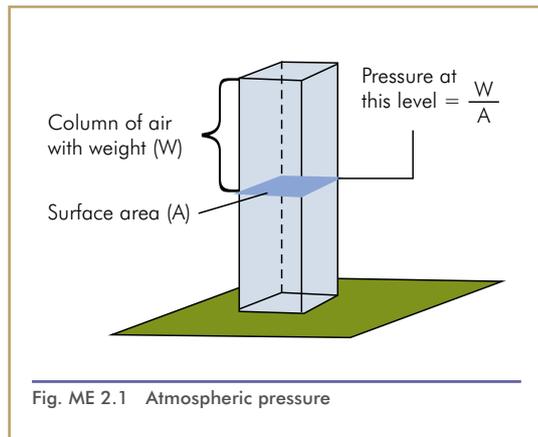


2 Atmospheric Pressure

2.1 Definition and Pressure Measurement

2.1.1 Definition

Pressure acts in all directions, up and sideways as well as down, but it is convenient in meteorology to regard atmospheric pressure as the weight of an air column acting on unit area, *see fig. ME 2.1.*

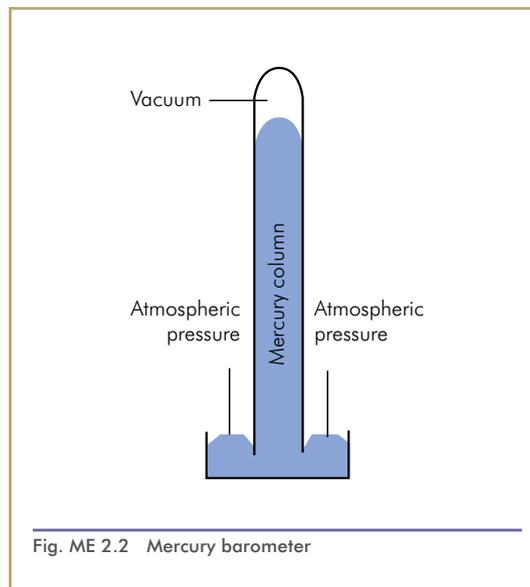


The units of pressure are Force divided by Area (or Force per Unit Area N/m^2 or Pa (Pascal)). The unit of pressure in meteorology is the hecto Pascal (hPa) which replaces the millibar (mb) which was in use in former times. However the units are of identical magnitude, therefore:

$$1 \text{ mb} = 1 \text{ hPa}$$

2.1.2 The Mercury Barometer

The Italian physicist Torricelli invented the Mercury barometer in the 17th century, *see fig. ME 2.2.*



Atmospheric pressure forces mercury to rise in an evacuated glass tube.

The unit of pressure was then mm Hg (Hg is the abbreviation for mercury). This unit has been replaced by the SI-unit hecto Pascal, hPa.

The reading of a mercury barometer has to be manually corrected for the temperature of the mercury column and gravity at each site.

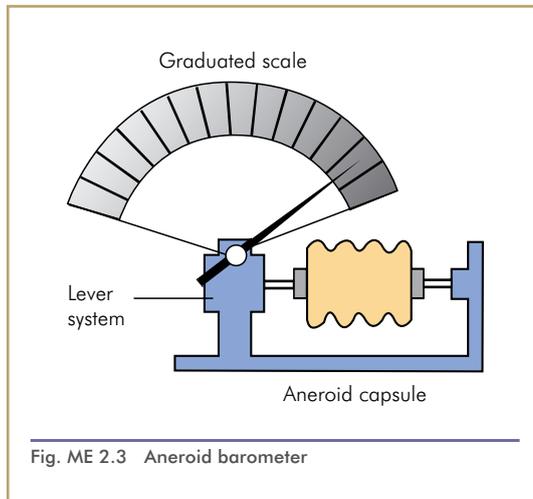
760 mm Hg = 1013 hPa

In the USA barometric pressure is still measured in inches Hg:

29.92 inches Hg = 1013 hPa.

