |
| <b>Consider:</b> Will there be dust, or other vapours apart from water?   |
| <b>Possible solution:</b> Relative humidity probes can be used (but only those specified for high temperatures). It may be possible to extract a sample flow of gas to a cooler temperature (but avoiding condensation). Check sensitivity to any chemicals given off during heating. |

| A compressed air supply line  |
|---|
| <b>Requirement:</b> Monitor air supply inside a pipeline to confirm level of dryness. May have some level of dust or oil in the gas stream  |
| <b>Consider:</b> Unsupervised use? Reading remotely? Any alarms needed?   |
| <b>Possible solution:</b> Typically a dew-point capacitive probe would be used. The sensor usually has a sintered filter (and upstream filtering of the gas flow may help to protect the sensor). Dew-point probes vary in their speed of response and long-term performance. |
| <b>Note:</b> The dew-point reading in a pressurised gas line is known as “pressure dew point”. The same gas expanded to atmospheric pressure would have a lower dew point.  |

| A climatic test chamber   |
|---|
| <b>Requirement:</b> A range of temperatures and humidities. May need to track rapid changes. There may be condensation at times (depending on the test performed).  |
| <b>Consider:</b> Response time. Robustness of instrument at hot and wet extremes. Check the actual planned range of test conditions.  |
| <b>Possible solution:</b> A few relative humidity sensors (probes) are designed to cope with a wide humidity and temperature range. Wet- and dry-bulb hygrometers (psychrometers) can be suitable, although they need careful setting up and maintenance. |

## 6 Calibration and traceability of measurement

### 6.1 Calibration

Like all measuring instruments, hygrometers don't always read exactly true. They can suffer from bias and long-term drift. Therefore calibration is essential for accurate humidity measurement.

Calibration is the comparison of an instrument against a reference value. For a hygrometer, this comparison might be against a calibrated reference hygrometer, using a chamber or other stable source of humid gas. The reference hygrometer should itself have a calibration traceable directly, or in multiple steps, back to an authoritative standard. This is known as *measurement traceability*.

Some users assume that calibration will leave an instrument "reading right". Not necessarily – calibration is not the same as adjustment.

A calibration certificate reports any instrument errors, and gives the uncertainty in these. Calibration corrections then need to be applied to instrument readings (or else taken into account as a source of uncertainty). With any measurement, the practical uncertainty in using the instrument is always more than on the calibration certificate.

Calibrations against reference hygrometers, using humidity generators, can be done in laboratories. A calibration lab may have accreditation (through UKAS in the UK) giving assurance that calibrations are traceable and competently performed. For some hygrometers there are also methods of "field calibration" - for example using salt solutions to generate values of relative humidity – which can also be made traceable.

Calibrations need to be repeated, because hygrometers can drift - due to conditions of use, or just due to sensor ageing. Choosing how often to calibrate depends on usage, risk of drift, and how critical the measurement is. Relative humidity instruments might be calibrated every 6 to 12 months (or more often if they are harshly treated). A reference hygrometer in a lab might be calibrated every 1 to 2 years.

Some calibration tips:

- Calibrate in terms of the quantity to be measured (such as relative humidity, or dew point, or other ...)
- Calibrate probe and hygrometer together (unless clearly advised otherwise by the manufacturer).
- Calibrate for the range and conditions of use

- Especially for dew-point probes used for more than one pressure or gas type, check whether calibration in air at atmospheric pressure is applicable (particularly for units expressed as mass or volume).
- A check is not a calibration. But checks against another instrument (if available) are highly useful. A check can help in assessing whether a hygrometer is functioning as expected, and whether repair or recalibration is needed.



## 6.2 Uncertainty of measurement

Every measurement is subject to some uncertainty, expressed as “±”, at a level of confidence (usually 95 %). For example, “50 %rh ± 3 %rh at a level of confidence of 95 %” means we are 95 percent sure the true value is between 47 %rh and 53 %rh.

Uncertainty in humidity measurement can come from various causes. It depends partly on the hygrometer, which might suffer from drift, short-term “noise”, limited resolution ... . Calibration uncertainty needs to be taken into account. If the condition being measured is unstable, this too contributes to uncertainty in the result – for example, temperature changes can cause uncertainty in relative humidity values.

