Amateur Astronomy for Beginners

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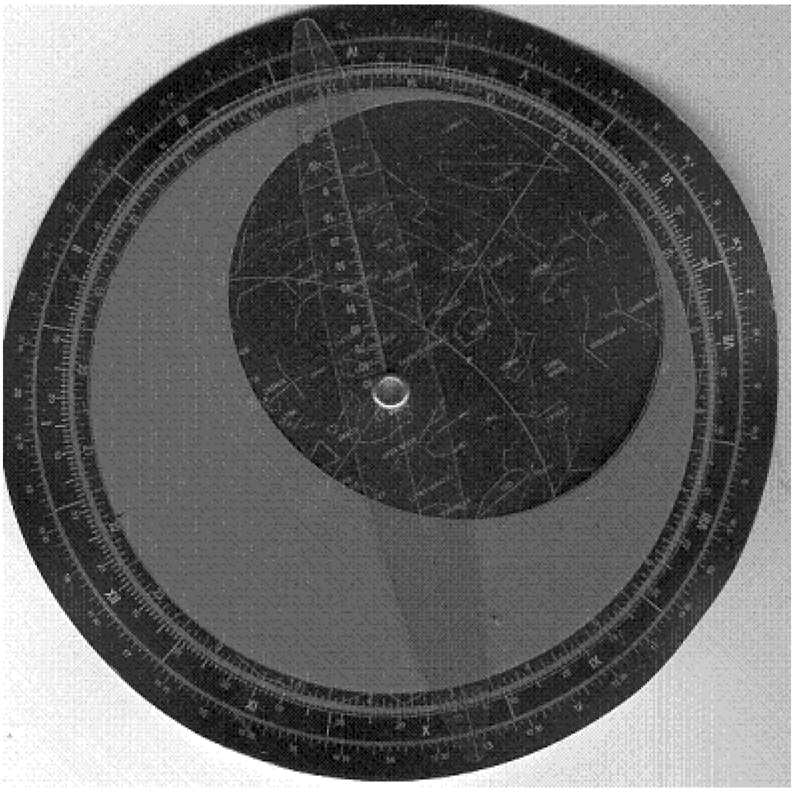
First Session

Welcome to a brief introduction to Amateur Astronomy. It does not matter whether you are nine or ninety years old. What matters is your interest or enthusiasm to learn new things or to remind you of things which you may have almost forgotten. I hope that everybody can learn from this introduction which should encourage you to look at the night sky more carefully and curiously, preferably far away from city lights.

The introduction is divided into different thematic sessions. Each of them almost certainly will not be finished in one evening. They may take two or three evenings each. They may also be extended by practical work with instruments, atlases, catalogues, cameras or simple computer work, depending on your interest and questions.

I am not going to use a lot of mathematics, hardly any, in fact - unfortunately, perhaps, for some of you, a great relief for others.

However, I strongly recommend to purchase a 'Philips' Planisphere' for a start (issued by George Philip and Son, Ltd., 12-14 Long Acre London WC2E 9LP). A planisphere shows which constellations/stars are above the horizon at any time of the day during the year.



1. A planisphere consists of a basic disk showing stars/constellations visible to the naked eye and a turnable mask defining the area of visibility.

I should like to divide each session into two parts. The first part (A) will be theoretical, dealing with Astronomy Basics; the second part (B) is practical, discussing problems arising in the context of naked-eye-, binocular- or telescopic observation. Keep in mind that learning to look at the night sky systematically, to use binoculars properly, particularly to observe with a telescope is like learning to drive. It takes time, quite a lot of patience – especially with our weather – and practice. You may feel frustrated initially, but don't give up! The stars will reward you more than enough.

First Session (will take two evenings)

The Visible Night Sky

A.

- Constellations
- Stellar Motion
- Elementary angular Measurement
- The Celestial Sphere I (Alt/Az system)

B.

- Naked- Eye Astronomy with a Planisphere
- Observing with Binoculars
- Observing with Telescopes

Second Session (will take two evenings)

Motions of Sun, Moon and Planets

A.

