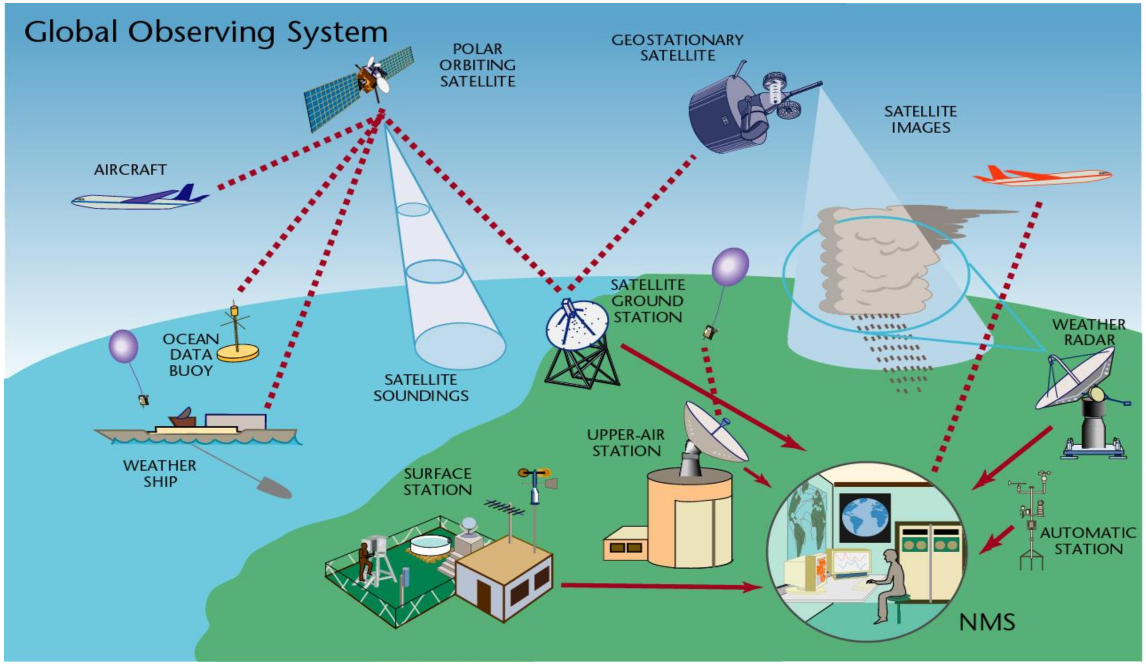
The Course of
Meteorological Instrumentation and Observations



MUSTANSIRIYAH UNIVERSITY
COLLEGE OF SCIENCES
ATMOSPHERIC SCIENCES DEPARTMENT

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SECOND STAGE

Welcome Students! ☺

TO LECTURE SIX

PRESSURE & WIND

Pressure

Pressure: Force F exerted by the air molecules over a given area A.

$p = \frac{F}{A}$ unit: $\mathrm{kg\,m^{-1}s^{-2}}$, Pascal $Pa = 1\,{}^{N}\!/\!{}_{m^2}$ where 100Pa = 1mb

- Atmospheric pressure is created by the weight of the atmosphere per unit area above the observation point, it can vary depending on ambient temperature, altitude and local weather conditions.
- It is a fundamental atmospheric quantity in providing synoptic information and because of its close relationship with height and atmospheric thickness.
- Accurate measurement by radiosondes, serve to define the dynamical state of the atmosphere.

There are two ways to look at pressure:

(1) the small scale action of <u>individual air molecules</u> or

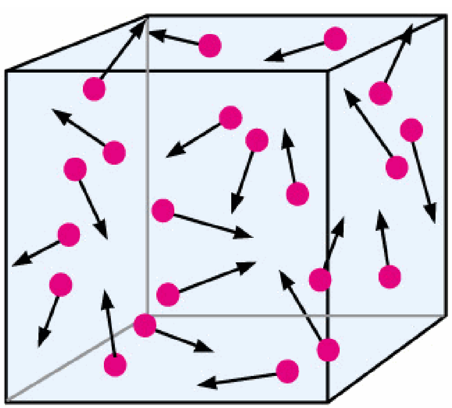
(2) the large scale action of a <u>large number of molecules</u>.

FYI

- On the ***small scale***, from the kinetic theory of gases, a gas is composed of a large number of molecules that are very small relative to the distance between molecules.
- The molecules of a gas are in constant, random motion and frequently collide with each other and with the walls of any container. During collisions with the walls, there is a change in velocity and therefore a change in momentum of the molecules (product of the mass and velocity). The change in momentum produces a force on the walls which is related to the gas pressure.

