RELATIVE HUMIDITY

OBJECT: To determine the relative humidity of the atmosphere.

METHOD:

Part I: Air is bubbled through a volatile liquid contained in a polished metal cup so that the evaporation of the liquid lowers the temperature of the cup. The temperature at which moisture begins to collect on the cup (the dew point) is observed. The pressures of saturated vapor at the dew point and at the temperature of the atmosphere are obtained from tables. The ratio of these pressures is the relative humidity.

Part II: The bulb of one of a pair of thermometers is covered with a wick saturated with water. These thermometers are whirled in air and their temperatures observed. These temperatures are used to compute the pressure of the water vapor in the atmosphere. This pressure and the pressure of water vapor required to saturate the atmosphere are used, as before, to determine the relative humidity.

THEORY: The molecules of a liquid are held together by attractive forces. However, since the molecules are in motion, due to thermal agitation, some of them will have sufficient velocity to escape from the surface against these attractive forces. This is called evaporation. Since the more energetic molecules are the ones that escape, it is clear that a liquid is cooled by the process of evaporation. Assume that the cylinder, Fig. 1, contains only water and its vapor. When equilibrium is established; the rate at which molecules escape from the surface is equal to the rate at which
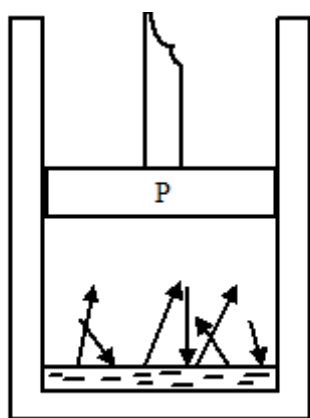

Fig. 1. The cylinder contains water and its vapor.

molecules return from the vapor to the liquid, and the region above the liquid is said to be saturated with water vapor. If

the average kinetic energy of the molecules is increased (by raising the temperature), a larger fraction of the molecules have sufficient energy to escape from the surface and the rate of evaporation is increased. This increased evaporation raises the density of the vapor (and hence the rate at which the molecules return to the liquid) until equilibrium is again established. From this it follows that the density of saturated water vapor and, therefore, the pressure of saturated vapor increases as the temperature rises.

If the volume occupied by the vapor is decreased by pushing down the piston P, while the temperature remains constant, water is changed from the vapor phase to the liquid phase but the density and pressure of the vapor are unchanged. As the piston is withdrawn, liquid is changed into vapor, but until the liquid has all disappeared there is no change in the pressure or the density of the vapor. It is obvious, therefore, that the values of the density and pressure of saturated water vapor depend *only* on the temperature. These values for certain temperatures are listed in Table I.

In the discussion above it was assumed that the region considered contained only water and its vapor. The conclusions are equally valid, however, if the region contains air or any other gas with which the water does not react chemically. The only effect of the air is to increase greatly the length of time required for equilibrium to become established; that is, for the region to become saturated. If open vessels of water are placed in a tightly closed room, the air eventually becomes saturated. Experience indicates, however, that the time required to produce saturation is extremely long.

The absolute humidity of the atmosphere is defined as the density D_A of water vapor actually in the air, usually measured in grams per cubic meter. The relative humidity R is the ratio of D_A to the density D_s of *saturated* water vapor at the temperature of the atmosphere. Since, if the temperature remains constant, the pressure of a gas or vapor is proportional to its density, relative humidity may be (and usually is) expressed as the ratio of pressure p_A of the water vapor in the atmosphere to the pressure p_s of saturated water vapor at the existing temperature, or, stated algebraically

$$R = p_A / p_s \qquad (1)$$

The hygrometric state of the air depends upon the relative humidity rather than upon the absolute humidity. If the relative humidity is, for example, 20 percent, the atmosphere contains only 20 percent of the moisture it is capable of holding at the existing temperature and the air is dry. The same amount of moisture, however, would saturate the air at a temperature sufficiently low.

