Lab 4: Atmospheric Humidity Model Answers
Required information is highlighted yellow

As with previous model answers, check your answers by comparing them to these model answers. See that they:

- match calculation processes /methods, and have the same units for measurement /calculation answers
- make conceptual sense and are consistent with model answers for worded answers.
- are consistent with the humidity values for your lab's measurement time as shown by the UNBC Wx Station graph at the end of this answer key.

N.B. For all data collection-based lab assignments, report and use your lab values. Do not alter your values to match model answer key values. Fix errors by using the correct methods but keep your measurements. See your Lab instructor if you can't determine whether your answers are correct before second submission.

1) **Humidity Lab Table 1:** Group #: **XX** ***(your sling instrument #)*** Recorder: **XX** ***(first & last name)***

Date of measurements: **Jan/Feb XX /20XX** ***(your Lab date)*** Partner(s): **XX** ***(list all, first & last names)***

Station pressure (hPa) at the time of measurements (from roof data): **922.2 hPa** ***(get value from instructor if missed)***
Use UNBC Weather Station 10-min average PStn value at your data collection time Unless you are in a pressurized building both the inside and outside air pressure are the same when measured at the same time.

Ambient weather conditions: 100% overcast; just below freezing, no precipitation, little wind ***(report the outside weather conditions during data collection)***

Observations:		**Sling Psychrometer**	**Home-use Hygrometer**	**Assman type Psychrometer**	**Roof Data** (Väisällä probe)
Inside: Location 1 = *classroom 8-129 (Teaching Lab)*					
Location 1	**T (⁰C)**	**21.5 ⁰C**	**20 ⁰C**	**22.4 ⁰C**	**N/A**
time:	**T_w (⁰C)**	**15.0 ⁰C**	**N/A**	**14.8 ⁰C**	**N/A**
13:30	**RH (%)**	**48% (Table interpolation)** * [**50%** -- calculated from ***e*** = **12.7** hPha]	**56 %** **(hygrometer reading)**	**44% (Table interpolation)** * [**45%** -- calculated from ***e*** = **11.8** hPha]	**N/A**
Inside: Location 2 = *Bentley Centre Hallway /*					
Location 2	**T (⁰C)**	**20.0 ⁰C**	**N/A**	**19.8 ⁰C**	**N/A**
time:	**T_w (⁰C)**	**13.0 ⁰C**	**N/A**	**11.8 ⁰C**	**N/A**
13:56	**RH (%)**	**44%** (calculated from ***e*** = **10.3** hPha) (**42%** -- Table interpolation)*	**N/A**	**37%** (calculated from ***e*** = **8.6** hPha) (**37%** - Table interpolation)*	**N/A**
Outside: *Teaching Lab – Teaching & Learning drop-off loop bike sheds*					
Outside	**T (⁰C)**	**-10.5 ⁰C**	**-10 ⁰C**	**-10.8 ⁰C**	**-10.45 ⁰C** (roof 3m temp)
time:	**T_w (⁰C)**	**-11 ⁰C**	**N/A**	**-11.2 ⁰C**	**N/A**
13:42	**RH (%)**	**84% (Table)*** [**84%** -- calculated from ***e*** = **2.3** hPa]	**90 %** **(hygrometer reading)**	**87% (Table interpolation)*** [**87%** -- calculated from ***e*** = **2.3** hPa]	**74.1 %** (roof 3m temp)

* *Using psychrometric tables to determine relative humidity (RH) isn't always possible for some humidity conditions as the psychrometric tables don't always span the wider range of temperatures we can experience. When this occurs, calculate RH instead. Both psychrometric table and calculated values are reported in these model answers to show they are consistent.*

2) Humidity Calculations and sample calculations: For atmospheric pressures use hectopascals (hPa) as the standard unit. Properly report and track units for each example calculation. Note:

- RH must be calculated.
- Interim results must contain sufficient significant digits to not limit future calculations.

a) *Your answers depend on your measured values. Check your answers by confirming your units and methods are correct; your process should be the same as done in the model calculations below.*

See your Lab instructor if you aren't sure that your answers are correct.

