Hygrometry refers to the measurement of atmospheric humidity. Several variables describe the quantity of water vapor in the atmosphere:

- Absolute humidity (\( \rho_v \)), i.e., density of water vapor
- Specific humidity (\( q \))
- Mixing ratio (\( w \))
- Vapor pressure (\( e \))
- Relative humidity (\( e/e_s \))
- Dewpoint (\( T_d \))
- Wet bulb temperature (\( T_w \))

Can convert from one variable to another with knowledge of temperature and pressure.

### Review: Saturation vapor pressure

The Clausius-Clapeyron equation gives the saturation vapor pressure over a plane surface of water as a function of temperature:

\[
e_s = e_{s0} \exp \left[ \frac{L}{R_v \left( \frac{1}{T_0} - \frac{1}{T} \right)} \right]
\]

- \( e_{s0} = 610.78 \) Pa
- \( T_0 = 273.15 \) K
- \( R_v = 461.5 \) J kg\(^{-1}\) K\(^{-1}\)
- \( L = (2.501 \times 10^6 \) J kg\(^{-1}\) \(- (2340 \) J kg\(^{-1}\) K\(^{-1}\))T\(^{-1}\)°C\)

**Saturation vapor pressure over water and ice**

The Clausius-Clapeyron equation also gives the saturation vapor pressure over ice as a function of temperature:

\[
e_i = e_{i0} \exp \left[ \frac{L_s}{R_v \left( \frac{1}{T_i} - \frac{1}{T} \right)} \right]
\]

- \( e_{i0} = 611.20 \) Pa
- \( T_i = 273.16 \) K
- \( R_v = 461.5 \) J kg\(^{-1}\) K\(^{-1}\)
- \( L_s = 2.834 \times 10^6 \) J kg\(^{-1}\)

**Saturation vapor pressure over ice**

**Saturation vapor pressure over water and ice**
Review: Dewpoint temperature
- The dewpoint temperature is the temperature to which a given air parcel must be cooled at constant pressure and water vapor content in order for saturation to occur.
- Substitute $e$ for $e_s$ and $T_d$ for $T$ in the Clausius-Clapeyron equation:

$$e = e_s \exp \left[ \frac{L}{R} \left( \frac{1}{T_0} - \frac{1}{T_d} \right) \right]$$

Review: Wet-bulb temperature
- The wet-bulb temperature is the temperature to which air may be cooled by evaporating water into it at constant pressure until it becomes saturated.
- $T - T_w$ is the wet-bulb depression

$$T_d \leq T_w \leq T$$

Methods of measuring humidity
- Thermodynamic methods
  - Psychrometer
- Hygroscopic substance
  - Hair hygrometer
- Condensation methods
  - Chilled mirror
- Sorption methods
  - Chemical
  - Electrical
- Diffusion methods
- Optical methods

Psychrometry
- Two temperature sensors
  - One temperature sensor measures the ambient (dry-bulb) temperature ($T$)
  - The other measures the wet-bulb temperature ($T_w$)

Psychrometry: $T_w$ vs. Relative Humidity
- Static sensitivity increases with increasing air temperature
- Static sensitivity increases with decreasing relative humidity

Psychrometry
- The psychrometric formula relates the wet-bulb depression ($T - T_w$) to vapor pressure

$$e = e_s(T_w) - \frac{pc}{edL}(T - T_w)$$

- Psychrometric constant:
  $$\gamma = \frac{pc}{edL} \approx 0.65 \ \text{mb at standard SLP}$$

- Experimentally, $e = e_s(T_w) - Ap(T - T_w)$
  $A=0.00062^{\circ}\text{C}^{-1}$ for water-covered wet bulbs
  $A=0.00054^{\circ}\text{C}^{-1}$ for ice-covered wet bulbs
Requirements for a successful psychrometric measurement

- Two well-matched thermometers
- Adequate ventilation (> 3 m s⁻¹)
- Radiation shield
- Distilled water to moisten the wick
  - Dissolved salts affect the evaporation rate
- Clean wick
  - Special psychrometer wick with no hydrophobic chemicals (not cotton)

Psychrometers

- Assmann psychrometer
- Sling psychrometer

Equilibrium sorption of water vapor

- Many hygrometers use the process of sorption to measure water vapor
  - Absorption: uptake of water into the bulk of the substance
  - Adsorption: surface retention of water molecules
  - Mass of water is proportional to relative humidity
- Consequences of sorption processes:
  - Material expands/contracts
  - Resistance or capacitance of material changes

Hair hygrometer

- The length of human and animal hair varies nonlinearly as a function of relative humidity
- Once used widely by the NWS
- Drawbacks: Drift, hysteresis, large lag times

Bulk polymer resistive sensor

- Measures resistance of a conductive polymer
- Sorbed water provides alternative conductive paths
- Resistance decreases as RH increases
Carbon hygristor

- As relative humidity increases:
  - Linear dimension increases
  - Distance between carbon particles increases
  - Resistance increases
- Used only on radiosondes

Capacitive sensors

- Porous Top Electrode (gold)
- Polymer
- Sensor Electrode (gold)
- Substrate

The dielectric constant of the polymer changes with relative humidity

Overview: Functional model for electric hygrometers

Vapor-liquid/vapor-solid equilibrium: Chilled mirror hygrometer

- Mirror cooled via Peltier effect until dew/frost forms
- Thermistor or RTD embedded in mirror detects T

Vapor-liquid/vapor-solid equilibrium: Chilled mirror hygrometer

NWS Model
HO83/1088

No dew/frost detected
Dew/frost detected
Spectroscopic Techniques

- Measure the attenuation of certain bands of radiation due to water vapor absorption
- Primary water vapor absorption bands:
  - 121.56 nm (0.12 μm) – Ultraviolet
    - Lyman-alpha emission line of atomic hydrogen
    - Fastest response of all humidity sensors
    - Terrible drift (i.e., within minutes)
  - 2.6 μm – Infrared
    - Expensive
    - Slow response

Spectroscopic Techniques

- Beer’s Law
  - The fraction of incident radiation, $\tau$, transmitted through an atmospheric path
    $$\tau = \frac{I(s)}{I_0} = \exp(-k_\lambda \rho_v ds)$$
  - $k_\lambda$: absorption coefficient (m$^2$ kg$^{-1}$)
  - $\rho_v$: water vapor density
  - $ds$: measurement path length
  - $I$: intensity of attenuated radiation
  - $I_0$: intensity of source radiation

Campbell Scientific KH20 Krypton Hygrometer

UV radiation emitted by a krypton lamp at 123.58 nm and 116.49 nm