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ASTRONOMY FOR THE ARMY

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IT is of no practical use to a soldier to be able to determine his latitude, his longitude, the error of his watch, or the true bearing of any natural feature he can see, with the aid of scientific instruments. On service he will have only his eyes, a compass and a watch to help him, and it is fair to assume that both compass and watch may be lost or broken.

The object of this paper is to show how the sun and stars can be used to replace either a compass or a watch, and, under certain conditions, to replace both.

This practical use of the sun and stars is open to every soldier, however unfamiliar with the science of astronomy he may be. Night operations tend to become more frequent with every campaign, and there is no reason why the stars should not be as helpful to the men of a strategic patrol as they are to the staff officer who directs a large column.

It is possible, with the help of a few simple tables, to calculate on any day, and at any place—

- (a) The time of sunrise and sunset,
- (b) The true bearing, and height above the horizon, of the sun at any hour of the day,
- (c) The true bearing of any bright star at rising and setting, and
- (d) The number of hours that such a star is above the horizon.

With these facts, and a knowledge of the apparent movements of the sun and stars in the heavens, it is possible, except when clouds entirely obscure the sky, to use the sun and stars instead of landmarks, and after a little practice, instead of watches.

As it is obvious that all the movements of celestial bodies, which are referred to in this paper, are *apparent* movements, the term will not be applied to them again.

Before any calculations are attempted, a few astronomical terms must be explained.

The *meridian* of a place is an imaginary circle on the surface of the earth, passing through both the North and South poles, and that place. When the sun is due N. or S. of a place it is said to be "on the meridian" of that place.

In Fig. 1 are shown the meridians of Greenwich and Calcutta.

The *latitude* of a place is its distance N. or S. of the equator, measured in degrees. A degree is about 70 land miles, and there are 90 degrees between either pole and the equator. A place which is nearer either pole than the equator is said to be in a "high latitude," while a place which is near the equator is said to be in a "low latitude."

Fig. 1.

In Fig. 2 the thick lines show the latitudes of Greenwich, 51° N. (high), and of Rio Janeiro, 23° S. (low).

The *longitude* of a place is its distance East or West of the meridian of Greenwich, measured in degrees or hours.

A degree is 4 minutes of time, and, as the earth rotates once in 24 hours, it is clear that there must be 360 degrees of longi-

Fig. 2

tude, 180 East and 180 West of Greenwich. Longitude can be measured from any meridian, and in French maps the meridian of Paris is taken as the "standard meridian."

In all British maps the meridian of Greenwich is the standard.

In Figs. 1 and 2 the dotted lines show the longitudes of Calcutta, 88° E., and of Rio Janeiro, 43° W.

The *celestial sphere* is an imaginary sphere, infinitely large, with the earth as centre.

The heavenly bodies appear to move on the surface of this sphere.

The *celestial equator* is an imaginary line on the surface of the celestial sphere, marking where the latter is cut by the plane of the equator of the earth.

To an observer standing on the equator the celestial equator divides the heavens into two equal parts, passing vertically over his head, and meeting the horizon at points due E. and W. of him.

To an observer who is not on the equator the celestial equator meets the horizon at points due E. and W. of him, but is tilted towards the N. or S. according as he is South or North of the equator.

The N. and S. poles of the heavens are two imaginary points on the celestial sphere vertically above the N. and S. poles of the earth. The sphere of the earth is, as it were, enclosed by the celestial sphere, whose N. and S. poles and equator correspond exactly to the poles and equator of the earth.

In Fig. 3 NQSE is the celestial sphere, N and S are the North and South poles of the heavens, and EQ is the celestial equator.

The *declination* of a heavenly body is its distance N. or S. of the celestial equator, measured in degrees.

In Fig. 4 the thick lines show the declinations of Arcturus (α Boötis), 20° N. and of Sirius (Canis Majoris), 17° S.

Fig. 4.

Fig. 5.

The declination of the sun is constantly changing, but the declinations of the stars are always the same. The stars appear

to revolve round the N. and S. poles of the heavens always at the same distance from the celestial equator.

It is clear from Fig. 5 that a star whose declination is, for example, 30° S. will, at the highest point of its path, pass directly over the head of an observer in latitude 30° S.

This connection between declination and latitude is useful when the paths of the sun and stars are being traced in the heavens.

An observer who wishes to learn the movements of the sun and stars in the heavens must be able to imagine the correct position of the celestial equator. In order to do this he must know his latitude and the direction of the true North. The latitude of any place in civilised countries can be obtained from maps, and even in uncivilised countries an estimate can rarely be 5 degrees wrong.

Methods of finding latitude and the direction of true North, where neither a map nor a compass is available, are given below in "Bearings by Stars." An observer, knowing his North point, can imagine the points, due E. and W. of him, where the celestial equator meets the horizon. Subtracting his latitude from 90° he obtains the height above the horizon of the highest point of the celestial equator. This point will be on his meridian, that is due S. of him if he is N. of the equator, and due N. of him if he is S. of the equator.

Fig. 6 explains this.