- Motions of the Sun
- Motions of the Moon
- Motions of the Planets
- Eclipses of Sun and Moon
- The Celestial Sphere II (Equatorial System)

B.

- How to set up your telescope
- Software to help you
- How to observe the Moon (as a serious start)

Third Session (will take two evenings)

Our Solar System

A.

- The Sun
- Planets and their moons
- Minor Planets/Asteroids
- Comets
- Meteorites

B.

- Observing techniques for solar system objects
- Beginning to take pictures/images

Fourth session (will certainly take more than two evenings)

Stars and Galaxies

A.

- Types of Stars, Clusters and Nebulae
- The magnitude system
- The Hertzsprung-Russell Diagram
- The inter-stellar Medium
- Types of Galaxies
- Cosmic Structure and History

B.

- Catalogues, Atlases, Website Information
- How to observe Stars and non-stellar objects
- Astrophotography/CCD imaging 1
- A very, very brief introduction to photometry and astrometry using the Mira AL 8 software (depending on interest, each of these may be advanced courses in future)

First Session

Finding Constellations

It is best to begin by looking at the night sky with your best instruments, your own eyes. Before you start using binoculars or a telescope you have to get a general idea of what you are looking at. Preferably, you should not just stargaze by yourself but have some assistance by someone who can show you the position of some of the planets, the brightest stars of the season and the major constellations: the Great Bear (Ursa major/ The Plough), Cassiopeia, Perseus, Andromeda, Pegasus etc.

The best assistance – apart from your parents, friends, members of the club – for learning to become familiar with the night sky and its constellation are four things:

- A planisphere (e.g. Philips' Planisphere)
- A star atlas (e.g. Norton's Star Atlas)
- A computer astronomy programme (e.g. the freeware 'Stellarium' and the 'Virtual Moon Atlas')
- A book like Antonin Ruekl's, *Constellation Guidebook,* Sterling Publishing Co., New York 2000

However, nothing replaces practicing to observe! Armchair astronomy clearly has its great benefits, but learning to observe means to begin to live with stars in a really engaged way. Observing is a skill which has to be learnt like learning to drive or learning a new language. The best that can happen to you on this never ending journey is somebody who can teach you a bit of this skill enthusiastically.

Here are some initial tasks for you:

Looking North:
Using a planisphere or a star atlas, find the Great Bear, Cassiopeia and the Pole Star (Polaris)

Evening Sky in Autumn

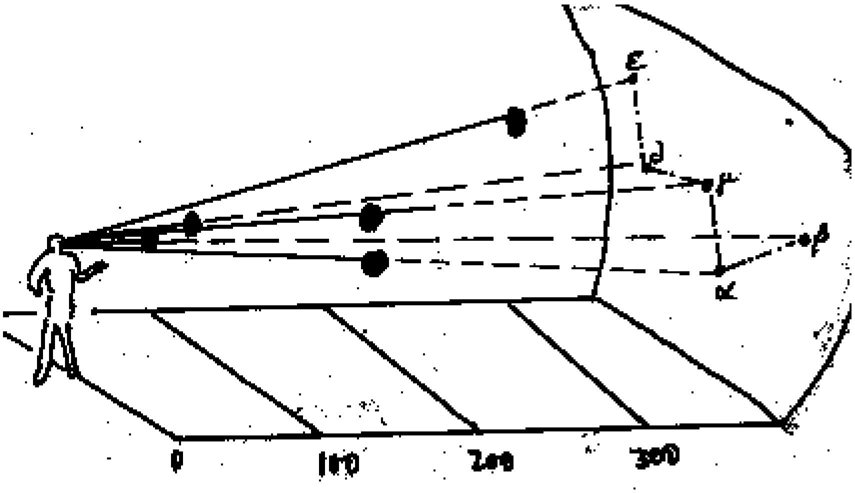
Looking from Northeast via East to South (high up):
Find Auriga (The Charioteer) and the star Capella, then Perseus, then Andromeda
Looking deep in the East:
Find the Bull (Taurus), the star Aldebaran and the Pleiades (Try also to look at the Pleiades with a pair of binoculars (10x50) but rest your arms on a stone wall or use a tripod with a binoculars adapter to steady the view.)
Looking South:
Find Pegasus
Looking South-West:
Find the Swan (Cygnus), the Lyre (Lyra) and the Eagle (Aquila)

