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## Standard Test Method of Measuring Humidity with Cooled-Surface Condensation (Dew-Point) Hygrometer<sup>1</sup>

This standard is issued under the fixed designation D 4230; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon ( $\epsilon$ ) indicates an editorial change since the last revision or reapproval.

<sup>ε1</sup> NOTE—Section 14 was added editorially in April 1996.

### 1. Scope

1.1 This test method covers the determination of the thermodynamic dew- or frost-point temperature of ambient air by the condensation of water vapor on a cooled surface. For brevity this is referred to in this method as the condensation temperature.

1.2 This test method is applicable for the range of condensation temperatures from 60°C to – 70°C.

1.3 This test method includes a general description of the instrumentation and operational procedures, including site selection, to be used for obtaining the measurements and a description of the procedures to be used for calculating the results.

1.4 This test method is applicable for the continuous measurement of ambient humidity in the natural atmosphere on a stationary platform.

1.5 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.* For specific precautionary statements, see Section 8.

### 2. Referenced Documents

#### 2.1 ASTM Standards:

D 1356 Terminology Relating to Sampling and Analysis of Atmospheres<sup>2</sup>

D 3631 Test Methods for Measuring Surface Atmospheric Pressure<sup>2</sup>

D 4023 Terminology Relating to Humidity Measurements<sup>2</sup>

### 3. Terminology

#### 3.1 Definitions:

3.1.1 For definitions of terms used in this test method, refer to Terminology D 4023.

3.1.2 For definitions of other terms in this method, refer to Terminology D 1356.

#### 3.2 Definitions of Terms Specific to This Standard:

3.2.1 *nonhygroscopic material*—material that neither absorbs nor retains water vapor.

3.2.2 *mirror (front surface)*—a polished surface, usually a metallic surface, on which condensates are deposited.

#### 3.3 Symbols:

$e$  = vapor pressure of water vapor in moist air.  
 $e_i$  = saturation pressure of water vapor in equilibrium with the plane surface of ice.

$e_w$  = saturation pressure of water vapor in equilibrium with the plane surface of water.

$f$  = enhancement factor.

$p_a$  = ambient pressure.

$p_c$  = mirror chamber pressure.

$r$  = mixing ratio.

$t$  = ambient air temperature.

$T_d$  = thermodynamic dew- or frost-point temperature.

$U_i$  = relative humidity with respect to ice.

$U_w$  = relative humidity with respect to water.

$x_v$  = mole fraction of water vapor.

$x_{vi}$  = saturation mole fraction of water vapor with respect to ice.

$x_{vw}$  = saturation mole fraction of water vapor with respect to water.

### 4. Summary of Test Method

4.1 The ambient humidity is measured with a dew- and frost-point hygrometer.

4.2 The mirror or some other surface on which the condensate is deposited is provided with the means for cooling and heating, detection of condensate, and the measurement of the temperature of the mirror surface.

### 5. Significance and Use

5.1 Humidity data is important for the understanding and interpretation of a number of phenomena. Atmospheric water vapor affects precipitation; the formation of dew and fog; the prediction of frosts damaging to agriculture; the potential

<sup>1</sup> This test method is under the jurisdiction of ASTM Committee D-22 on Sampling and Analysis of Atmospheres and is the direct responsibility of Subcommittee D22.11 on Meteorology.

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<sup>2</sup> *Annual Book of ASTM Standards*, Vol 11.03.

danger of forest fires; and the propagation of electromagnetic energy. It affects evaporation from rivers, lakes, reservoirs, oceans, and snow and ice surfaces. It affects the transpiration of moisture from soils, growing crops, and forest.

## 6. Interferences

6.1 This method is not applicable if other constituents in the atmosphere condense before water vapor.

## 7. Apparatus

7.1 *Dew-point hygrometers*, specifically designed for meteorological observations are available commercially. A schematic arrangement of a typical optical dew-point hygrometer is shown in Fig. 1.

7.1.1 The sample air flows through a small chamber.

7.1.2 Within the chamber is a mirror or surface on which the condensate can be deposited.

7.1.3 A beam of light from an incandescent lamp, light emitting diode or other suitable light source shines on the mirror.