O is a place on the earth's surface whose latitude is 50° N. (e.g., Dinant, in Belgium). ZNRQSHE is the celestial sphere. Z is the imaginary point vertically over O, called the zenith, N is the North pole of the heavens, EQ is the celestial equator, and HR is the horizon.

The latitude of O is 50° N., that is, the angle EOZ is 50° . As the angle ZOH is 90° , the angle EOH must be 40° , or, in other words, E, the highest point of the celestial equator, is 90° minus 50° (the latitude) above the horizon.

E is also on the line NZS, that is, on the meridian of O, and therefore, as O is North of the equator, E is due South of O.

To an observer who remains in the same latitude the path of a star through the heavens is always the same, from the time it rises above the horizon to the time of its setting, although it does not pass across the heavens at the same time every night.

If the observer moves to a place in a different latitude he will notice that the star, though rising and setting at approximately the same points as before, swings up to a different height on the meridian, because the celestial equator is tilted up at a different angle.

An observer who knows the declination of a star and his own latitude can, at any moment when the star is above the horizon, trace the rest of its path through the heavens. He knows the correct position of the celestial equator, and he knows that the star always keeps at the same distance from the celestial equator.

Summing up the above points, an observer who knows his latitude and the direction of true North can at any moment trace the path of any star he can see, provided he has some table giving that star's declination.

Table IV., at the end of this paper, gives the declinations of all the principal stars.

It is not quite so easy to trace the path of the sun in the heavens, because the sun's declination changes every day, or, in other words, the sun does not always keep the same distance from the celestial equator.

Whereas an observer at Greenwich, latitude 51° N., will see Sirius night after night during the month of January rise about S.E. by E., swing up to a height of 22° on the meridian, and then sink down to its setting about S.W. by W., he will find that the sun rises every day at a slightly different point in the East, swings up to a slightly different height on the meridian, and sets at a correspondingly different point in the West. If, however, he has a table, such as Table II., giving the declination of the sun for every month of the year, he will be able, provided he knows the date in addition to his latitude and the direction of true North, to trace the sun's path in the heavens on any day of the year.

RULE I.

A rule can be given for predicting the height of the sun at noon (its greatest height during the day) at any place on any day.

Find the latitude of the place, and the declination of the sun (from Table II.).

If both are N., or both are S., subtract the smaller from the greater, and subtract the remainder from 90° .

If one is N., and the other S., add them together, and subtract the sum from 90° .

EXAMPLE I.

Required the height of the sun at noon:—

- (a) At Aldershot on 9th May.
- (b) At Bulawayo on 22nd December.
- (c) At Dinant (Belgium) on 30th October, and
- (d) At Melbourne on 22nd June.

- (a) Latitude 51° N. (from map).
Declination 17° N. (from Table II).

Subtract 34° from 90° .
Required height is 56° .

- (b) Latitude 20° S. (from map).
Declination $23\frac{1}{2}^\circ$ S. (from Table II).

Subtract $3\frac{1}{2}^\circ$ from 90° .
Required height is $86\frac{1}{2}^\circ$.

- (c) Latitude 50° N. (from map).
Declination $13\frac{1}{2}^\circ$ S. (from Table II).

Subtract $63\frac{1}{2}^\circ$ from 90° .
Required height is $26\frac{1}{2}^\circ$.

- (d) Latitude 38° S. (from map).
Declination $23\frac{1}{2}^\circ$ N. (from Table II):

Subtract $61\frac{1}{2}^\circ$ from 90° .
Required height is $28\frac{1}{2}^\circ$.

Figs. 7, 8, 9 and 10 explain the above examples. There is no necessity to draw a figure unless Rule I. has been forgotten.

Fig. 7.

(a) ALDERSHOT, May 9th.

ZOE (latitude) = 51°
 $\therefore$ EOH (tilt of celestial equator) = 39° .
 Sun OE (declination) = 17°
 Sun OH (height of sun) =
 $\text{Sun OE} + \text{EOH} = 17^\circ + 39^\circ$
 $= 56^\circ$.

It is evident from Table II., in conjunction with Rule I., that an observer at, for example, Aldershot, between 22nd December of one year and 22nd June of the next, will see the

Fig. E.

(5) BULAWAYO, Dec. 22nd.

ZOQ (latitude) $= 20^\circ$.
 $\text{Sun } OQ$ (declination) $= 23\frac{1}{2}^\circ$.
 $\therefore \text{Sun } OZ = 3\frac{1}{2}^\circ$.
 $ZOR = 90^\circ$.
 $\text{Sun } OR$ (height of sun)
 $= ZOR - \text{Sun } OZ$
 $= 90^\circ - 3\frac{1}{2}^\circ = 86\frac{1}{2}^\circ$.

sun swing up higher every day at noon, till on 21st March it follows the celestial equator throughout its path across the heavens, and therefore reaches a height of 39° at noon.

From 21st March onwards the sun is North of the celestial equator, and swings up still higher day by day until on 22nd June it reaches its greatest height of $62\frac{1}{2}^\circ$. After 22nd June

Fig. G.