- On the ***small scale*** ,the pressure of a gas is a measure of the average **linear momentum** of the moving molecules of a gas.

- On the ***large scale***, the pressure of a gas is a state variable, like the temperature and the density.



- If a gas is static and not flowing, the measured pressure is the same in all directions which is the **static pressure**. But if the gas is moving, the measured pressure depends on the direction of motion. This leads to the definition of the **dynamic pressure**.

- Measuring pressure can only be done when you compare it against another known pressure. This pressure is called the ***reference pressure***. Depending on what the reference pressure is, gives us three different categories: absolute pressure, gage pressure, and differential pressure.

- The atmospheric pressure must be measured as absolute pressure, Its value at mean sea level is approximately

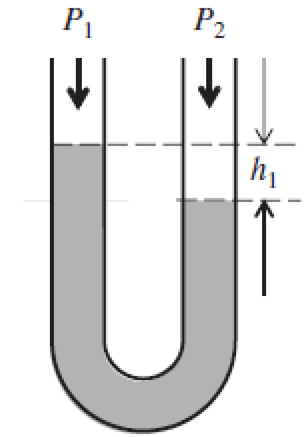
$$1\ atm = 1013.25 mb = 760 mm\ Hg = 29.92 in\ Hg$$

- Surface pressure measurements are conventionally corrected for the variation in pressure with height, which shows a reduction of about **1 hPa per 10 m** of altitude near the surface.
- The pressure as observed without correction for altitude is known as the ***station pressure***, whereas the ***mean sea level pressure*** is that corrected to the universally agreed sea level datum.
- A measuring instrument for atmospheric pressure is known as a ***barometer***, and one able to produce a chart record is known as a *barograph*.
- The desirable accuracy in pressure measurement at the surface or aloft is about ±0.1 hPa, equivalent to 1 part in 10^4, which is a very demanding requirement for a routine scientific measurement.

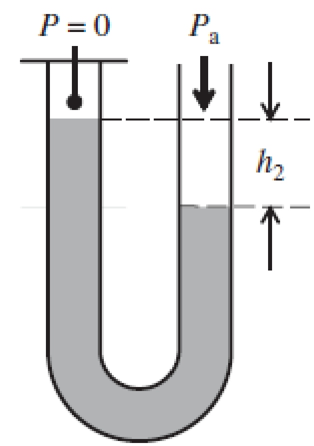
Barometers

- Instruments to measure atmospheric pressure have been used for over three centuries, and have been traditionally divided into two broad categories, depending on whether they use a **liquid** (usually mercury) as the sensing element, **or not** (*aneroid* barometers).
- Mercury barometers measure pressure by determining the height of a liquid column, which is related to pressure by the hydrostatic equation.
- Aneroid barometers use a thin metal chamber or diaphragm, having a membrane which deforms under pressure differences which can be measured mechanically or electronically.

Liquid barometers

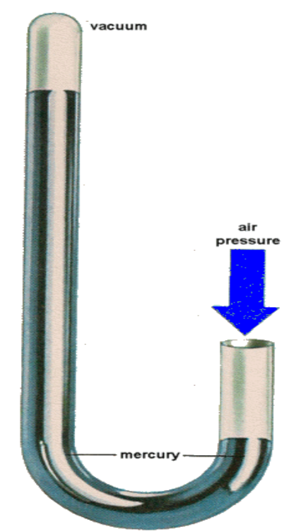


Pressure differences can be measured by the change in position of a liquid in a tube. <u>If the tube is made symmetric</u>, such as in a ‘U’ shaped tube, the difference in height of the fluid between one side and the other depends directly on the pressure difference applied and the density of the liquid concerned.



The difference in height Δh is related to the pressure difference ΔP by the **hydrostatic equation** $\Delta P = \Delta h \rho g$,