7.1.4 Dew or frost is detected with an electro-optic device.

7.1.5 The mirror is cooled by a Peltier thermoelectric element. Peltier cooling is a convenient method for unattended and automatic instruments.

7.1.6 Preferred methods of sensing mirror temperature are resistance thermometers, thermistors, and thermocouples.

7.1.6.1 The temperature sensors shall be attached to or embedded in the mirror to measure the temperature of the surface of the mirror.

7.1.7 Suitable control circuitry shall be provided to maintain a constant quantity of condensate on the mirror.

7.1.8 Suitable provisions shall be provided to compensate for the contamination of the surface of the mirror.

### 7.2 Auxiliary Equipment:

7.2.1 Provision shall be provided for assuring air flow past the dew-point mirror.

7.2.2 Readout instrumentation is available with the dew-point hygrometer.

## 8. Precautions

### 8.1 Safety Precautions:

8.1.1 The hygrometer shall be packaged in a suitable enclosure for application in industrial or outdoor environment.

8.1.2 Electrical connectors and cables shall be suitable for the outdoor environment.

8.1.3 Appropriate voltage surge protection circuitry must be incorporated.

### 8.2 Technical Precautions:

8.2.1 The accuracy of a cooled-surface condensation hygrometer is degraded by the presence of water-soluble materials. A mirror-cleaning schedule, consistent with the contamination rate, is necessary to maintain the initial calibration accuracy. The user must determine the required maintenance schedule for the specific site, by comparison of calibrations made before and after cleaning.

8.2.2 Caution in performing this method should be taken if the indicated mirror temperature is between 0°C and -30°C. Below freezing, the initial formation of the condensate on the surface of a mirror may be either dew or frost. In the case of nonfiltered atmospheric air, the supercooled water usually does not persist long on a mirror surface and quickly changes to frost. The only positive method for determining the state of the condensate is by visual observation of the mirror surface.

8.2.2.1 The following illustrates the magnitude of the error involved when dew or frost is not differentiated: The saturation vapor pressure of supercooled water at -30°C corresponds to saturation vapor pressure of ice at -27.2°C; dew point of -20°C corresponds to frost point of -18.0°C; -10°C dew point corresponds to frost point of -8.9°C. (The frost point temperature is approximately 90 % of the dew-point temperature in degrees Celsius.)

8.2.3 A positive method for identifying the state of the condensate is to visually observe the condensate on the mirror with the aid of a microscope or other optical magnifier.

8.2.4 A finite length of time is required for the condensate to deposit on the mirror and for the hygrometer to reach equilibrium with the ambient humidity. The response of the hygrometer depends on the humidity of the ambient air, and on such factors as the ventilation rate of the ambient air past the mirror, the sensitivity of the condensate detector, and the maximum cooling rate of the hygrometer. The worst case occurs during the initial dew-point reading after clearing the mirror of all condensates. The time it takes the hygrometer to reach equilibrium after clearing the mirror will vary from instrument to instrument. As an illustration of the magnitude of this time, the following are approximate times required by a hygrometer to reach equilibrium after clearing the mirror.

8.2.4.1 For dew points warmer than 0°C: 5 min after clear.

8.2.4.2 For dew points 0°C to -20°C: 5 to 20 min after clear.

8.2.4.3 For dew points -20°C to -40°C: 20 min to 1 h after clear.

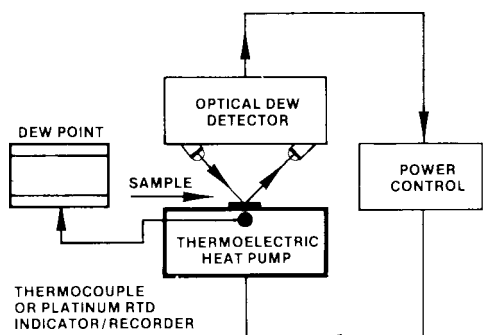
8.2.4.4 For dew points -40°C to -60°C: 1 h to 2 h after clear.

8.2.4.5 For dew points -60°C to -70°C: 2 h to 6 h after clear.

8.2.5 The pressure differential between the mirror chamber and the ambient shall not be greater than 0.5 % that is, not more than 500 Pa.

8.2.6 The thermometer must measure the temperature of the mirror surface and not be influenced by the ambient air temperature.

