Temp, Humidity & Dew Point ONA

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The _Temp, Humidity & Dew Point_ ONA (Often Needed Answers)

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A plain text version of this text can also be found on:
http://mmf.ruc.dk/~bek/relhum.htm

1)
Introduction:

From the discussions on the newsgroup sci.geo.meteorology this is a collection of some formulae and texts that reflect on connections of temperature, humidity and dew point temperature (BeK):

Air will normally contain a certain amount of water vapour. The maximum amount of water vapour, that air can contain, depends on the temperature and, for certain temperature ranges, also on whether the air is near to a water or ice surface. If you have a closed container with water and air (like a beaker) then there an equilibrium will develop, where the air will contain as much vapour as it can. The air will then be saturated with respect to water vapour.
The real world outside is not closed, so that the air normally will contain less vapour as it could. Sources of vapour are evaporation processes from water and ice surfaces and transpiration from plants and respiration from animals. The expression "evapotranspiration" takes into consideration plants' large share of evaporation over land areas.
Sinks of water vapour are clouds or condensation on surfaces.
Dew is created when a surface temperature has such a low temperature that the air chills to the dew point and the water vapour condenses. Physically at the dew point temperature the vapour loses the energy that it gained at evaporation, the latent energy, again.

The precipitable water (total column water vapor) is strongly correlated ($r > 0.9$) with the surface dew point on most days. Exceptions to the rule include days when a cold front has passed and during other transient events. (Kerry Andersen)

NET readings :
http://covis2.atmos.uiuc.edu/guide/wmaps/general/rhdef.html
http://njnie.dl.stevens-tech.edu/curriculum/oceans/rel.html
http://www.mtc.com.my/fpub/lib/drying/ch11.htm

2)
Formulae:

Enough for dry physical theories; here comes the practice.

For some people skipping this and going directly to the examples would be the most rewarding. Especially as they treat the conversion of relative humidity and psychrometer temperatures. (BeK)

```
Vapor pressure (e) is the fraction of the ambient pressure that is
due to the fraction of water vapor in the air.
Saturation vapor pressure (es) is the maximum vapor pressure that the
air can support (non supersaturated) at a given temperature.

e  can vary from 0 (verrry dry) to the maximum, es.
es is a function of temperature es(T).


Relative humidity (RH) is 100% times the ratio of the environmental
vapour pressure, e(T), to the saturation vapour pressure es(T).

        RH = 100% * e(T)/es(T)


The environmental vapour pressure is the saturation vapour pressure
at the dew point or

        e(T) = es(Td)

so RH becomes

        RH = 100% * es(Td)/es(T)

In other words: if you have a parcel of air and cool it until the
water vapor in it condenses then you have reached the saturation point.
At this point you will measure the same vapour pressure as in your
original air probe.



Some more elaborate expressions follow here:

es0 = reference saturation vapor pressure (es at a certain temp,
                                           usually 0 deg C)
    = 6.11 hPa

T0  = reference temperature (273.15 Kelvin,  Kelvin = degree C +
                                                      273.15)

Td  = dew point temperature (Kelvin)

T   = temperature (Kelvin)

lv  = latent heat of vaporization of water (2.5 * 10^6 joules
```

per kilogram)

```
Rv  = gas constant for water vapor (461.5 joules* Kelvin / kilogram)

e  = es0 * exp( lv/Rv * (1/T0 - 1/Td))
es = es0 * exp( lv/Rv * (1/T0 - 1/T))

RH= e/es * (100%) = relative humidity !!!!
```

So just above is the answer to many questions in the direction of how to calculate the relative humidity if you have the dew point and air temperature.

There are some simple and more complicated formulas for the saturation vapour pressure at a given temperature.

A simple first guess (assuming the latent heat of vaporization is constant with temperature) would be:

```
        log10(es) = 9.4041 - 2354/T
or
           ln(es) = 21.564 - 5420/T
```

where T is in Kelvin (i.e., 273.15+T(C)). {After inverting the logarithms es in given in hPa.}

Another approximation (Magnus' formula) would be

```
        log10(es) = -2937.4/T - 4.9283*log10(T) + 23.5470
```

In the following the input gets a little more complicated. Here we also shall distinguish between the saturation vapour pressure over ice or water. Both are different, as the molecular forces bind much more in an ice crystal than in a water bobble. So the saturation pressure esW will be larger than esI (W for water, I for ice).