2.1.3 Aneroid Barometer

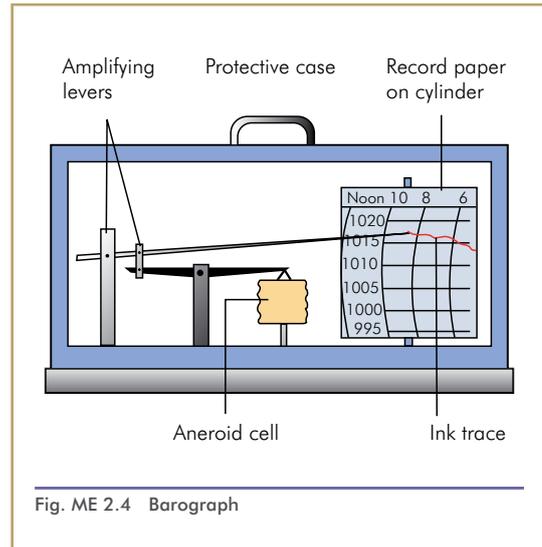
The aneroid barometer consists of a flexible metallic capsule which is partially evacuated. It compresses under small increases in air pressure and the capsule compression/expansion is converted by a lever system to drive a pointer on an amplified scale. It is a much more convenient and portable system than a mercury barometer, *see fig. ME 2.3.*



2.1.4 The Barograph

The barograph is an aneroid barometer used in conjunction with a recording drum. Instead of a needle and graduated scale the lever mechanism moves a pointer which leaves an ink trace on a scaled recording paper wrapped around the drum. This leaves a permanent record of the pressure

variations. This is used to provide a meteorologist with the pressure tendency, or rise and fall of pressure over time and is an important forecasting tool, *see fig. ME 2.4.*



2.2 Pressure Reduction to Mean Sea Level and Pressure Systems

2.2.1 Pressure at the Surface

QFE

The atmospheric pressure measured on a barometer at an airfield is known as the QFE or Aerodrome Pressure.

The QFE varies widely, both from day to day and place to place, due to variations in the weight of the air column above the surface

2.2.2 Pressure at Mean Sea Level

QFF

Since QFE is measured at station level, it is not immediately usable for meteorological purposes because of the differences in altitude of the observing stations. In order to

be usable in meteorology all pressures need to be measured at the same level. Therefore QFE values have to be adjusted to Mean Sea Level (MSL) and the adjusted pressure is known as QFF.

In temperate latitudes QFF varies between 970 hPa and 1030 hPa, but occasionally pressure falls as low as 900 hPa or rises as high as 1060 hPa.

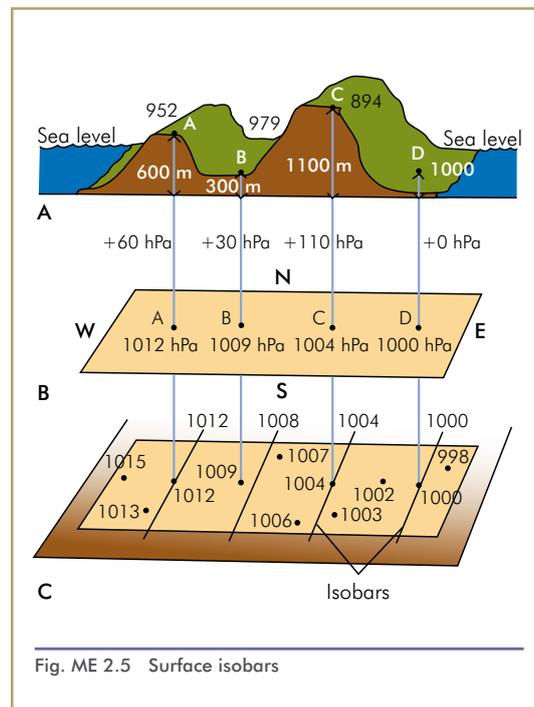
In different countries different methods are used to calculate this QFF. Sometimes the method is dependent on season. All methods use the observed temperature at the station and some type of assumed temperature profile down to or up to sea level. In meteorology this is called reduction.

Once reduction is done, all points with the same QFF can be joined up with lines of constant pressure referred to as isobars.

2.2.3 Pressure Systems

In order to forecast weather it is important to know the distribution of pressure at mean sea level.

Isobars are usually drawn at intervals 1, 2, 4, 5 or 10 hPa, the custom varies with latitude and country. Local barometric pressures at observation stations (QFE) above sea level are adjusted for the difference in height to bring them all to a common datum, normally Mean Sea Level (MSL) to enable a chart of pressure distribution to be drawn known as a synoptic chart. The adjusted MSL pressures are known as the QFF, *see fig. ME 2.5.*



Pressure Patterns Revealed by the Isobars are:

Anticyclones or Highs

These are regions where the pressure at its centre is highest relative to its surroundings. The circulation is clockwise in the northern hemisphere and anticlockwise in the southern hemisphere.