Suppose the temperature of a polished metal cup is lowered to the point (called the dew point) at which dew begins to form on the surface of the cup. Obviously the moisture in the atmosphere is sufficient to produce saturation at the dew point. The dew-point method of measuring humidity is illustrated by the following example. Assume that the room temperature is 20°C and the dew point is 5°C. Since the moisture in the air is sufficient to produce saturation at 5°C, the pressure p_A is 6.54mm of mercury (Table I). If the air were saturated at 20°C, the *pressure p_s* would be 17.55mm of mercury. The relative humidity is, therefore, 6.54mm ÷ 17.55mm or 37.3 percent. It is assumed above that the pressure exerted by the vapor is not changed by lowering its temperature to the dew point. This is a justifiable assumption but the reasons for it should be understood. Since the room is not tightly sealed, cooling the cup does not change the pressure in the room nor does it change the fraction of the pressure due to the vapor. It should be obvious, however, that due to the decrease in volume, the *density* of the water vapor at the dew point is greater than the density of this vapor at room temperature.

It is assumed that, as ordinarily used, a thermometer reads the temperature t_R of the atmosphere. If, however, the bulb of the thermometer is covered with a wick wet with water, the thermometer reading t_w (called the wet-bulb temperature) is less than t_R. Since the temperature depression ($t_R - t_W$) is due to evaporation and since the rate of evaporation depends upon the relative humidity, the temperature depression is a measure of the hygrometric state of the atmosphere. It is found that if the velocity of the wind at the wet bulb exceeds 3 meters per second, the vapor pressure p_A is given by the equation

$$p_A = p_W - 0.00066B(t_R - t_W) \qquad (2)$$

where p_w is the pressure of saturated water vapor at temperature t_w and B is the barometric pressure. The pressures p_A, p_W, and B must all be measured in the same units, usually in millimeters of mercury, and the temperatures are in degrees centigrade. The form of this equation follows from a theoretical investigation by Maxwell. The constant 0.00066 has been determined by careful experimental work.

APPARATUS: A dew-point hygrometer, two thermometers, aspirator bulb, methylene chloride or some other volatile liquid, a sling psychrometer, either a glass shield or a telescope, and access to a barometer are required.

A dew-point hygrometer, Alluard's form, is shown in Fig. 2. A polished metal container for the volatile liquid is mounted on a heat insulating support. By means of two short horizontal tubes on the cover of the container, air may be forced through the apparatus. The tube shown connected to the
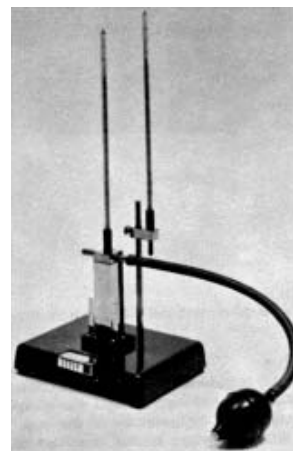

Fig. 2. Dew-point Hygrometer

aspirator bulb terminates in a fine vertical tube extending almost to the bottom of the cup. The other tube extends through the cover only. It can be seen, therefore, that by operating the bulb a stream of air is bubbled through the liquid. This produces rapid evaporation and the cup is cooled. The temperature is lowered to the point at which dew collects on the surface of the cup. It is sometimes difficult to determine exactly when condensation begins. If the observer compares the appearance of the cup with that of the U-shaped polished metal plate, thermally insulated from the cold cup, it is easier to judge when this point has been reached. If the left-hand tube is connected to a filter pump or some other suction device, the aspirator bulb may be dispensed with. In this case the airflow may be controlled by means of a pinchcock on the connecting rubber tube.

A wet- and dry-bulb hygrometer is called a psychrometer. If the ventilation of the psychrometer is produced by whirling, the instrument is called a sling psychrometer. A sling psychrometer is shown in Fig. 3.

PROCEDURE:
Part I: Starting with the dew-point cup about two thirds full of methylene chloride (or some other volatile liquid), reduce the temperature of the liquid, by passing a stream of air through it, until moisture begins to collect on the cup. After making a few practice runs take five readings of the temperature at which the moisture appears and five readings at which the moisture disappears. The average of these readings is the dew point t_D.

