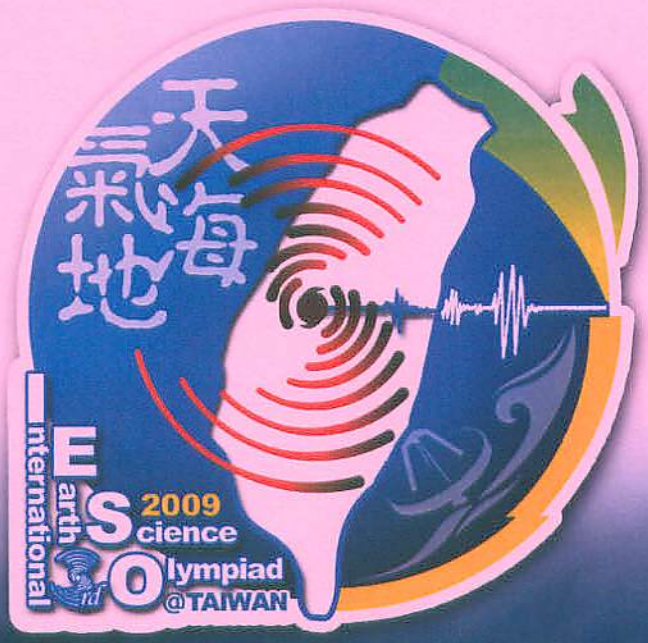
The 3rd International Earth Science Olympiad



Practical Test-Atmosphere

(Part II)

18 September 2009

Taipei, Taiwan

Student Name:	Nationality:

Mentor's Signature:_____

希言自然，故飄風不終朝，驟雨不終日。孰爲此者？天地。

To seldom speak is the essence of nature. Why the winds and storm do not last whole day? Because the earth that manifests the winds and storm is constantly changing.

《老子道德經》第廿三章

Laozi Tao Te Chin 4th Century BC

南方有倚人焉曰黃繚，問天地所以不墜不陷，風雨雷霆之故。惠施不辭而應，不慮而對，遍爲萬物說。

In the south, there was a man of extraordinary views, named Huang Liao, who asked Shi how it was that the sky did not fall nor the earth sink, and what was the cause of wind, rain, and the thunder's roll and crash. Shi made no attempt to evade the questions, and answered him without any exercise of thought, talking about all things.

《莊子雜篇》天下第三十三

Zhuangzi Tian Xia 4th Century BC.

Instructions for the practical test (Part II of Atmosphere):

- **Please write your name and nationality in English on the cover page.**
- **The time allotted for this examination (Part II of Atmosphere) is 40 minutes.**
- **Please write your answers legibly. Illegible answers will be counted as incorrect.**
- **Please keep your answers short and focus on the key points.**
- **Please write your answers only on the white test booklet provided.**
- **You may respond to questions either in English, your native language, or a combination of both.**
- **Read the entire question group carefully before starting to answer. Each question has a point value assigned, for example, (1 pt).**
- **For some questions, you will be asked to provide your answers on the figures. Please do so carefully.**
- **Any inappropriate examination behavior will result in your withdrawal from the IESO.**

2009 IESO Practical Test

(Atmosphere, Part II)

Atmospheric Humidity Measurement and Calculation (50 pts total)

Water vapor (H_2O) in our atmosphere leads to cloud formation and precipitation in the hydrological cycle. It is also an important greenhouse gas. Therefore, the ability to measure the amount of water vapor (i.e., atmospheric humidity) accurately is very important. In this practical test, you will use a "psychrometer" to measure the humidity and answer a total of 6 related questions.

You will need to complete the following tasks: [**Task A**] measure "dry-bulb" and "wet-bulb" temperatures and calculate the "wet-bulb depression", [**Task B**] calculate the actual vapor pressure from your data, and [**Task C**] express your result as different humidity variables. All of the methods and variables involved will be explained as you follow the procedure described below.

[Task A] Measure "dry-bulb" and "wet-bulb" temperatures (T and T_w) and calculate the "wet-bulb depression" (D, and $D = T - T_w$) using a psychrometer.

A psychrometer (shown in Fig. 1) is a common instrument used to measure humidity. It consists of two identical thermometers, one measures the "dry-bulb" (actual) temperature (T) and the second is wrapped in a porous "wick" (i.e. threads of cloth). When in use, the wick of this second thermometer is moistened and exposed in air stream, and its reading is called the "wet-bulb" temperature (T_w). Please follow the steps below to measure T and T_w (see Fig. 2): During this process, great care should be taken to avoid any influence on the readings by your presence. Also, be careful that the dry-bulb thermometer must remain dry.

