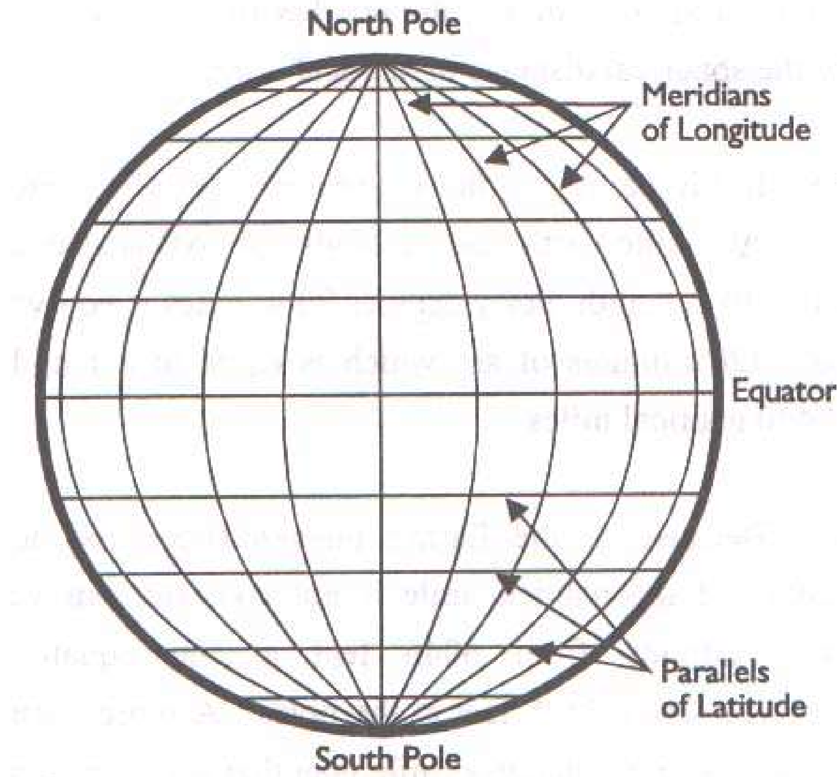
CHAPTER 1

THE EARTH

The earth is not a perfect sphere, there is a slight bulge at the Equator and a flattening at the Poles. The earth's shape is described as an oblate spheroid. The polar diameter is 6860.5 nm which is 23.2 nm shorter than the average equatorial diameter of 6883.7 nm. This gives a compression ratio of 1/2967 which for all practical purposes can be ignored. Cartographers and Inertial Navigation systems will take the true shape of the earth into account.



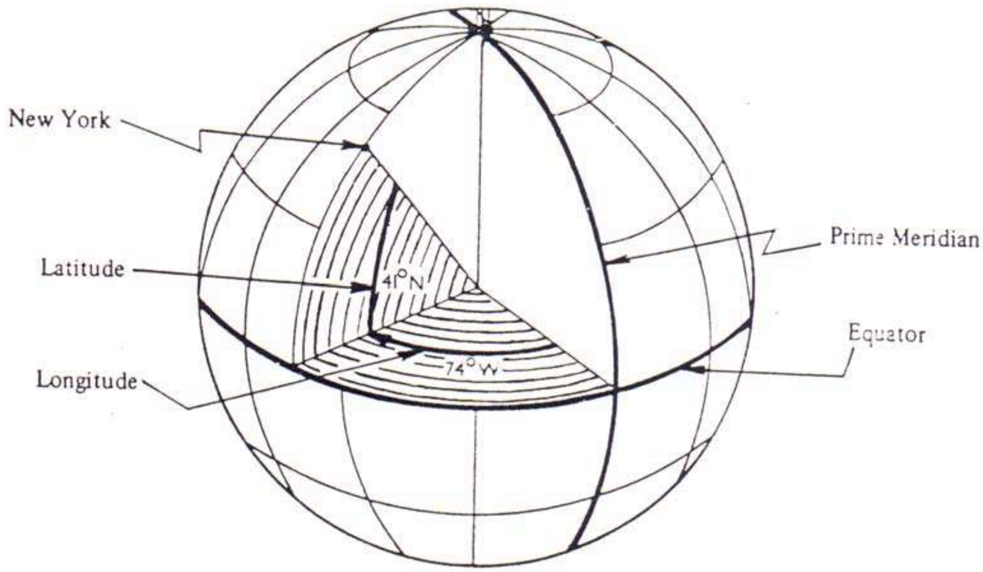
PARALLELS OF LATITUDE

Parallels of Latitude are small circles that are parallel to the Equator. They lie in a 090° and 270° Rhumb Line direction as they cut all Meridians at 90°.

LATITUDE

The Latitude of a point is the arc of a Meridian from the Equator to the point. It is expressed in degrees and minutes North or South of the Equator. It can be presented in the following forms.

