CHAPTER 04

Compass Traverse

4.1 Introduction

- The word **traverse means to pass across.**
- In compass surveying, the direction of survey lines are measured with a compass and thus is known as compass surveying.
- The lengths of survey lines are measured with a tape or a chain.
- In surveying, the traverse consists of a series of straight lines connected together to form an open or a closed traverse.
- The end points of the traverse lines are called as **traverse stations.**
- At each of the traverse station where the traverse lines meet, an angle is formed which is measured with compass.
- Compass being light and handy, and is thus used for reconnaissance survey.

4.2 Traversing Methods

Traversing methods are classified as the basis of the instrument used for measuring the angle at the traverse station. Thus according to the type of instrument used, traversing methods can be classified as:

(a) Chain Traverse: In chain traverse, the directions of the traverse lines are fixed by taking adequate ties near the traverse stations. Chain traverse is not a precise method of traversing.

(b) Compass Traverse: Here in this method of traversing, the angles are measured with the help of a magnetic compass. But magnetic compass itself has its own limitations and thus accuracy of compass traverse is also very limited.

(c) Plane Table Traverse: It is a unique method of traversing in a way that traverse can be plotted directly in the field but it is not a very precise method.

(d) Stadia Traverse: In stadia traverse, the length of the traverse lines, the angles between the traverse lines and the elevations of the traverse stations are determined with the help of an instrument called tacheometer. This method gives elevations of traverse stations also in addition to provide horizontal control.

(e) Theodolite Traverse: In this method of traversing, the angles are measured with the help of a theodolite. It is the most precise method of traversing in order to have an accurate horizontal control.

4.3 Traverse Surveying versus Chain Surveying

Table 4.1 *Traverse surveying v/s Chain surveying*

Traverse Surveying	Chain Surveying
Its framework consists of series of lines forming an open or a closed polygon.	Its framework consists of series of triangles.
Here angles at traverse stations are measured and thus these can be plotted without constructing triangles.	Here because no angles are measured, these are plotted using triangles.
It is used for relatively large areas.	It is used for small areas and for fairly flat terrains.

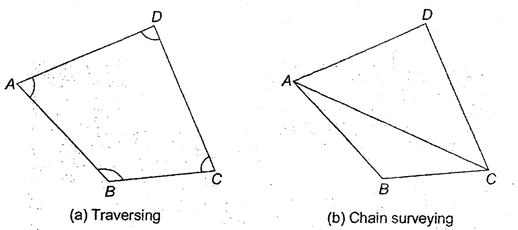


Fig. 4.1 *Traversing and chain surveying*

4.4 Types of Traverse

(a) Closed traverse (b) Open traverse

4.4.1 Closed Traverse

- This type of traverse initiates from one traverse station and terminates either at the same starting station or at some other traverse station whose location is already known.
- In link traverse as shown in Fig. 4.2(b), the location of traverse stations *A* and *E* are known with respect to reference stations *A′* and *E′* respectively.
- Any error in closed traverse can easily be detected and thus can easily be adjusted.

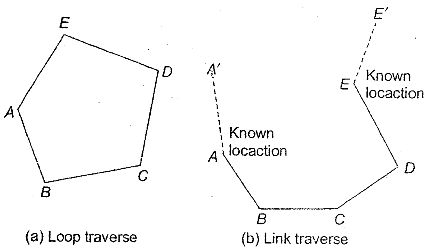


Fig. 4.2 *Closed traverse*

4.4.2 Open Traverse

- An open traverse initiates from one station whose location is known but terminates at a station whose location is neither known nor established.
- Open traverse is generally used for aligning a railway line or a highway or canal etc. An open traverse cannot be properly checked and adjusted.

4.5 Meridians

- The direction of a line is expressed in terms of horizontal angle which the line makes with a reference line.
- This direction of line is generally measured in clockwise direction.
- This fixed reference line is called as **meridian.**

Four types of meridians are used in surveying viz.:

(a) True meridian (b) Magnetic meridian
(c) Grid meridian (d) Arbitrary meridian

4.5.1 True Meridian

- True meridian of the point P is the great circle passing through P and the geographical north and south poles of the earth.
- Alternatively, true meridian may be defined as the plane passing through the point P on the surface of earth and containing the earth's axis of rotation.
- For plane surveying, true meridian is taken as the plane passing through the point P on the surface of earth and north and south poles of the earth.
- The geographical poles are the points of intersection of earth's axis of rotation with the surface of earth. These geographical poles are also called as **true poles.**
- True meridian at a point is determined from astronomical observations to the Sun and the stars. True meridian is fixed and does not change with time.

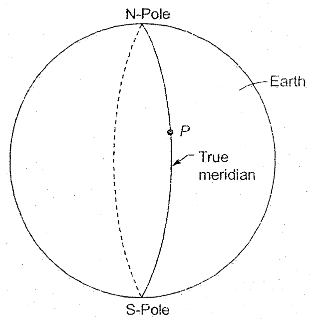


Fig. 4.3 *True Meridian*

- True meridian of various points on the surface of earth actually converge at the poles but for plane surveying, these are assumed to be parallel to each other.

4.5.2 Magnetic Meridian

- Magnetic meridian at a point is the direction indicated by a freely suspended balanced magnetic needle at that point.
- It is very important that magnetic needle should not be affected by the magnetic forces other than that of earth in order to obtain the correct direction of magnetic meridian.
- The earth is sort of a very large magnet with its north pole located at the south end of geographic north.
- The magnetic poles are not fixed in position and they change their positions continuously due to the reasons still not known.
- The freely suspended magnetic needle comes to rest in a position parallel to the line passing through the magnetic north and south poles, and hence it indicates the direction of magnetic meridian at that place.

4.5.3 Grid Meridian

- In order to survey a very large area, say, survey of a state or a country, true meridian of a central place is often taken as the reference meridian for the whole state or the country. This reference meridian is called as grid meridian. The meridians of all other places are assumed to be parallel to the grid meridian.

- A line parallel to the grid meridian and passing through the point on the surface of earth indicates the direction of grid north and grid south.

4.5.4 Arbitrary Meridian

- It is the meridian that is taken in any convenient arbitrary direction.
- Any reference line can be taken as arbitrary meridian.
- Many a times, the direction of first traverse line is taken as arbitrary meridian.
- It is a good practice to select arbitrary meridian roughly along the direction of true meridian.
- Arbitrary meridian is used to determine the relative directions of various traverse lines of a traverse.

4.6 Bearing

The bearing of a horizontal line is the angle which it makes with the reference line/meridian. There are four types of bearings as described below.

4.6.1 True Bearing

- True bearing of a line is the horizontal angle which the line makes with the true meridian.
- Since true meridian does not change with time and thus true bearing also remains constant.
- The true bearing of a line is also called as **azimuth**.
- True bearing is measured from the north in clockwise direction. In astronomical and geodetic surveying, true meridian is measured from true south.
- True bearing of a line is determined from astronomical observations.