Ridge or Wedge

A region of isobars extending away from a high centre. Pressure along the line of the ridge is higher than its surroundings.

Depressions or Lows (or Cyclones)

These are regions where the pressure at its centre is lowest relative to its surroundings. The circulation is anticlockwise in the

northern hemisphere and clockwise in the southern hemisphere.

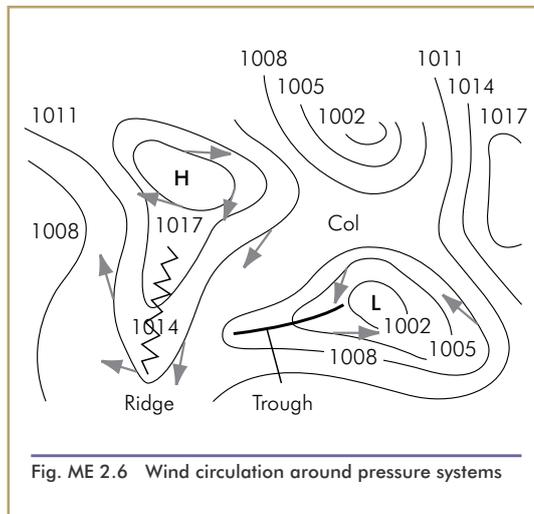
Trough

A trough is a region of isobars extending away from a low centre and may have sharp curvature. Pressure along the line of the trough is lower than its surroundings.

Col

A col is a region of nearly uniform pressure situated between a pair of highs and a pair of lows.

Wind circulation around pressure systems is usually along the isobars, *see fig. ME 2.6.*

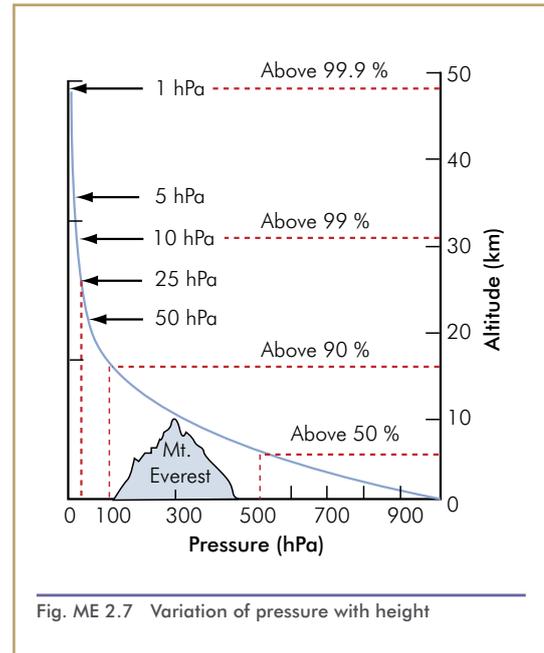


2.3 Vertical Pressure Distribution

2.3.1 Variation of Pressure with Height

The pressure at any level in the atmosphere is equal to the weight of air column above a surface of 1m^2 . It follows therefore that pressure must reduce with height in the

atmosphere as the weight of the air column above reduces. How much it reduces depends upon the gravitational acceleration and density of the air column, *see fig. ME 2.7.* From *fig. ME 2.7* it can be seen that the most



rapid decrease in pressure with height is in the troposphere up to about 500 hPa at which point about 50% of the atmosphere is below this level. The rate of pressure decrease with height begins to decrease significantly as one approaches the tropopause. The pressure will of course be determined by the density of the air above.

Table ME 2.1 shows the height change at various altitudes for a pressure change of 1 hPa.

Height	Height difference for a change of 1 hPa
MSL	27 ft
18 000 ft (500 hPa)	50 ft
39 000 ft (200 hPa)	100 ft

Table ME 2.1 Height variation for 1 hPa pressure change at various heights

2.4 Atmospheric Density

2.4.1 Density

Density is defined as mass per unit volume, expressed in kg/m^3 . When air is heated it expands, and the same mass (or weight) occupies a larger volume and so density becomes less. As pressure decreases with height the density of the air is decreasing as well. This will also be dependent on the temperature of the air as warm air is less dense than cold air and warm columns of air will be taller than cold air columns.

Assume two columns of air both have the

same height and surface pressure. If one column is cooled while the other is heated, the colder column will be more dense and contain less air above the fixed datum of 10 000 ft. The warm column will expand, decreasing in density and pushing more air above the fixed datum, *see fig. ME 2.8*.

