Meteorology 432

Barometry

Spring 2013

Basics Revisited

- Objective: Measure the static pressure exerted by the atmosphere.
- Static Pressure: Force per unit area in the absence of air motion.
- In this case, pressure is just the weight (per unit area) of the column of air above you.

Dynamic Pressure

- Pressure exerted by wind flow.
  - Momentum transfer air particles impinging on a surface of unit area.

- $\Delta P = \frac{1}{2} C \rho V^2$
  - ΔP = pressure error from static conditions
  - C = coefficient whose magnitude is close to unity.
  - ρ = air density
  - V = wind speed

Direct/Indirect

- Direct measurement of pressure
  - Instruments that balance the force of the atmosphere against something.
  - Liquid column.
  - Spring (aneroid barometer).

- Indirect measurement of pressure
  - Boiling point of liquid exposed to atmospheric pressure.

Direct Measurement

- Manometer
  - Differential measurement.
  - Absolute measurement.
  - Measure the difference in height of the two columns.
  - Requires two measurements of height.

- Mercury barometer
  - Column of mercury in a glass tube with a reservoir of mercury at the bottom and is sealed at the top (near vacuum).
  - Weight of column is balanced against the force of the atmosphere.
  - Height of the column relative to the surface of mercury in the reservoir is determined by the attached scale.

Why Mercury?

- High Density
  - 13534 kg/m^3
  - Allows column to be of reasonable length.
- Low vapor pressure
  - Has little impact on the vacuum at the top.
- Easily purified and is chemically stable
  - Vapor is toxic – Extreme care must be used.
- Is liquid between ~ -39 ºC to 357 ºC.

Sources of Error

- Dynamic wind pressure
  - Can be several hPa.
  - How do you overcome this?
- Density of mercury is a function of temperature.
  - Make temperature correction (C_T).
- Local Gravity must be known correctly.
  - Make gravity correction (C_G).
- Air or water vapor at top of tube (not vacuum).
- Barometer must be kept vertical.
- Mercury must be pure.
- In small tubes, surface tension will cause a meniscus
  - For 5mm tube, ~200 Pa (~0.2% of standard atmosphere).
  - For 13mm tube, ~27 Pa
  - Index Correction (C_I)

Corrections

- Ideal barometer: static pressure as the only input.

- Reality: static pressure, dynamic pressure, and temperature are inputs
  - This results in errors that need to be corrected.

- To convert a raw barometer reading (p_1) to station pressure (p_s), we need to apply an index correction (C_x), temperature correction (C_T), and gravity correction (C_G).

Index Correction (C_x)

- Obtained by comparison with a reference barometer.
- Usually is included on a card that comes with the barometer.
- If no index correction is given, assume is zero.
  - Quote this as being “unknown”, and set it equal to zero.

Temperature Correction (C_T)

- Developed from known thermal expansion coefficients for mercury *and* for the scale.
  - Volume change in mercury reservoir.
  - Length change of scale.

- $C_T = - P_1 (\beta - \alpha) T$
  - β = volume expansion coefficient of mercury (p. 21).
  - α = linear expansion coefficient of the scale.

- By introducing this correction, we effectively reduce our pressure measurement to 0˚C

- For a brass scale, $C_T = -1.63\text{x}10^{-4} P_1 T$.

Gravity Correction (C_G)

- Let the index and temperature corrected pressure be P_2.
  - $P_2 = P_1 + C_x + C_T$.
- If we are at a place with standard gravity ($g_o = 9.80665$ m/s^2), P_2 is final true pressure.
- If g deviates from g_o, we need to make a gravity correction.
  - If you go north, gravity increases.
    - Your weight increases by 0.5% as you go from equator to pole, this is approximately one pound for the average person.
  - If you go up, gravity decreases.

Example 1

- A mercury barometer reads: p_1 = 941.23 hPa; the temperature T = 21.2 ºC. The index correction is unknown (zero). The latitude is 40.00º and the elevation is 652m. Calculate the station pressure.