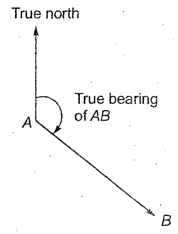


Fig. 4.4 *True bearing*

4.6.2 Magnetic Bearing

- The magnetic bearing of a line is the horizontal angle which it makes with the magnetic north.
- Since magnetic meridian changes gradually with time and thus magnetic bearing also gets changed with time. For this reason only, magnetic bearing is used in small and relatively less important survey works.
- The magnetic bearing is determined from either the *Prismatic Compass* as Whole Circle Bearing (WCB) or from *Surveyor's* compass as Quadrantal Bearing (*QB*).

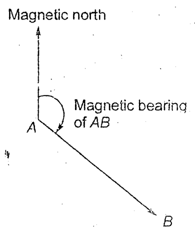


Fig. 4.5 *Magnetic bearing*

4.6.3 Grid Bearing

The grid bearing of a line is the horizontal angle which it makes with the grid meridian.

4.6.4 Arbitrary Bearing

Arbitrary bearing of a line is the horizontal angle which it makes with the arbitrary meridian.

4.7 Bearings Designation

(a) Whole circle bearing system (b) Quadrantal bearing system

4.7.1 Whole Circle Bearing System

- In this system, the bearing of the line is measured from the north in clockwise direction.
- Thus whole circle bearing (abbreviated as **WCB**) of a line is the horizontal angle which the line makes with the north end of the reference meridian.
- The WCB of a line can vary from 0° to 360°.

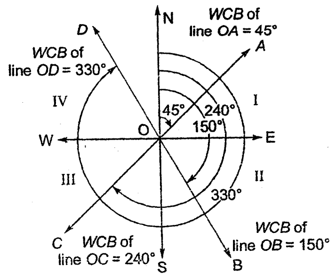


Fig. 4.6 *WCB system*

4.7.2 Quadrantal Bearing System

- The quadrantal bearing of a line (abbreviated as *QB*) is the acute angle which the line makes with the meridian.
- Quadrantal bearing is measured either from north end or south end as the case may be i.e. whichever is nearer to the line. The quadrantal bearing of a line can vary from 0° to 90°.
- Letters *N*, *E*, *W* and *S* are used respectively for north, east, west and south.

While writing the quadrantal bearing, the following steps are followed:

Step-1: First write either *N* or *S* if the line is nearer to the north or south, as the case may be.

Step-2: Write the angle (usually in degrees) which the line makes with the north or south, as the case may be.

Step-3: Write letter *E* if line is in either I or II quadrant or W if line is in either III or IV quadrant.

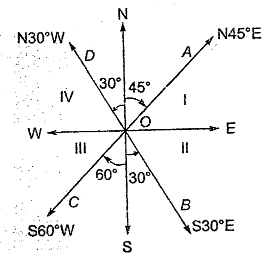


Fig. 4.7 *Quadrantal bearing system*

The whole circle bearing can be converted to quadrantal bearing and vice-versa.

Table 4.2 Conversion table for WCB and QB

Line	Quadrant	WCB	QB
OA	I	θ = 0° to 90°	NθE
OB	II	θ = 90° to 180°	S(180° – θ)E
OC	III	θ = 180° to 270°	S(θ – 180°)W
OD	IV	θ = 270° to 360°	N(360° – θ)W

4.8 Fore Bearing and Back Bearing

- **Fore bearing** (abbreviated as *FB*) is the bearing of the line in the direction of progress of survey while **back bearing** (abbreviated as *BB*) is the bearing of the line opposite to the direction of progress of survey.
- The difference of *FB* and *BB* of a line is always 180° if both the stations are perfectly free from local attractions.

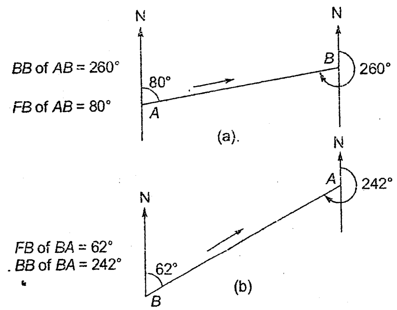


Fig. 4.8 *FB and BB*

4.9 Magnetic Needle

- It is magnetized iron in the form of long, narrow strip.
- It is freely suspended at its centre of gravity and takes turn in the horizontal plane and aligns itself parallel to lines of magnetic force of earth at that location of magnetic needle.
- The pivot which carries the needle must be extremely fine so as the reduce the friction.
- Magnetic needles used in surveying are provided with a lever which is used to lift-off the needle from the pivot.

In surveying, two types of magnetic needles are used viz.:

(a) **Edge bar needle:** This type of needle is used in surveyor's compass.

(b) **Broad needle:** This type of needle is used in prismatic compass.

4.9.1 Characteristic of a Good Magnetic Needle

- The magnetic needle should be perfectly straight and symmetrical.
- The two axes of needle viz. the magnetic axis and the geometrical axis should coincide.
- For good results, magnetic needle should be sensitive and not the sluggish.
- The ends of the needle and the pivot point should lie in the same horizontal and vertical plane.
- The pivot should be extremely fine and also hard.
- The needle centre should exactly lie on the pivot.
- In order to increase the stability of needle, the centre of gravity of the needle should be close to the pivot as possible.

4.10 Using the Surveyor's Compass

Surveyor's compass is used to measure quadrantal bearing of a line. After the necessary temporary adjustments, the needle is released to swing freely on the pivot. In order to determine the quadrantal bearing of a line (say *PQ*), then compass is set up at *P*. The compass is then turned so that the object vane is directed to the ranging rod at station *Q*. Thus the line of sight is now along *PQ*. Bring the hair of the object vane exactly over the ranging rod by rotating the compass, if required. Take the reading on the graduated ring at north end of the needle. The surveyor is required to move to the position near the north end of the needle for taking the reading. This gives the quadrantal bearing of the line *PQ*.

4.11 Using the Prismatic Compass

The prismatic compass is used to measure the whole circle bearing (WCB) of a line, say line *AB*. The compass is set up at station *A* and temporary adjustments are done. Then turn the compass box till the ranging rod at station *B* gets bisected by the vertical hair in the vane when looked through the slit in the eye vane. Take reading of the aluminium ring through the aperture in the prism mounting. Read the graduation where the vertical hair of the object vane when produced appears to cut the image of the graduated ring.

4.12 Permanent Adjustment of a Compass

Permanent adjustments are those adjustments which are not done in a routine manner but are carried out only when it is suspected that the instrument is not functioning well or are done in the factory.

4.12.1 Permanent Adjustment of Surveyor's Compass

(a) **Adjustment of levels:** This adjustment is required in the compass which is provided with two level tubes at right angles to each other. When the bubble is at the center of tube then the tangential line to the bubble will be normal to the direction of vertical axis of rotation. Thus level adjustments are done to make the vertical axis perfectly vertical when bubbles of both the level tubes are at the center.

(b) **Adjustment of sight vanes:** When the instrument is levelled, the sight vanes must be vertical. For this a plumb bob is hanged with a string at a short distance away from the compass. Level the compass and look at the string through the sight vanes. Check whether the vertical hair in one vane and the edges of slit in the other vane are parallel to the string. If not, then adjustment is required. For this, remove the affected vane from the compass and do filing of higher side of its base where it rests on the compass. Alternatively, insert a suitable packing at the other end of the base of vane. Repeat the adjustment till the sight vanes are exactly vertical when the compass is levelled.

(c) **Adjustment of sensitivity of bubble:** Level the compass and lower the needle gently on its pivot. If the needle comes to rest quickly, then the needle is not sensitive and it requires adjustment. Loss of sensitivity is due to the loss of magnetism of needle or due to wear of the pivot point or both.

For adjustment, re-magnetize the needle by placing it into a solenoid coil powered with strong *DC*. Sharpen the pivot by rubbing it with fine oil stone.

(d) **Adjustment of straightness of the needle:** The needle must be absolutely straight. If bent, it requires adjustment. The bending of needle may be either in the horizontal plane or the vertical plane.

- **Bending of needle in vertical plane :** Lower the needle gently on the pivot and observe if the needle is accompanied by vertical sea-saw motion of the ends. If yes then it needs adjustment. For adjustment, take the needle out, bend it in the vertical plane. Repeat this process till the sea-saw motion ceases.
- **Bending of needle in horizontal plane:** Take readings of both the ends of the needle for different positions of zero mark. If difference of these readings is always some constant other than 180°, then needle is bent in horizontal plane but pivot coincides with the center of graduated ring. If the difference is not constant and it varies with different positions of zero mark, then both needle and pivot needs adjustment. In this case also, needle is adjusted first and pivot is adjusted later.

(e) **Pivot adjustment:** The pivot must lie at the geometric center of the graduated ring. Read both ends of the needle for different positions of graduated ring. If the difference is not 180° and it varies with various positions of graduated ring, then pivot needs adjustment.

4.12.2 Permanent Adjustment of Prismatic Compass

The permanent adjustments of prismatic compass are similar to those of Surveyor's compass with slight differences which are as follows:

(a) **Adjustment of levels:** In prismatic compass, there are no level tubes and thus adjustment of levels is not required.

(b) **Adjustments of sight vanes:** The sight vanes in prismatic compass are not adjustable.

(c) **Adjustments of needle and pivot:** Needle in the prismatic compass cannot be straightened.

4.13 Prismatic Compass versus the Surveyor's Compass

Table 4.3 *Surveyor's compass v/s Prismatic compass*

S. No.	Characteristic	Surveyor's compass	Prismatic compass
1.	Magnetic needle	Edge bar needle is used and it acts as an index	Board needle is used which is hidden below the aluminum ring. It does not act as an index.
2.	Graduation	Graduated ring is attached to the box and ring rotates with the box. Graduations are embrossed from 0° to 90° in the four quadrants. Zero points are marked with *N* and *S*.	Graduated ring is attached to the needle and remains stationary when the box is roted. Graduations are embrossed from 0° to 360° clockwise from zero at the south end.
3.	Sighting vanes	Object vane consists of a metal frame with vertical hair. Eye vane also consists of a metal frame with a fine slit. Readings are taken by directly looking down through the glass and reading the north end of the needle.	Object vane consists of a metal frame with vertical hair. Eye vane also consists of a small frame with a fine slit near the prism. Readings are taken through the vertical side of the prism provided at the eye vane.
4.	Reading	Sighting and reading are done separately and that too from different positions. After sighting the object, the observer moves around and takes the reading at the north end of the needle.	Sighting and reading are done simultaneously from the same position of the observer.
5.	Support requirement	This cannot be used without a support like tripod etc.	This can be held in hand while taking the observation but it is better to use tripod with it.

4.14 Magnetic Declination

- It is quite a common phenomenon that the magnetic meridian and the true meridian at a place generally do not coincide.
- The horizontal angle which the magnetic meridian makes with the true meridian is called as **magnetic declination** (also sometimes referred to as **declination**).

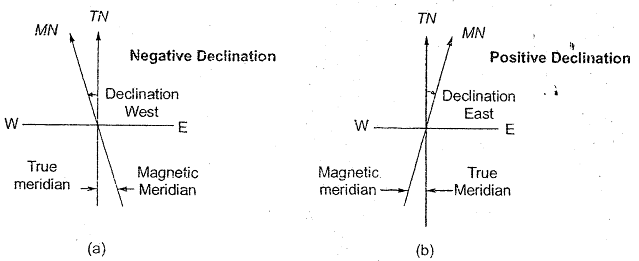


Fig. 4.9 *Magnetic declination*

- **Negative declination:** When magnetic north lies towards the west of true north, then the declination is said to be negative.
- **Positive declination:** If the magnetic north lies towards the east of true north, then declination is said to be positive.
- The magnetic declination at a place can be measured in the field by establishing the true meridian by astronomical observations followed by determination of magnetic bearing of the line.

Isogonic lines: Declination varies from place to place and also from time to time at the same place. This variation of declination at different places is studied with the help of **isogonic lines** which are the lines passing through the points on earth's surface having the same declination at a particular time. Now the earth's magnetic field is not uniform and thus isogonic lines do not form the complete great circles. These lines get radiate from the north and south poles of the earth and then follow irregular paths.

Agonic lines: A special case of isogonic lines are the **agonic lines** which represents the isogonic lines with zero declination. Thus at all the points on agonic lines, the true meridian and the magnetic meridian coincide.

4.15 Variations in Magnetic Declination

Magnetic declination at a place does not remain constant and also does not remain same at all the points on the earth. Thus magnetic declination changes from time to time at a place and from place to place at a particular time.

At a place, there are four types of variation in magnetic declination viz.:

(a) Secular variation (b) Annual variation
(c) Diurnal variation (d) Irregular variation

4.15.1 Secular Variation

- The secular variation of declination at a place occurs continuously over a long period of time.
- In general, there is a gradual shift in the earth's magnetic field in one direction, in about 150 years.
- Thus the cycle time is 300 years.
- There exists no reliable method of measuring this secular variation.
- Also the change from year to year is not uniform at a place.
- The lines of equal angle changes are called as **isopars.**

Secular variation at a place must be taken into account when going through the old survey records.

4.15.2 Annual Variation

The variation of declination from year to year at a place from the mean position of the year is called as annual variation in declination. The annual variation is independent of secular variation at a place.

4.15.3 Diurnal Variation

The variation of declination in one day from the mean position is called as diurnal variation. This variation depends on locality (being greater near the poles than equator), season (greater in summers than winters), time (greater during the day and smaller in night) and year (diurnal variation changes from year to year).

4.15.4 Irregular Variation

Occurrence of magnetic storms and also the magnetic disturbances cause a change in the earth's magnetic field, in an irregular manner. Such variations in declinations are quite unpredictable and random. Some of the causes of irregular variation in declination are the earthquakes, volcanic disturbances etc. Depending on the magnitude of disturbances, irregular variation in declination can be quite large, of the order of up to 2°.

4.16 Effect of Variation in Magnetic Declination on Survey Works

- As the magnetic meridian changes from time to time at a place and thus magnetic bearings of lines also get changed. So magnetic bearing is not a fixed quantity. While dealing with old survey records, the direction of survey lines need to be determined as of date from the knowledge of magnetic declination of the place.
- Thus survey records must contain the information about the date of survey, magnetic declination and the annual change in secular variation in magnetic declination.

4.17 True Bearing from the Magnetic Bearing

If magnetic declination at a place is known, then true bearing of the survey line can be computed from the magnetic bearing.

When declination is towards the east, then,

$$\text{True bearing} = \text{Magnetic bearing} + \text{Declination}$$

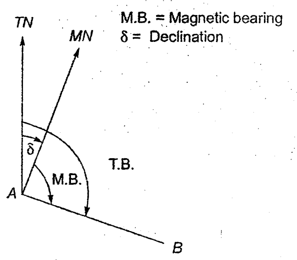


Fig. 4.10 *Positive declination*

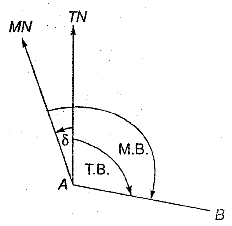


Fig. 4.11 *Negative declination*

When declination is towards the west, then,

$$\text{True bearing} = \text{Magnetic bearing} - \text{Declination}$$

4.18 Dip

A freely suspended magnetic needle aligns itself parallel to earth's magnetic field lines i.e., the longitudinal axis of the magnetic needle lies in the plane of magnetic material. This establishes the direction of magnetic north and south. However, a magnetic needle which has aligned itself along the earth's magnetic field lines may not remain perfectly horizontal and may incline itself with the horizontal. This vertical angle which the magnetic needle makes with the horizontal is referred to as dip. This dip is zero at equator and 90° at magnetic poles of earth.

Isoclinic lines: These are the lines which join points on earth with same value of dip.

Aclinic lines: These are special case of isoclinic lines which join points of zero dip.

4.19 Local Attraction

- Ideally, the magnetic needle of a compass should align itself along the earth's magnetic field lines only i.e., magnetic field developed due to the earth only.
- However, many a times, there are certain magnetic materials present which influence the earth's magnetic field and magnetic needle aligns itself along the direction of resultant magnetic field and thus needle does not give the true direction of earth's magnetic lines.
- Some of the magnetic materials are iron articles like rails, chains, arrows etc. and current carrying conductor.
- The amount of deviation of magnetic needle is proportional to the amount of local attraction present.

4.19.1 Detection of Local Attraction

The local attraction at a place can be detected by measuring the fore bearing and back bearing of a line at that place. Ideally, the difference of fore and back bearing of a line should be 180° but if it is not, then the place is definitely affected by local attraction.

4.20 Errors in Compass Surveying

1. Instrumental Errors

These errors are associated with the defects in the instrument itself like:

(a) The magnetic needle is sluggish or has lost its magnetism.
(b) The needle is not absolutely straight.
(c) The pivot is not at the center of the graduated circle.
(d) The pivot is blunt i.e. not sharp.
(e) The plane of sight is not vertical.
(f) The line of sight does not pass through the center of graduated ring in the prismatic compass.
(g) The graduated ring of the prismatic compass is not truly horizontal.

Most of the above instrumental errors can be eliminated by permanent adjustments of the instrument.

2. Sighting Errors

These errors occur due to sighting and due to wrong manipulations like:

(a) Compass is not properly centered on the station.
(b) Compass is not properly levelled.
(c) Ranging rod is not properly bisected at the station.
(d) Observation of bearings not properly noted down.
(e) Parallax in surveyor's compass while taking the reading of bearings.
(f) Reading the graduated ring from the wrong direction in prismatic compass.

All the above and other similar errors can be eliminated by taking suitable precautions.

3. Errors Due to External Factors

These errors occur due to external factors like:

(a) Change in atmospheric magnetism due to storms etc.
(b) Magnetic storms due to seismic activities.
(c) Variation in magnetic declination.
(d) Local attraction due to magnetic items made of iron, nickel or cobalt.

4.21 Plotting a Compass Traverse

A compass traverse must be plotted only after proper checking of bearings of the traverse lines and after suitable corrections has already been applied. Before commencing the actual plotting work, a rough plot of the traverse to some suitable scale must be plotted to have an idea about the size and the shape of the compass traverse.

The following methods are generally used for plotting a compass traverse:

(a) Parallel meridian method (b) Included angles method

(c) Method of tangents (d) Method of chords

(e) Rectangular co-ordinate method (f) Paper protractor method

4.21.1 Parallel Meridian Method

- In this method of plotting the compass traverse, a meridian line is drawn at each of the traverse station.
- After deciding upon the starting station (let it is station *A*, as shown in Fig. 4.12), a line representing the meridian is drawn through *A*.
- The bearing of the first line *AB* is then drawn using protractor.
- The length *AB* is marked off to some scale on the plot. This locates the next station *B*.
- Now another meridian line is drawn through *B* and the process goes on till all the traverse stations are plotted.
- For a perfectly closed traverse, the last line must meet with the starting station *A* else there is a closing error in traverse which needs to be adjusted.

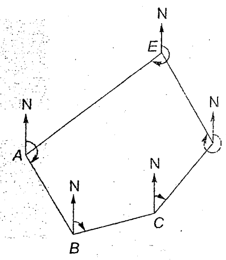


Fig.4.12 *Parallel meridian method*

4.21.2 Included Angles Method

- In this method of plotting the compass traverse, the meridian line is drawn only at the first station (say *A*).
- The bearing of line *AB* is plotted and its length scaled off on the plotted line. Thus point *B* is located.
- At the point *B*, included $\angle ABC$ is plotted with a protractor and the length *BC* is scaled off. This gives the point *C*. This process goes on till the last station is plotted.

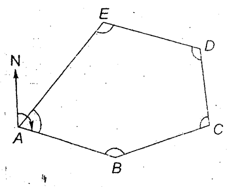


Fig.4.13 *Included angle method*

4.21.3 Method of Tangents

- This method of plotting the compass traverse uses the tangents of angles between the various lines of the traverse. The starting point A is fixed and meridian line is drawn through *A*.
- On the meridian through *A*, a suitable length AB_1 is marked on meridian as shown in Fig. 4.14.
- A perpendicular is then drawn through B_1 of length $AB_1 \tan\theta_1$ where θ_1 is the reduced bearing of line *AB*. This gives the point B_2 and thus the orientation of traverse side *AB*.

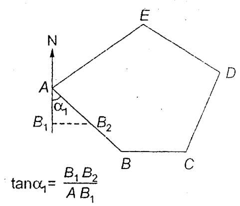


Fig. 4.14 *Method of tangents*

- On line AB_2, distance *AB* is scaled off which gives the position of point *B*. This process goes on till all the points have been plotted.

4.21.4 Method of Chords

- This method is very similar to the method of tangents but here a geometric construction is required.
- After fixing the position of point *A* and the drawing the meridian line through *A*, an arc of suitable radius is drawn with A as center(say arc B_1B_3), intersecting the meridian line at B_1. Now with B_1 as center and radius equal to $2AB_1\sin(\alpha_1/2)$, draw an arc intersecting the arc B_1B_3 at B_2. Join points *A* and B_2 which fixes the direction of traverse line *AB*.
- From point *A*, distance *AB* is scaled off on line AB_2 which gives the position of point *B*. This process goes on till all the points have been plotted.

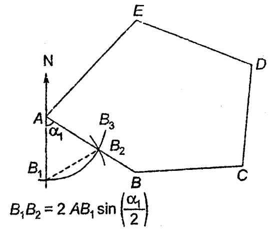


Fig. 4.15 *Method of chords*

4.21.5 Rectangular Co-ordinates Method

- This is the most accurate method of plotting any type of traverse.
- Before commencing the actual plotting work, the co-ordinates of all the traverse stations are calculated. This method is discussed in more detail in the chapter on Vernier theodolites.

4.21.6 Paper Protractor Method

- Here a large circular paper protractor is used.
- The bearings of all the traverse lines are plotted with a protector at a suitable point *O* somewhere in the middle of the paper.
- Through point *O*, a line representing the meridian is drawn. The protractor is then placed on the meridian line such that its 0° and 180° marks coincide with the meridian line.
- The bearings of all the traverse lines are marked with respect to the meridian through *A*.
- After deciding upon the point *A*, line *AB* is drawn parallel to the bearing of line *AB* through *O*.
- Length *AB* is scaled off which gives the position of point *B*. This process goes on till all the traverse points are plotted.

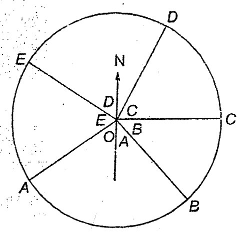


Fig.4.16 *Paper protector method*

4.22 Limits of Accuracy

1. The angular error of closure (or summation error) should not be greater than $15\sqrt{N}$ minutes where N is the number of sides of the traverse. Also the error per bearing should not be greater than 15 minutes.
2. The degree of accuracy is defined as:

$$\text{Degree of accuracy} = \frac{\text{Linear error of closure}}{\text{Perimeter of the traverse}}$$

The degree of accuracy of compass traverse should not be greater than 1/600. For rough work, this accuracy limit is 2/600 (i.e. 1/300).

Illustrative Examples

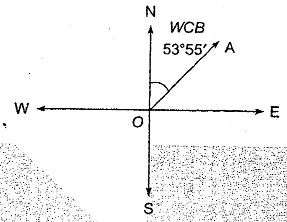
Example 4.1 Convert the following *WCB* into *QB*:

(a) 53° 55′ (b) 175° 45′

(c) 222° 35′ (d) 305° 55′

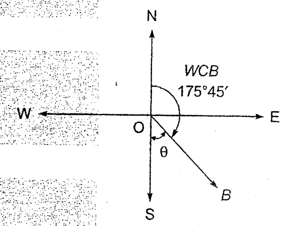
Solution:

(a)



$QB = N\,53°\,55'\,E$

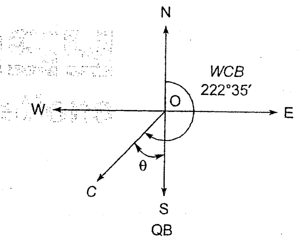
(b)



$$\begin{aligned}\theta &= 180° - WCB\\ &= 180° - 175°\,45'\\ &= 179°\,60' - 175°\,45'\\ &= 4°\,15'\end{aligned}$$

∴ $QB = S\,4°\,15'\,E$

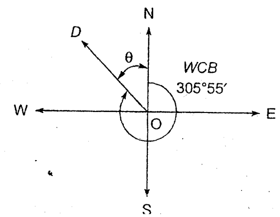
(c)



$$\begin{aligned}\theta &= 222°\,35' - 180°\\ &= 42°\,35'\end{aligned}$$

∴ $QB = S\,42°\,35'\,W$

(d)



$$\begin{aligned}\theta &= 360° - 305°\,55'\\ &= 359°\,60' - 305°\,55'\\ &= 54°\,05'\end{aligned}$$

∴ $QB = N\,54°\,05'\,W$

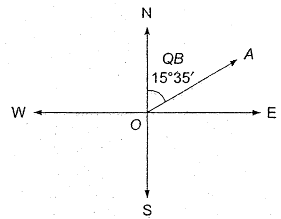
Example 4.2 Convert the following *QB* into *WCB*:

(a) *N* 15° 35′ *E* (b) *S* 36° 37′ *E*

(c) *S* 44° 43′ *W* (d) *N* 24° 56′ *W*

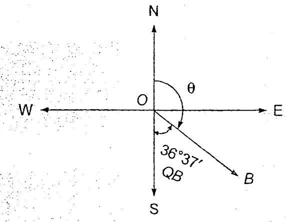
Solution:

(a)



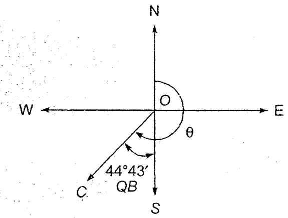
$WCB = 15°\,35'$

(b)



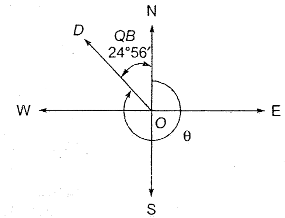
$$\begin{aligned}WCB &= \theta\\ &= 180° - 36°\,37'\\ &= 179°\,60' - 36°\,37'\\ &= 143°\,23'\end{aligned}$$

(c)



$$\begin{aligned}WCB &= \theta\\ &= 180° + 44°\,43'\\ &= 224°\,43'\end{aligned}$$

(d)

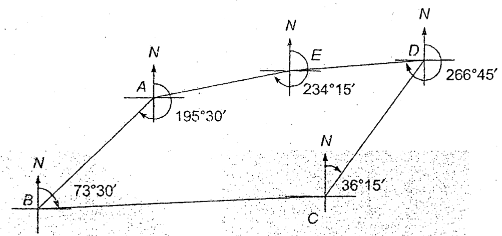


$$\begin{aligned}WCB &= \theta\\ &= 360° - 24°\,56'\\ &= 359°\,60' - 24°\,56'\\ &= 335°\,04'\end{aligned}$$

Example 4.3 The fore bearings and back bearings of the sides of a traverse *ABCDE* are as given below. Find the included angles of the traverse *ABCDE* and the stations affected by local attraction.

Line	FB	BB
AB	190° 30′	17°
BC	73° 30′	250° 30′ 14° 30′
CD	36° 45′	14° 30′
DE	234° 15′	84° 45′
EA		57° 0′

Solution:



In case there is not local attraction, then difference of *FB* and *BB* must be exactly 180°.

BB of line $AB = FB$ of line $AB - 180°$
$= 195° 30' - 180° = 15° 30'$

But BB of line AB as given $= 17°$

∴ Error $= 17° - 15° 30' = 1° 30'$

∴ Correction $= -1° 30'$

BB of line $BC = 73° 30' + 180' = 253° 30'$

But BB of BC as given $= 250° 30'$

∴ Error $= 250° 30' - 253° 30' = -3°$

∴ Correction $= +3°$

BB of line $CD = 36° 15' + 180° = 216° 15'$

But BB of CD as given $= 214° 30'$

∴ Error $= 214° 30' - 216° 15' = -1° 45'$

∴ Correction $= +1° 45'$

BB of line $DE = 266° 45' - 180° = 86° 45'$

But BB of DE as given $= 84° 45'$

∴ Error $= 84° 45' - 86° 45' = -2°$

∴ Correction $= +2°$

BB of line $EA = 234° 15' - 180° = 54° 15'$

But BB of DA as given $= 57°$

∴ Error $= 57° - 54° 15' = 2° 45'$

∴ Correction $= -2° 45'$

Thus there is no traverse line whose *FB* and *BB* differ exactly by 180°. But included angles are not affected by local attraction.

∴ $\angle A = FB$ of $AB - BB$ of EA
$= 195° 30' - 57° 0' = 138° 30'$

$\angle B = FB$ of $BC - BB$ of AB
$= 73° 30' - 17° 0' = 56° 30'$

$\angle C = (360° - BB$ of $BC) + FB$ of CD
$= (360° - 250° 30') + 36° 15'$
$= 109° 30' + 36° 15' = 145° 45'$

$\angle D = FB$ of $DE - BB$ of CD
$= 266° 45' - 214° 30' = 52° 15'$

$\angle E = FB$ of $EA - BB$ of DE
$= 234° 15' - 84° 45'$
$= 233° 75' - 84° 45' = 149° 30'$

Thus $\angle A + \angle B + \angle C + \angle D + \angle E$
$= 138° 30' + 56° 30' + 145° 45' + 52° 15' + 149° 30'$
$= 542° 30'$

But sum of all the angles should be $(n-2)\,180°$ where n = No. of sides of polygon
$= (5-2)180° = 540°$

∴ Error $= 542° 30' - 540' = 2° 30'$

∴ Correction $= -2° 30' = -150'$

Distributing this correction in all the angles of the traverse equally, correction per angle $= \dfrac{-150'}{5} = -30'$

∴ $\angle A = 138° 30' - 30' = 138°$
$\angle B = 56° 30' - 30' = 56°$
$\angle C = 145° 45' - 30' = 145° 15'$
$\angle D = 52° 15' - 30' = 51° 45'$
$\angle E = 149° 30' - 30' = 149°$
Sum $= 540° = (n-2)\,180°$ (OK)

Now the difference of *FB* and *BB* is least for the line *AB* (= 1° 30′) i.e. the error between *FB* and *BB* is least for the line *AB*.

Dividing this error equally between the stations *A* and *B*, correction per station is $\dfrac{1°30'}{2} = 45'$

∴ Correct FB of $AB = 195° 30' + 45' = 196° 15'$

∴ Correct BB of $AB = 196° 15' - 180° = 16° 15'$

∴ Correct FB of BC = Correct BB of $AB + \angle B$
$= 16° 15' + 56° = 72° 15'$

∴ Correct BB of $BC = 72° 15' + 180° = 252° 15'$

∴ Correct FB of $CD = \angle C - (360°$ − Correct BB of $BC)$
$= 145° 15' - (360° - 252° 15')$
$= 145° 15' - 107° 45' = 37° 30'$

∴ Correct BB of $CD = 37° 30' + 180° = 214° 30'$

∴ Correct FB of DE = Correct BB of $CD + \angle D$
$= 217° 30' + 51° 45' = 269° 15'$

∴ Correct BB of DE = Correct FB of $DE - 180°$
$= 269° 15' - 180° = 89° 15'$

∴ Correct FB of EA = Correct BB of $DE + \angle E$
$= 89° 15' + 149° = 238° 15'$

∴ Correct BB of $EA = 238° 15' - 180° = 58° 15'$

Corrected bearings are tabulated below:

Line	FB	BB	Difference
AB	196° 15′	16° 15′	180°
BC	72° 15′	252° 15′	180°
CD	37° 30′	217° 30′	180°
DE	269° 15′	89° 15′	180°
EA	238° 15′	58° 15′	180°

Example 4.4 (a) The magnetic bearing of a line *AB* is 110° 43′. If magnetic declination is 10° 05′*E*, then what is the true bearing of the line *AB*? (b) If declination in the above question is 15° 07′ *W* with the same magnetic bearing, then what is the true bearing?

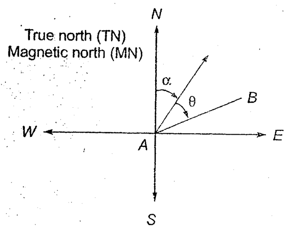
Solution:

(a) Let,

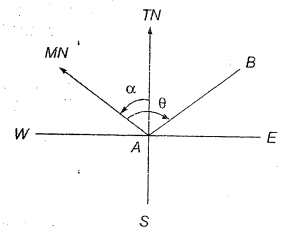
$$\theta = \text{Magnetic bearing of } AB$$
$$= 110°\ 43'\ E$$
$$\alpha = \text{Declination} = 10°\ 05'\ E$$

∴ True bearing = Magnetic bearing + Declination

$$= \theta + \alpha$$
$$= 110°\ 43' + 10°\ 05'$$
$$= 120°\ 48'$$



(b)



True bearing = θ − α

$$= 110°\ 43' - 15°\ 07'$$
$$= 95°\ 36'$$

Example 4.5 Three vessels *P*, *Q* and *R* start their voyage from a station three different directions at the same time. The speed of all the three vessels is 35 knots. Their bearings were observed to be *N* 60°*E*, *S* 35° *E* and *S* 05° *E*. After two hours, the captain of vessel *Q* determines the bearings of *P* and R w.r.t. his own vessel *Q*. There after, he calculates the distances. What are the bearings and the distance as calculated by captain of vessel *Q*?

Solution:

1 knot = 1.8 km/h

∴ 35 knots = 1.8 × 35 km/h

= 63 km/h

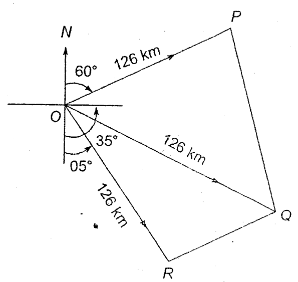
∴ In two hours, distance of vessel

P from station O = 63 × 2 = 126 km

Similarly, distance of vessel *Q* from station *O* is 2 hrs = 126 km

$$\angle QOR = 35° - 05° = 30°$$

In Δ*QOR*, *OQ* = *OR* = 126 km



∴ ΔQOR is isosceles

$$\therefore \quad \angle R = \angle OQR = \frac{180-30}{2} = 75°$$

$$\angle POQ = (90° - 60°) + (90° - 35°) = 85°$$

In Δ*POQ*, *PO* = *QO* = 126 km

∴ DPOQ is isosceles

$$\therefore \quad \angle P = \angle OQP = \frac{180-85°}{2} = 47.5°$$

WCB of *P* = 60°

WCB of *Q* = 60° + ∠*POQ* = 60° +85° = 145°

and *WCB* of *R* = 180° − 05° = 175°

In Δ*POQ*,
$$\frac{OP}{\sin\angle PQO} = \frac{PQ}{\sin\angle POQ}$$

$$\Rightarrow \quad PQ = 126 \times \frac{\sin 85°}{\sin 47.5°} = 170.25 \text{ km}$$

In Δ*ROQ*,
$$\frac{OQ}{\sin\angle R} = \frac{OR}{\sin\angle ROQ}$$

$$\Rightarrow \quad QR = 126 \times \frac{\sin 30°}{\sin 75°} = 65.22\text{km}$$

Distance of *P* from *Q* after 2 hours = 170.25 km

and distance of *R* from *Q* after 2 hours = 65.22 km

Example 4.6 The magnetic bearing of sun at noon is 179°. What is the magnetic declination? What will be the declination if bearing of the sun is 189° ?

