pressure to an area of LOW pressure under the influence of a Pressure Gradient Force (PGF). *(Fig. ME 6.3).*

The net force directed from higher to lower pressure is called the:

Pressure Gradient Force
It acts at 90° to the isobars
The Pressure Gradient Force is expressed as pressure difference over a given distance:

$$PGF = \frac{\Delta p}{d}$$

Where Δp = Change in pressure
d= distance over which pressure change occurs.

Closely spaced isobars indicate steep pressure gradients, strong forces and high winds. Conversely widely spaced isobars indicate shallow pressure gradients, weak forces and light winds.

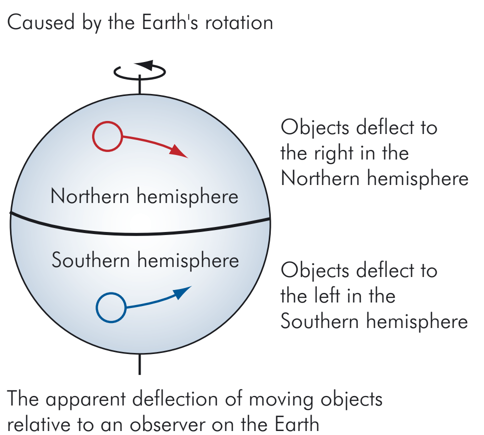

Fig. ME 6.4 Coriolis force

6.3.2 Coriolis (Geostrophic) Force

All unsteered bodies in motion over the surface of the earth are subject to a deflecting force to the right in the northern hemisphere, and to the left in the southern hemisphere, due to the earth's rotation. This force is known as the Coriolis Force, and it plays a vital part in determining the direction followed by the wind. It is an apparent force due to the rotation of the earth. It always acts at 90 degrees to the direction of movement of the air swinging it to the left in the southern hemisphere and to the right in the northern hemisphere. *(Fig. ME 6.4)*

$$\text{Coriolis force} = 2\Omega\rho V \sin(\theta)$$

Ω = Earth's angular velocity (radians/sec)
ρ = Air density
V = Windspeed
θ = Latitude

Newton states that a body will continue in a state of rest or uniform motion unless acted upon by an external force, and this law clearly includes the particles of air whose motion is known as wind. The most obvious force to act on a particle of air is the pressure gradient if it exists. At first glance, the result should be a wind from high pressure directly towards low pressure. The speed of the wind would depend solely upon the size of the pressure gradient force, the steeper the pressure gradient the stronger the flow, and the wind would eventually equalise the pressures, and so remove the pressure gradient. In practice, such a simple situation does not apply because the earth rotates and its rotation gives rise to Coriolis or Geostrophic Force. When this force is taken into account, the theoretical wind which results is called the Geostrophic Wind.

6.3.3 Geostrophic Wind (GW)

Given a pressure distribution in the northern hemisphere with isobars evenly spaced (i.e. a uniform pressure gradient) as shown in the diagram below, a particle of air at A will move initially in the direction AB, under the influence of the Pressure Gradient Force which always acts directly from high pressure to low pressure at right angles to the isobars.

As soon as the particle begins to move, however, it acquires a speed of V knots, and becomes subject to a Geostrophic Force of magnitude 2ΩρVSin(lat). Assuming the example occurs in the northern hemisphere, this deflecting force acts to the right of the initial path of the particle of moving air, which is therefore deflected to the right, arriving at C instead of at B. The path followed is therefore a curve AC.

This process is repeated via D and E until such time as a steady state is reached at F, where the air is moving uniformly under the influence of balanced forces (when the PGF and GF are in balance). This can only occur when the two forces are equal in magnitude and opposite in direction. The PGF has a fixed and unalterable direction across the isobars from high pressure to low. For the GF to be opposite in direction it too must be at right angles to the direction of motion, which must therefore be along the isobars. The direction of flow is therefore determined. The speed of flow can be deduced from the fact that as well as having to be opposite in direction, GF and PGF must also be equal in magnitude. At this point balanced geostrophic flow is achieved and the wind flows along the isobars in the absence of other forces. *(Fig. ME 6.5).*