(c) DINANT, Oct. 30th.

ZOE (latitude) $= 50^\circ$.
 $\therefore EOH$ (tilt of celestial equator) $= 40^\circ$.
 $\text{Sun } OE$ (declination) $= 13\frac{1}{2}^\circ$.
 $\text{Sun } OH$ (height of sun)
 $= EOH - \text{Sun } OE$
 $= 40^\circ - 13\frac{1}{2}^\circ$
 $= 26\frac{1}{2}^\circ$.

the sun gets lower every day, until on 23rd September it is on the celestial equator again. Finally, on 22nd December, it only swings up to a height of $15\frac{1}{2}^\circ$, its lowest height of the year.

In the tropics, that is between the latitudes of $23\frac{1}{2}^{\circ}$ N. and $23\frac{1}{2}^{\circ}$ S. (between Assouan and the Northern Transvaal in Africa, and anywhere S. of Calcutta in India) an observer must remember that during certain months of the year the sun will be due N. of him at noon, and for the rest of the year due S. of him at noon.

The two days of the year on which the sun at noon will be vertically over his head will be the days on which the sun's declination is the same as his latitude.

(d) MELBCURNE, June 22nd.

$$\begin{aligned} \text{ZOQ (latitude)} &= 38^\circ. \\ \therefore \text{QOH (tilt of celestial} \\ &\text{equator)} = 52^\circ. \\ \text{Sun OQ (declination)} &= 23\frac{1}{2}^\circ. \\ \text{Sun OH (height of sun)} \\ &= \text{QOH} - \text{Sun OQ} \\ &= 52^\circ - 23\frac{1}{2}^\circ \\ &= 28\frac{1}{2}^\circ. \end{aligned}$$

Anywhere outside the tropics an observer knows that the sun at noon is always S. of him if he is in northern latitudes, and always N. of him if he is in southern latitudes.

Rule I. also applies if it is required to find the height of a star on the meridian (its greatest height during the night).

The date does not matter, as the declination of a star is the same all the year round.

EXAMPLE II.

Required the height of Vega (α Lyrae) on the meridian of Dinant, on any date in the year.

Latitude 50° N. (from map).

Declination 39° N. (from Table IV).

Subtract 11° from 90° .

Required height is 79° .

Fig. 11 explains this.

VEGA AT DINANT.

$ZOE \text{ (latitude)} = 50^\circ$.
 $\therefore EOH \text{ (tilt of celestial equator)} = 40^\circ$.
 $\text{Vega } OE \text{ (declination)} = 39^\circ$.
 $\text{Vega } OH \text{ (height of star)} = \text{Vega } OE + EOH$
 $= 39^\circ + 40^\circ$
 $= 79^\circ$.

When it is remembered that stars rise 4 minutes earlier every night it will be evident that in every month some stars will not be above the horizon during the night. They will rise and set during the day.

The question of the selection of suitable stars will be dealt with later.

The necessity of fixing in the imagination the tilt of the celestial equator cannot be too strongly urged upon any who would make an intelligent use of the sun and stars.

A sound knowledge of the movements of the sun and stars, and the changes to which those of the sun are liable, is essential before any practical use can be made of them, and it is only by means of the celestial equator that the paths of the sun and stars can be traced.

An observer who has gained this knowledge may reasonably consider the question of using the heavenly bodies for time and bearings.

TIME BY THE SUN.

The first point to be remembered is that the time of sunrise and sunset varies in different latitudes. On only two days in the year, 21st March and 23rd September, does the sun rise at 6 a.m. and set at 6 p.m. all the world over.

EXAMPLE III.

Required the time of sunrise and sunset on 9th May at Dinant.

The latitude of Dinant is 50° N. (from map). 9th May is nearer the longest day than the shortest day.

From Table I., for latitude 50° , the sun rises at 3.55 a.m. on the longest day, when its declination is $23\frac{1}{2}^\circ$

But it is known that the sun rises at 6 a.m. when its declination is 0.

Therefore the sun rises 125 minutes (6-3.55) before 6 a.m. for a change in declination of $23\frac{1}{2}^{\circ}$.

From Table II., on 9th May, the sun's declination is 17° N.

Therefore, by proportion, the sun rises $\frac{125 \times 17}{23\frac{1}{2}}$ (or 90) minutes before 6 a.m. for a change in declination of 17° .

That is, the sun rises at 4.30 a.m. and sets at 7.30 p.m. on 9th May at Dinant.

This can be done for any day at any place, as only the sun's declination, and the latitude of the place, are required for the calculation.

Knowing the times of sunrise and sunset, and the sun's height at noon (by Rule I.), an observer can obtain the sun's height at any hour of the day.

EXAMPLE IV.

Required the height of the sun at every hour between sunrise and sunset on 30th October at Maritzburg (Natal).

Latitude is 30° S., and 30th October is nearer the longest day.

From Table I., for latitude 30° , the sun rises at 5.2 a.m. on the longest day, when its declination is $23\frac{1}{2}^{\circ}$.