There is no “typical uncertainty” for a humidity measurement. But very broadly ... in ideal conditions, relative humidity measurements might achieve uncertainty within ± 2 %rh to ± 3 %rh. Under difficult conditions this could be ± 5 %rh to ± 10 %rh, or even worse. The best dew-point measurements could be as good as ± 0.05 to ± 0.1 °C, in a lab, using the best condensation hygrometers. In worse conditions, and using less sophisticated dew-point probes, uncertainty of several degrees is not unusual, especially at very dry levels (all uncertainties at 95 % confidence).

## 7 Humidity measurement: some do's and don'ts

Do ...

- Make use of the manual, and of manufacturer's advice
- Have the instrument calibrated, and take account of any calibration corrections required
- Let the instrument reach the temperature of the location
- Allow time for the humidity reading to stabilise (especially for dry gases)
- Record measurement results with suitable care
- Be clear when expressing humidity differences. A change of 10 % of reading is not the same as a change of 10 %rh.
- Check any hygrometer that has been exposed to extreme conditions or contaminants

Don't ...

- Don't handle humidity sensors roughly. Don't abuse well-mounted sensors by treating them as coat hooks!
- Don't use sensors outside the temperature or humidity range specified by the manufacturer – this could cause a shift in calibration.
- Don't expose sensors to condensation - unless you know they are can definitely tolerate this
- Don't "mix and match" humidity probes with different electronics units – unless they are definitely designed for this. Instrument suppliers can advise if a probe is a "self-contained" interchangeable unit with its own signal processing inside

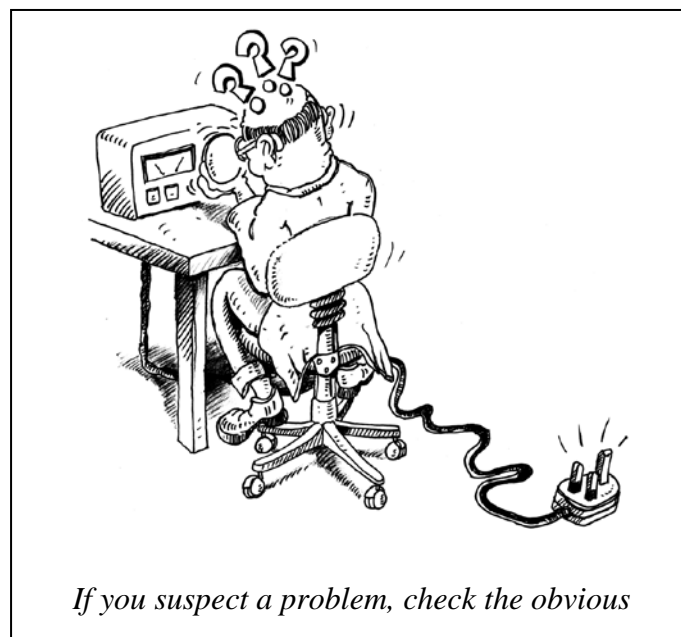
Watch out for ...

- Droplets, or stray water in any form: if present, humidity measurements may be misleading
- Dust – most instrument types
- Pressure differences (dew point) or temperature differences (relative humidity)

## 8 What can go wrong - troubleshooting

If you suspect hygrometer readings may be incorrect:

- Make sure all equipment is switched on and all cables are connected
- Consider whether the hygrometer and the conditions have had long enough to stabilise
- Check that the temperature is as expected (particularly for relative humidity measurement).
- Check the most recent calibration certificate, in case the hygrometer simply has a large calibration error. If so, applying a suitable calibration correction should bring the result to a realistic value.
- Consider comparing against another hygrometer as a check.
- Beware of human error ... mistakes in recording, mis-reading, wrongly numbering sets of sensors ...