8.2.7 All materials, which come into contact with the



**FIG. 1 Schematic of a Thermolectric Cooled Condensation Hygrometer**

sample air before it reaches the dew-point mirror, shall be nonhygroscopic. Metal, glass, polytetrafluoroethylene, or stabilized polypropylene are examples of suitable materials. Polyvinyl chloride tubing must be avoided.

## 9. Sampling

9.1 Automatic dew-point hygrometers provide an output which may be recorded continuously. Modern data loggers sample temperature-sensor output periodically, convert the analog sensor signal to a digital form, and store the data. The proper sampling interval depends on the data application (see 13.2).

9.2 Locate a blower or pump, which can be used to move the air sample through the mirror chamber, downstream of the dew-point mirror.

9.3 Select the site or location so that the measurement data represents the water vapor content of the ambient atmosphere.

9.3.1 Select the location so that it is normally not influenced by a local water vapor source. (Of course, if the purpose is to measure the effects of a local source that is, water cooling ponds, etc., then it is necessary to locate the site downwind from the source.)

9.3.2 Place the automatic dew-point hygrometer away from any paved surfaces that may be wet, the immediate influence of trees and buildings, and as far as practicable, not too close to steep slopes, ridges, cliffs, or hollows. Avoid dusty areas.

9.3.3 Mount the instrument over a surface which is representative of the area.

9.4 The successful application of this method requires that all the materials which come in contact with the sample air upstream of the dew-point mirror be nonhygroscopic.

9.5 The materials which come in contact with the sample air upstream of the dew-point mirror might be wetted by rain, dew, or frost; for example, dew forming on a surface in the early morning. Design the sampling system to minimize these deleterious effects.

## 10. Calibration

10.1 Provide the calibration data for the thermometer, used for measuring the condensation temperature with the hygrometer. Consult the manufacturer's operating manual for calibrating the thermometer readout instrumentation.

10.2 The cooled-surface condensation (dew-point) method is considered to be an absolute or fundamental method for measuring humidity. This method requires an accurate measurement of the temperature of the surface of the dew-point mirror. It is not uncommon for the dew-point temperature to be more than 35 K colder than the ambient air temperature. To measure this temperature accurately, without being influenced by the warmer ambient and the colder heat-sink temperature, requires careful placement of the dew-point thermometer.

10.3 Therefore, in addition to the temperature calibration of the thermometer, (see 10.1), a humidity calibration must also be performed to verify the proper operation of the hygrometer (see Annex A1). The following are additional examples of factors that can affect the accuracy of the measurement: extraneous thermal emfs, heat leakage through the thermometer leads, self-heating of the thermometer, poor thermal contact, temperature gradient across the mirror, etc.

## 11. Procedure

11.1 *Selection of Sampling Site*—Select sampling site as indicated in 3.3 and also in 1.3.2 of the World Meteorological Organization, *Guide to Meteorological Instrument and Observing Practices (1)*.<sup>3</sup>

11.2 Consult the manufacturer's operating manual for start-up procedures.

11.3 Perform necessary calibration as indicated in Section 10. The dew-point thermometer will not undergo large shifts (.05°C) in calibration unless it is subjected to physical shock. If the thermometer read-out instrumentation is subjected to varying ambient temperatures, the read-out instrumentation checks must be over the expected range of ambient temperatures. The frequency with which these checks are required will be determined by the stability of the readout instrumentation.

11.4 Check and verify that all necessary variables are measured and recorded to compute the humidity in the desired unit(s) see also 8.2.1.

NOTE 1—In general, it is recommended that ambient temperature and pressure (the pressure in the mirror chamber should not differ from the ambient pressure by more than 0.5 %) and the dew-point temperature be measured and recorded. The ambient pressure is to be measured according to Test Methods D 3631. This will enable other users of the data to calculate in the different units of humidity.

## 12. Calculations

12.1 In the meteorological range of pressure and temperature, the saturation vapor pressure of the pure water phase and of the moist air will be assumed to be equal. This assumption will introduce an error of approximately 0.5 % of reading or less. See Appendix X1.