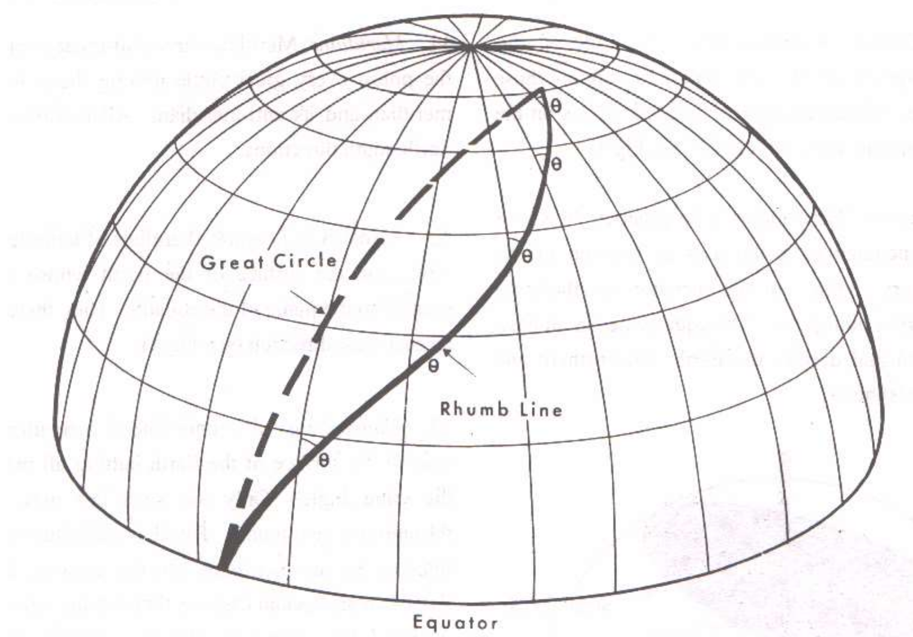
N 27:30   27:30 N   27°30'N   35°25'45"S   35:25:45S



LONGITUDE

The Longitude of a point is the shorter arc of the Equator measured East or West from the Greenwich Meridian. It can be presented in the following forms.

E032:15   32°15' E   32:15 E   65°24W   65°24’38”W   65:24:38 W



GREAT CIRCLE GC

A Great Circle is a circle drawn on the surface of a sphere whose centre and radius are those of the sphere itself. A Great Circle divides the sphere into two halves. The Equator is a Great Circle dividing the earth into the Northern and Southern Hemispheres. On a flat surface the shortest distance between TWO points is a straight line. On a sphere the shortest distance between two points is the shorter arc of a Great Circle drawn through the two points. To fly from Europe to the West Coast of America the shortest distance is of course a Great Circle which usually takes the least time and fuel used. A Great Circle cuts all Meridians at different angles.

RHUMB LINE RL

A Rhumb Line is a curved line drawn on the surface of the earth which cuts all Meridians at the same angle. An aircraft steering a constant heading of 065°(T) with zero wind will be flying a Rhumb Line.

MERIDIANS

Meridians are Great semi-circles that join the North and South Poles. Every Great Circle passing through the poles forms a Meridian and its Anti-Meridian. All Meridians indicate True North or 000°(T) and 180°(T). As Meridians have a constant direction they are Rhumb Lines as well as Great Circles.

EQUATOR

The Equator cuts all Meridians at 90° providing a True East-West or 090°(T) and 270°(T) erection. As the Equator cuts all Meridians at 90° it is a Rhumb Line as well as a Great Circle.

SMALL CIRCLE

A Small Circle is a circle drawn on a sphere whose centre and radius are **not** those of the sphere itself.

DIRECTION

TRUE NORTH

True North is the direction of the Meridian passing through a position.

TRUE DIRECTION

Aircraft Heading or Track is measured clockwise from True North. It is usually expressed in degrees and decimals of a degree, e.g. 092°(T)   107.25° GC   265.37° RL

MAGNETIC NORTH

Magnetic North is the direction in the horizontal plane indicated by a freely suspended magnet influenced by the earth's magnetic field only.

VARIATION

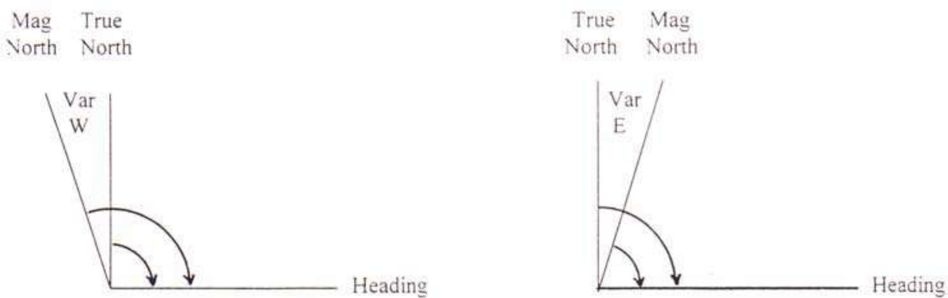
Variation is the angular difference between True North and Magnetic North

Variation is Westerly when Magnetic North is West of True North

Variation is Easterly when Magnetic North is East of True North

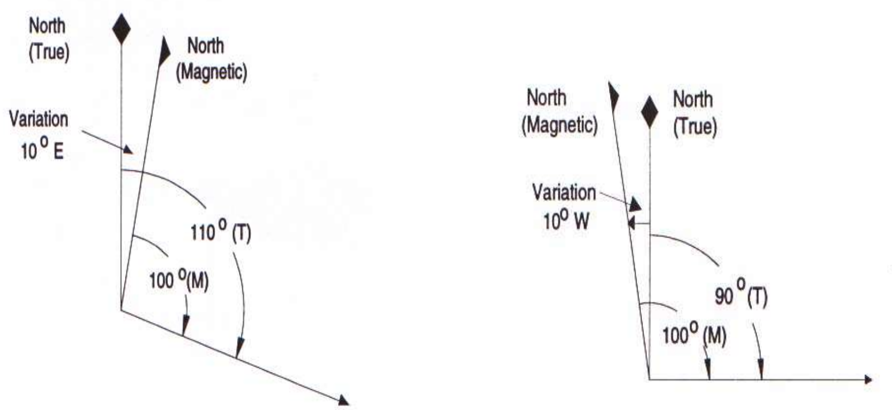
MAGNETIC DIRECTION (M)