In taking the temperature at which the dew appears, the temperature should fall slowly as the dew point is approached. To judge accurately when the first trace of moisture appears, the apparatus must be placed in a

Fig. 3. Sling Psychrometer

favorable light and the appearance of the cup and the polished metal plate beside it compared. To keep the liquid stirred while the temperature is rising, it is advisable not to stop the flow of air entirely but to reduce the rate of flow so that only an occasional bubble passes through the liquid. A careful experimenter will find that the temperature at which the dew appears differs from the temperature at which the dew disappears by only a few tenths of a degree. Note the temperature of the atmosphere at the beginning of the experiment and again at the end. The average of these thermometer readings is t_R.

Care must be taken that evaporation from the body and the moisture in the breath does not affect the results. The moisture added to the atmosphere in one minute by an average person in repose is sufficient to saturate approximately 60 liters of air at 20°C. To circumvent this source of error the observer should take the observations either through a glass shield or through a telescope placed at a considerable distance from the hygrometer. Care also should be taken to protect the hygrometer from drafts.

Having determined the dew point, use Eq. (1) and Table I to compute the value of the relative humidity. From the relative humidity and the density of saturated vapor at the existing temperature determine the absolute humidity. Compare the absolute humidity thus determined with the density of saturated vapor at the dew point.

Part II: Saturate the wick on the wet-bulb thermometer by dipping it into pure water. Whirl the psychrometer rapidly for fifteen or twenty seconds. Stop and read the thermometers quickly, the wet bulb first. Keep the readings in mind and repeat. Continue this procedure until it is quite evident that the wet-bulb reading is a minimum. Record the wet-bulb reading t_w and the dry-bulb reading t_R. If Fahrenheit

thermometers are used, convert the readings to degrees centigrade. To prevent breakage, keep well away from furniture and other obstructions while whirling the psychrometer. Read the barometer.

Use Eq. (2) to compute the vapor pressure in the atmosphere. Determine the relative humidity, the absolute humidity, and the dew point. Compare these results with those obtained in Part I.

Repeat this part of the experiment at other places designated by the instructor.

QUESTIONS: 1. What effect does whirling have on the temperature of the wet bulb? Explain.

2. Compare the absolute humidity and relative humidity of outdoor air and air in heated rooms in winter. Give reasons for the answers.

3. The outside of a glass bottle is silvered. Would this make a satisfactory dew-point cup? Explain.

4. It is assumed in this experiment that the dry-bulb thermometer gives atmospheric temperature. This is not true in bright sunlight. Explain.

5. Make a rough estimate of the mass of water vapor in the room in which the experiment was performed.

6. Explain how a chemical drying agent might be used to measure absolute humidity.

7. Show that the density of saturated vapor at the dew point is $D_A(t_R + 273)/(t_D + 273)$.

TABLE I

Showing pressure in p_s (in millimeters of mercury) and density D_s (in grams per cubic meter) of vapor saturated at temperature t (in degrees centigrade).

t	p_s	D_s	t	p_s	D_s	t	p_s	D_s
-14	1.37	1.53	1	4.92	5.19	16	13.64	13.63
-13	1.50	1.67	2	5.29	5.56	17	14.54	14.48
-12	1.64	1.82	3	5.68	5.95	18	15.49	15.37
-11	1.80	1.98	4	6.10	6.36	19	16.49	16.31
-10	1.96	2.16	5	6.54	6.80	20	17.55	17.30
-9	2.14	2.35	6	7.01	7.26	21	18.66	18.34
-8	2.34	2.55	7	7.51	7.75	22	19.84	19.43
-7	2.55	2.77	8	8.04	8.27	23	21.09	20.58
-6	2.78	3.01	9	8.61	8.82	24	22.40	21.78
-5	3.02	3.26	10	9.21	9.40	25	23.78	23.05
-4	3.29	3.53	11	9.85	10.01	26	25.24	24.38
-3	3.58	3.83	12	10.52	10.66	27	26.77	25.77
-2	3.89	4.14	13	11.24	11.35	28	28.38	27.23
-1	4.22	4.48	14	11.99	12.07	29	30.08	28.76
0	4.58	4.85	15	12.79	12.83	30	31.86	30.37