## 9 Special cases

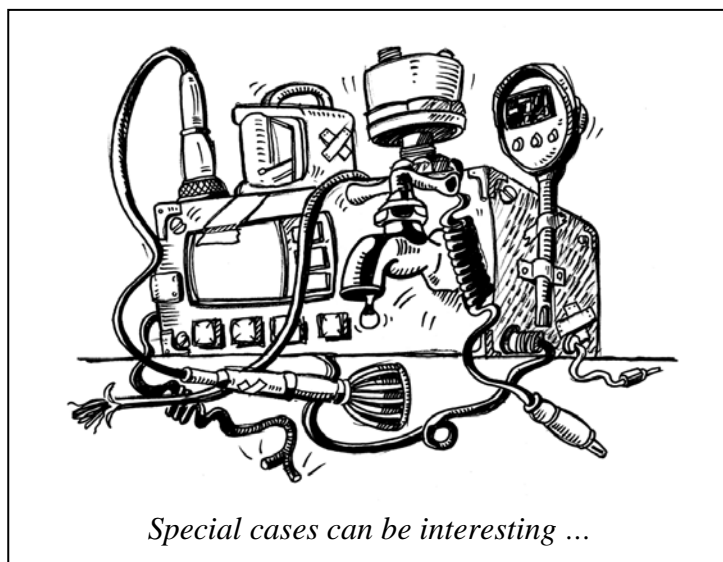
Be prepared to seek advice - some humidity measurements need special care:

**Temperature change** - if measuring gas at one temperature and using it at another, measured values may need converted or interpreted. In particular, relative humidity falls when temperature rises (and rises when temperature falls).

**Pressure change** – if measuring at gas at one pressure and using it at another, measured values may need to be converted or interpreted. Some humidity parameters change when gas is expanded (examples are: dew point and mass of water per unit volume).

**Low (vacuum) pressures** – humidity measurements can be made below atmospheric pressure, but need some thought to set up and interpret.

**Non-air gases** – humidity is measured in a wide variety of gases, such as fuel gas (“natural gas”) and various process gases. Take care to choose a measurement method suitable for the particular gas. Beware of humidity readings displayed in units that are gas-dependent, and be ready to interpret (convert) for the gas used. Wherever units related to mass, or volume (“ppm”) are displayed, they may be internally calculated with an assumption of measuring in air.



**Harsh environments** – Dust, vibration, condensation, airborne droplets, chemicals ... all pose challenges to most hygrometers.

**Older hygrometers** – modern electronic humidity sensors have increasingly long lifespans, if treated well. If you are using a relative humidity sensor or dew-point probe that you know to be old, don't expect the best performance. Some older hygrometers may suffer from drift, slowed response, etc.

## 10 Humidity calculations and conversions

Just a few tables are given here, to give some idea of scale and conversions between humidity values in different units. See the *Further Reading* section for sources of more detailed information.

### 10.1 Tables

#### Air temperature, dew point, and relative humidity

Approximate values of relative humidity are shown for a selection of dew points and air temperatures.

**Table 1. Values of relative humidity at selected temperatures and dew points**

| Air temperature / °C       | 0                       | 5   | 10  | 15  | 20  | 25  | 30  | 35  | 40  | 50  |
|----------------------------|-------------------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| Dew-point temperature / °C | Relative humidity / %rh |     |     |     |     |     |     |     |     |     |
| 0                          | 100                     | 70  | 50  | 36  | 26  | 19  | 14  | 11  | 8   | 5   |
| 5                          | -                       | 100 | 71  | 51  | 37  | 28  | 21  | 16  | 12  | 7   |
| 10                         | -                       | -   | 100 | 72  | 53  | 39  | 29  | 23  | 17  | 10  |
| 15                         | -                       | -   | -   | 100 | 73  | 54  | 40  | 30  | 23  | 14  |
| 20                         | -                       | -   | -   | -   | 100 | 74  | 55  | 42  | 32  | 19  |
| 25                         | -                       | -   | -   | -   | -   | 100 | 75  | 56  | 43  | 26  |
| 30                         | -                       | -   | -   | -   | -   | -   | 100 | 75  | 58  | 34  |
| 35                         | -                       | -   | -   | -   | -   | -   | -   | 100 | 76  | 46  |
| 40                         | -                       | -   | -   | -   | -   | -   | -   | -   | 100 | 60  |
| 50                         | -                       | -   | -   | -   | -   | -   | -   | -   | -   | 100 |

**Vapour concentration (also known as volumetric humidity or absolute humidity)**

The table shows the approximate mass of water (in grams) contained in a cubic metre (m<sup>3</sup>) of saturated air at a total pressure of 101 325 Pa (1013.25 mbar). Unsaturated air will contain comparatively less.