But the sun rises at 6 a.m. when its declination is 0. Therefore sunrise is 58 minutes before 6 a.m. for a change in declination of $23\frac{1}{2}^{\circ}$.

From Table II., on 30th October, the sun's declination is $13\frac{1}{2}^{\circ}$ S.

Therefore sunrise is $\frac{58 \times 13\frac{1}{2}}{23\frac{1}{2}}$ minutes before 6 a.m. for a change in declination of $13\frac{1}{2}^{\circ}$.

That is, the sun rises at 5.27 a.m., and sets at 6.33 p.m. on 30th October at Maritzburg.

By Rule I. the sun's height at noon is $73\frac{1}{2}^{\circ}$.

A table of times and heights can now be made.

At 5.27 a.m. and 6.33 p.m. the sun's height is 0.

„ 6 a.m.	„ 6 p.m.	„ „ „ „ „ „	6°.
„ 7 a.m.	„ 5 p.m.	„ „ „ „ „ „	17°.
„ 8 a.m.	„ 4 p.m.	„ „ „ „ „ „	28 $\frac{1}{2}$ °.
„ 9 a.m.	„ 3 p.m.	„ „ „ „ „ „	40°.
„ 10 a.m.	„ 2 p.m.	„ „ „ „ „ „	51°.
„ 11 a.m.	„ 1 p.m.	„ „ „ „ „ „	62°.
„ noon	„ „ „ „ „ „	„ „ „ „ „ „	73 $\frac{1}{2}$ °.

If an observer possesses any rough means of measuring the height of the sun, for example, the clinometer on a cavalry sketching board, he can obtain his time from the above table.

In order to be independent of a clinometer an observer should be able to measure the height of a heavenly body by the palm of his hand held at arm's length.

The number of degrees that the palm measures can be obtained at any time by taking the height of a roof, church spire, or any natural feature, and measuring the height with the palm of the hand.

A more convenient method in low latitudes, where the sun is high in the heavens between the hours of 9 a.m. and 3 p.m., is for an observer to obtain the time by the length of his shadow.

This necessitates the use of a protractor. Each angle in the above table of times and heights is plotted with a protractor off a line AB (Fig. 12), for example AC_1 , AC_2 , AC_3 , etc. A con-

Fig. 12

venient number of divisions along any edge of the protractor are taken to represent the observer's height, DE, and this edge of the protractor is moved along at right angles to AB, until DE just fits in between AB and AC_1 , AB and AC_2 , and all the remaining angles in turn.

Then AE, measured by the same divisions as were used to measure DE, is the length of the observer's shadow at the hours corresponding to the angles BAC_1 , BAC_2 , etc.

The shadow-lengths can be added to the tables of times and heights given above.

For the sake of this example the observer's height is assumed to be 6 feet.

Hour.	Height of Sun.	Length of Shadows.
5.27 a.m. and 6.33 p.m....	0	—
6 a.m. „ 6 p.m....	6°	Too long to be of use.
7 a.m. „ 5 p.m....	17°	20 feet.
8 a.m. „ 4 p.m....	28½°	11 „
9 a.m. „ 3 p.m....	40°	7 „
10 a.m. „ 2 p.m....	51°	5 „
11 a.m. „ 1 p.m....	62°	3 „
Noon ...	73½°	1 foot 6 inches.

After a little practice, shadow-lengths can be accurately judged while on the march, and the inconvenience of halting and looking into the glare of the sun is avoided.

BEARINGS BY THE SUN.

When the sun is on the meridian of a place the time is said to be apparent noon at that place. It must be remembered that only in April, June, the last week in August, the first in September, and the last week in December, is apparent noon the same as mean noon (12 o'clock). For the rest of the year apparent noon may be either before or after 12 o'clock, and may differ by as much as 16 minutes. It is evident that the sun at 12 o'clock may be some degrees from the meridian.

For this reason the sun at 12 noon must never be used for determining the magnetic variation of a compass, although the shadows it throws may well be used as aids to marching on a compass bearing.

RULE II.

A rough rule, which can only be used in high latitudes, where the sun does not rise to a great height in the heavens, is given for finding the direction of true N. and S. with a watch. In N. latitudes point the hour hand to the sun, and the direction of true S. will lie midway between the hour hand and 12. In S. latitudes point 12 to the sun, and the direction of true N. will lie midway between 12 and the hour hand.

The declination of the sun on 21st March and 23rd September is 0. In other words, on those two days, and only on those two days, the sun is on the celestial equator, and will therefore, all the world over, rise due E., follow the celestial equator through the heavens, and set due W.

On every other day the sun rises N. of E. or S. of E., according to the time of year, the amount of its departure from true E. varying with the latitude of the observer.

Table III. gives the departures (from true E. and W.) of the sun at sunrise and sunset on the longest and shortest days of the year, for different latitudes.

EXAMPLE V.

Required the bearings of the sun at different times of the day on 30th October at Maritzburg.

The latitude is 30° S., the sun's declination $13\frac{1}{2}^{\circ}$ S.

From Table III. the greatest departure for latitude 30° is 27° .

That is, the departure is 27° for a declination of $23\frac{1}{2}^{\circ}$.

