Air Density and Humidity
Meteorology & Climatology

Environmental Science Degree

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Date Performed:	______________
Partners:	______________
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Abstract

In this lab session the dewpoint temperature (τ), relative humidity (h), and water vapor pressure (e) at the laboratory are measured. Using these data the dry air density at standard conditions of pressure ($p = 1\,\mathrm{atm}$) and temperature ($T = 273.15\,\mathrm{K}$) is computed.

1 Introduction

According to Dalton Law, the air pressure in the lab is the sum of dry air pressure (p_d) plus the **partial pressure of water vapor** (e). Therefore $p = e + p_d$ with $p_d >> e$.
The partial water vapor pressure, also called vapor pressure and vapor tension, and denoted by e has a maximum value that depends on the temperature which is denoted with the uppercase letter, $E = E(T)$.
Relative humidity of an air parcel is defined as $h = 100\frac{e}{E}$, therefore $0 \leq h \leq 100$, and is dependent on the water vapor content of the air (through e) and of temperature (through E).
Dewpoint temperature (τ) of an air parcel is defined as the temperature to which a given air parcel must be cooled *at constant pressure and constant water vapor content* in order for saturation to occur.
In order to measure water vapor contents of the air the device used is a **hygrometer** and among the different types of hygrometer a psychrometer, a sling psychrometer, and a simple chilled mirror dewpoint hygrometer.
The knowledge of e, h, or τ makes possible to assess the mass of water vapor in a sample of air and, combining these results with T and p measurements after some manipulations with the state equation of ideal gases the density of dry air at standard conditions can be obtained.

2 Objectives

The objective of this lab session is to *measure the lab air humidity* using three different types of hygrometers and use these measurements to compute *dry air density at standard conditions*.
As a bonus, a second objective of the lab session is to appropriately identify the *possible sources of errors and your results possible uncertainties*.

3 Theoretical Basis and Lab Procedures

3.1 Mirror dewpoint hygrometer e measurement

The first measurements performed are done with the chilled mirror dewpoint hygrometer (see the schematic view in Fig. 1). A small quantity of *N-pentane* is introduced into the metalic hygrometer cyllinder, such that the tip of the digital thermometer rests very close to the surface of the *N-pentane* or just below it.

IMPORTANT NOTE: **Please, note that N-pentane is a clear colorless liquid with a petroleum-like odor. It is highly flammable and its vapors may cause drowsiness or dizziness. It may be fatal if once swallowed enters airways. Handle with care.**

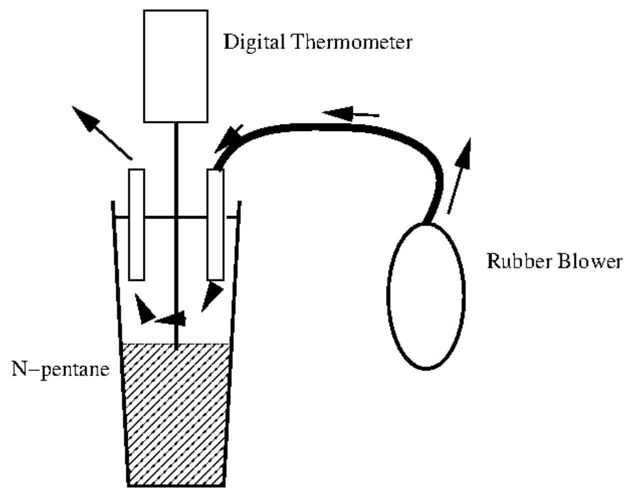

Figure 1: Scheme of the chilled mirror dewpoint hygrometer.

The chilled mirror dewpoint hygrometer makes possible a direct measurement of the dew point temperature. The forced circulation of air over the *N-pentane* surface making use of the rubber blower produces a decrease of temperature due to the evaporation of the highly volatile substance. This lowers the temperature on the metallic tube and once the dewpoint temperature is reached condensation starts and minute water drops can be seen on the metallic surface. Record the dew point temperature τ. This procedure should be repeated four times and *the mean value of the four measured dewpoint temperatures is the air dewpoint temperature and the standard deviation of the values its error*.

IMPORTANT NOTE 2: **You should stop blowing air at the first signals of condensation (can be quite complicated to appreciate), do not wait till water is clearly visible as once reached this point then the temperature is for sure much lower than the actual dew point.**

One of the main objectives of this lab session is that you understand why the saturation vapor tension of a mass of air at the dewpoint temperature is equal to the vapor tension of the air mass

$$e = E(\tau) \; . \tag{1}$$

Thus, you can find the value of the vapor tension for the lab air as $e = E(\tau)$ from the data in Tab. 1 performing a linear interpolation if necessary.
Once e is known, the laboratory air temperature (T_{lab}) can be measured and $E(T_{lab})$ can be obtained from Tab. 1, and the relative humidity of the air can be computed as

$$h = 100\frac{e}{E} = 100\frac{E(\tau)}{E(T_{lab})} \; . \tag{2}$$

3.2 Measuring relative humidity with psychrometers

A dry and wet-bulb pyschrometer is used and the dry bulb temperature and the wet-bulb depression records are used to obtain the air relative humidity h making use of the associated *psychrometric table*. Making use of the $E(T_{lab})$ value from the previous subsection the value of e for the lab air can be obtained from Eq. (2).
The same procedure is performed for the sling psychrometer with its *psychrometric table*.

3.3 Dry air density at standard conditions

Normalized dry air density is characterized by the following parameters

- Vapor tension: $e = 0\,\mathrm{hPa}$.
- Air Temperature: $T_0 = 273.15\,\mathrm{K}$.
- Air pressure: $p_0 = 1013.25\,\mathrm{hPa}$.