The pressure at 10 000 ft in the cold column will therefore be less than the pressure at 10 000 ft in the warm air column. This will create pressure differences aloft and result in winds aloft.

The rate of decrease of pressure with height is therefore greater in the cold air than in the warm air, so at any height above the surface the pressure aloft will be lower in the cold air than in the warm air.

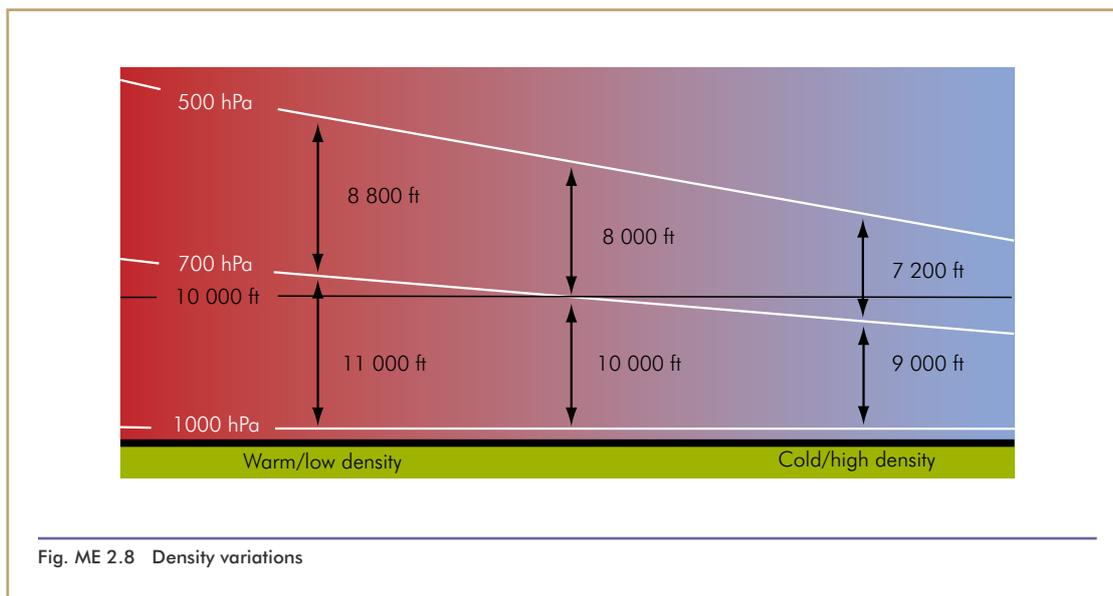


Fig. ME 2.8 Density variations

2.4.2 Density of Dry and Moist Air

As stated earlier, dry air is made up of 78% nitrogen and about 21% oxygen. When water vapour is introduced into the air it displaces the O₂ and N₂ molecules. The atomic mass of N₂ is 28 and O₂ is 32, both heavier than H₂O with an atomic mass of 18. Thus the density of moist air is less than the density of dry air.

2.4.3 Behaviour of Air

Air behaves according to the Ideal Gas Equation

$$p = T \times \rho \times C$$

or *Equation of State* as it is sometimes called.

2.4.4 Pressure and Height Calculations

It is also useful to know what increase of height corresponds to a pressure change of 1 hPa for any particular value of temperature and pressure. A rough estimate may be made using the following formula: (Note, this formula need not be memorised for exam purposes).

$$\frac{96T}{p} \text{ ft/hPa}$$

Where:

- T is mean temperature on the Kelvin scale and
- P is the mean pressure in hPa.

Thus at a sea level pressure of 1013 hPa and 15°C (288K) there is approximately a height

change of 27 ft for 1 hPa pressure change, and 50 ft at 500 hPa.

Due to variations in surface pressure and density of the air column aloft a more accurate method of calculating the height between layers in the atmosphere is used for the calculation. Data from the upper air is obtained by sending up a radiosonde.

The data is then used to calculate the thickness or height of the various layers in the atmosphere and then used to derive the absolute height of the isobaric surfaces above mean sea level and so to construct contour charts. The pressure/height formula is used for calculation.

$$h_2 - h_1 = 221.1 \times T \times (\log_{10} p_1 - \log_{10} p_2)$$

While it is not necessary to remember or use the formula in the examination it is reproduced here to emphasise that the height of the pressure levels in the atmosphere is directly dependent on the mean temperature (T), of the atmospheric column above the surface.