12.2 Calculate the ambient relative humidity with respect to water as follows.

$$(U_w)_{t,p_a} = \frac{P_a e(t_d)}{P_c e_w(t)} 100 \% \quad (1)$$

where:

$(U_w)_{t,p_a}$	= relative humidity with respect to water, %, at temperature $t$ and pressure $p_a$ ,
$P_a$	= average barometric pressure, Pascal (Pa) during the sampling period,
$P_c$	= average absolute pressure, Pa, in the dew-point mirror chamber during the sampling period,
$e(t_d)$	= saturation vapor pressure, Pa, at condensation temperature $t_d$ , °C, where $t_d$ is the average value during the sampling period, see Note 2, and
$e_w(t)$	= saturation vapor pressure, Pa, over water at ambient temperature $t$ , °C, where $t$ is the average value during the sampling period. See Appendix X3.

NOTE 2—If the condensate on the mirror is water (dew), use the saturation vapor pressure over water, Appendix X3, corresponding to the

<sup>3</sup> The boldface numbers in parentheses refer to the references at the end of this method.

condensation temperature  $t_d$ . If the condensate is ice (frost), use the saturation vapor pressure over ice, Appendix X4, corresponding to the condensation temperature  $t_d$ .

12.3 Calculate the relative humidity with respect to ice as follows:

$$(U_i)_{t,p_a} = \frac{P_a e(t_d)}{P_c e_i(t)} 100 \% \quad (2)$$

where:

$(U_i)_{t,p_a}$  = relative humidity with respect to ice, %, at temperature  $t$  and pressure  $p_a$ ,

$e_i(t)$  = saturation vapor pressure, Pa, over ice at ambient temperature  $t$ , °C, where  $t$  is the average value during the sampling period, see Appendix X4, and

$P_c, P_a, e(t_d)$  = see 12.2

12.4 Calculate the mixing ratio as follows:

$$r = 0.622 e(t_d) / [p_c - e(t_d)] \quad (3)$$

where:

$r$  = mixing ratio and

$e(t_d), p_c$  = see 12.2.

12.5 Calculate parts per million by mass as follows:

$$\text{ppm}_m = r \times 10^6 \quad (4)$$

12.6 Calculate parts per million by volume as follows:

$$\text{ppm}_v = e(t_d) / [p_c - e(t_d)] \times 10^6 \quad (5)$$

### 13. Precision and Bias

13.1 The estimated precision for this method is valid only for *constant* ambient humidity and the precision varies with the condensation temperature as shown in Fig. 2. The precision is based on single-laboratory and multioperator-device test.

13.2 The estimated bias of the dew-point hygrometer, as

shown in Fig. 2, is valid only for constant ambient humidity. This is true especially for low-condensation temperatures. The bias varies from  $\pm 0.4^\circ\text{C}$  for condensation temperatures above freezing to  $\pm 2.0^\circ\text{C}$  at condensation temperature  $-70^\circ\text{C}$ . All uncertainties are at the 95 % confidence level.

13.3 If the standard deviation is equal to or less than the values listed in 13.3.1, the ambient humidity is assumed to be sufficiently constant so that the bias curve given in Fig. 2 is valid.

13.3.1 The following criteria shall be used to determine whether the ambient humidity is constant:

Condensation Temperature (°C)	Duration of Sampling Time (min)	Number of Readings Taken Over Equally Spaced Time Intervals	Calculated Standard Deviation (°C)
-70	120	10 to 25	$\pm 0.5$
-60	90	10 to 25	$\pm 0.4$
-50	60	10 to 25	$\pm 0.3$
-40	30	10 to 25	$\pm 0.2$
-25	20	10 to 25	$\pm 0.15$
-10	15	10 to 25	$\pm 0.1$
60	15	10 to 25	$\pm 0.1$

13.4 The following is an example on use of the table in 13.3.1:

13.4.1 If the indicated condensation temperature is  $-50^\circ\text{C}$ , take 10 to 25 readings taken at equally spaced time interval for a period of approximately 60 min, compute the average value (in this case  $-50^\circ\text{C}$ ) and the standard deviation. If this calculated standard deviation is equal to or less than  $\pm 0.3^\circ\text{C}$ , the ambient humidity is assumed to be constant and the bias of the reading at  $-50^\circ\text{C}$  is  $\pm 1.2^\circ\text{C}$  (See Fig. 2). See also 8.2.2.