1. Vapor pressure (e):

```
                            dew point temperature in degrees C.
                           /
     e  = 6.1078 * 10 ** ((TD * A)/(TD + B)) in hPa
```

2. Saturated vapor pressure (es):

```
es = 6.1078 * 10 ** ((T * A)/(T + B))
                       \
                        temperature in C

              A =   7.5 } for use in vapor pressure
              B = 237.3 } with respect to WATER

            * A =   9.5 } for use in vapor pressure
              B = 265.5 } with respect to ICE
```

3. Absolute virtual temperature (TV):

```
                            vapor pressure
                           /
TV = (T + 273.15)/(1-0.379*e/Press)
                               \
                                total pressure
```

TV does take into consideration that you could try to condense all the water vapour in your air parcel and use the condensation heat to warm up the air. This is a first way to distinguish different air parcels that may have the same temperature but have different relative humidity.

4. Mixing ratio (W):

```
                            vapor pressure
                           /
                  .62197 e                    grams water
              W = --------                    -------------
                     P - e                    grams dry air
                      \                            |
                       total pressure              |
                                           Thus 12 g/Kg comes
out
                                           as .012
```

5. Wet Bulb
Vapor Pressure
Dew Point (P365, Smithsonian for first part)

$$\frac{E_w - e}{Press\,(T-T_w)} = .000660\,(1 + .00115\,T_w)$$

Therefore:

$$e = E_w - Press\,(T-T_w)\,(.000660)\,(1 + .00115\,T_w)$$

Tw = Wet bulb temperature (degrees C.)
Ew = Saturated vapor pressure at temperature Tw
e = Vapor pressure in air
Press = Total barometric pressure (units same as Ew, e)
T = Air temperature (degrees C.)

e is the vapor pressure in the air, which is the vapor pressure at the dew point temperature. To solve for the dew point temperature, use the formula:

e = 6.1078 * 10 ** ((Td * A)/(Td + B)) in hPa

let $C = \log_{10}(e/6.1078)$

Then:

$$C\,T_d + C\,B = A\,T_d$$

$$T_d = \frac{B*C}{A-C} \quad \text{Dew point in degrees C}$$

where A = 7.5
B = 237.3

All the above saturation pressure temperature relationships are relatively uncomplicated. Here one that is more mindboggling:

A saturation-pressure-curve which is valid for a total pressure of 1000 hPa. "This curve was computed by approximating the standard steam table for pure water using the least square method by a Bulgarian colleague. I experienced it to be quite exact, but I'd be glad to be corrected." (Dr Haessler)

```
Psat  = 610.710701 + 44.4293573*t + 1.41696846*t^2 +
        0.0274759545*t^3 + 2.61145937E-4*t^4 + 2.85993708E-6*t^5
```

The pressure is in Pa, the temperature in degrees Celsius (C).

Relative Humidity then is:

```
Phi = Psteam/Psat = (Ptot/Psat)*x / ((Rair/Rsteam)+x),
```

where x is the absolute humidity in kilogramm water per kilogramm of dry air,
Rair and Rsteam are the specific gas constants for air and steam, where
Rair/Rsteam has a value of 0.622.

For the handling:

1. Calculate the saturation pressure at Your dew point, giving Your steam pressure.
2. Calculate the saturation pressure at Your temperature.
3. Divide'em (see above) to get Your relative humidity.
4. Calculate Your absolute humidity, if desired.
5. Mail me for further informations, if necessary.
6. The reverse way is possible.

For the pressure dependence of relative humidity:
If air and steam behave as ideal gases, there is no pressure dependence.
This is so around 1000 hPa (+-100hPa, approx.).

NET reading :
http://www.mindspring.com/~pjm/pmtherm.html (free psychrometer program)
http://nwselp.epcc.edu/elp/wxcalcsc.html (Perl-scripts)

CAUTIONS:

Good psychrometers

a) Air velocity

k (and A) don't really become (sorta) independent of the air velocity past your wet bulb until velocities above 3 meters/ second. Velocities greater than 1 m/s are sufficient at temperatures of 60 C or more.
The worse your arrangement, (less adiabatic, i.e. the more extraneous energy radiates/conducts into the water) the steeper k over velocity becomes for lower velocities. So you can compensate poor design to some extent by cranking up that fan.

k and A are really device-dependent. This k (and A, of course) strictly refers to the "Assmann psychrometer" only - two radiation shields, thermal insulation, fan downstream from the thermometers. k should be similar for any well-made psychrometer.

b) Adiabatic wet bulb

Shield it from radiative & conductive errors, i.e. all energy to vaporize the water must come from the air and thus be reflected in thetaf.