Therefore the departure is $\frac{27 \times 13\frac{1}{2}}{23\frac{1}{2}}$ for a declination of $13\frac{1}{2}^{\circ}$.

That is, the departure is 15° .

The sun's declination is S., therefore the departure is S.

The sun, from Example IV., rises at 5.27 a.m. and sets at 6.33 p.m. It is due N. at noon.

A table of times and bearings can now be made.

<i>Time.</i>	<i>True bearing of sun.</i>
5.27 a.m. (sunrise)	105°
6 a.m. ...	96°
7 a.m. ...	80°
8 a.m. ...	64°
9 a.m. ...	48°
10 a.m. ...	32°
11 a.m. ...	16°
Noon ...	360°
1 p.m. ...	344°
2 p.m. ...	328°
3 p.m. ...	312°
4 p.m. ...	296°
5 p.m. ...	280°
6 p.m. ...	264°
6.33 p.m. (sunset)	255°

From this table it is clear that if an observer has a watch he can obtain bearings at any hour, or if he has a compass he can obtain time. If he has neither watch nor compass he must combine the table of times, heights of sun, and shadow-lengths with the table of times and bearings.

Measuring either the height of the sun or the length of his shadow he will then be able to obtain both time and bearings.

TIME BY STARS.

Every star is moving in space, some towards the sun, others away from it, but the stars are so far removed from the earth that the fastest moving star will not alter its relative position to the naked eye in less than 25 years.

The principal constellations must be learnt by heart. This is only a question of practice on clear nights with a reading lamp and a good star-chart.

When the constellations have been learnt it is easy to master their movements in the heavens, as their distances from each other and from the celestial equator are always the same.

It has already been mentioned that stars rise 4 minutes earlier every day.

If the time of rising of a star has been recorded on any particular date, and some weeks later the observer's watch is broken, he can obtain his time by the rising of that star.

RULE III.

About the end of February the pointers of the Plough are horizontal at 6 p.m., upright at midnight, and horizontal again at 6 a.m. Fig. 13 explains this.

The rule for any date on which the Plough is visible is, Note the angle which the pointers make with a vertical straight edge (such as a stick or pencil) at sunset. When the pointers have swung round 90° six hours will have elapsed.

After a little practice 3 hour intervals (45°) can be estimated, and finally single hour intervals (15°).

Fig. 13 illustrates two 6 hour intervals.

Positions of the Plough towards the end of February.

In Fig. 14 the inclination of the pointers at sunset was observed to be 60° to the vertical. When the pointers were

At sunset the inclination was estimated to be 60° to the vertical.

At the 2nd observation the inclination was estimated to be 15° to the vertical.

Therefore interval was $\frac{60-15}{15}$ (or 3) hours after sunset.

At the 3rd observation the inclination was estimated to be 0. Therefore the interval was $\frac{60}{15}$ (or 4) hours after sunset.

observed again, their inclination was 15° to the vertical. Therefore the time was 3 hours after sunset.

The pointers were again observed some time afterwards, and were found to be upright. The time was therefore 4 hours after sunset.

In S. latitudes the Southern Cross can be used in a similar manner.

At the end of March the Cross is on its side at 6 p.m., upright at midnight, and on its side again at 6 a.m. (Fig. 15.)

Rule III. applies again for any date on which the Cross is visible. Fig. 16 illustrates this. The constellation of Orion is very useful to an observer on the equator, as it rises due E.

At sunset the inclination was estimated to be 15° to the vertical.

At the 2nd observation the inclination was estimated to be 15° to the vertical

Therefore the interval was $\frac{15+15}{15}$ (or 2) hours after sunset.

At the 3rd observation the inclination was estimated to be 90° to the vertical

Therefore the interval was $\frac{15+90}{15}$ (or 7) hours after sunset.

of him, passes vertically over his head, and sets due W. of him, every hour producing a change of 15° in height.

Stars on or near the celestial equator are 12 hours above the horizon all the world over.

A star that is N. of the celestial equator is more than 12 hours above the horizon to an observer who is N. of the equator, and less than 12 hours above the horizon to an observer who is S. of the equator. For example, an observer at Dinant (Latitude 50° N.) will notice that α Arietis (Declination 23° N.) is practically the same length of time above the horizon as the sun on 22nd June, namely, about 16 hours.

EXAMPLE VI.

Required the number of hours that (a) Pollux and (b) Antares are above the horizon at Dinant.

(a) The latitude is 50° N., the declination 28° N.

The number of hours will be greater than 12.

From Table I., for latitude 50° , the sun rises at 3.55 a.m., when its declination is $23\frac{1}{2}^\circ$.

(The time of sunrise on the longest day is taken, as the required number of hours will be greater than 12.)

It is known that the sun rises at 6 a.m. when its declination is 0.

Therefore the sun rises 125 minutes before 6 a.m. for a change in declination of $23\frac{1}{2}^\circ$.

Therefore by proportion the sun would rise $\frac{125 \times 28}{23\frac{1}{2}}$

(or 149) minutes before 6 a.m. if it had a declination of 28° (the declination of Pollux).

That is, the sun would rise at 3.31 a.m. and set at 8.29 p.m., being 16 hours 58 minutes above the horizon.

Therefore Pollux is 16 hours 58 minutes above the horizon.

(b) The latitude is 50° N., the declination 26° S.

The number of hours will be less than 12.

From Table I., for latitude 50° , the sun rises at 8.5 a.m., when its declination is $23\frac{1}{2}^\circ$.

(The time of sunrise on the shortest day is taken, as the required number of hours will be less than 12.)

By proportion, as above, the sun would rise $\frac{125 \times 26}{23\frac{1}{2}}$

(or 138) minutes after 6 a.m. if it had a declination of 26° (the declination of Antares).

That is, the sun would rise at 8.18 a.m. and set at 3.42 p.m., being 7 hours 24 minutes above the horizon.

Therefore Antares is 7 hours 24 minutes above the horizon.

The number of hours that a star is above the horizon may be a useful thing to know, if the time of the star's rising is noted, as midway between its rising and its setting the star will be on the meridian.

BEARINGS BY STARS.

The Pole Star, or Polaris (α Ursae Minoris), is only $1\frac{1}{4}^\circ$ away from the N. pole of the heavens, so that, at any time when it is visible, it may be used to give the direction of true North. It can also be used if a rough test of the magnetic variation of a compass is required, though for an accurate determination of magnetic variation a more complicated observation is necessary.

It is obvious from Figs. 6, 7, 9, and 11 that the height of the Pole Star above the horizon is the latitude of the observer, since in each case the angle N O R is equal to the angle Z O E .

This fact may be useful, when the pointers of the Plough are obscured by clouds, for finding the Pole Star.

RULE IV.

The pointers of the Plough can be used to obtain the direction of true North when the Pole Star is obscured by clouds or below the horizon. When the pointers are upright they are on the meridian. When they are in any other position the N. point can be obtained by spacing 5 times the distance between them in the direction in which they point. This can be seen from Fig. 13. The belt of Orion rises due E. and sets due W. in all latitudes so that if it is observed at rising or setting the true E. and W. line can be obtained.

The Pole Star is invisible anywhere south of latitude 10° N., while the Southern Cross comes into sight in latitude 20° N.

RULE V.

When the Southern Cross is upright it is on the meridian. When it is in any other position the S. point can be obtained by spacing $3\frac{1}{2}$ times its height in the direction of its length. This can be seen from Fig. 15.

RULE VI.

When α and β Centauri, the two pointers to the Southern Cross, are horizontal, the direction of true S. lies midway between them. Fig. 17 illustrates this.

The above are rough rules which are extremely useful. But an observer must not be restricted to a few constellations. He should be able to make use of any bright star in the heavens.

To an observer on the equator all stars rise North or South of true E. the exact amount of their declinations. Capella, for example, rises N.E. and sets N.W.

Roughly, the same rule holds good for any place in the tropics, but to obtain greater accuracy Table V. is given.

Fig. 17

EXAMPLE VII.

Required the bearings of Arcturus (α Boötis) on a night that it is visible at Dinant. The latitude is 50° N., the declination (from Table IV.) is 20° N. The sum is less than 80° .

From Table V. 14° must be added.

Therefore Arcturus rises 34° N. of E., and sets 34° N. of W.

Its height on the meridian (by Rule I.) is 60° .

EXAMPLE VIII.

Required some stars that might be useful for rough bearings in Maritzburg.

The latitude is 30° S.

From Table V. 2° must be added for every 10° of a star's declination.

Therefore Vega will rise roughly N.E. and set N.W.

Arcturus will rise roughly E.N.E. and set W.N.W.

Sirius will rise roughly E.S.E. and set W.S.W. and so on.

If the number of hours that each of these stars is above the horizon is calculated, an observer can determine at what length of time after rising each star will be on the meridian.

EXAMPLE IX.

It is required to march W.S.W. at Fashoda. What stars may be useful?

The latitude is 10° N.

From Tables IV. and V. Sirius sets at 18° S. of W., β Scorpii at 21° S. of W., and Antares at 27° S. of W.

If none of these are in the W. at the time of marching, some known star that is setting must be taken, its bearing calculated, and the march made at the necessary angle to it.

As regards the selection of useful stars on any night of the year, an observer should note at sunset any known star that is near the meridian. From Table VI. he can then see which of the principal stars will be visible during the night.

TIME BY THE MOON.

The moon rises roughly 50 minutes later each day.
 The first quarter rises at noon and sets at midnight.
 Full moon rises at sunset and sets at sunrise.
 The last quarter rises at midnight and sets at noon.
 The movement of the moon is too irregular for it to be used for bearings.

TABLE I.

Times of Sunrise and Sunset on the longest and shortest days of the year for different latitudes.

—						Sunrise.	Sunset.
						a.m.	p.m.
Equator	...	...	...	...	...	5.58	6.2
						6.2	5.58
Latitude, 10°	...	...	...	...	...	5.42	6.18
						6.18	5.42
„ 20°	...	...	...	...	...	5.24	6.36
						6.36	5.24
„ 30°	...	...	...	...	...	5.2	6.58
						6.58	5.2
„ 40°	...	...	...	...	...	4.35	7.25
						7.25	4.35
„ 50°	...	...	...	...	...	3.55	8.5
						8.5	3.55
„ 60°	...	...	...	...	...	2.45	9.15
						9.15	2.45

The declination of the Sun on these days is $23\frac{1}{2}^{\circ}$.

In N. latitudes the longest day is 22nd June, the shortest 22nd December.

In S. latitudes the longest day is 22nd December, the shortest 22nd June.

In obtaining the time of Sunrise on any particular day use the earlier time in the above table if the day in question is nearer the longest day of the year, and the later time if the day is nearer the shortest day.

In obtaining the number of hours that a star is above the horizon use the earlier time if the number will be greater than 12, the later if the number will be less than 12.

TABLE II.

Approximate declination of the Sun on the 1st day of each month :—

	N.	S.
1st January	—	23°
1st February	—	17°
1st March	—	8°
1st April	4°	—
1st May	15°	—
1st June	22°	—
1st July	23°	—
1st August	18°	—
1st September	9°	—
1st October	—	3°
1st November	—	14°
1st December	—	22°

The Sun's declination is 0 on 21st March and 23rd September, and is $23\frac{1}{2}^{\circ}$ N. on 22nd June and $23\frac{1}{2}^{\circ}$ S. on 22nd December.

The declination of the Sun on any day other than the 1st of a month must be obtained by interpolation in the above table.

Example. Required the declination of the sun on (a) 9th May and (b) 25th September.

(a) Declination on 1st May is 15° N., and on 1st June is 22° N.

The change in declination is $+7^{\circ}$ in 31 days.

Therefore the change in 8 days will be $+2^{\circ}$, and the Sun's declination on 9th May will be 17° N.

(b) Declination on 1st September is 9° N., and on 1st October is 3° S.

The change is -12° in 30 days.

Therefore the change will be -10° in 24 days, and the Sun's declination on 25th September will be 1° S.

TABLE III.

Departures of the Sun at Sunrise and Sunset on the longest and shortest days of the year for different latitudes :—

Equator	...	...	...	...	23°	North of E. and W. on June 22nd.
Latitude 10°	...	...	...	...	24°	
" 20°	...	...	...	...	25°	
" 30°	...	...	...	...	27°	
" 40°	...	...	...	...	31°	South of E. and W. on December 22nd.
" 50°	...	...	...	...	38°	
" 60°	...	...	...	...	53°	

The declination of the Sun on these days is $23\frac{1}{2}^{\circ}$.

TABLE IV.

Declinations of the Principal Stars.

This table is only to be used if the sum of the latitude and declination is less than 80°.

α Ursæ Majoris (Dubhe) ...	62° N.	β Orionis (Rigel) ...	8° S.
δ Ursæ Majoris ...	54° N.	α Virginis (Spica) ...	11° S.
α Persei ...	50° N.	α Canis Majoris (Sirius) ...	17° S.
η Ursæ Majoris ...	50° N.	β^1 Scorpii ...	20° S.
α Aurigæ (Capella) ...	46° N.	δ Canis Majoris ...	26° S.
α Cygni (Deneb) ...	45° N.	α Scorpii (Antares) ...	26° S.
β Persei (Algol) ...	41° N.	ϵ Canis Majoris ...	29° S.
α^2 Lyræ (Vega) ...	39° N.	α Piscis Australis (Fontenay) ...	50° S.
α Geminorum (Castor) ...	32° N.	α Columbæ ...	34° S.
β Tauri... ...	29° N.	ζ Argûs ...	40° S.
β Geminorum (Pollux) ...	28° N.	α Phœnicis ...	43° S.
The Pleiades ...	24° N.	α Gruis ...	47° S.
α Arietis ...	23° N.	α Argûs (Canopus) ...	53° S.
α Boëtis (Arcturus) ...	20° N.	β Aræ ...	55° S.
α Tauri (Aldebaran) ...	16° N.	δ Crucis... ...	57° S.
δ Pegasi (Algenib) ...	15° N.	α Pavonis ...	57° S.
α Pegasi (Markab) ...	15° N.	δ Crucis ...	53° S.
β Leonis (Denebola) ...	15° N.	α Eridani (Achernar) ...	58° S.
α Leonis (Regulus) ...	12° N.	β Crucis... ...	59° S.
α Aquilæ (Altair) ...	9° N.	η Argûs ...	59° S.
α Orionis (Betelgueux) ...	7° N.	α^2 Centauri ...	60° S.
δ Orionis (Bellatrix) ...	6° N.	β Centauri ...	60° S.
α Canis Minoris (Procyon) ..	5° N.	α^1 Crucis... ..	63° S.
δ Orionis	Equator.	α Trianguli Australis ...	69° S.

FOR DEPARTURES. TABLE V.

In Latitude 10°	add 1°	for every 20°	of star's declination.
" 20°	add 1°	" 10°	" "
" 30°	add 2°	" 10°	" "
" 40°	add 4°	" 10°	" "
" 50°	add 7°	" 10°	" "
" 60°	double the declination		for stars close to celestial equator.

TABLE VI.

Intervals between Rigel and each of the principal stars on any meridian.

—	Hrs.	Mins.	—	Hrs.	Mins.
β Orionis (Rigel) ...	0	0	η Ursæ Majoris ...	8	34
γ Orionis (Bellatrix) ...	0	10	β Centauri ...	8	47
β Tauri ...	0	10	α Boötis (Arcturus) ...	9	1
δ Orionis... ..	0	17	α^2 Centauri ...	9	23
α Columbæ ...	0	26	β^1 Scorpii ...	10	50
α Orionis (Betelgueux)	0	40	α Scorpii (Antares) ...	11	14
α Argûs (Canopus) ...	1	12	α Trianguli Australis ...	11	29
α Canis Majoris (Sirius)	1	31	β Aræ ...	12	8
ϵ_2 Canis Majoris... ..	1	45	α Lyræ (Vega) ...	13	21
δ Canis Majoris ...	1	55	α Aquilæ (Altair) ..	14	36
α Geminorum (Castor)	2	19	α Pavonis ...	15	8
α Canis Minoris... ..	2	24	α Cygni (Deneb) ...	15	28
(Procyon)					
β Geminorum (Pollux)	2	30	α Gruis ...	16	52
ζ Argûs	2	50	α Piscis Australis ...	17	42
			(Fomalhaut)		
α Leonis (Regulus) ...	4	53	α Pegasi (Markab) ...	17	50
η Argûs	5	31	γ Pegasi (Algenib) ...	18	58
α Ursæ Majoris (Dubhe)	5	48	α Phœnicis ...	19	12
β Leonis Denebola) ...	6	34	α Eridani (Achernar) ...	20	24
γ Ursæ Majoris... ..	6	39	α Arietis ...	20	52
δ Crucis	7	0	β Persei (Algol) ...	21	52
α Crucis... ..	7	11	α Persei ...	22	8
γ Crucis	7	16	The Pleiades ...	22	30
β Crucis	7	32	α Tauri (Aldebaran) ...	23	21
α Virginis (Spica) ...	8	10	α Aurigæ (Capella) ...	24	0

It is clear from the above table that Sirius will cross the meridian $1\frac{1}{2}$ hours after Rigel, and the Pleiades $1\frac{1}{2}$ hours before Rigel.

Books of Reference :—

- "The People's Atlas of the Stars," by Rev. James Gall (*Gall and Inglis*).
- "The Story of the Heavens," by Sir Robert Ball (*Cassell and Co.*).
- "Astronomy of To-day," by C. C. Dolmage (*Seeley and Co.*).
- "Sidelights on Astronomy," by Simon Newcomb (*Harpers*).
- "Scouting and Reconnaissance in Savage Countries," by Captain C. H. Stigand (*Hugh Rees*).
- "Hints to Travellers," Royal Geographical Society.

APPENDIX.

THE CAUSE OF THE SUN'S APPARENT ANNUAL SWING.

The sun is the centre of the solar system, and the earth is one of 8 planets that are known to be revolving round it.

The earth revolves once round the sun in 365.256 days, and the orbit of this revolution is not a circle, but an ellipse (Fig. A).

The earth's distance from the sun is constantly changing, but the incidence of the seasons is not due to this change. It is due to the fact that the axis of the earth, round which the earth rotates, is inclined at an angle of $66\frac{1}{2}^{\circ}$ to the plane of the earth's orbit, or, in other words, that the equator of the earth is inclined at an angle of $23\frac{1}{2}^{\circ}$ to the plane of the earth's orbit.

Summer in Europe is when the earth is farthest from the sun, because in that position the sun's rays on Europe are nearer the vertical than in any other position of the earth.

Fig. A represents the orbit of the earth round the sun seen from above.

Fig. B represents the same orbit seen from the side.

It is clear from Fig. C (an enlargement of the vernal equinox of Fig. B) that on 21st March the sun is bisected by

the plane of the equator of the earth, and therefore will appear to be vertically over the equator during one rotation of the

Fig. C.

earth (24 hours). That is, the sun will appear to move along the celestial equator on 21st March.

The same is obviously true of 23rd September.

It is also clear from Fig. D that on 22nd June the sun will appear to be vertically over latitude $23\frac{1}{2}^{\circ}$ N., that is, it will

Fig. D.

appear to move across the heavens at a distance of $23\frac{1}{2}^{\circ}$ N. from the celestial equator.

Similarly, as shown in Fig. E, on 22nd December the sun will appear to be vertically over latitude $23\frac{1}{2}^{\circ}$ S.

22nd June and 22nd December are the northern and southern limits of the swing, 21st March and 23rd September the middle points of it.

In any intermediate position of the earth the sun will appear to be between 0 and $23\frac{1}{2}^{\circ}$ N. or S. of the celestial equator according as the earth is nearer the June or December position.