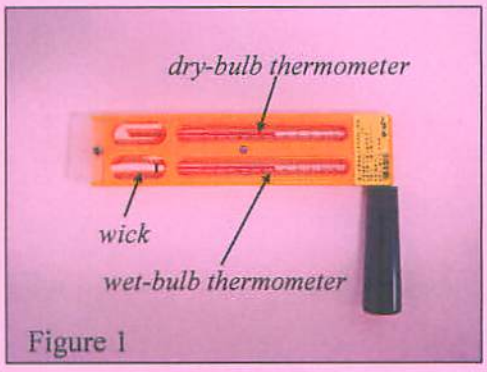


Figure 1


Figure 2a


Figure 2b


Figure 2c

Step 1: Open the small container at the bottom, and drip (add) water with the pipette to fully

moisten the wick inside (Fig. 2a). Then close the cap.

Step 2: Pull and rotate the handle outward to 90 degrees. Swing the psychrometer gently (for about 10 rounds) to increase airflow (Fig. 2b). Now the web-bulb temperature (T_w) should drop gradually.

Step 3: When the wet-bulb reading becomes steady, read both the dry-bulb and wet-bulb temperatures (T and T_w, both in °C, Fig. 2c).

Question 1 (exercise): (20 pts)

Please repeat steps 1 to 3 three times and complete the table below (Table 1). Then, calculate the mean values of T and T_w, and use them to determine the web-bulb depression D (where $D = T - T_w$). Please use °C for all units, and take the readings to one decimal place. (2 pts each reading of T and T_w, 4 pts for D)

Answer: Table 1: Result of psychrometer measurements (all in °C).

	First reading	Second reading	Third reading	Mean
T	23.5	23.5	23.5	23.5
T_w	18.4	18.5	18.6	18.5
D				5.0

P.S.: The answers here are only an example. Each student may have different readings, which are used to obtain the correct answers for Questions 3 through 6.

Question 2: (6 pts)

From your measurements, it should be clear that $T_w < T$ (i.e., $D > 0$). Which of the following processes do you think is responsible for this result?

(A) Freezing (B) Condensation (C) Deposition

(D) Melting (E) Evaporation (F) Sublimation

Answer: E

[Task B] Find the saturation vapor pressure (e_s) at T_w and calculate the actual vapor pressure (e).

Humidity is measured by the vapor pressure (e) which is the partial pressure of water vapor in the air. The value of e (in hPa, where 1 hPa = 100 Pa) can be determined from the following equation:

$$e = e_{sw} - \gamma D, \qquad \text{Equation (1)}$$

where e_{sw} is the saturation vapor pressure (in hPa) at web-bulb temperature T_w, D is the wet-bulb depression (in °C), and γ is a constant at 0.66 hPa K^{-1} at sea level.

Question 3: (6 pts)

Please find e_{sw} from Table 2, and calculate the actual vapor pressure (e) using Equation (1). Note that the saturation vapor pressure (e_s) is only a function of temperature, as shown in Table 2. Show your method and calculations clearly. Please include units in your calculation, and give your answer to one digit below the decimal (1 decimal place).

Answer:

$T_w = 18.5°C$, from Table 2, $e_{sw} = e_s(18.5°C) = 21.29$ hPa and $D = 5.0°C = 5.0$ K.
Substitution these values into Eq. (1) yields:
$e = 21.29 \text{ hPa} - 0.66 \text{ hPa K}^{-1} \times 5.0 \text{ K} = 17.99 \text{ hPa} \approx 18.0 \text{ hPa}$.

Table 2: Saturation vapor pressure over water (from Smithsonian Meteorological Tables)

* Example of how to read Table 2: For instance, to find out the saturation vapor pressure at 17.3°C, go to the row labeled "17" and the column labeled ".3", so e_s = 19.74 hPa.