	Table 2: Humidity Measure	*INSIDE- classroom (Taylor Sling Psychrometer # 3)*	*OUTSIDE (Taylor Sling Psychrometer # 3)*
	T	21.5 ^{0}C	-10.5 ^{0}C
	T_w	15.0 ^{0}C	-11 ^{0}C
i)	*e*	12.71 hPa (or 1271 Pa)	11.14 hPa (or 1114 Pa)
ii)	*r*	8.69 g kg^{-1}	7.61 g kg^{-1}
iii)	*vpd*	12.79 hPa (or 1279 Pa)	1.56 hPa (or 156 Pa)
iv)	*RH*	49.8%	87.7%
v)	T_d	10.5 °C	8.5°C
vi)	ρ_v	9.34 × 10^{-3} kg m^{-3}	8.50 × 10^{-3} kg m^{-3}

For example /sample calculations: Always identify the values you used in each calculation at the start of your answer. The labels i) to vi) in Table 2 above match the following example calculations.

Note: The notation $e^*_{(Tw)}$ indicates *the saturation vapour pressure (e^*) at the wetbulb temperature (T_w) AND NOT e^* multiplied by T_w .*

The saturation vapour pressure (e^*) is read from the saturation vapour pressure curve (the e vs T* or T_w *graph).*

These sample calculations use the INSIDE *T* and T_w measurements listed in Table 2 above.

i)

$$T = 21.5^0C \qquad T_w = 15.0^0C \qquad \lambda = 66\frac{Pa}{^0C} = 66\frac{Pa}{^0C} \times \frac{1hPa}{100\,Pa} = 0.66\frac{hPa}{^0C}$$

$$e = e^*_{(T_w)} - \lambda\,(T - T_w)$$

$$e = 1700Pa - 0.66\frac{hPa}{^0C}(21.5^0C - 15.0^0C)$$

$$e = 12.71hPa$$

ii)

$$r = \frac{0.622 \times e}{P - e} x1000 \frac{g}{kg} \qquad P = Stn.\,\text{Pr}essure = 922.2\,\text{hPa} \qquad e = 12.71\,hPa$$

$$r = \frac{0.622 \times 12.71\,hPa}{(922.20 - 12.71)hPa} x1000 \frac{g}{kg}$$

$$r = 8.69 \frac{g}{kg}$$

iii)

$$e^*_{(T)} = 25.50\ hPa \qquad e = 12.71\ hPa$$

$$vpd = (e^*_{(T)} - e) = (25.50 - 12.71)hPa = 12.79\,hPa$$

iv)

$$e^*_{(T)} = 25.50\ hPa \qquad e = 12.71\ hPa$$

$$RH = \frac{e}{e^*_{(T)}} x100\% = \frac{12.71\ hPa}{25.50\ hPa} x100\% = 49.8\%$$

iv)

T_d = 10.5 ^{0}C

This is found using the e vs T_d graph and locating e on the hPa side of the of the graph and reading the corresponding dew point temperature (T_d) from the temperature axis. [Understand that the saturation vapour pressure – temperature curve, is also the vapour pressure - dew point curve.]

vi)

$$e = 12.71\ hPa \qquad R_v = 4.62 \frac{hPa\ \ m^3}{kg\ \ K} \qquad T = 21.5^0C$$

$$e = \rho_v R_v T \quad \text{rearrange to:} \quad \rho_v = \frac{e}{R_v T} \qquad Note:\ ^0C + 273.15 = K$$

$$\rho_v = \frac{12.71\ hPa}{(4.62 \frac{hPa\ \ m^3}{kg\ \ K})\ (21.5^0 + 273.15)K} = 9.34 \times 10^{-3}\ \frac{kg}{m^3}$$

b) Identify sources of error (human, method, and instrument) associated with using each of the instruments in this lab. Comment on which instrument you think is most precise, least precise, and why.