### 14. Keywords

14.1 dew-point; humidity; hygrometer; saturation; temperature; dew-point; vapor pressure

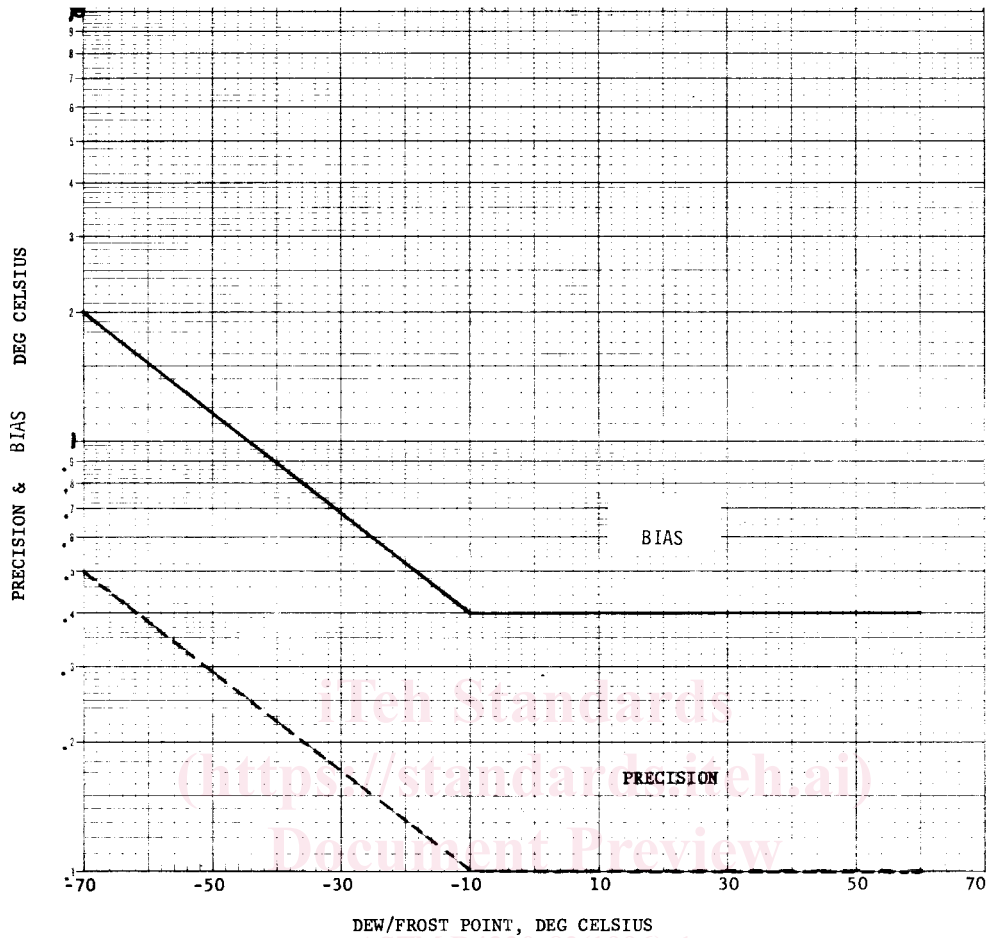


FIG. 2 Precision and Bias Versus Dew/Frost Point

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## ANNEXES

### (Mandatory Information)

#### A1. LABORATORY CALIBRATION OF DEW-POINT HYGROMETER

A1.1 An accurate method for the calibration of the hygrometer is to test the instrument with a humidity generator that produces air of known humidity (2).

A1.2 An alternative method is by direct comparison with a secondary or working standard hygrometer when both instruments are subjected to the same, preferably constant, humidity.

NOTE A1.1—Secondary standard hygrometers are characterized by long term repeatability and predictable behavior when verified to be performing properly. Working standard hygrometers are characterized by satisfactory (which meet the users requirements) precision and stability when calibrated against a humidity generator or intercompared with a secondary standard.