In wetting the wet bulb, use distilled water. Salty scale on your "sock" can change the vapor pressure, and will really mess measurements near zero. Use enough water to hit steady-state conditions well before you start to dry out.

If you use a wick for continuous wetting, make it long enough so that conductive errors are minimized, and it is cooled to the wet bulb temperature by the time it gets near the thermometer. Make sure enough water can reach the wet bulb, so don't overdo the "long enough" part.

Don't get anything but the wet bulb wet. Getting the radiation shield or the thermal insulation wet will introduce errors.

Keep direct sunlight off. A great way to pump heat into your "adiabatic" system. Don't ever paint the outside black. Many commercial humidity meters are a pretty black finish. They will be sensitive to indirect sunlight (and other radiative sources). Humidity measurements are VERY sensitive to temperature!

c) Supercooled water and ice below freezing

Your measurement will become screwy below freezing, as you cannot really distinguish between supercooled water (evaporation) and ice (sublimation) in your wet bulb, and the vapor pressures differ. And Lueck says supercooled water can be present as low as -12 C. It suggests manually scraping the wet bulb to ensure that supercooled water turns to ice.

And note that humidity measurements never are terribly accurate, 2% error in absolute hum. are pretty good, depending on where you are in terms of temp and water content. Anything that reads "relative humidity=52.783 %" is guessing (if you paid less than 100k$...:-)

Thomas Prufer

Wet bulb temperature is really defined by the psychrometer and is not an atmospheric water vapor property (compared with Td which has a firm definition)!!!! The above computations assume the standard psychrometer equation, but the psychrometer constant (0.00066*P in kPa/C) is a theoretical value that is not always matched even by very good psycrchrometers. PLEASE note this psychrometer constant depends directly on atmospheric pressure so it's value is not a "universal" constant!

Terry Howell

NET readings:
http://www.uswcl.ars.ag.gov/exper/relhumeq.htm
http://nwselp.epcc.edu/elp/rhsc.html
http://storm.atmos.uiuc.edu/covis2/visualizer/help/general/rh.dwp.html

3)
Examples

1. EXAMPLE X M P L X M P L X M P L X M P L X M P L
>My problem is the following. I want to calculate wetbulb temperature
>(Tw) where my input is drybulb temperature (T) and relative humidity
>(rH). (Pieter Haasbroek)

Pieter:

Your problem can be solved explicitly using the methods from Jensen et al. (1990) ASCE Manual No. 70 (see pages 176 & 177) using the

```
following steps and equations:

1)  compute e as [es(T)*rH/100]
    where es(T) = 0.611*EXP(17.27*T/(T+237.3)) in kPa
    T is drybulb temp in C

    e = (rH/100)* 0.611*EXP(17.27*T/(T+237.3))
    where e is ambient vapor pressure in kPa

2)  compute dewpoint temperature (Td)
    Td = [116.9+237.3ln(e)]/[16.78-ln(e)] in C

3)  compute wet bulb temperature (Tw)
    Tw = [(GAMMA*T)+(DELTA*Td)]/(GAMMA+DELTA)
    GAMMA = 0.00066*P where P is ambient barometric pressure in kPa
    DELTA = 4098*e/(Td+237.3)^2

This method should be close, especially when Tw is close to Td (DELTA
should be evaluated at (Tw+Td)/2.

For example:

 T = 25C
rH = 50%
assume elev is sea level and P = 100 kPa.

1)  es(25) = 0.611*EXP(17.27*25/(25+237.3)) = 3.17 kPa
    e = (50/100)* es(25) = 1.58 kPa

2)  Td = [116.9+237.3*ln(1.30)]/[16.78-ln(1.30)] = 13.85 C

3)  GAMMA = 0.00066*100 = 0.066 kPa/C
    DELTA = 4098*(1.58)/(13.85+237.3)^2 = 0.103 kPa/C
    Tw = [(0.066*25)+(0.103*13.85)]/(0.066+0.103) = 18.21 C

CHECK ANSWER:

    EW(Tw) = 0.611*EXP(17.27*18.21/(18.21+237.3)) = 2.09 kPa
    e  = EW(Tw) - GAMMA*(T-Tw)
    e  = 1.58 - 0.066*(25-18.21) = 1.64 kPa

The exact answer for Tw is about 17.95C
    EW(18.0) = 2.07 kPa;  e = 1.60 kPa
    EW(17.9) = 2.05 kPa;  e = 1.58 kPa
    EW(17.95) = 2.06 kPa; e = 1.59 kPa
```

```
Thus,
    ERROR  e = [(1.64 - 1.58)/1.58]*100 = 3.1%
    ERROR Tw = [(18.2-17.95)/17.95]*100 = 1.4%



2. EXAMPLE      X M P L   X M P L   X M P L   X M P L
>Hello:-
>I am looking for the algorithm to convert wet/dry bulb temperatures to /
>from rH (and moisture content as well, for that matter).
>I know the Psychometric charts, but they are difficult to use accurately
>in software. Anyone have a pointer to appropriate equations?
>Thanks in advance! (Spehro Pefhany)

Answer
(I shall find a formula in SI units, please be patient, BeK)

pw = psf  - p * A * (theta - thetaf)

theta: dry bulb temp., Kelvin or Celsius
thetaf: wet bulb temp.,   "
psf: Saturation pressure at temp thetaf, see 1.), in Torr (mm Hg)
pw: Vapor pressure of ambient air, in Torr (mm Hg)
p: pressure of ambient air, in Torr
A: optimally (see below) 0.66 * 10e-3 * (1/C)

3.) The short way round:

We're in your backyard: p = 755 Torr, 0 C < theta < 50 C.

pw = psf - k (theta - thetaf)

phi = pw/psf

phi: relative humidity.
k= p*A = 0.5 Torr/degree

Higher temperatures:
   thetaf about 60 C: k is about 0.52
   thetaf about 80 C: k is about 0.53


(Formula suggested by A. Sprung, 1888)
```

3. EXAMPLE X M P L X M P L X M P L X M P L

This question is _often_ asked:

>I have the air pressure (p), the temperature (T) and the
>relative humidity (rH) and want to calculate the specific humidity
>(i.e. the mass of water vapour to the humid air)?

First: This air pressure that you have, is actually the total pressure, i.e. it is the sum of the pressure of the dry air (pair) PLUS the share from the water vapour (pw).

Then calculate the saturation pressure (es) from one of the formulas given above.

Then multiply by the relative humidity (rh). This gives you the ambient water vapour pressure, (e).

Then the specific humidity is given by the following formula:

$$rho = \frac{R_L}{R_W} \; \frac{e}{p + e(R_L / R_W - 1)}$$

WHERE:

$R_L / R_W = 0.62197$ (see the example for the mixing ratio)

4. EXAMPLE X M P L X M P L X M P L X M P L

> Could somebody send or post the method, or fomula, used to calculate
> dewpoints. I have hunted the local library but am unable to find it.

Here it is:

Td = B / ln(A * 0.622 / w p)

where:

B = 5420 K

A = 2.53 E8 kPa

w = water vapor mixig ratio
p = local pressure

5. EXAMPLE X M P L X M P L X M P L X M P L

>I'm wondering if anyone could please give me the formula for the
>calculation of dewpoint temperature given relative humidity, current
>temperature, and station pressure

First calculate the saturation vap. pres. es (Pa) at temperature T (oC):

es = 610.78 * exp {A T / (T + B) }

where es in Pa, A = 17.2694 and B = 237.3 for T>0 otherwise 265.5.
Then calculate the actual vapour pressure e (Pa) using

e = rH / 100 * es

where rH is the rel.hum in %. Finally invert the equation for es since e = es(Td). The dewpoint temperature Td (oC) is then obtained from

Td = B f / { 1 - f }

where

f = ln (e / 610.78) / A

(Based on Monteith and Unsworth, 1990, Principles of Environmental Physics, sec.ed., Arnold, London, 291pp. ISBN 0-7131-2931-X.
Note however that their equation 2.25 for Td is wrong)
N.J. Bink

6. EXAMPLE X M P L X M P L X M P L X M P L

I need some help with calculating RH. Our control system allows us to read
> dry bulb temp and enter the specific humidity (g/kg of dry air). We are
> looking for a formula to calculate a RH setpoint to use for control. As
> the dry bulb temp changes the system would calculate the new RH setpoint
> to maintain the same specific humidity.