Evening Sky in Winter

Looking South-East:
Find the Twins (Gemini) and Procyon (in the Little Dog/ Canis minor)
Looking South:
Orion; Sirius in the Great Dog/Canis maior); Aldebaran in the Bull and the Pleiades; Perseus above the Pleiades, Auriga and Capella
Looking South-West to West:
Andromeda; Cassiopeia

After you have practiced identifying these constellations using a planisphere or a star atlas it will be easy for you to find all the major constellations and brightest stars in the evening sky of spring and the summer. If you need light for looking at a star map or a planisphere while observing the night sky, use a red flashlight. It does not ruin your night vision which takes your eyes about 20 minutes to restore! Remember: It is always good to ask someone for assistance. Be humble, not overambitiously trying to find or solve everything on your own. It only means that you will learn less!

Constellations are our common aid to orient ourselves in the starry sky. However, they are our own inventions due to our lack of seeing stellar distances in space. For us, stars look like being fixed permanently on a hemisphere having the same distance from us. Nothing could be further from the truth! They do not form physically existing groups of stars since the stars are for the most part too far apart from each other, moving mostly in different directions. Take the example of Cassiopeia:



Stellar Motions (general)

If you feel strong enough to stay out for a whole night watching the stars you can see that they move – very slowly but surely – relative to the horizon. When you look from East to South to West you can see that they appear to rise in the East, and describing an arc in the sky they reach their highest position (culmination) in the South and continue their path setting in the West.

However, you do not have to stay up all night in order to see that the stars move. Look East near the horizon (or look West near the horizon) and you can see after a few minutes that the stars rise from the horizon (or sink down below the horizon in the West). If you look through a telescope which has no drive following stellar motion, a star in your field of view of the eyepiece probably drifts out of it in less than a minute. What you see as the apparent motion of the stars is – in reality – the earth's rotation!

When you look North you will notice that constellations such as the Great Bear or Cassiopeia move like a clock whose hands move *anticlockwise*. Look at the constellations of the Great Bear and of Cassiopeia and compare their relative position to the horizon every full hour of the night. They appear to rotate around a center, the celestial pole – roughly identical with the star Polaris, in a period of roughly 23 hours and forty five minutes (a stellar day = 23h 56m 4.1sec). For our purposes at present we may say that they rotate around the celestial pole in a day. In the past, people have used the Great Bear and Cassiopeia as a clock to tell the time at night. Of course, not the constellations rotate around the polar axis, but the polar axis is the earth's axis and the rotation is the earth’s rotation. However, what you see is not a delusion; it is just that you have to get used to the phenomenon of relative motion!

A second set of tasks

If you have a wide lens camera (28 mm to 35 mm) with a shutter which can be kept open for long-time exposure, using 200 ASA film, try to set it on a tripod in a really dark spot and take a sequence of images with exposure times of 5, 15, 30 minutes. (Don’t worry about over-saturating the image or the Schwarzschild effect). Take the first sequence of the Pole Star region including the Great Bear and Cassiopeia. Take a second sequence facing East, a third one facing South and a fourth one facing West. Of course, you need not take all these sequences in one night. You may take several nights for it.

You have recorded apparent celestial motion, identifiable in the star trails. (You can even measure the length of star trails and measure how their length relates to the whole circle of which they are a section. In this case, you can determine angular speed (see next section). You have really recorded the earth’s rotation.