**Table 2. Mass of water vapour per cubic metre of saturated air**

|                                    |     |     |     |      |      |      |      |      |
|------------------------------------|-----|-----|-----|------|------|------|------|------|
| Temperature / °C                   | 0   | 5   | 10  | 15   | 20   | 25   | 30   | 35   |
| Water vapour / (g/m <sup>3</sup> ) | 4.9 | 6.8 | 9.4 | 12.9 | 17.4 | 23.1 | 30.5 | 39.8 |

For air at atmospheric pressure, a few comparative values are shown of dew point (frost point), saturation vapour pressure, and amount fraction.

**Table 3: Comparison of humidity values**

| Dew-point temperature<br>(frost point below 0 °C)<br>°C | Saturation<br>vapour pressure<br>Pa | Amount fraction (fraction of vapour<br>in total amount of air) |                            |
|---|-------------------------------------|--|----------------------------|
|   |                                     | Percent (%)  | Parts in 10 <sup>6</sup> * |
| 100   | 101419                              | 100  |                            |
| 80  | 47695                               | 47   |                            |
| 60  | 20065                               | 20   |                            |
| 40  | 7421                                | 7.3  |                            |
| 20  | 2349                                | 2.3  |                            |
| 10  | 1233                                | 1.2  |                            |
| 0   | 614                                 | 0.6  |                            |
| -10   | 261                                 | 0.3  |                            |
| -20   | 103                                 | 0.1  | 1024                       |
| -40   | 12.9                                |  | 127                        |
| -60   | 1.1                                 |  | 11                         |
| -80   | 0.06                                |  | 0.5                        |

\*(informally known as “parts per million”)



## 10.2 Humidity calculations



Humidity calculations are not fully covered here, but are detailed in some of the further reading in the next section.

Generally, there are methods for calculating and converting between humidity values in terms of dew point, relative humidity, vapour pressure, and all others. Most humidity calculations involve several steps. For example, there is no single-step calculation to convert relative humidity to dew point. To do this you would use air temperature to calculate saturation vapour pressure, then use this with relative humidity to calculate actual vapour pressure, and then use that to calculate dew-point temperature.

Some hygrometer companies provide software for making humidity conversions. This is often a good alternative to struggling with pen, paper and calculator. Either way, humidity calculations need to be made carefully, with some understanding.

Example: relative humidity can be calculated from vapour pressures as follows:

$$\text{Relative humidity (in percent)} = \frac{e}{e_s} \times 100$$

where

$e$  is the actual vapour pressure of water, and

$e_s$  is the saturation vapour pressure of water at the actual temperature and pressure.

(This equation illustrates how relative humidity denotes a fraction of saturation at a given temperature.)

## 11 Further reading

### On humidity:

*A Guide to the Measurement of Humidity* Published by the Institute of Measurement and Control, 1996, 68 pp, ISBN 0-904457-24-9

<http://www.npl.co.uk/publications/guide-to-the-measurement-of-humidity>

**BS1339:1 – Humidity - terms definitions and formulae**

**BS1339:2 – Humidity calculation functions, tables and user guide (CD – ROM)**

**BS1339:3 – Guide to the measurement of humidity**

### On measurement generally:

*A Beginner's Guide to Measurement*, Good Practice Guide No. 118

<http://www.npl.co.uk/publications/beginners-guide-to-measurement/>

### On measurement uncertainty:

*A Beginner's Guide to Uncertainty in Measurement*, Bell, S A, Measurement Good Practice Guide No. 11, March 2001. <http://www.npl.co.uk/publications/a-beginners-guide-to-uncertainty-in-measurement>

*UKAS M3003 The Expression of Uncertainty and Confidence in Measurement*, Edition 2, January 2007 <http://www.ukas.com/library/Technical-Information/Pubs-Technical-Articles/Pubs-List/M3003.pdf>

## 12 Keywords and definitions for humidity

Some humidity terms, and words with specialised usage for humidity, are defined below. Some definitions are based on *A Guide to the Measurement of Humidity*. Fuller and more rigorous definitions can be found in *BS1339 - 1: Humidity - Terms definitions and formulae*. In a few cases, usage of certain terms varies in different fields of activity.