Aircraft Magnetic Heading or Magnetic Track is measured clockwise from Magnetic North, which is sometimes referred to as the Magnetic Meridian, e.g. 100°(M)



Heading 090°(T) Var 20°W 110°(M) | Heading 090°(T) Var 20°E 070°(M)

VARIATION WEST MAGNETIC BEST | VARIATION EAST MAGNETIC LEAST



COMPASS NORTH (C)

Compass North is the direction indicated by the compass needle in an aircraft. Magnetic Fields in the aircraft will attract the compass needle away from Magnetic North causing Compass Deviation.

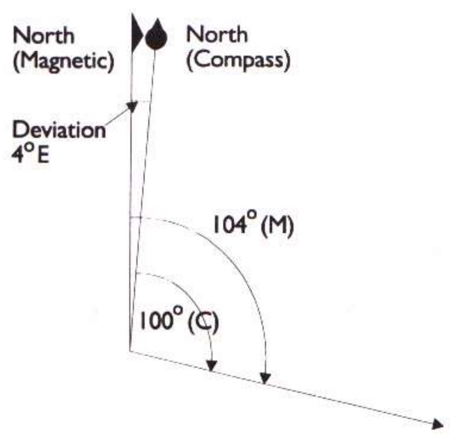
DEVIATION

The angular difference between Compass North and Magnetic North.

Deviation is Westerly when Compass North is to the West of Magnetic North
Deviation is Easterly when Compass North is to the East of Magnetic North

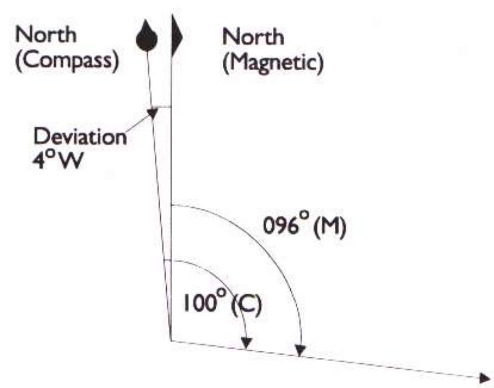
DEVIATION EAST COMPASS LEAST

Heading I00°(C) Dev+4°e 104°(M)



DEVIATION WEST COMPASS BEST

Heading 100°(C) Dev-3°w 096°(M)



Deviation West is Negative (-)

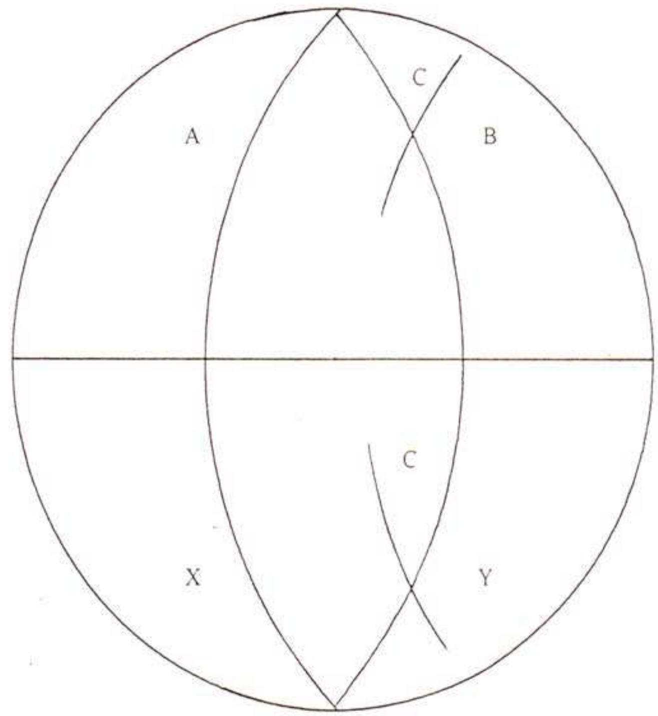
Deviation East is Positive (+)

Deviation is a correction to Compass Heading to give Magnetic Heading

CONVERGENCY AND CONVERSION ANGLE

CONVERGENCY

Meridians are Semi Great Circles joining the North and South Poles. They are parallel at the Equator. As the meridians leave the Equator either Northwards or Southwards they converge and meet at the Poles.



Convergency is defined as the angle of inclination
Between two selected meridians measured at a given Latitude.

Considering the two meridians shown above, one at 20W and the other at 20E. The Change of Longitude (**Ch. Long**) or Difference in Longitude (**D Long**) between the two meridians is 40°.

At the Equator (Latitude 0°) they are parallel, the angle of convergence is 0°. At the Poles (Latitude 90°) they meet, and the angle of convergence is the Difference of Longitude, 40°.

At any intermediate Latitude the angle of inclination between the same two meridians will between 0° and 40° depending on the Latitude.

This is a sine relationship, convergence varies as **Sine Mean Latitude**. Convergency also varies as the Change of Longitude between the two meridians. The greater the Ch. Long, the greater the convergency.

Convergency = Ch. Long x Sine Mean Latitude

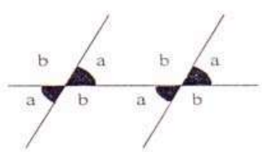
Ex 1. Calculate the value of Convergence between A (N 45:25 E 025:36) and B(N 37:53 E042:17).