At position F

$$PGF = GF$$

and $$GF = 2\Omega\rho V \sin(\theta)$$

so $$PGF = 2\Omega\rho V \sin(\theta)$$

and $$V = \frac{PGF}{2\Omega\rho \sin(\theta)}$$

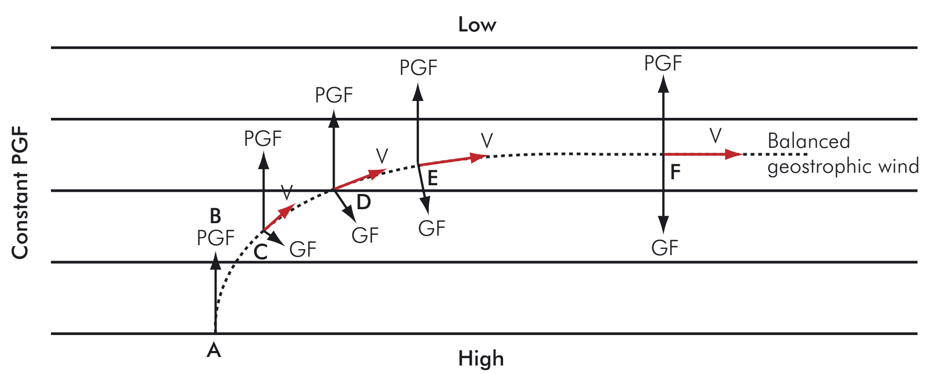

Fig. ME 6.5 Geostrophic wind

A useful figure to remember is that at UK latitudes, a pressure gradient of 4 mb/100 nm gives a geostrophic wind speed of about 30 kt.

6.3.4 Buys Ballot's Law

The reasoning behind the Geostrophic Wind explains Buys Ballot's Law, which states that if an observer stands with his back to the wind, the lower pressure is on his left in the Northern Hemisphere and on his right in the Southern Hemisphere.

6.3.5 Geostrophic Scale

From a chart of pressure distribution, the direction of the geostrophic wind can be determined simply by inspecting the direction of the isobars, and applying Buys Ballot's Law. To find the speed we use a geostrophic scale, normally provided on most isobaric charts. The closer the isobars the higher the PGF, and the stronger the windspeed. We therefore measure the isobar spacing, and, starting from extreme left hand side of the scale, read the windspeed in knots. (Scales, like charts, are usually based on a 2 or 4 mb isobar spacing.) *(Fig. ME 6.6).*

6.3.6 Conditions Necessary for Geostrophic Flow

The geostrophic wind was earlier described as a somewhat theoretical wind. This arises because of assumptions already made, if not stated. The wind can only be considered truly geostrophic provided that:

- The isobars are straight and parallel. This does not often occur in nature, and curved isobars cause an additional force to be brought into play, modifying the balance of forces

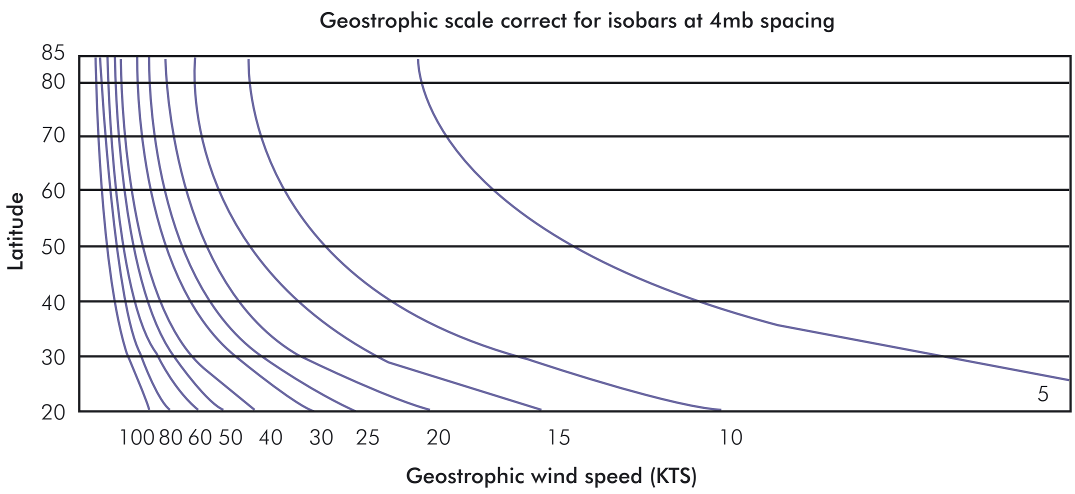

Fig. ME 6.6 Geostrophic wind scale

- The pressure distribution is not changing with time. This again is unlikely in practice and, when isobars are diverging or converging, the meteorologist has to allow for an isallobaric force

- The latitude is greater than about 10° N or S. The value of the sine of the latitude becomes so small at very low latitudes that the geostrophic wind formula gives a very high windspeed for even a nominal pressure gradient, with an infinite windspeed at the equator where Sin(lat) = 0. The formula is not valid at latitudes of 10° N or S, or less.