Tempe-rature °C	Metric units .0 hPa	.1 hPa	.2 hPa	.3 hPa	.4 hPa	.5 hPa	.6 hPa	.7 hPa	.8 hPa	.9 hPa
10	12.27	12.36	12.44	12.52	12.61	12.69	12.78	12.86	12.95	13.03
11	13.12	13.21	13.30	13.38	13.47	13.56	13.65	13.74	13.83	13.93
12	14.02	14.11	14.20	14.30	14.39	14.49	14.58	14.68	14.77	14.87
13	14.97	15.07	15.17	15.27	15.37	15.47	15.57	15.67	15.77	15.87
14	15.98	16.08	16.19	16.29	16.40	16.50	16.61	16.72	16.83	16.94
15	17.04	17.15	17.26	17.38	17.49	17.60	17.71	17.83	17.94	18.06
16	18.17	18.29	18.41	18.52	18.64	18.76	18.88	19.00	19.12	19.25
17	19.37	19.49	19.61	19.74	19.86	19.99	20.12	20.24	20.37	20.50
18	20.63	20.76	20.89	21.02	21.16	21.29	21.42	21.56	21.69	21.83
19	21.96	22.10	22.24	22.38	22.52	22.66	22.80	22.94	23.09	23.23
20	23.37	23.52	23.66	23.81	23.96	24.11	24.26	24.41	24.56	24.71
21	24.86	25.01	25.17	25.32	25.48	25.64	25.79	25.95	26.11	26.27
22	26.43	26.59	26.75	26.92	27.08	27.25	27.41	27.58	27.75	27.92
23	28.09	28.26	28.43	28.60	28.77	28.95	29.12	29.30	29.48	29.65
24	29.83	30.01	30.19	30.37	30.56	30.74	30.92	31.11	31.30	31.48
25	31.67	31.86	32.05	32.24	32.43	32.63	32.82	33.02	33.21	33.41
26	33.61	33.81	34.01	34.21	34.41	34.62	34.82	35.03	35.23	35.44
27	35.65	35.86	36.07	36.28	36.50	36.71	36.92	37.14	37.36	37.58
28	37.80	38.02	38.24	38.46	38.69	38.91	39.14	39.37	39.59	39.82
29	40.06	40.29	40.52	40.76	40.99	41.23	41.47	41.71	41.95	42.19
30	42.43	42.67	42.92	43.17	43.41	43.66	43.91	44.17	44.42	44.67
31	44.93	45.18	45.44	45.70	45.96	46.22	46.49	46.75	47.02	47.28
32	47.55	47.82	48.09	48.36	48.64	48.91	49.19	49.47	49.75	50.03
33	50.31	50.59	50.87	51.16	51.45	51.74	52.03	52.32	52.61	52.90
34	53.20	53.50	53.80	54.10	54.40	54.70	55.00	55.31	55.62	55.93
35	56.24	56.55	56.86	57.18	57.49	57.81	58.13	58.45	58.77	59.10
36	59.42	59.75	60.08	60.41	60.74	61.07	61.41	61.74	62.08	62.42
37	62.76	63.11	63.45	63.80	64.14	64.49	64.84	65.20	65.55	65.91
38	66.26	66.62	66.99	67.35	67.71	68.08	68.45	68.82	69.19	69.56
39	69.93	70.31	70.69	71.07	71.45	71.83	72.22	72.61	72.99	73.39
40	73.78	74.17	74.57	74.97	75.37	75.77	76.17	76.58	76.98	77.39

Question 4: (6 pts)

Assume that point A represents the initial state and point B represents the final state of the cooling process of the air measured by the wet-bulb thermometer. In Fig. 3 below, please plot the locations of points A and B with crosses (x). Then, draw an arrow connecting them to indicate the cooling process. Please label both points and the direction of the arrow clearly.

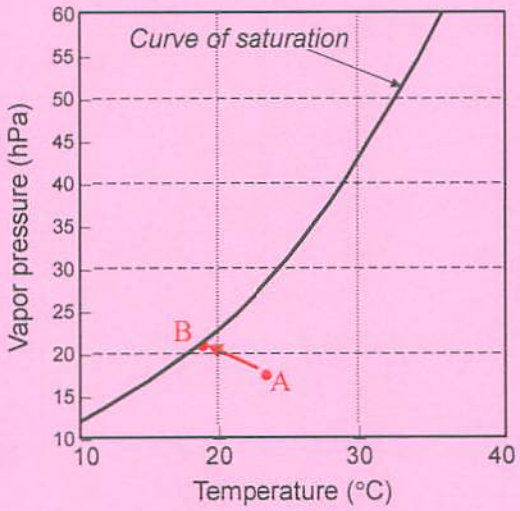


Figure 3: The cooling process of air measured by the wet-bulb thermometer.

[Task C] Convert the humidity into mixing ratio (r) and relative humidity (RH).

Several other variables can also indicate atmospheric humidity, such as mixing ratio (r) and relative humidity (RH). You will need to use the information provided below to calculate r and RH. Show your method and calculations as clearly as possible. Include all appropriate units.

Question 5: (6 pts)

The mixing ratio (r) is the ratio of the mass of water vapor to that of dry air. It is therefore dimensionless. The relationship between r and vapor pressure (e) is:

$$r = \frac{\varepsilon e}{p - e} \qquad \text{Equation (2)}$$

where p is 1013.25 hPa, and ε is the ratio of the molecular weight of water vapor to that of dry air ($\varepsilon = 0.622$). In the space below, please calculate r and express it in units of g kg^{-1} (grams per kilogram). Give your answer to one digit below decimal (1 decimal place).

Answer:

From $e = 17.99$ hPa, $r = \dfrac{0.622 \times 17.99\ hPa}{1013.25\ hPa - 17.99\ hPa} = 0.01124 \approx 11.2\ \text{g kg}^{-1}$.

Question 6: (6 pts)

The relative humidity (RH) is the ratio of actual vapor pressure (e) to the saturation vapor pressure at the actual temperature (e_s). It is expressed as a percentage (%) and

$$RH = \frac{e}{e_s(T)} \times 100\%. \qquad \text{Equation (3)}$$

In the space below, please use Equation (3) to calculate RH (in %), and give your answer to one digit below decimal (1 decimal place).

Answer:

From the measurement, $T = 23.5$°C, so from Table 2, $e_s(23.5\text{°C}) = 28.95$ hPa. Also, $e = 17.99$ hPa. Substitute these values into Eq. (3) to yield:

$$RH = \frac{17.99\ \cancel{hPa}}{28.95\ \cancel{hPa}} \times 100\% = 62.14\ \% \approx 62.1\ \%.$$