Solution:

At noon, the Sun is exactly over the time median of the place. Thus true bearing of the line joining the sun and the place is either 0° or 360° if it is to the north and 180° if it is to the south of the place.

Now magnetic bearing is less than true bearing and thus declination is towards east.

∴ Declination = 180° − 179° = 01°*E*

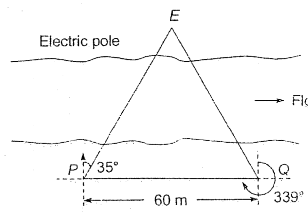
In the second case,

Declination = 189° − 180° = 09° *W*

Example 4.7 Width of a river is required to be determined which is flowing from East to West. On the Southern bank, two points *P* and *Q* are selected distant 60 m apart. The bearing of an electric pole on Northern bank of the river was observed to be 35° and 339° from *P* and *Q* respectively. What is the width of the river?

Solution:

$$\angle EPQ = 90° - 35° = 55°$$
$$\angle EQP = 339° - 270° = 69°$$
$$\angle PEQ = 180° - (55° + 69°) = 56°$$



From since law,

$$\frac{EP}{\sin\angle EQP} = \frac{EQ}{\sin\angle EPQ} = \frac{PQ}{\sin\angle PEQ}$$

$$\Rightarrow \quad \frac{EP}{\sin 69^\circ} = \frac{60}{\sin 56^\circ}$$

$$\Rightarrow \quad EP = 67.566 \text{ m}$$

$$\therefore \quad \text{Width of river} = EP \sin \angle EPQ$$

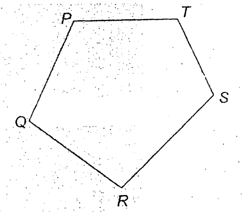
$$= 67.566 \times \sin 55^\circ = 55.347 \text{ m}$$

Example 4.8 A compass traverse *PQRSTP* was run anticlockwise and following readings were obtained. Local attraction was suspected. Determine the correct bearing of the traverse lines.

Line	FB	BB
PQ	149° 50′	330° 15′
QR	78° 53′	255° 43′
RS	42° 45′	222° 45′
ST	301° 53′	124° 53′
TP	212° 17′	32° 02′

Solution:

Line	FB	BB	FB – BB
PQ	149° 50′	330° 15′	–180° 25′
QR	78° 53′	255° 43′	–176° 50′
RS	42° 45′	222° 45′	–180° 00′
ST	301° 53′	124° 53′	+179° 44′
TP	212° 17′	32° 02′	+180° 15′



Thus the difference of *FB* and *BB* of line *RS* is exactly 180°.

∴ Both stations *R* and *S* are having no local attraction.

⇒ All bearings measured from stations *R* and *S* are correct.

⇒ *BB* of line *QR* is correct which is 255°43′

∴ Correct *FB* of *QR* = 255° 43′ – 180° = 75° 43′

But measured *FB* of *QR* = 78° 53′

∴ Error in *FB* of QR = 78° 53′ – 75° 43′ = 0.3° 10′

∴Correction to be applied in *FB* of *QR* = –03° 10′

Thus a correction of –03° 10′ is needed in all the bearings measured from station *Q*.

Measured *BB* of *PQ* = 330° 15′

∴ Correct *BB* of *PQ* = 330° 15′ – 03° 10′ = 327° 05′

∴ Correct *FB* of *PQ* = Correct *BB* of *PQ* – 180°

= 327° 05′ – 180° = 147° 05′

But measured *FB* of *PQ* = 149° 50′

∴ Error in measured *FB* of *PQ* = 149° 50′ – 147° 05′ = 02° 45′

∴Correction needed in *FB* of *PQ* = –02° 45′

∴A correction of –02° 45′ is needed in all the bearings measured at *P*.

Measured *BB* of *TP* (from station *P*) = 32° 02′

∴ Correct *BB* of *TP* = 32° 02′ – 02° 45′ = 29° 17′

∴ Correct *FB* of *TP* = Correct *BB* of *TP* + 180° = 209° 17′

But measured *FB* of *TP* = 212° 17′

∴ Error in measured *FB* of *TP* = 212° 17′ – 209° 17′ = 03° 00′

∴Correction to be applied in *FB* of *TP* = –03° 00′

∴A correction of –03° 00′ is needed in all the bearings measured from *T*.

∴ Correct *BB* of *ST* = Observed *BB* of *ST* + Correction

= 124° 53′ – 03° 00′ = 121° 53′

∴ Correct *FB* of *ST* = Correct BB of ST + 180° = 301° 53′

Observed *FB* of *ST* = 301° 53′ which is correct.

Line	FB	BB
PQ	147° 05′	327° 05′
QR	75° 43′	255° 43′
RS	42° 45′	222° 45′
ST	301° 53′	121° 53′
TP	212° 17′	29° 17′

Example 4.9 A traverse *PQRP* was surveyed. The magnetic bearing of side *PQ* was found to be 20° 15′. The bearing of sun was observed to be 179° 35′ at local noon. Compute the magnetic bearings and true bearings of all the lines. Traverse *PQR* is an equilateral triangle.

Solution:

At local moon, true bearing of sun = 180°

But observed magnetic bearing of sun = 179° 35′

∴ Declination = 00° 25′ E

Given *FB* of *PQ* = 20° 15′

∴ *BB* of *PQ* = 20° 15′ + 180° = 200° 15′

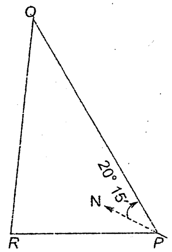
∴ *FB* of *QR* = 200° 15′ + 60° = 260° 15′

∴ *BB* of *QR* = 260° 15′ – 180° = 80° 15′

∴ *FB* of *RP* = 80° 15′ + 60° = 140° 15′

∴ *BB* of *RP* = 140° 15′ + 180° = 320° 15′

∴ *FB* of *PQ* = 320° 15′ + 60° = 380° 15′ = 20° 15′ (OK)



Line	Magnetic bearing		True bearing	
	FB	BB	FB	BB
PQ	20° 15′	200° 15′	20° 40′	200° 40′
QR	260° 15′	80° 15′	260° 40′	80° 40′
RP	140° 15′	320° 15′	140° 40′	320° 40′

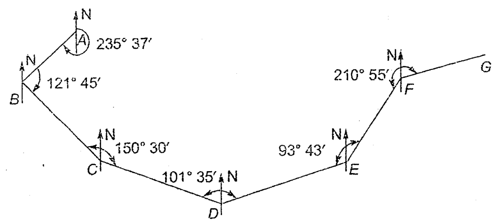
Example 4.10 In an open traverse *ABCDEFG*, the magnetic bearing of line *AB* was found to be 235° 37′. The included angles were measured as

∠*ABC* = 121° 45′ ∠*BCD* = 150° 30′ ∠*CDE* = 101° 35′

∠*DEF* = 93° 43′ ∠*EFG* = 210° 55′

What is the bearing of line *FG*?