A	N 45:25	E 025:36
B	<u>N 37:53</u>	<u>E042:17</u>
	N 41:39 Mean Latitude	16:41 Change of Longitude

$$
\begin{aligned}
\text{Convergency} &= \text{Ch. Long}^\circ \times \text{Sin Mean Latitude} \\
&= 16^\circ 41' \times \text{Sin } 41^\circ 39' \\
&= 16.6833^\circ \times \text{Sin } 41.65^\circ \\
&= 11.0874^\circ
\end{aligned}
$$

NOTE Both Mean Latitude and Change of Longitude must be changed into decimal notation.

Grade 1 Geometry refresher - If two parallel lines are intersected by a third line.



angles a are equal

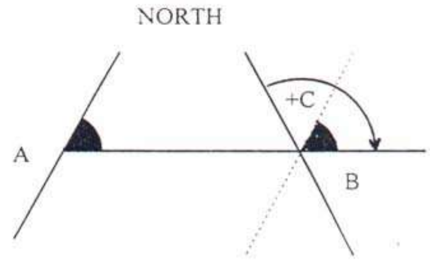
angles b are equal

The Great Circle (GC) Track crosses every Meridian at a different angle

THE MERIDIANS CONVERGE TOWARDS THE NEARER POLE

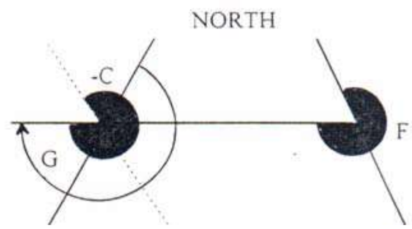
NORTHERN HEMISPHERE

Initial GC Track A to B	075°
Convergency	+38°
GC Track at B	113° GC



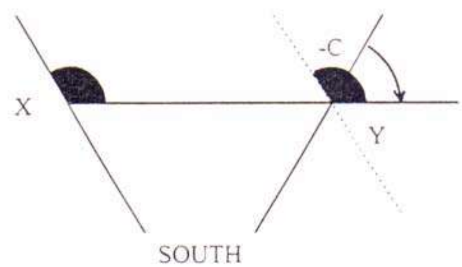
The Meridian passing through A is paralleled through B (dashed line). The two solid angles (Initial Track) are equal. The angle of Convergency is added to the Initial GC Track at A to give the GC track at B.

Initial GC Track F to G	285° GC
Convergency	- 33°
GC Track at G	252° GC

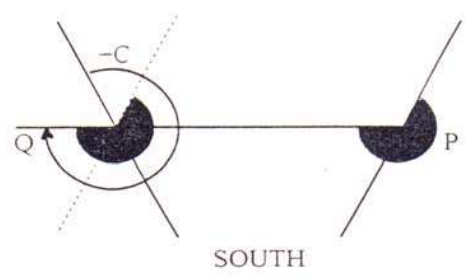


SOUTHERN HEMISPHERE

Initia
Conv Initial GC Track X to Y 125° GC
GC 1 Convergency - 43°
GC Track at Y 082° GC



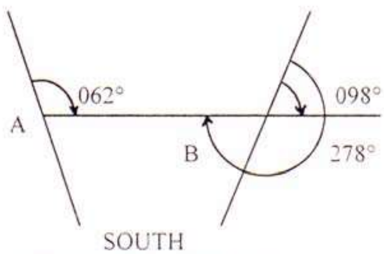
Initial GC Track at P	257° GC
Convergency	+38°
GC Track at Q	295° GC



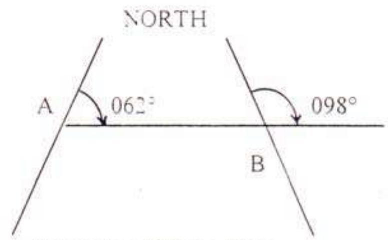
CONVERGENCY = CHANGE OF LONGITUDE x SIN MEAN LATITUDE
CONVERGENCY = DIFFERENCE BETWEEN INITIAL AND FINAL GC TRACKS

Q 1. A and B are in the same hemisphere
The Great Circle Track from A to B is 062°
The Great Circle Track from B to A is 278°

(a) In which hemisphere are A and B?
(b) What is the value of Convergence between A and B?



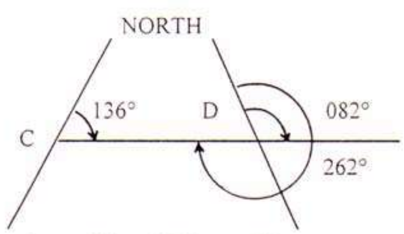
Impossible 098° > 062°
Angle at B must be physically larger



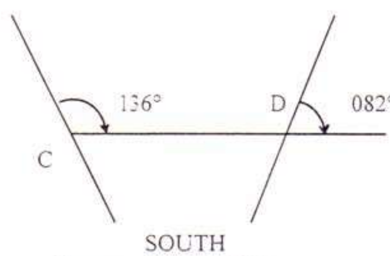
Correct as 098° > 062°
both physically and numerically
098° - 062° Convergency 36°

Q2. C and D are in the same hemisphere
The Great Circle bearing of D from C is l36° (bearing of D measured at C)
The Great Circle bearing of C from D is 262° (bearing of C measured at D)

(a) In which hemisphere are C and D?
(b) What is the value of Convergency between C and D?