Instruments Used:

- Home Hygrometer (a mechanical spring temperature & humidity sensor)
- Sling psychrometer and Assmann psychrometer – both use psychrometery to measure humidity
- [Väisällä Temperature RH probe (don't consider its error as we don't provide it's precision information)]

Home-use (mechanical) hygrometer: because of its design (bi-metallic strip technology) measurements are coarse with between +/-5% up to +/-15% uncertainty. Units of the same type have high variability. The instrument's materials and precision are not indicated on inexpensive models, and can change without notice. It is most likely to have large calibration errors, and is not reliably adjustable. Unfortunately reading errors are often not fixed even after the instruments are re-calibrated. Mechanical hygrometers work best in the 30% to 90% RH range. They are most often used for tracking large humidity changes over long periods of time. Most are used in homes, especially basements to understand if mold growth could be a problem Mechanical hygrometers respond to humidity changes very slowly

- **Human error:**
  - Reading the scale improperly
  - reading before the instrument has adjusted to its surroundings
  - poorly situating the instrument
- **Method errors:**
  - Large calibration errors and considerable hysteresis
  - is not adjustable so readings can't be corrected even if calibrated
  - no dry end calibration
- **Instrument error:**
  - bi-metallic strip technology has a measurement uncertainty between +/-5% up to +/-15% (or more)
  - coarse precision of the instrument scale
  - works best in the 20% to 90% RH range

Both sling and Assmann psychrometers use psychrometry to determine humidity. Psychrometery is the standard method for directly measuring humidity. It is used as the calibration standard for other humidity sensors. Instrument accuracy depends on the quality of the thermometers used, the ability to aspirate the thermometers properly, and ensuring the wet bulb thermometer is moist (or properly frozen if below zero temperatures) while measurements are being made .

Sources of error for the sling psychrometer and the Assman psychrometer readings include *(always rank your error lists from largest to smallest impacts)*:

- **Human errors:**
  - mistakes in reading high precision temperatures scales accurately (Assmann psychrometers most affected)
  - not wetting the wet bulb thermometer properly or accidently wetting both thermometers; not using deionized water or having dirty wet bulb socks (as this alters evaporation rates)
  - leaving insufficient time for the wet bulb temperature to reach an equilibrium value before taking a measurement
  - insufficient ventilation of the wet bulb (Sling psychrometers most affected. This is less of a problem with the Assman psychrometers as its ventilation rate is regulated).
- **Method error:** Few issues (if there are any they are associated with ventilation and wet-bulb wetting; since these can be controlled if the equipment is properly cared for, they are really human errors)
- **Instrument error:** Thermometer quality determines how precisely each thermometer can sense the temperature; this depends on the thermometer bore trueness /quality which makes more accurate readings, and the diameter of the bore with thinner bores being able to measure with greater precision. The greater the thermometer cost, the greater the precision.

Most Precise/Least Precise and Why:
Of our instruments, the most accurate and precise are the Assman type psychrometers; they have:

- the most precise thermometers – they can be read to 0.1 of a degree
- the most accurate thermometers – their thermometers are manufactured with thin, high quality even bores (i.e. they few if any irregularities along the tube lengths)
- the most responsive thermometers – as they have very thin bores

- a regulated ventilation rate for the wet bulb – either motorized or wind-up motor
- thermometers that are shielded from radiation if situated poorly they are less affected

c) Which of the above measures of humidity (e, r, vpd, RH, T_d, ρ_v) are of use in comparing the actual amounts of moisture in the outside and inside air? [HINT: think about which measures of humidity depend only upon the amount of water vapour, and not upon other quantities.]

Only e, r and T_d are useful when comparing the actual moisture content of inside and outside air.

This is because the other measures of humidity (vpd, RH, ρ_v) depend on differences in temperature as well as differences in moisture content. Consequently, it is impossible to separate a variation in humidity caused by temperature from a variation in humidity caused by moisture. *For example, relative humidity indicates how close air is to saturation and is used frequently as it is a comfort index. It can change in response to moisture or air temperature changes. (see Lab 4 slides regarding RH issues)*.

Because e and T_d are directly related to each other through the saturation vapour pressure curve (specifically, the e vs T_d graph), they only depend on the amount of moisture in the air and the atmospheric pressure (i.e. total air pressure). Since air pressure inside and outside is the same (unless you are in a pressurized building), e and T_d are suitable for comparing inside and outside humidity.

[Note: with rising or falling atmospheric pressure (i.e. air pressure changes due to changes in altitude or weather systems), e and T_d *will vary due to changes in pressure. However, when indoor and outdoor humidity measurements are made under the same air pressure, e and* T_d *show moisture content differences.]*

The only humidity measure that depends solely on moisture content is r. Consequently, it is suitable for comparing inside and outside humidities, and moisture content at different altitudes in the atmosphere.

d) Explain any humidity differences between the locations.