I propose and easy solution.

We start with the formula for the mixing ratio:

$$w = \frac{0.622 * e}{p - e}$$

and transform it with the formulas for the Saturation vapor pressure (es), resulting in:

$$rH = \frac{w0 * p}{es(T)*(1 + w0)}$$

where:
p is the total measured pressure and
w0 is the specific humidity (w) at the start of the run, which is supposed to stay constant.
To give an example with the same starting conditions as in the example above, see the following table:

rel. err.	w'	rh'	es(T)	T
1.1%	0.016	60%	2.645	22
1.3%	0.016	56%	2.810	23
1.4%	0.016	53%	2.985	24
1.6%	0.016	50%	3.169	25
1.8%	0.016	47%	3.363	26
2.1%	0.016	44%	3.567	27
2.3%	0.016	42%	3.781	28

As you can see w' equals w0, but the relative humidity changes of course.

NB
By now you should be able to solve your undergraduate humidity calculations really by yourselves. But, looking at the text for the mixing ration, given above, most of you could have gained knowledge of this formula by yourselves, I guess.

4)

Literature hints:

For the book and paper aficionados of the readers check out this:

'If your really interested in this stuff, I (Kerry Anderson) suggest
the book "Atmospheric Thermodynamics" by Irabarne and Godson."'
But unfortunately I learned this book is out of stock
(amazon.com). Instead I could recommend:
"Fundamentals of Atmospheric Dynamics and Thermodynamics"
Paperback, Amazon.com Price: $29.00; Published by
World Scientific Pub Co. Publication date: May 1992
ISBN: 9971978873

"Most introductory texts on meteorology will have one
or two paragraphs on the matter." (K Anderson)

"(Based on Monteith and Unsworth, 1990, Principles of Environmental
Physics, sec.ed., Arnold, London, 291pp. ISBN 0-7131-2931-X.
Note however that their equation 2.25 for Td is wrong)."
N.J. Bink

"My sources (other than experience) are all German books
(Thomas Prufer):"
(ue equals u¨, BeK)
Lueck, Winfired: Feuchtigkeit - Grundlagen, Messen, Regeln.
Muenchen: R. Oldenbourg, 1964. Good basics.

Sonntag, D.: Hygrometrie: Ein Handbuch der Feuchtigkeitsmessung in
Luft und anderen Gasen. (6 vols.) Berlin: Akademie, 1966 - 1968
Also contains a very detailed description of nearly everything on the
market in 1966-68.

Heinze, D.: Einheitliche, methodische Beschreibung von
Gasfeuchte-Messverfahren. Dissertation an der Technischen Hochschule
Ilmenau, 1980
Comprehensive block and signal diagrams with the Laplace functions (!)
of nearly all humidity measurement methods. Nearly unobtainable,
unfortunately.
(Thomas Prufer)

5)
Committment:

This ONA was collected and provided to you by Bernd Kuemmel (bek@mmf.ruc.dk).

I admit to have used especially the willing help and the contributions of the of the following people:

Pierre-Alain Dorange, Forrest M. Mims III, Kerry Anderson, Len Padilla, Ralf Haessler, Pieter Haasbroek, Terry Howell, David F Palmer, Thomas Prufer, N.J. Bink, Richard Harvey, Spehro Pefhany, and of course - Ilana Stern

during the ongoing improvement of the ONA.

Yours sincerely

Bernd Kuemmel

6)
Outlook:

I have put other peoples warnings on psychrometers now before the examples, I have also included some NET readings peeking to other sites with information on the subject, BeK.

7)
Signature:

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Disclaimer: They do not necessarily agree with all this.

User Contributions:

1 **mark scollen** Jan 3, 2015 @ 4:04 am

dry air 25C, wet air 17C, need to find relative humidity and dew point, my table only goes to 10C difference.

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Send corrections/additions to the FAQ Maintainer:
Bernd Kuemmel <BEK@mmf.ruc.dk>

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