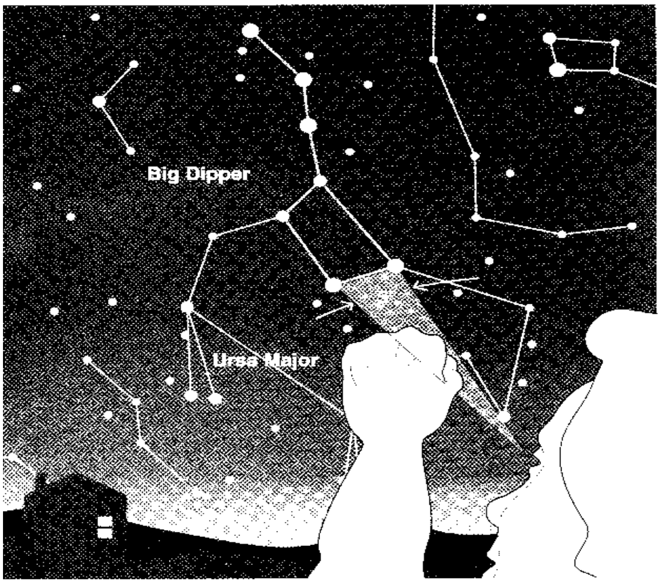
Angular Measurement

How can you measure how far apart stars appear in the night sky? Don’t you need highly specialised equipment for this? Remember that you possess two very useful instruments: your eyes and your arms and hands. Your hands can be used as a sighting device when held at arm’s length. With their help you can measure the angular distance between the stars.

Angular measurement is based on dividing the circumference of the circle. A circle is divided into 360 degrees of arc. Each degree is divided into 60 arcminutes; each arcminute is divided into 60 arcseconds.

You can use your arm and your hand to measure degrees of arc of *angular distance* between stars. You can also measure the *angular size* of the sun and the moon. Extend your arm, hold up your middle finger and try to cover your image of the sun. The sun is covered by half a fingertip. Its angular size is 30 minutes of arc, i.e. half a degree. The separation of the so-called pointer stars in the Great Bear (the two stars pointing to the Pole Star: see the subsequent picture) may be an example for measuring angular distance rather than angular size: Extend your arm, make a fist holding it between the two pointer stars. The angle between the two pointer stars in the Great Bear is about 5 degrees of arc, or half a fist held at arm’s length.

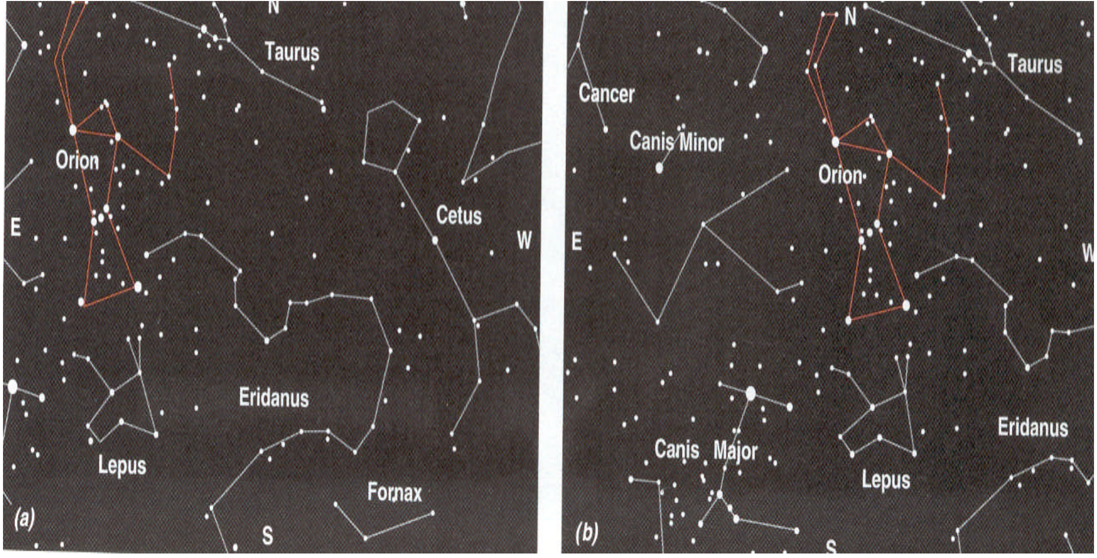
- The fingertip of your middle finger equals 1 degree
- The bottom bone of your index finger equals 6 degrees
- The middle bone of your index finger equals 4 degrees
- The top bone of your index finger equals 3 degrees
- Your fist from the knuckle of your little finger to the knuckle of your index finger equals 10 degrees
- Your hand spread out wide covers 18 degrees from the tip of your little finger to the tip of your thumb.