Impossible 082° < 136°
Angle at D must be physically smaller than C

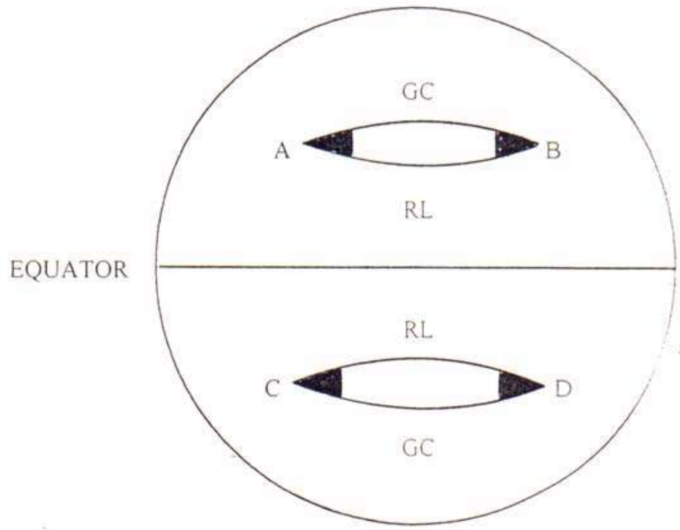


Correct 082° < 136°
136° - 082° Convergency 54°

CONVERSION ANGLE CA

CONVERSION ANGLE = DIFFERENCE BETWEEN GREAT CIRCLE AND RHUMB LINE

Conversion Angle (CA) is used to change Great Circle bearings and tracks into Rhumb Line bearings and tracks or vice versa.



Conversion Angle at A equals Conversion angle at B

THE GREAT CIRCLE IS ALWAYS NEARER THE POLE
THE RHUMB LINE IS ALWAYS NEARER THE EQUATOR

CONVERSION ANGLE = ½ CONVERGENCEY

CONVERGENCY = TWICE CONVERSION ANGLE

CONVERGENCY = CHANGE OF LONGITUDE° x SIN MEAN LATITUDE

CONVERSION ANGLE = ½ CHANGE OF LONGITUDE° x SIN MEAN LATITUDE

CONVERSION ANGLE = DIFFERENCE BETWEEN GREAT CIRCLE AND RHUMB LINE

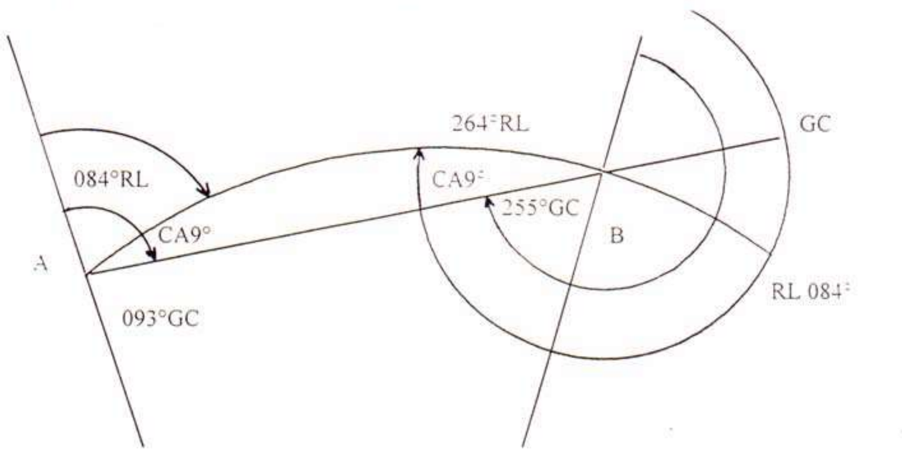
CONVERGENCY - DIFFERENCE BETWEEN INITIAL AND FINAL GREAT CIRCLES

The Rhumb Line is a constant direction. If the Rhumb Line track from A to B is 100º, then the Rhumb Line track from B to A is 280º. You can always take the reciprocal of a Rhumb Line, NEVER A GC.

Initial GC track A to B is 080° GC, initial GC track B to A is 300° GC (Conversion angle 20°)

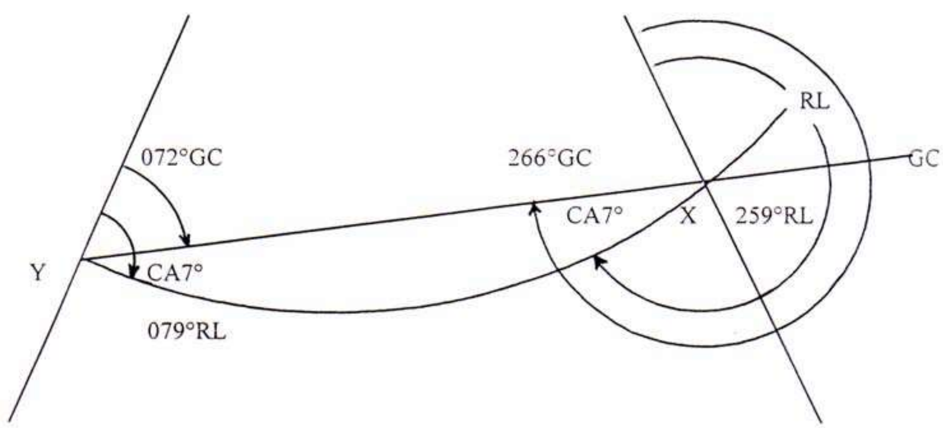
Q3 The Great Circle bearing of A from B is 255° GC
The Rhumb Line bearing of B from A is 084° RL

If both positions are in the Southern Hemisphere the Great Circle bearing of B from A is :-



Bearing of A from B	255° GC	Bearing of B from A	084°RL
Conversion Angle	9°	Conversion Angle	9°
Bearing of A from B	264° RL	Bearing of B from A	093° GC

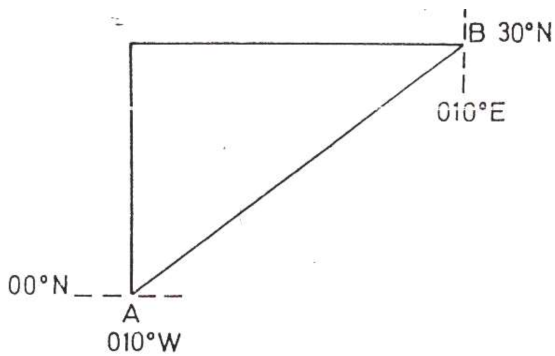
Q4 The Great Circle bearing of X from Y is 072° GC
The Rhumb Line bearing of Y from X is 259° RL



Bearing of Y from X	259° RL		
Bearing of X from Y	079° RL	Bearing of Y from X	259° RL
Conversion Angle	7°	Conversion Angle	7°
Bearing of X from Y	072° GC	Bearing of Y from X	266° GC

THE CALCULATION OF RHUMB LINE TRACKS AND DISTANCES

Departure must be used when determining rhumb line tracks and distances.
Calculate the rhumb line track and distance between A (00° N and 010° W) and B (° N 010° E).

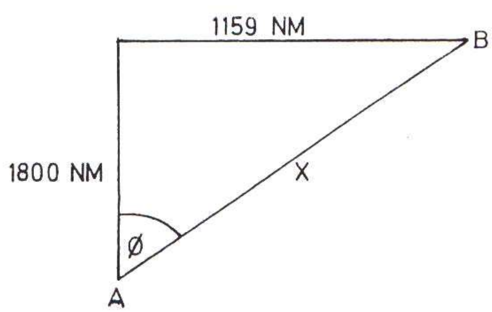


In order to express the dLAT in nm's :

dLAT	=	30°
	=	1800'
	=	1800 nm (No Departure)

In order to express the dLONG in nm's,

DEP (nm)	=	dL' x COS MID LAT
	=	1200' x COS 15°
	=	1159 nm



To determine angle A :

$$\text{TAN } \varnothing = \frac{1159 \text{ nm}}{1800 \text{ nm}}$$

$$\text{TAN } \varnothing = 0.6438$$

$$\varnothing = 32.8^{\circ} \text{ (rhumb line track A - B)}$$

To determine distance x, use Pythagoras:

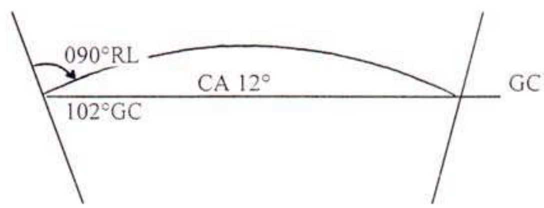
$$x^2 = 1800^2 + 1159^2$$

$$x^2 = 4583281 \text{ nm}$$

$$x = \sqrt{4583281 \text{ nm}}$$

$$x = 2141 \text{ nm (rhumb line distance A - B)}$$

Q5 The Great Circle Track from A (S 32:25 E 019:45) to B is 102°
If B is on the same parallel of Latitude the Longitude of B is :-



If two positions are on the same parallel of Latitude the Track is 090°/270° RL

If CA is 12°, then Convergency is 24°

Convergency = Ch. Long x sin Latitude
24° = Ch. Long x sin 32°25'

$$\frac{24°}{\sin 32.4167°} = \text{Ch. Long } 44.7701° = 44°46' \text{ East of E } 019{:}45 = \text{E } 064{:}31$$

It is important to note that this method of determining rhumb line tracks and distances is very limited in terms of its accuracy

DISTANCE

KILOMETRE (KM.)
A Kilometre is 1/10 000 th. part of the average distance from the Equator to either Pole
It generally accepted to equal 3280 feet.

STATUTE MILE (SM)
Defined in British law as 5280 feet

NAUTICAL MILE (NM)
A Nautical Mile is defined as the distance on the surface of the earth of one minute of arc at the centre of the earth. As the earth is not a perfect sphere the distance is variable.

At the Equator 1 NM is 6046.4 feet At the pole 1 NM -is 6078 feet

For navigation purposes the Standard Nautical Mile is 6080 feet (South Africa and UK)

ICAO 1 NM = 1852 metres or 6076.1 feet

Most navigational electronic calculators use 1 NM = 6076.1 feet. To answer questions in the CAA examinations any of the following may be used :-

1 NM = 6080 feet or 1853 metres   1 NM = 6076.1 feet: or I852 metres

Conversion Factors   1 Foot = 12 inches
1 Inch = 2.54 Centimetres

As one minute of arc is 1 NM, then Great Circle distance along a Meridian can be calculated. One minute of Latitude is 1 NM and 1Degree of Latitude is 60 NM.

The Great Circle distance from N75:30 E065:45 to N82:15 W114:15 is:-

As W114:15 is the anti-meridian of E065:45 the Great Circle distance is along a Meridian over the Pole where 1° of Latitude equals 1 nm.

N 75:30 to the Pole = 14°30' change of Latitude (14°=x 60 = 840 nm-30 nm) = 870nm
Pole to N 82:15 = 7°45' change of Latitude (7° x 60 = 420nm + 45nm) = 465nm + 870nm = 1335nm

CHANGE OF LONGITUDE (CH. LONG) or DEPARTURE DISTANCE

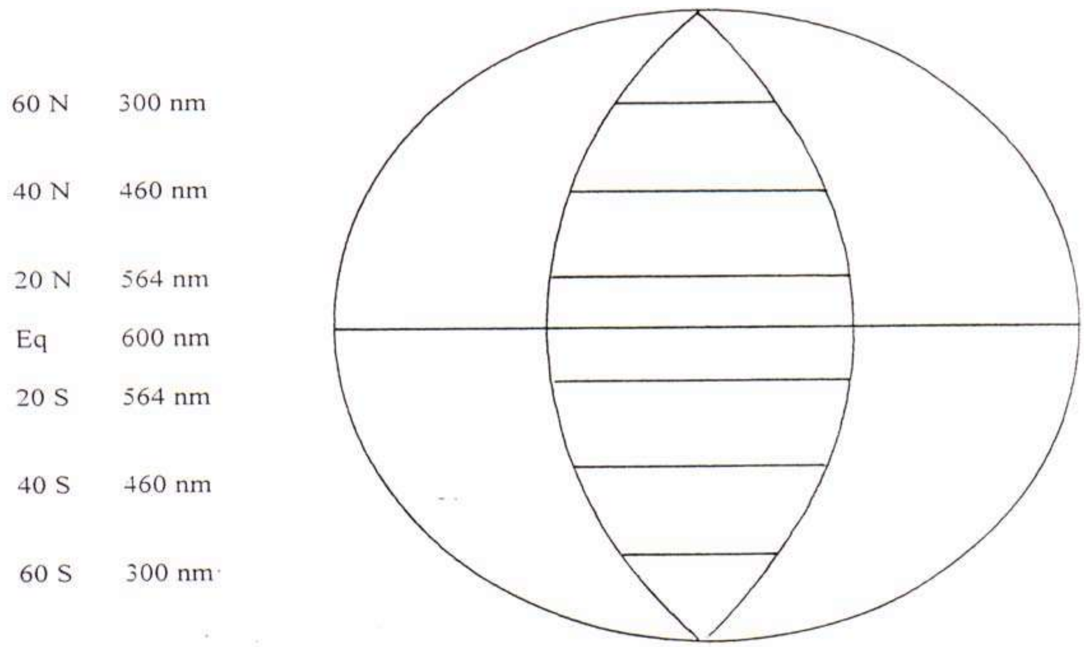
Departure is the distance in Nautical Miles along a parallel of Latitude in an East-West direction.

At the Equator, two meridians (5W and 5E) have a change of Longitude of 10 of arc. As the Equator is a Great Circle, 10 of arc equals 600 nautical miles. As Latitude increases, either to the North or to the South, the meridians converge, and the distance between them decreases, until they meet at the Poles where the distance between them is zero.
Departure (nm) = ch long (mins) x cos mean lat:

The departure between any 2 points is thus a function of their latitudes and the change of longitude, and the relationship is given by

$$\text{Where mean lat} = \frac{\text{lat A + lat B}}{2}$$

E 032:45	W 067:25	Both East or West SUBTRACT
E 021:15	E 027:30	One East & One West ADD
11:30Ch.Long	94:55 Ch. Long	



DEPARTURE = CHANGE of LONGITUDE (in minutes) x COSINE LATITUDE

Q1 The distance from A (N 20:10 E 005:00) to B (N 20:10 \V 005:00) is :-

Departure = Ch. Long x cos Lat
= 10° x 60 x cos20°10'
= 600 x cos 20.1667°
= 563.2163 nm

Q2 An aircraft leaves A (E 012:30) and flies along the parallel of S 29:30 in an Easterly direction. After flying 1050 nm its Longitude is :-

Departure = Ch. Long x cos Lat
1050nm = Ch. Long xcos29°30'

$\frac{1050\text{ nm}}{\cos 29.5°}$ = 1206.4 minutes of Longitude

$\frac{}{60}$ = 20° 06' 24" Easterly
+ 12° 30'
032° 36' 24" E

Q3 An aircraft in the Northern Hemisphere flies around the world in an Easterly direction at an average groundspeed of 515 Kts in 14 hours. The Latitude at which the aircraft flew was :-

Departure	=	Ch. Long cos Latitude
GS 515 x 14 Hrs	=	360° x 60 x cos Lat

$$\frac{7210}{21600} = \quad \text{cos Lat} = 70°\ 30'\ \text{N}$$

DISTANCE ALONG A PARALLEL OF LATITUDE IS DEPARTURE
DISTANCE ALONG A MERIDIAN IS CHANGE OF LATITUDE

As a Meridian is a Great Circle, then the arc of Change of Latitude can be converted into nautical miles.

Q4 The shortest distance from A (N 78:15 W 027:13) in B (SS3:30 E 15.2:4-) is :-

As E 152:47 is the anti-meridian of W 027:13, A to B is the arc of a Great Circle.

N 78:15 to the North Pole	=	11:45 Change of Latitude
North Pole to N 82:30	=	7:30 Change of Latitude
		19:15 Change of Latitude

19° x 60 = 1140nm+ 15 minutes = 1155nm shortest (GC) distance A to B

Q5 An aircraft departs A (N 25:13 W017:25) and flies a track of 090°(T**)** at GS 360 for I hour 35 minutes. Then the aircraft flies a track of I80° (T) for I hour 55 minutes and arrives at position;

Departure = Ch. Long x cos Latitude

N 25:13 W 017:25 ;

Track 180°
Change of Latitude

Departure = Ch. Long x cos Latitude

$$\frac{\text{Departure}}{\text{cos Lat}} = \text{Ch. Long}$$

$$\frac{\text{GS360 x 1:35}}{\text{cos 25:13}} =$$ 630 minutes of Longitude = 10°30-East of W 017:25 = W 006:55

Track 180° = Change of Latitude

Old Latitude N 25:13
11:30

GS360 x 1:55 = 690nm = 11°30 Southern-Change of Latitude = position N 13:43 W 006:55

RADIO BEARINGS

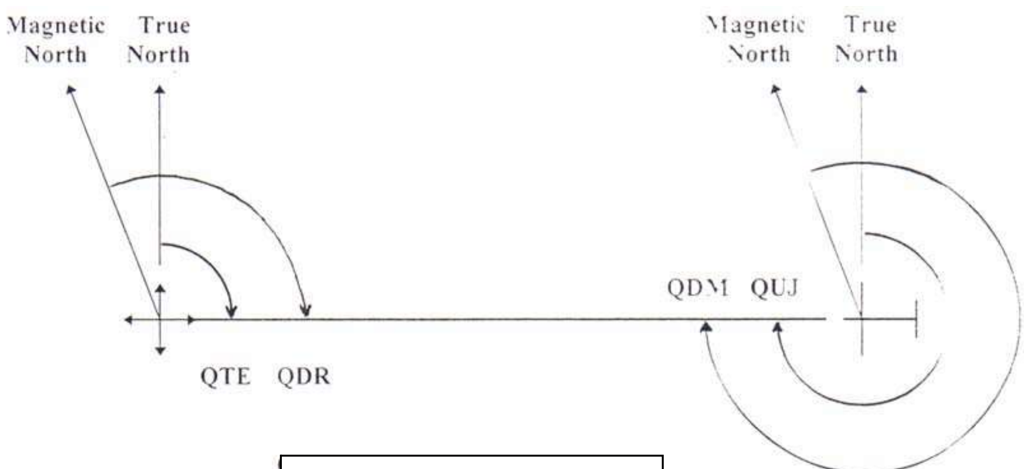
VHF D/F   VERY HIGH FREQUENCY - DIRECTION FINDING   VDF

Major airports in South Africa have a VDF service, it is usually on the Approach frequency and will provide radio bearings to aircraft on request. The aircraft transmits on the appropriate frequency and direction finding equipment at the airport will sense the direction of the incoming radio wave. The bearing will be passed to the aircraft in Q-code form.

Q CODE	QTE	**TRUE** bearing **FROM** the VDF station
	QDR	**MAGNETIC** bearing **FROM** the VDF station
	QUJ	**TRUE** track **TO** the VDF station
	QDM	**MAGNETIC** track **TO** the VDF station

QDM	±Variation = QUJ
±180°	±180°
QDR	±Variation = QTE

Take the shortest route to change one bearing to another



QDM	±Variation	QUJ
±180°		±180°
QDR	=Variation	QTE

VOR VOR Radials are Magnetic bearings **QDR**
RMI Readings are Magnetic tracks to the VOR **QDM**

RMI BEARINGS (VOR & ADF)

Usually termed RMI READING which is **QDM** (for ADF RMI ± DEV= QDM)

ADF BEARINGS

ADF Relative bearings are measured from the Fore and Aft axis of the aircraft.
ADF Relative bearings must be converted into True Bearings (QTE) before they can be plotted on a chart.

RELATIVE BEARING + TRUE HEADING = QUJ ± 180° = QTE

MAGNETIC VARIATION AT THE AIRCRAFT IS ALWAYS USED WITH ADF BEARINGS

ADF bearing	095° Relative
Heading (T)	+ 057°
QUJ	152° (T) TO NDB
	± 180°
QTE	332° (T) FROM NDB

ADF bearing	200° Relative
Heading (T)	318°
QUJ	518°
Subtract	360°
QUJ	158° (T) TO NDB
	± 180
QTE	338° (T) FROM NDB

QUESTIONS

1. The great circle bearing from A to B is 260°. Convergency 12°. Southern hemisphere.

   i) What is the rhumb line bearing from B to A?

   ii) What is the great circle bearing from B to A?

2. Positions A and B are in the same hemisphere. The great circle bearing from A to B is 140°. The great circle bearing from B to A is 330°.

   i) In which hemisphere are A and B?

   ii) What is the rhumb line bearing from B to A?

3. At what latitude on earth is the convergency twice the value of convergency at 25°N?

4. Position A (40° N 170° E). Position B is on the same parallel of latitude. The great circle bearing from A to B is 082°.

   What is the longitude of position B?

5. What is the rhumb line distance from A (30° N 070° E) to B (30° N 085°E)?

6. An aircraft flies around the world on a rhumb line track of 090° at a ground speed of 480 Kts. The flying time if 19 hours.

   At what latitude did the aircraft fly?

7. An aircraft (G/S 480 Kts) departs position A (20° N 010°E) on a track of 360° for 3 HRS. It then turns onto a track of 270° for 2 HRS 30. It then turns onto a track of 180° for 4 hours.

   What is the position of the aircraft at the end of the 3rd leg?

8. What is the shortest distance between A (065° N 13° 30’ W) and B (78° N 166° 30’E)?