Example 2

- A mercury barometer reads: p_1 = 940.50 hPa; the temperature T = 25.2 ºC. The index correction is unknown (zero). The latitude is 40.00º and the elevation is 552m. Calculate the station pressure.

How accurate do we need to be?

- How accurately must the latitude and elevation be determined?
  - Do we need to measure the exact height of the barometer?

- For an error of 0.05 hPa, how close do we need to be?

Aneroid Barometer

- Aneroid: Without fluid.

- Evacuated chamber with a flexible diaphragm that moves in response to applied pressure.
  - Somewhat similar to pressure transducer.

- The restoring force is a spring or may be part of the diaphragm itself.

Calibration Equation

- Consider a simple, evacuated, aneroid chamber with a flat metallic diaphragm on one side

- Calibration equation variables
  - P = Pressure
  - E = modulus of elasticity
  - y = deflection of the diaphragm center (raw output)
  - t = diaphragm thickness
  - R = diaphragm radius
  - v = Poissons ratio: typicall 1/3 for metals.

- Find Static sensitivity
  - Simplify

Static Sensitivity

- Plot diaphragm deflection vs. pressure
  - Transfer plot
  - Non-linear
  - Static sensitivity decreases as pressure increases.
- Deflections are very small, typically on the order of the diaphragm thickness.
- The non-linearity is troublesome, yet aneroid barometers are popular devices.
  - Inexpensive, simple
  - How can this be?

Real Aneroids

- Corrugated diaphragms.
  - Simple fix that makes the static sensitivity nearly constant.
  - Nearly a linear sensor.
- Two corrugated diaphragms welded together.
  - Space between diaphragms is evacuated.
- Deflection of diaphragm either drives a dial display or provides an electric output.

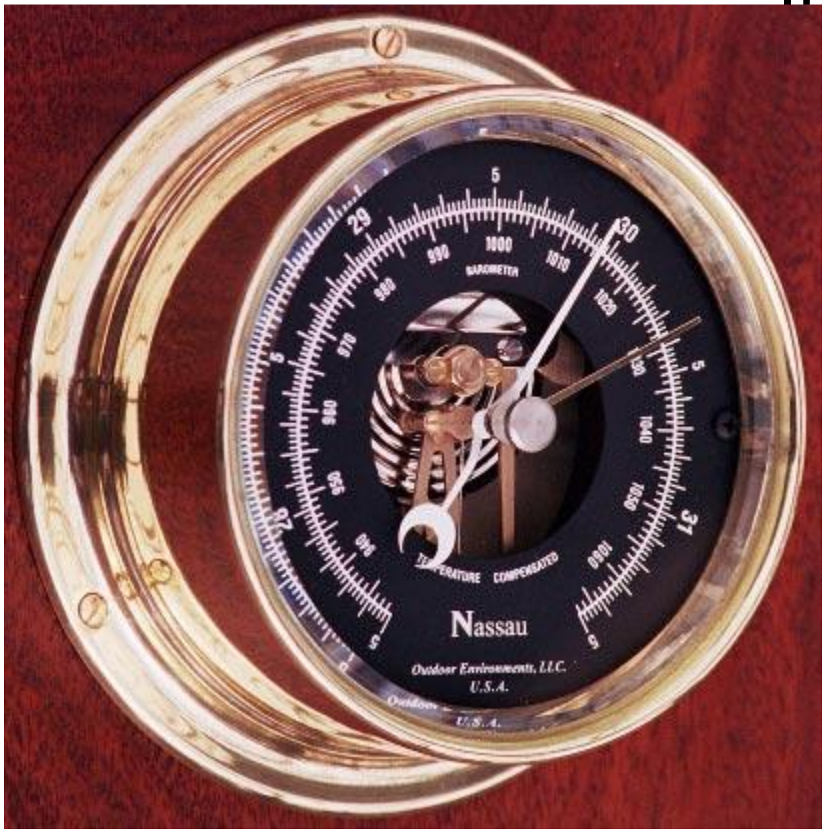
Aneroid Errors

- Exposure errors similar to those in mercury barometers
  - Dynamic pressure
  - Harder to correct than mercury.
- Temperature effects of all sorts.
- Drift due to diaphragm creep.
  - Unpredictable, but periodic checks will account for it.
  - Drift is not a problem in mercury barometers.