We can also measure (roughly, of course) *angular speed*. Using your fist, you can also determine how many degrees stars move per hour relative to the horizon. The only extra instrument you need is your wrist watch which tells you the time which the star needs to move from A to B. Your fist can tell you which distance (angle) the star has covered. Angular speed equals angle per minute/hour.

Motion of Orion in mid December, 10-12pm:

10pm 12pm



South South

Orion moved 30 degrees in two hours.

(Pictures taken from M.Zeilik, Astronomy, p. 6)

A third set of tasks

a. Measure the *angular size* of the Sun and the Moon
b. Measure the *angular distance* between the brightest stars in the Great Bear, Cassiopeia and Orion
c. Measure the *angular speed* of Sirius (in Winter) or any other bright star near the meridian

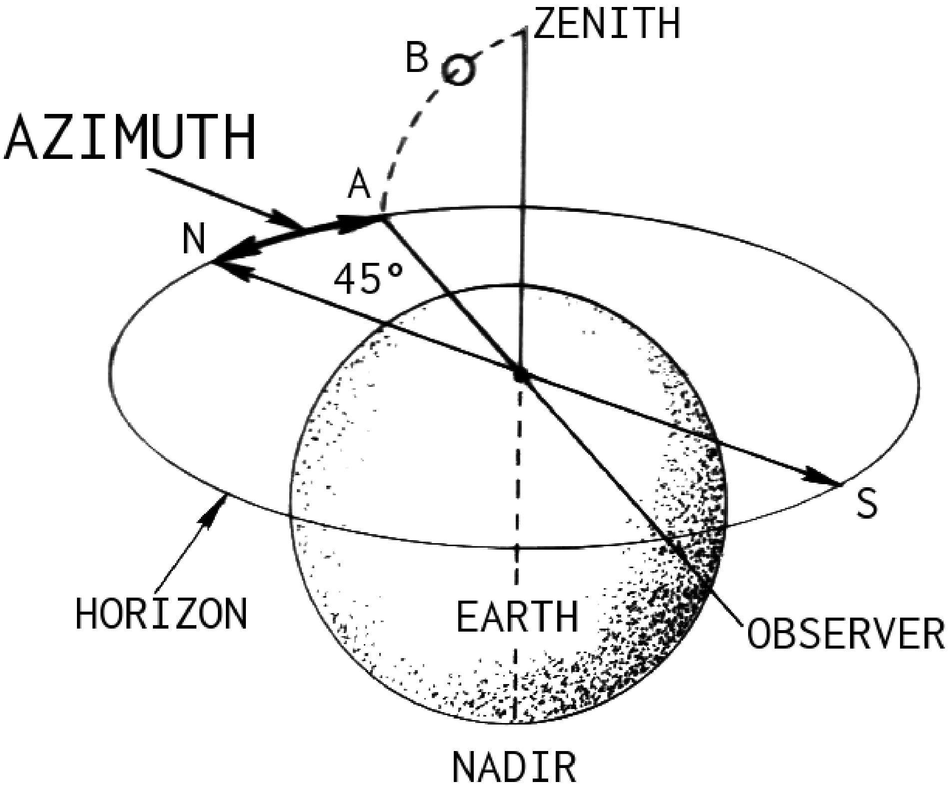
We have only considered angular speed of stars moving either from East to West or in a circumpolar fashion. Their angular speed is 15 degrees per hour. We have not considered the angular speed of the Moon or of the planets or, indeed, the apparent daily angular speed of the sun (of 1 degree per day) in the opposite direction due to their proper motion! This will have to be explained later.