Comparing your inside and outside e values will indicate if there are real moisture differences. The key in explaining your answer is to think about moisture sources and sinks in the two different environments.

In these model answers the inside classroom moisture was a bit higher than the outside moisture (even though the outside RH is almost double the inside RH). The capacity of cold air to hold moisture is smaller, consequently the outside RH is higher even though the moisture is less. The actual moisture content (e) inside is greater than that outside because wet shoes, clothes, and perspiring / breathing humans are moisture sources. In some buildings humidifiers can add moisture to inside air to make the RH more comfortable. UNBC doesn't currently use humidifiers. What does your data show?

e) If the heating system indoors jammed, and temperatures rose considerably what would happen to the values of e, RH, T_d, r?

Moisture values that do not depend on temperature will not change. So, e, T_d, and r will not change. Because RH depends on temperature, it will decrease when the temperature goes up.

3. A cool winter Canadian air mass with a temperature of -4°C and a relative humidity of 91% meets a warm air mass sweeping northward from Texas with a temperature of 17 °C and a relative humidity of 28%. In the mixing process will the southern border of the Canadian air gain or lose water vapour content? Calculate and explain.

This question requires you to work out actual moisture content of the two air masses and then compare them. The given RH values cannot be used directly for comparison because the temperatures of the two air masses are not equal. The airmass with the highest actual moisture content will lose moisture when it mixes with the drier airmass.

Determine the moisture content (e) for the Canadian air mass:

T = -4°C

So from figure 4.1: $e^*_{(-4)}$ = 4.40 hPa *and using:*

$$RH = \frac{e}{e^*_{(T)}} \times 100\% \qquad rearrange\ to: e = e^*_{(T)} \times \frac{RH}{100\%}$$

$$e_{Canadian\,air\,mass} = 4.40 hPa\ (0.91) = 4.004\, hPa = 4.00\, hPa$$

Then determine the moisture content for the Texas air mass:

T = 17°C *therefore:*

$e^*_{(17)}$ = 19.50 hPa

$$RH = \frac{e}{e^*_{(T)}} \times 100\% \qquad rearrange\ to: e = e^*_{(T)} \times \frac{RH}{100\%}$$

$$e_{Texas\,air\,mass} = 19.5 hPa\ (0.28) = 5.46 hPa$$

By determining *e* for both air masses we know that the Texan air is actually more humid (i.e. have more moisture content). In mixing with the Texan air mass, the southern border of the Canadian air will become more humid and increase its moisture content.

2025 UNBC Wx Stn GRAPH for our observation days **(Below and next page)**

See the following UNBC Wx Station graph for humidity observations during our labs (each short tick mark = 3 hours).

In 2025 Tue and Wed labs were making observations near sunset, while Thursday labs were making measurement at about midday. Tue and Wed had a mix of sun and cloud with Tue being more overcast than Wed. The Thu lab had the lowest sunshine and very light snow (few flakes). All days had temperatures near zero, with Tue's labs having values just below zero, Wed's labs having values just above zero, and Thu having the most interesting conditions as temperatures were at zero with very light snow making psychrometry challenging as latent heat (phase change energy) could be detected in some thermometer values (Tw values were greater than T values - see your instructor if this impacted your values and this explanation isn't clear). All labs had unfrozen wet bulb thermometers. The pressure was falling throughout this period.

Viewing the humidity plot: Notice how air temperature (**T** - red plotted line) and the relative humidity (**RH** - fluorescent blue line) mirror each other for much of the period; showing how **RH** is dependent on temperature. Where they don't (Wed & Thu night) **RH** is at saturation and the dew point temperature (**Td – dark blue** line) overlaps the air temperature (**T** - red plotted line).

On Thu notice how the air mass moisture change is seen in the graph when all three plots are dropping throughout the day as a drier, colder airmass comes into our area, and the air temperature (**T**) and relative humidity (**RH**) are not mirroring each other.

2025 GRAPH Lab times:

Tues Jan 28 (PM lab), **Wed, Jan 29** (PM lab), **Thu Jan 30** (midday lab)