**A2. FIELD CALIBRATION OF DEW-POINT HYGROMETER**

A2.1 Install a secondary or working standard hygrometer adjacent to the working hygrometer and run an intercomparison test. It is very important that the standard and the working hygrometers are sampling the same air mass. The exhaust air from both hygrometers must not be mixed with the intake air sample.

A2.2 If there is a fixed bias between the readings of the two hygrometers, interchange the positions of the two instruments to determine if the bias is due to sampling problems.

A2.3 The intercomparison test should continue until con-

stant humidity indications, as defined in 13.2, are seen on both instruments. If the sample condensation temperature is steady, the duration of the test will be shorter than when there are large fluctuations in humidity.

A2.4 The tests should be performed during periods when the relative humidity is low and also during periods when the relative humidity is high. (A one-point verification check is sufficient if the working hygrometer had been calibrated prior to the installation in the field.)

**APPENDIXES**

(Nonmandatory Information)

**X1. SATURATION VAPOR PRESSURE OF MOIST AIR<sup>4</sup>**

X1.1 Moist air does not behave precisely like an ideal gas (3). The product of the mole fraction of the water vapor and the pressure  $p_a$  is not generally equal to the pressure that would be exerted by the water vapor if it existed alone in the same volume as the mixture had at the same temperature. The effective saturation pressure of water vapor in equilibrium with a plane surface of liquid or solid water in the presence of an admixed gas differs from the saturation vapor pressure of the pure phase and is expressed as follows:

$$f = x_w p_a / e_s = (1 - x_a) P_a / e_s \quad (X1.1)$$

- where:
- $f$  = enhancement factor, see Appendix X2,
  - $x_w, x_a$  = mole fractions of the water vapor and of the air, respectively, in the saturated mixture,
  - $p_a$  = total pressure above the surface of the condensed phase (water or ice),
  - $e_s$  = pure phase saturation vapor pressure of water substance at the temperature of saturation, and
  - $x_w p_a$  = effective water vapor pressure at the given pressure and temperature of saturation.

X1.2 The percentage relative humidity with respect to water of a moist air at absolute pressure  $p_a$  and temperature  $t$  is defined as follows:

$$U_x = 100(x_v/x_{vw})_{p_a,t} \% \text{ and} \quad (X1.2)$$

using Eq X1.1, Eq X1.2 can be expressed in the following form:

$$U_x = 100 \frac{p_a f(p_c, t_d) e(t_d)}{p_c f_w(p_a, t) e_w(t)} \% \quad (X1.3)$$

where:

- $p_w, p_c, e(t_d)$  and  $e_w(t)$  = see 12.2,
- $f(p_c, t_d)$  = the enhancement factor at pressure  $p_c$  and condensation temperature  $t_d$ . If the condensate on the mirror is water use  $f_w$  (water) and if the condensate is ice use  $f_i$  (ice)—see Appendix X2 for values of  $f_w$  and  $f_i$ , and
- $f_w(p_a, t)$  = the enhancement factor for water at pressure  $p_a$  and air temperature  $t$ . See Appendix X2 for values of  $f_w$ .

X1.3 Similarly, the percentage relative humidity with respect to ice is as follows:

$$U_i = 100 \frac{p_a f(p_c, t_d) e_i(t_d)}{p_a f_i(p_a, t) e_i(t)} \quad (X1.4)$$

- where:
- $p_w, p_c, e(t_d)$  = see 12.2,
  - $e_i(t)$  = see 12.2,
  - $f(p_c, t_d)$  = see X1.2, and
  - $f_i(p_a, t)$  = the enhancement factor for ice at pressure  $p_a$  and temperature  $t$ . See Appendix X4 for values of  $f_i$ .

X1.4 The mixing ratio for moist air is as follows:

$$r = 0.622 f(p_c, t_d) e(t_d) / [p_c - f(p_c, t_d) e(t_d)] \quad (X1.5)$$

where:

- $p_c$  and  $e(t_d)$  = see X1.2, and
- $f(p_c, t_d)$  = see X1.2.

X1.5 The parts per million by volume is expressed as follows:

$$\text{ppm}_v = f(p_c, t_d) e(t_d) / [p_c - f(p_c, t_d) e(t_d)] \times 10^6 \quad (X1.7)$$

<sup>4</sup> The fundamental concepts and definitions of moist air properties are described in detail by Harrison (3).