The Celestial Sphere

The azimuth system

Imagine you stand on the Hill of Tara or on any piece of land from which you can see a vast area of land in all directions. You think that you stand on a huge plane disk. When you look up to the sky – provided there are no clouds – you may also believe that it forms a gigantic hemisphere above the disk on which you stand, with you at the centre. Of course, you know that the far distant circular line dividing the disk from the sky is called *horizon***.** High above, precisely above you in the sky, there seems to be a special (invisible) ‘point’, called *zenith* (from the Arabic expression ‘samt ar-ras’ = direction of the head, where ‘samt’ was inaccurately read as ‘cenit’ in the Middle Ages).

You may also assume that there is another hemisphere underneath the disk on which you stand, with another ‘point’ on the hemisphere precisely underneath you, called *nadir* (from the Arabic ‘nathir’=opposite). Your own position in this case is that of an observer positioned in the centre of a spherical world between zenith and nadir.



We all learnt a bit of geometry. We all know that a full circle can be subdivided into 360 degrees of arc and that a quarter of a circle forms 90 degrees. Hence, we may say that the horizon forms a circle of 360 degrees.

But where do you start counting? Where is 0 degrees? Once we know where the 0 mark is on the horizon, we shall be able to mark 90 degrees , 180 degrees, 270 degrees and 360 degrees. So where is 0 degrees? Of course, you could simply decide that some tree at a distance marks 0 degrees for you. Somebody else might decide otherwise. However, if you have to explain to somebody else in which direction you saw a star and you say that you saw it in the direction of 0 degrees, he/she would not know what direction you mean unless he/she stood in the same spot as you and knew the tree which you used as marker.

However, there is another way of fixing the point of 0 degrees. It is based on the stars and/or the sun. They never seem to rest. Most of them appear to rise above the horizon in some part of the sky, to reach a highest point in the sky (*culmination*) and then begin to sink down below the horizon almost opposite the region from where they rose. The direction in which most stars culminate is called *South*. You can now draw a geometrical line (a great circle) starting from the zenith through the point of culmination of a star on the celestial sphere to the line of horizon, and from this first intersection with the horizon to the nadir, from the nadir up to the second intersection with the horizon exactly opposite the first intersection and continue it to the zenith. This line is called the *meridian* line. (It is called ‘meridian’, because the sun at the equinoxes culminates at midday crossing this line(lat. ‘meridies’ for midday)). This line defines 180 degrees azimuth (‘azimuth’ is derived from the Arabic word ‘al simt’ = direction). 0 degrees azimuth is North. Hence, it defines North and South. Of course, another great circle (going from zenith to horizon to nadir to horizon to zenith) forming an angle of 90 degrees to the meridian defines East and West.

We can use this division of lines on our celestial sphere to determine the position of a star in the sky. We can identify a star by determining the direction in which it is to be seen in terms of the degree of arc on the horizon – starting from 0 degrees azimuth = North. A star has 180 degrees azimuth if it culminates in the South; it is 270 degrees azimuth when it stands in the West; it is 90 degrees azimuth if it is in the East etc.

However, we still have to determine how high the star is above the horizon. Its elevation above the horizon can be measured by determining the degree of the angle which its position in the sky forms with the horizon. In this case we have determined its *altitude* (lat: altitude = hight). It is 0 degrees altitude if it is exactly positioned on the horizon; it is 90 degrees altitude if it is in the zenith.

This system of geometrical lines which permits the exact identification of the position of a celestial object on the celestial sphere is called the **azimuth system**. It is one of the oldest systems we know.

Dobson telescopes, very popular among beginners, are Alt/Az mounted, for instance; some telescopes are equatorially (polar) mounted (the equatorial system will be explained next time); some are adjustable both to the Alt/Az or Equatorial system.

(To be continued)

Second Session

Let us return to things that we can see rather than construct geometrically when we look up at the sky. (Philosophers discuss if this distinction is sound). Brushing away the clouds we can see the sun, the moon and some – unfortunately not all - of the planets (Mercury (if you are lucky), Venus, Mars, Jupiter, Saturn), using only our eyes as instruments. We know that they are there, but we may know only vaguely how they move relative to the horizon during a day, a month, a year or even during longer periods than a year. This session will remind you of the most basic movements of our celestial neighbours which were probably known before the time when Newgrange or Stonehenge were built (roughly 3.200 BC or later). Our whole life is based on most of them.