The first step consists of measuring the density of the lab air making use of a glass sphere with two valves, a precision balance, and a vacuum pump. The mass of the glass sphere full of air, m_1, is measured. Afterwards, the air is extracted with the pump and the mass of the sphere without air is measured, m_0. The mass of air in the sphere is $m_{air} = m_1 - m_0$.
In order to calculate V_{air}, the volume occupied by the gas, *taking care of not breaking the vacuum into the sphere*, we proceed to fill it with the water provided in a beaker and we measure the water temperature T_w. We measure the weight of the sphere with water inside, m_2, and the mass of water into the sphere is $m_{water} = m_2 - m_0$. From Tab. 2 we can compute the water density at T_w temperature and thus the density of the air is

$$\bar{\rho} = \frac{m_{air}}{V_{air}} = \frac{m_1 - m_0}{m_2 - m_0}\rho_w(T_w) \ . \tag{3}$$

It can be demonstrated that the density of humid air $\bar{\rho}$ can be expressed as a function of dry air density (ρ_d), vapor tension (e) and dry air pressure (p_d) as follows

$$\bar{\rho} = \rho_d \left(1 + \epsilon \frac{e}{p_d}\right) \ , \tag{4}$$

where ϵ is the ration of water and dry air molecular masses: $\epsilon = M_w/M_d = 0.622$.
We continue measuring the laboratory air pressure and temperature, p and T and the dry air density at this conditions, ρ_d is related to the dry air density value at standard conditions rho_0 with the formula

$$\rho_0 = \rho_d \frac{T}{T_0}\frac{p_0}{p_d} \ . \tag{5}$$

Taking Eq. (4) into account we obtain

$$\rho_0 = \bar{\rho}\,\frac{T}{T_0}\,\frac{p_0}{p}\,\left[1 - (1-\epsilon)\frac{e}{p}\right]^{-1} \ . \tag{6}$$

The standard density ρ_0 is then computed making use of the different values of the vapor tension obtained in the first part of the lab session and the results obtained as well as their errors should be discussed.

4 Experimental Data

4.1 Mirror dewpoint hygrometer measurements

τ_1	τ_2	τ_3	τ_4	$\bar{\tau}$	σ_τ

Dewpoint Temperature: $\tau \pm E_\tau =$ ______________________

Air Temperature: $T \pm E_T =$ ______________________

4.2 Wall psychrometer measurements

Dry bulb temperature: $T_{\text{dry}} =$ ________________ Wet bulb temperature: $T_{\text{wet}} =$ ________________

Relative humidity[1]: $h \pm E_h =$________________

4.3 Sling psychrometer measurements

Dry bulb temperature: $T_{\text{dry}} =$ ________________ Wet bulb temperature: $T_{\text{wet}} =$ ________________

Relative humidity[2]: $h \pm E_h =$________________

4.4 Standard air density measurements

m_0	m_1	m_2	T_w

Water density[3]: $\rho_w(T_w) \pm E_{\rho_w} =$ ______________

Atmospheric pressure: $p =$ ______________________

[1]Consider that the wall psychrometer relative humidity values have a 5% relative error.
[2]Consider that the sling psychrometer relative humidity values have a 3% relative error.
[3]You can consider an error equal to half of the interval of density values in the table for the considered temperature.

5 Results and Conclusions

5.1 Mirror dewpoint hygrometer results

Vapor tension: $e = E(\tau) =$ ______________________

Saturation vapor tension $E = E(T) =$ ______________________

Relative Humidity: $h = 100\frac{e}{E} = 100\frac{E(\tau)}{E(T)} =$ ______________________

5.2 Wall psychrometer results

Vapor pressure: $e \pm E_e =$ ______________________

5.3 Sling psychrometer results

Vapor pressure: $e \pm E_e =$ ______________________

5.4 Standard air density measurements

Air density: $\overline{\rho} \pm E_{\bar{\rho}} =$ ______________________

Standard air density (hygrometer): $\rho_0 =$ ______________________

Standard air density (psychrometer): $\rho_0 =$ ______________________

Standard air density (sling psychrometer): $\rho_0 =$ ______________________

A Data Tables

T (°C)	E (mb)	T (°C)	E (mb)
0	6.11	17	19.37
1	6.56	18	20.62
2	7.05	19	21.96
3	7.57	20	23.37
4	8.13	21	24.86
5	8.72	22	26.42
6	9.35	23	28.09
7	10.05	24	29.84
8	10.72	25	31.68
9	11.48	26	33.61
10	12.27	27	35.65
11	13.21	28	37.80
12	14.01	29	40.05
13	14.97	30	42.42
14	15.97	31	44.93
15	17.04	32	47.56
16	18.17	33	50.30

Table 1: Water vapor saturation tension E as a function of temperature.

T (°C)	ρ (g/cm^3)	T (°C)	ρ (g/cm^3)
0	0.999841	16	0.998943
1	0.999900	17	0.998775
2	0.999941	18	0.998596
3	0.999965	19	0.998406
4	0.999973	20	0.998205
5	0.999965	21	0.997994
6	0.999941	22	0.997772
7	0.999902	23	0.997540
8	0.999849	24	0.997299
9	0.999782	25	0.997047
10	0.999701	26	0.996785
11	0.999606	27	0.996515
12	0.999498	28	0.996235
13	0.999377	29	0.995946
14	0.999244	30	0.995649
15	0.999099		

Table 2: Distilled water density as a function of temperature.

References

Ahrens, C. (2006). *Meteorology Today*. International student edition. Cengage Learning.

Stull, R. (2000). *Meteorology for Scientists and Engineers*. Earth Science Series. Brooks/Cole.

Stull, R. (2015). *Practical Meteorology*. UBC.