Why use them?

- With all of these errors, why should we use them?
- Readily automated.
- Very portable
  - Insensitive to orientation and motion.
- No gravity correction.

Images



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Outdoor Environments, LLC.
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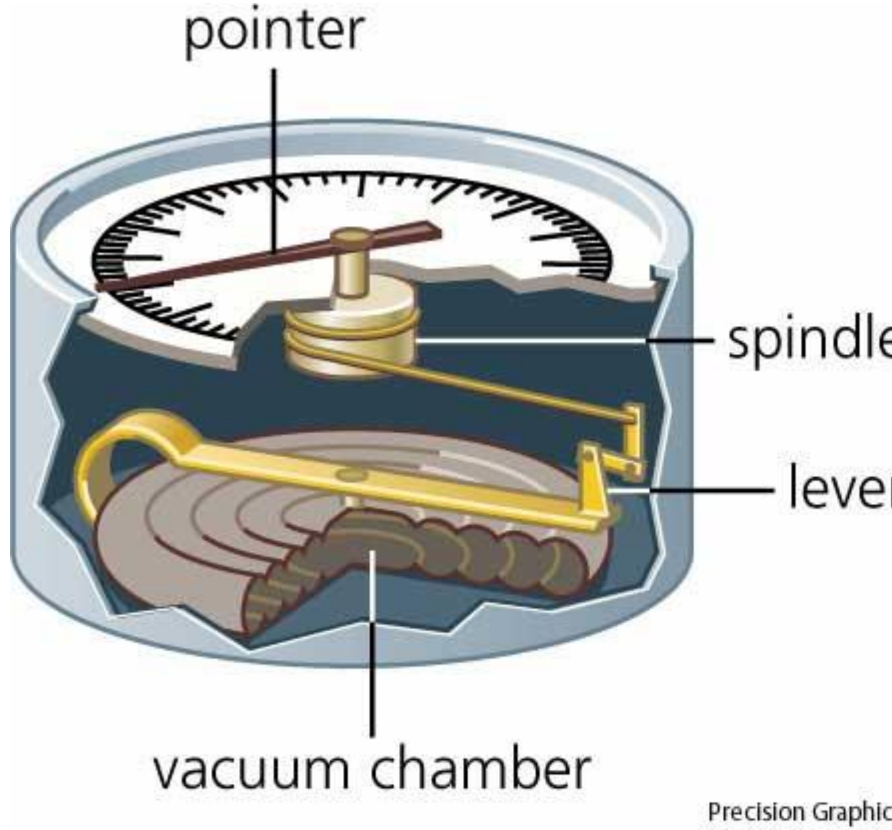
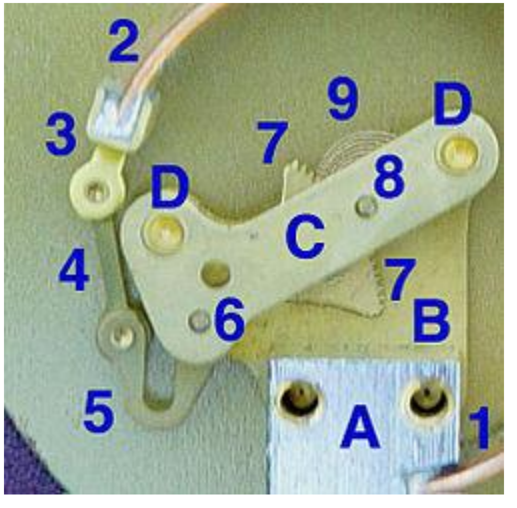


pointer
spindle
lever
vacuum chamber
Precision Graphics

Bourdon tube



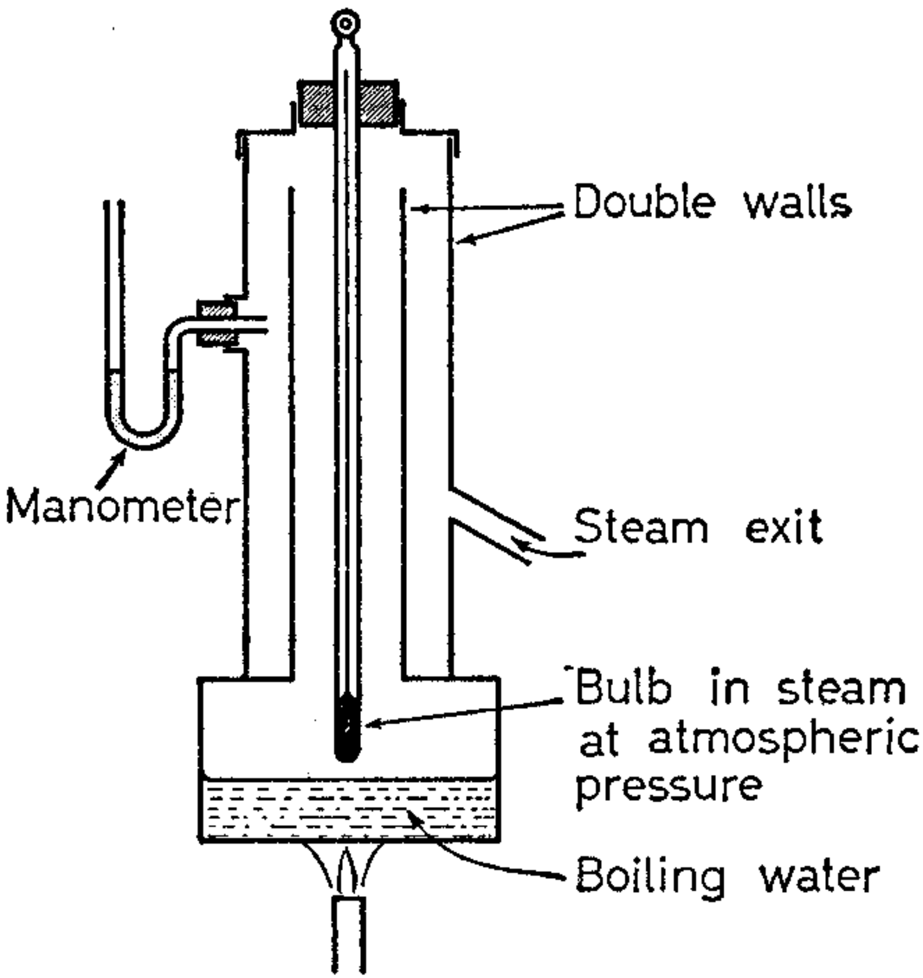
Indirect Pressure Measurements

- Does not respond directly to the force due to the atmospheric pressure, but responds to some other variable that is a function of pressure.

- For example, the boiling temperature of a liquid depends on the atmospheric pressure.
  - Decreases with decreasing pressure

Hypsometer

- Literally, height meter.
- Flask with hypsometric fluid, heated to maintain a continuous boiling.
- Temperature sensor to measure the boiling temperature.
  - Must be positioned carefully to obtain a representative boiling temperature.


Double walls
Manometer
Steam exit
Bulb in steam
at atmospheric
pressure
Boiling water

Hypsometer


acumenlabware.com

Hypsometer - S_s

- Static sensitivity near sea-level is very poor.
  - A large change in pressure produces a small change in the boiling temperature.
  - High performance temperature sensors are required.

- Limited range of applications.