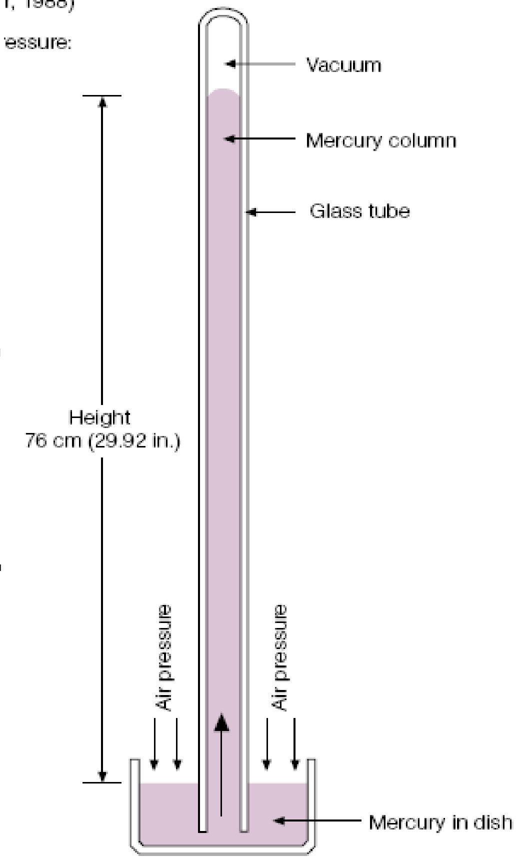
where ρ is the liquid’s density and g acceleration due to gravity. The pressure difference and height difference are related by $P_2 - P_1 = h1 \rho g$,



but, <u>if the tube is sealed and evacuated</u>, to establish a vacuum, the atmospheric pressure and height vary directly together as $P_a = h_2 \rho g$,

This configuration is adapted to provide the operating principle of the **liquid barometer**.

A **mercury-in-glass** barometer is a standard instrument for measuring **static pressure**. In this instrument, two columns connected at the base are used, one evacuated and sealed at the top of the column and so subject to no pressure, and the other exposed to the atmosphere at the top. The difference in height between the two columns depends on the atmospheric pressure and the known density of mercury and is therefore used to infer the pressure.

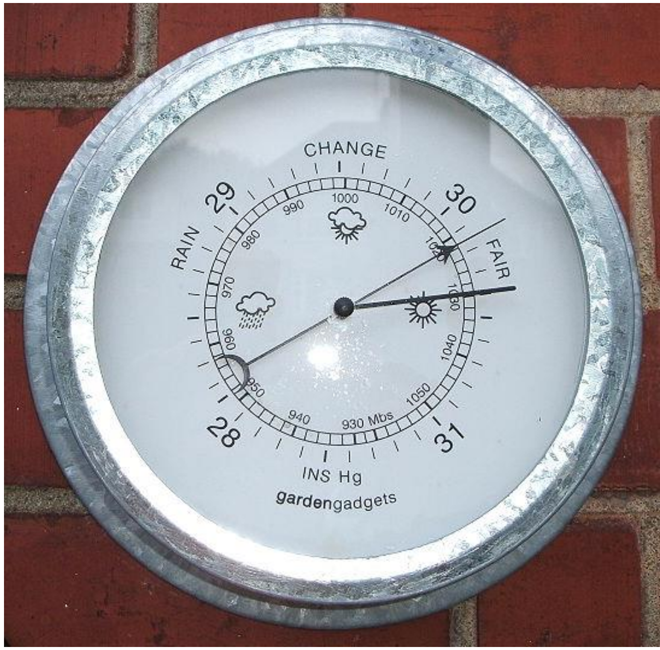


Mercury has a low vapor pressure at the temperatures required, and is easily cleaned.

It does not wet the glass walls of tubes, which leads to formation of a convex meniscus, providing a well-defined measurement datum.

A disadvantage is that mercury does show appreciable thermal expansion, also mercury barometers are not very portable so are unsuitable for remote automatic data logging. Usually used as free standing devices for station barometers.Mercury is a cumulative poison, absorbed through the skin.

Aneroid Barometer



Aneroid barometers are more convenient to use than mercury barometers and avoid the hazard associated with use of mercury.

An aneroid barometer uses a small, flexible metal box called an aneroid cell (sensor). This aneroid capsule (cell) is made from an alloy of beryllium and copper. The evacuated capsule (or usually more capsules) is prevented from collapsing by a strong spring. Small changes in external air pressure cause the cell to expand or contract. This change in dimension can be monitored mechanically or electrically.

This expansion and contraction drives mechanical levers such that the tiny movements of the capsule are amplified and displayed on the face of the aneroid barometer. The properties of the mechanism limits accuracy of the dial reading, as it may stick or exhibit hysteresis.