Solution:



FB of AB = 235° 37′
FB of BC = (235° 37′ – 180°) + 121° 45′ = 55° 37′ + 121° 45′ = 177° 22′
FB of CD = 150° 30′ – (180° – 177° 22′) = 150° 30′ – 02° 38′ = 147° 52′
FB of DE = 101° 35′ – (180° – 147° 52′) = 101° 35′ – 32° 08′ = 69° 27′
FB of EF = (180° – 69° 27′) – 93° 43′ = 110° 33′ – 93° 43′ = 16° 50′
FB of FG = 210° 55′ – (180° – 16° 50′) = 210° 55′ – 163° 10′ = 47° 45′

Objective Brain Teasers

Q.1 The annual variation of magnetic declination at a place is caused because of rotation of:
(a) Earth about Sun
(b) Earth about its own axis
(c) Moon about Sun
(d) Moon about Earth

Q.2 Which of the following reference is used in geodetic survey?
(a) Arbitrary (b) True
(c) Magnetic (d) Data in sufficient

Q.3 What is the value of included ∠AOB if bearings of line AO and OB respectively are 40° and 130°?
(a) 270° (b) 90°
(c) 210° (d) None of these

Q.4 Agonic lines pass through points of:
(a) equal dip (b) equal declination
(c) equal altitude (d) Zero declination

Q.5 The quadrantal bearing of a line is determined by
(a) Surveyor's compass
(b) Prismatic compass
(c) Clinometer
(d) Sextant

Q.6 The horizontal angle between the true meridian and magnetic meridian is referred to as:
(a) Declination (b) Dip
(c) Bearing (d) Contour

Q.7 The WCB of a line is $\frac{5\pi}{3}$ radians. Its quadrantal bearing is:
(a) N 60° W (b) S 60° E
(c) N 60° E (d) S 60° W

Q.8 Pick the correct statement
(a) Magnetic equator is an aclinic line
(b) Magnetic equator is an isoclinic line
(c) Magnetic equator is an isogonic line
(d) None of the above

Q.9 Lines joining points of equal dip are called as:
(a) Agonic lines (b) Aclinic lines
(c) Isoclinic lines (d) Isogonic lines

Q.10 In any survey work, it is preferable to use true meridians since:
(a) they are easy to locate
(b) they do not vary with time
(c) they converge at poles
(d) they facilitate easy computations

Q.11 Which of the following statements is correct?
(a) Local attraction affects included angles
(b) The position of E and W are interchanged in prismatic compass
(c) Dip of magnetic needle is the angle between the magnetic north and the true north
(d) None of the above

Q.12 Select the correct statement for prismatic compass
(a) Its least count is 20 minutes
(b) It has inverted graduations
(c) It measures QB
(d) Zero mark is towards north (N) mark

Q.13 Diurnal variation is larger
(a) at magnetic equator
(b) in winter than in summer
(c) in summer than in winter
(d) All of the above

Q.14 If FB of line AB is 30° and BB of line BC is 280° then ∠ABC is
(a) 120° (b) 150°
(c) 175° (d) 110°

Q.15 What is the value of dip at the location of magnetic poles?
(a) 45° (b) 0°
(c) 90° (d) 75°

Q.16 The value of dip at equator is
(a) 0° (b) 45°
(c) 90° (d) 60°

Q.17 If declination at a place is 6° 30′ W, then the bearing of a line having magnetic bearing of S 29° 35′ E is ________
(a) S 36° 05′ E (b) N 30° 05′ W
(c) S 29° 35′ W (d) Data insufficient

Q.18 Given below are some of the properties of prismatic compass. Choose the correct option.
(i) Graduations are in WCB with 0° at south end and 180° at north end.
(ii) The graduated ring does not rotate along with line of sight
(iii) The graduations are marked inverted and reading is taken from a prism
(a) (ii) and (iii) (b) (i) and (iii)
(c) (i) and (ii) (d) (i), (ii) and (iii)

Q.19 Isopars are the lines
(a) joining equal changes in magnetic declination
(b) joining equal magnetic declination
(c) joining equal dips
(d) None of these

Q.20 Aclinic lines are the lines joining
(a) points of equal dip
(b) points of equal declination
(c) points of zero dip
(d) points of equal magnetic bearing

Answers

1. (a)	2. (b)	3. (b)	4. (d)	5. (a)
6. (a)	7. (a)	8. (a)	9. (c)	10. (b)
11. (d)	12. (b)	13. (c)	14. (d)	15. (c)
16. (a)	17. (a)	18. (d)	19. (a)	20. (c)

Student's Assignments

Ex.1 Convert the following QB to WCB:
(a) N 07° 35′ E (b) S 16° 25′ W
(c) N 30° 37′ W (d) S 33° 25′ E

Ans. (a) 0.7° 35′, (b) 196° 25′
(c) 329° 23′ (d) 146° 35′

Ex.2 Convert the following WCB to QB:
(a) 37° 39′ (b) 103° 03′
(c) 225° 35′ (d) 301° 30′

Ans. (a) N 37° 39′ E (b) S 76° 57′ E
(c) S 45° 35′ W (d) N 58° 30′ W

Ex.3 The bearings of three sides of a triangle ABC are
AB = 70°, BC = 135°. CA = 275°
Compute the interior angles of triangle ABC

Ans. ∠A = 25°, ∠B = 115°, ∠C = 47°

Ex.4 In an old survey plan, the magnetic bearing of aline is S 51° E when the magnetic declination was 0.3° 35′ W. To what bearing should it be set now if present magnetic declination is 01° 30′ E?

Ans. S 57° 05′ E

Ex.5 Given below are FBs and BBs of a closed traverse $PQRS$. Identify which stations are affected by local attraction? Find the corrected bearings. If declination is 3.5° W then compute the true bearings.

Line	FB	BB
PQ	S 55° 30′ E	N 55° 30′ W
QR	N 68° 15′ E	S 66° 00′ W
RS	N 49° 30′ W	S 44° 45′ W
SP	S 20° 15′ W	N 17° 45′ E

Ans. PQ = S 59° 30′ E, QR = N 64° 15′ E, RS = N 51° 15′ W, SP = S 13° 45′ W

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