Apparent Motions of the Sun

Daily motion of the Sun

The presence or absence of the sun in the sky defines one of our most fundamental natural cycles: Day and Night. We normally say that it is daytime between sunrise and sunset. We are able to measure daytime by simply putting up a stick on a plane surface (let us call this a gnomon = Greek: the one who knows {the time}) and observe the motion and varying length of its shadow on a sunny day relative to the ground and the horizon. In the old days, farmers in Connemara measured the time of day like that when they were working on the bog.

The shadow is longest twice a day, at sunrise and at sunset. It is shortest once a day, at local midday – when the sun is at its highest position in the sky (culmination). We can understand the continuous decrease of the length of the shadow as morning, its culmination as midday and its continuous decrease after its shortest length as afternoon/evening.

Hence, midway between sunrise and sunset the sun culminates (= our local midday) and then sets. The interval from one midday to the next defines a solar day .Therefore, a solar day is one cycle of day and night, not just the time between sunrise and sunset.

The sun clearly appears to move westward by 360 degrees during a day. We know now that this is really the Earth’s rotation around its own axis which causes our impression of the motion of the sun. However, imagine that you were able to see the stars and constellations during the day – irrespective of sunlight. Then, not relative to your horizon but relative to the stars, you would notice that the sun does not only move from east to west, simply following the Earth’s rotation, but that it also moves eastward very slowly by roughly one degree per day. This may be really confusing. But don’t despair. It is relative motion again. Not the sun moves, but the earth! What you see, in this case, is not the effect of the earth’s rotation, but the annual orbital motion of the earth around the sun taking roughly a degree per day. It takes a year to complete. It took people thousands of years to grasp that the earth orbits around the sun in a year rather than the reverse.

NOTE: You need not read the following if you are an absolute beginner!

A task for the advanced beginner:
You can actually observe this solar motion indirectly. Try to find the constellation of Gemini (Twins), for instance, when it is about to set in the west in June. Let us assume that the sun has moved below the horizon about an hour ago. Gemini is still visible in the West but beginning to sink below the horizon. The next constellation to follow is Cancer (Crab) which is still perfectly visible in the West.

Look West 3 weeks later, about an hour after the sun has set. Part of Gemini will still be visible – just about. Cancer is almost about to sink below the horizon. (Provisional conclusion: The sun has moved in the direction of Cancer, because it must now be in Gemini).

Wait until the end of July. The sun sets and the setting constellation of which you may still see the remaining stars is Cancer. (Conclusion: the sun has moved from Gemini into Cancer – and will move into Leo (Lion) as the month goes on). A clear motion against the daily east-west motion!

If you have a computer programme such as *Stellarium* you can simulate this motion relatively easily.

Continue reading

Annual motion of the Sun

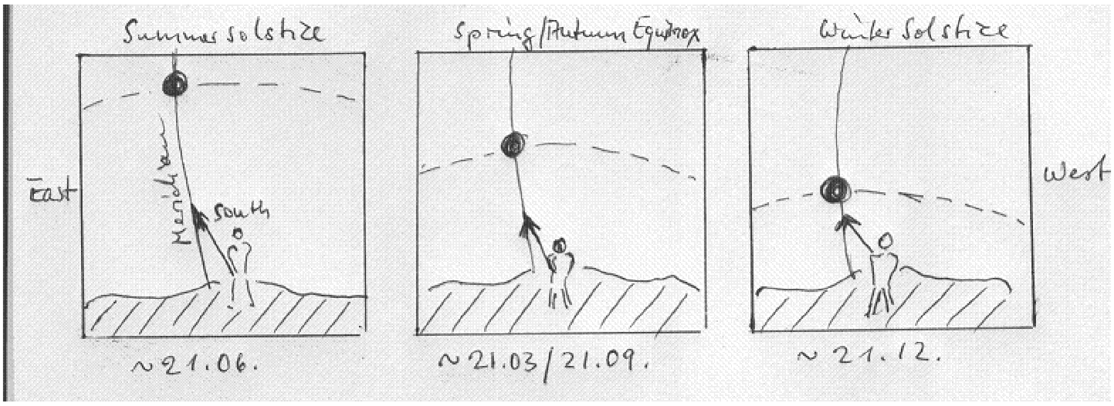
Observing (in the Northern hemisphere) the length of the shadow of your stick in the ground (the gnomon’s shadow) at midday shows that its minimum length also changes from day to day. Hence, the elevation (altitude) of the sun in the sky varies with the seasons when it passes the meridian. In summer, the sun rises in a much more northerly direction from East rather than East strictly speaking, stands higher in the sky at midday than in winter, spring or autumn, and sets in a more northerly direction from West rather than West strictly speaking. Since the sun’s path in the visible sky around this time is, therefore, the largest within the year, it is daylight longer than at any other time of the year.