Barographs

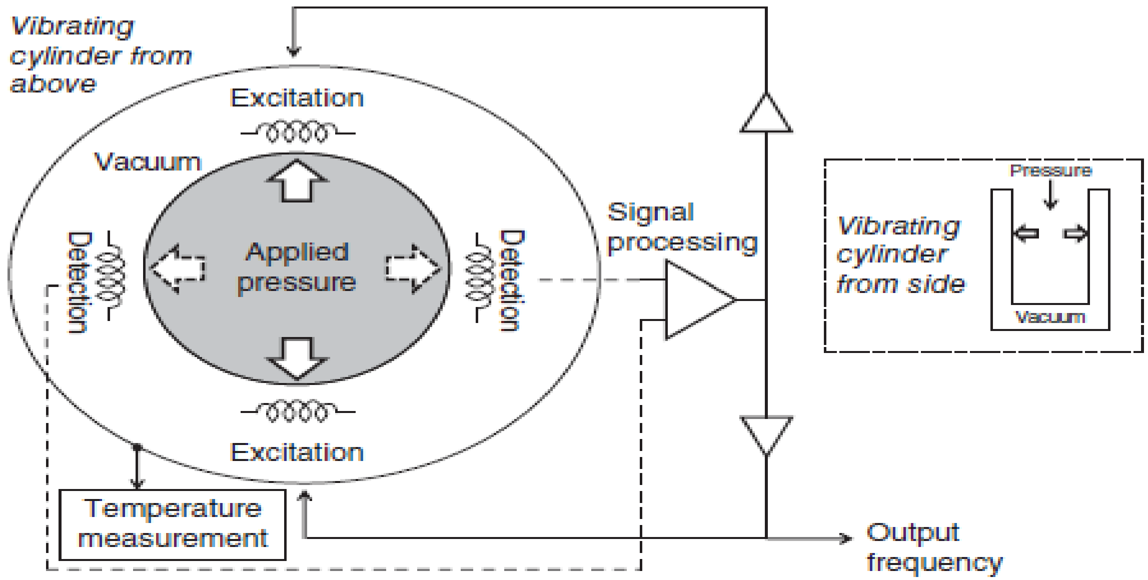
- In a barograph, multiple aneroid capsules are connected together “to increase the sensitivity to pressure changes” to move a needle on a smoked foil or to move a pen upon paper, both of which are attached to a drum moved by clockwork.
- The barograph is usually set up to measure the mean sea level pressure without correction, as, although not very accurate (±1 hPa), its importance is in providing a continuous record of pressure tendency.

Flexible diaphragm sensors

- These are based on a similar principle to that of an aneroid capsule, but rely either on detecting the flexing of a thin silicon diaphragm with changes in pressure, or changes in capacitance associated with changes in the separation between the diaphragm and a fixed plate. The latter type of sensor can be very small and light, and is used in radiosondes for measuring the pressure at the altitude reached by the instrument package.
- An alternative approach is to couple the diaphragm to a resistive strain gauge, for a direct electrical output related to pressure. Such sensors are suitable for **remote and automatic pressure measurements**, but suffer from substantial temperature errors. Compensation systems, temperature characterisation or temperature stabilisation are therefore required.

Vibrating cylinder barometer

- A vibrating cylinder barometer is capable of very high accuracy and stability.
- The operating principle is based on detecting the natural frequency of oscillation in the 'hoop' vibrating mode of a thin-walled cylinder (open to the atmosphere), which is surrounded by a near vacuum.
- The oscillations are excited by magnetic forces from electromagnetic coils placed around the cylinder and detected by the induced current in detector coils. A feedback signal processing system is used to 'tune' the forcing to the natural frequency of the cylinder to sustain the oscillations.



- The natural frequency obtained is measured using a frequency counter.
- The natural frequency of the cylinder depends on both the pressure and density of the air inside the cylinder, but shows a complicated non-linear response which has to be obtained empirically by calibration.
- (The influence of density is also allowed for by measuring the temperature of the sensor.) Precision versions of this instrument are able to measure atmospheric pressure to an accuracy of better than ±0.05 hPa, and with a resolution of 0.01 hPa.

Table 7.1 Sensing methods used in barometry

Pressure sensor	Barometric parameter	Measurement method	Typical accuracy
Mercury column	Column length	Mechanical scale, sometimes with a vernier system	±0.1 hPa
Aneroid capsule	Capsule dimension	Mechanical dial; change in frequency of resonant circuit coupled inductively	±1 hPa
	Precision aneroid device – dimension change of bellows	Micrometer	±0.1 hPa
Hypsometer	Boiling point of a liquid	Temperature	
Vibrating cylinder	Resonant frequency of cylinder	Frequency	±0.05 hPa
Electronic diaphragm	Capacitance between diaphragm and reference plate	Capacitance (via resonant frequency)	±0.5 hPa
	Resistance of strain gauge bonded to diaphragm	Resistance	