- There is no friction. The geostrophic wind is assumed to blow above the friction layer, at a height of 2000 ft and above

By recognising these limitations, the meteorologist can make allowances for the frequent departures from geostrophic conditions, and arrive at a reasonably accurate assessment of a likely windspeed. The remainder of this section will deal with departures from geostrophic flow.

6.3.7 Effect of Latitude and Air Density on Geostrophic Winds

As shown in the previous section on Geostrophic Wind, the PGF is directly proportional to the wind speed V and Sin(lat).

$$PGF = 2\Omega\rho V \sin(\theta)$$

Provided the PGF remains constant with increasing latitude the geostrophic wind speed will therefore decrease with increasing latitude. (Note that Sin0°=0 and Sin 90°=1). This means that for winds to increase at higher latitudes there must be stronger pressure gradient forces to compensate for the latitude effect. Thus the Geostrophic Wind speed V, is directly proportional to the PGF and inversely proportional to the isobar spacing - the closer the isobars, the stronger the PGF and the stronger the wind.

This also means that Coriolis force is zero at the equator and is a maximum at the poles. In equatorial latitudes the Coriolis Force is effectively zero and will not swing the winds to the right or left depending on the hemisphere.

If the formula is rearranged to make V, the Geostrophic Wind the subject, then the following can be deduced.

$$V = \frac{PGF}{2\Omega\rho \sin(\theta)}$$

In the above equation it can be seen that the density term ρ is now part of the denominator term. Thus as the density decreases with height and the PGF term remaining constant, the term V will increase. Thus the Geostrophic Wind speed will increase with height due to the decreasing air density.

6.4 Gradient Winds

A Gradient Wind is that wind which is constrained to blow within curved isobars adjusted in speed. Air circulating along a curved path must have a net inward acting force to maintain the curved path, called the Cyclostrophic Force (CF). Around the low it is provided by the net difference between Pressure Gradient Force (PGF) and the Geostrophic Force (GF). This means that GF must be less than PGF and consequently The Gradient Wind (G_L) around the low is less than The Geostrophic

Wind (V). Around the high, the cyclostrophic force(CF) is provided by the difference between GF and PGF. In this case the GF is greater than the PGF. Thus around the high the Gradient Wind (G_H) is greater than the Geostrophic Wind. The precise amount of speed modification depends on the isobar curvature, the latitude and the speed of the wind itself. Forecasters usually use tables to determine the amount of speed modification.

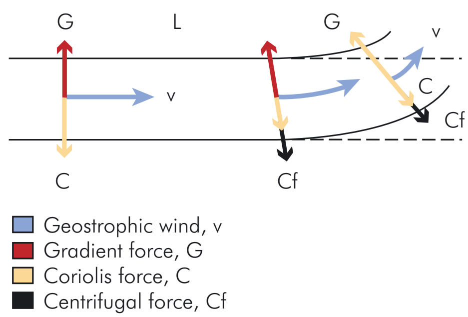

Fig. ME 6.7 Gradient wind

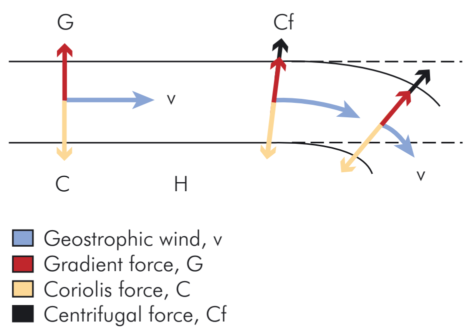

Fig. ME 6.8 Gradient wind

6.4.1 The Cyclostrophic Wind

In small scale sharply curved pressure systems and in cyclones at low latitudes the PGF is much larger than the Coriolis force while the outward acting centrifugal force increases. This results in a cyclostrophic balance where pressure gradient and centrifugal forces compensate each other. The resulting flow is known as a Cyclostrophic wind. Examples of this are the Tornado and Dust Devil.

Fig. ME 6.9 Tornado

6.5 Wind Near The Surface

6.5.1 Friction

Air moving over the earth's surface is subject to friction, which has the obvious effect of reducing the windspeed. The degree of friction depends on the surface. Over the sea the friction is less than over land, where the nature of the surface can vary from treeless prairies to mountainous regions. The depth of the layer affected also varies, and the associated turbulence depends on the: