Hygrometry

Hygrometry refers to the measurement of atmospheric humidity

- Several variables describe the quantity of water vapor in the atmosphere
  - Absolute humidity (ρ_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

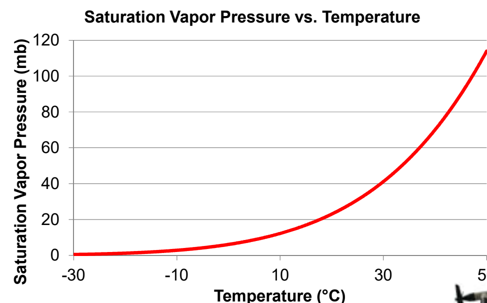
Review: Saturation vapor pressure

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

$$e_s = e_{s_0} \exp\left[\frac{L}{R_v}\left(\frac{1}{T_0} - \frac{1}{T}\right)\right]$$

  - e_{s_0} = 610.78 Pa
  - T_0 = 273.15 K
  - R_v = 461.5 J kg^{-1} K^{-1}
  - L = (2.501×10^6 J kg^{-1}) − (2340 J kg^{-1} K^{-1})$T_{°C}$

Saturation vapor pressure is a function of temperature



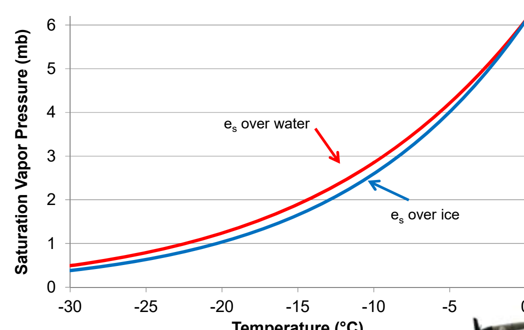
Saturation vapor pressure over ice

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

$$e_{s_i} = e_{s_t} \exp\left[\frac{L_s}{R_v}\left(\frac{1}{T_t} - \frac{1}{T}\right)\right]$$

  - e_{s_t} = 611.20 Pa
  - T_t = 273.16 K
  - R_v = 461.5 J kg^{-1} K^{-1}
  - L_s = 2.834×10^6 J kg^{-1}

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:

$$e = e_{s_0} \exp\left[\frac{L}{R_v}\left(\frac{1}{T_0} - \frac{1}{T_d}\right)\right]$$

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

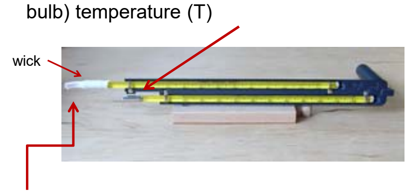
$$T_d \le T_w \le T$$

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

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

$$e = e_s(T_w) - \frac{pc_{p_d}}{\varepsilon L}(T - T_w)$$

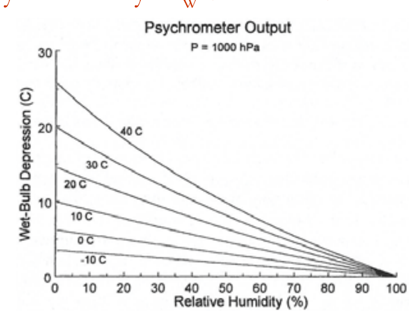
- Psychrometric constant:

$$\gamma = \frac{pc_{p_d}}{\varepsilon L} \approx 0.65\,\frac{\text{mb}}{\text{K}} \text{ at standard SLP}$$

- Experimentally, $e = e_s(T_w) - Ap(T - T_w)$

A=0.00062°C^{-1} for water-covered wet bulbs
A=0.00054°C^{-1} for ice-covered wet bulbs

Psychrometry: T_w vs. Relative Humidity



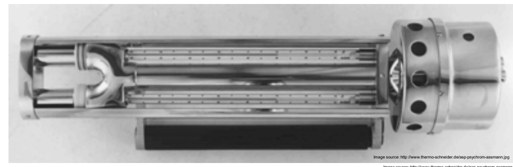
- Static sensitivity increases with increasing air temperature
- Static sensitivity increases with decreasing relative humidity

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

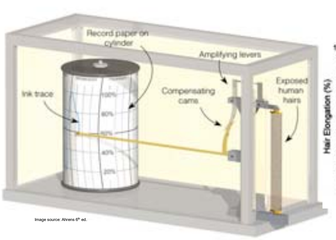
Psychrometers

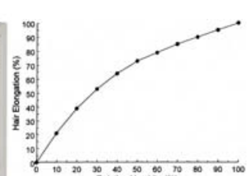
Psychro-dyne

Equilibrium sorption of water vapor

- Many hygrometers use the process of sorption to measure water vapor
  - Ab<u>sorption</u>: uptake of water into the bulk of the substance
  - Ad<u>sorption</u>: 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

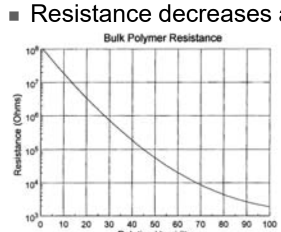




- The length of human and animal hair varies nonlinearly as a function of relative humidity
- Once used widely by the NWS
- Drawbacks: Drift, hysteresis, large lag times

Bulk polymer resistive sensor

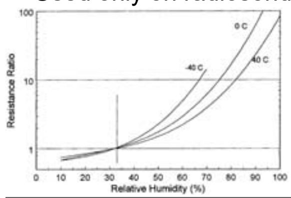
- Measures resistance of a conductive polymer
- Sorbed water provides alternative conductive paths
- Resistance decreases as RH increases



Elan HM2000 series precision bulk-polymer RH sensor

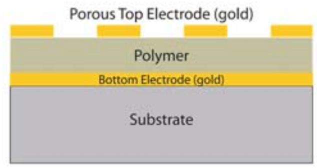
Carbon hygristor

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



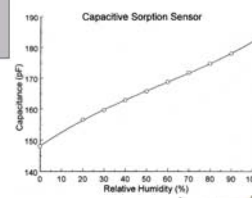
Lockheed Martin Mark II Microsonde carbon hygristor

Capacitive sensors

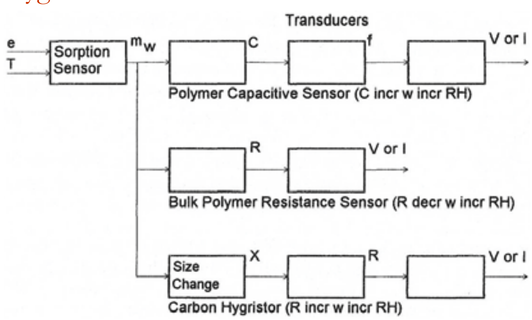


The dielectric constant of the polymer changes with relative humidity

Vaisala HMP45C



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

NWS Model HO83/1088

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

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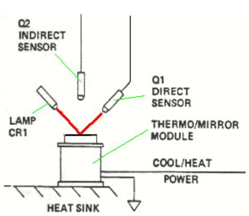
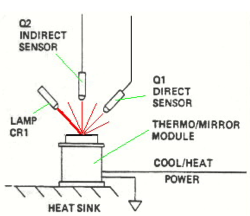


No dew/frost detected



Dew/frost detected

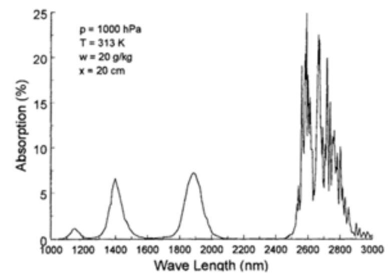
Vapor-liquid/vapor-solid equilibrium: Chilled mirror hygrometer

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

Infrared Water Vapor Absorption



Spectroscopic Techniques

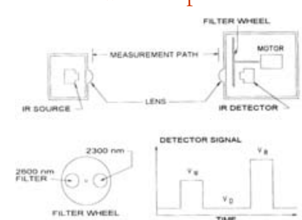
- Beer's Law
  - The fraction of incident radiation, τ, transmitted through an atmospheric path

$$\tau = \frac{I(s)}{I_0} = \exp(-k_\lambda \rho_v ds)$$

  - k_λ: absorption coefficient (m^2 kg^{-1})
  - ρ_v: water vapor density
  - ds: measurement path length
  - I: intensity of attenuated radiation
  - I_0: intensity of source radiation

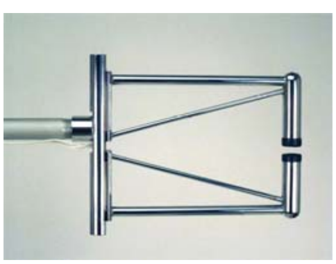
Spectroscopic Techniques

Schematic of an IR water vapor sensor



- Requires two filters to compensate for drift or dirty lenses:
  - Reference band
  - Absorbing band

Spectroscopic Techniques



Campbell Scientific KH20 Krypton Hygrometer

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