**Absorption (of water vapour)** - retention (of water vapour) by penetration into the bulk of a material

**Adsorption (of water vapour)** - retention (of water vapour) as a surface layer on a material

**Amount fraction (amount-of-substance fraction)** - amount (number of *moles*) of a component as a fraction of the total amount of substance present. Also known as “mole fraction”. May be written with no units (said to be “dimensionless”, or of “dimension 1”) for example “water vapour in nitrogen at a mole fraction of 0.005 (or 5 parts in  $10^3$ )”. Alternatively in “moles of water per mole of gas”.

**Dew point (dew-point temperature)** - temperature at which dew, or condensation, forms, on cooling a gas. Expressed in units of temperature e.g. degrees Celsius ( $^{\circ}\text{C}$ ). See also **frost point**. Dew (as supercooled water, not ice) can sometimes occur several degrees below normal freezing point of  $0^{\circ}\text{C}$

**Dry-bulb temperature** - measured air temperature, (term particularly used along with "wet-bulb" temperature for a psychrometer, or wet- and dry-bulb hygrometer).

**Frost point (frost-point temperature)** - The temperature at which frost forms on cooling a gas. Expressed in units of temperature, e.g. degrees Celsius, ( $^{\circ}\text{C}$ ). (See also **dew point**.)

**Humidity** - presence of water vapour in air or other gas.

**Hygrometer** - any instrument for measuring humidity

**Hygroscopic** - tending to absorb water vapour

**Mass fraction** – fraction expressing mass of component per total mass of substance present. May be written with no units (said to be “dimensionless”), for example “water vapour in nitrogen at a mass fraction of 0.002 (or 2 parts in  $10^3$ )”. Alternatively in mass units such as “kilograms of water per kilogram of (humid) gas”.

**Mass ratio (mixing ratio)** - Mass of water vapour per unit mass of dry air. May be written with no units (said to be “dimensionless”), but often expressed in grams of water per kilogram of dry gas.

**Moisture** - liquid water or water vapour in any form, including water within a material

**Moisture content** – general term for water content in gases, (or in solids and liquids (where it may mean water or other volatile components such as oils or alcohols).

**Mole** - Amount of substance which contains as many elementary entities as there are atoms in 12 grams of carbon 12. Expressed in moles (symbol: mol).

NOTE: When the mole is used, the elementary entities must be specified as atoms, molecules, etc.

**Mole fraction** – see *amount fraction*

**Partial pressure (of water vapour)** - The part of the overall pressure exerted by the water vapour component in a gas. Expressed in units of pressure such as pascals (Pa) (or millibars (mbar))

**Parts per million (ppm)** - informal way of expressing trace water content (amount fraction or ratio; mass fraction or ratio; or volume fraction or ratio). “1 ppm” means “1 part per million” or “1 part in  $10^6$ ”.

**Probe** - the part of an instrument that houses the sensor, typically linked to a display unit by a cable

**Relative humidity** - The ratio of the actual vapour pressure to the saturation vapour pressure, commonly expressed as a percentage (unit symbol %rh).

**Saturation vapour pressure (of water)** - maximum pressure of water vapour that can exist at a given temperature. Expressed in units of pressure such as pascals (Pa), (or in non-SI units such as millibars (mbar))

**Sensor** - active or sensing part of a measuring instrument. Term also loosely used to refer to a humidity probe, transmitter or entire hygrometer.

**Transmitter** – instrument (hygrometer) that normally gives an electrical output (analogue or digital) rather than a displayed value.

**Vapour concentration (also known as volumetric humidity or absolute humidity)**  
- mass of water vapour present in unit volume of moist air at a given temperature and pressure. (See also Section 10.1)

**Vapour pressure** – see *partial pressure*

**Volume fraction** - fraction expressing volume of component per total volume of substance present. May be written with no units (said to be “dimensionless”), for example “water vapour in nitrogen at a volume fraction of 5 parts per million (or 5 parts in  $10^6$ )”.

**Wet-bulb temperature** - temperature of a wet-bulb thermometer in a psychrometer, where evaporative cooling is used to measure humidity.