Because the sun at this time of year culminates highest in the sky at midday – compared with its culminations during the rest of the year - the length of the gnomon’s shadow at midday is the shortest in the whole year. When this happens, we say that it is **summer solstice** (roughly 21. June) - (lat.: ‘solstitium’ = standstill of the sun)

The opposite is the case in winter, when the sun has its lowest culmination at midday of the whole year and the shadow of the gnomon at that time is therefore the longest at midday (around 21st December). In winter, the sun rises in a much more southerly direction from East rather than East strictly speaking, stands much lower in the sky at midday than in summer, spring or autumn, and sets in a more southerly direction from West rather than West strictly speaking. The arc of the sun described during daylight hours is the smallest in the year and hence these are the days with the fewest daylight hours. We say that this is **winter solstice**.

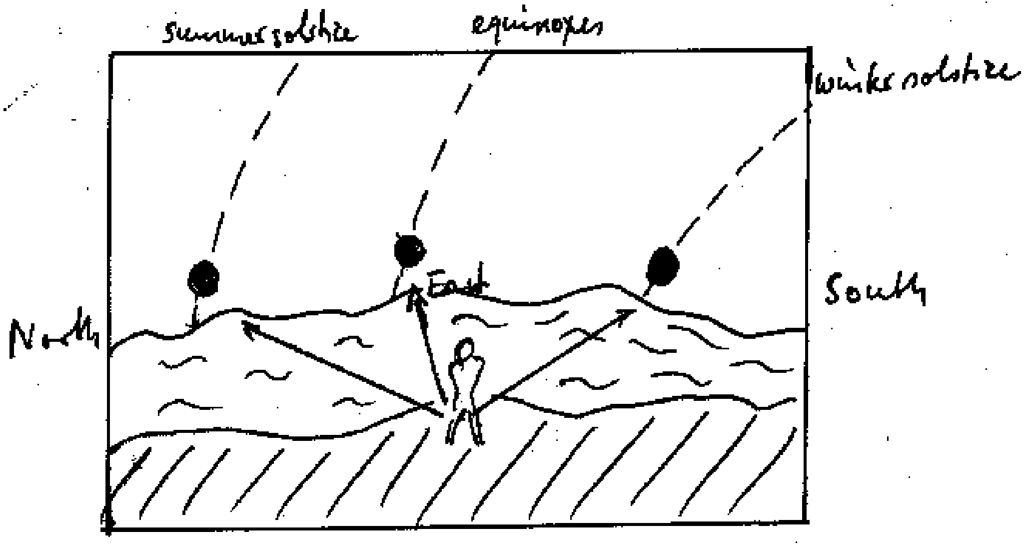
But we all know that there is a time in the year – twice, in fact – when day and night have equal lengths, when the sun culminates somewhere in between the culminations of summer/winter solstices and rises exactly in the East and sets exactly in the West.. These are the times of **spring (vernal) equinox** (roughly 21st March) and **autumn equinox** (roughly 21st September) - (lat.: ‘aequinoctium’ = equality of night {and day}).

Obviously, the sun appears to move up (from winter solstice to spring equinox to summer solstice) and down (from summer solstice to autumn equinox to winter solstice) in the sky during the year – relative to the horizon - when it rises, culminates passing the meridian and sets each day:

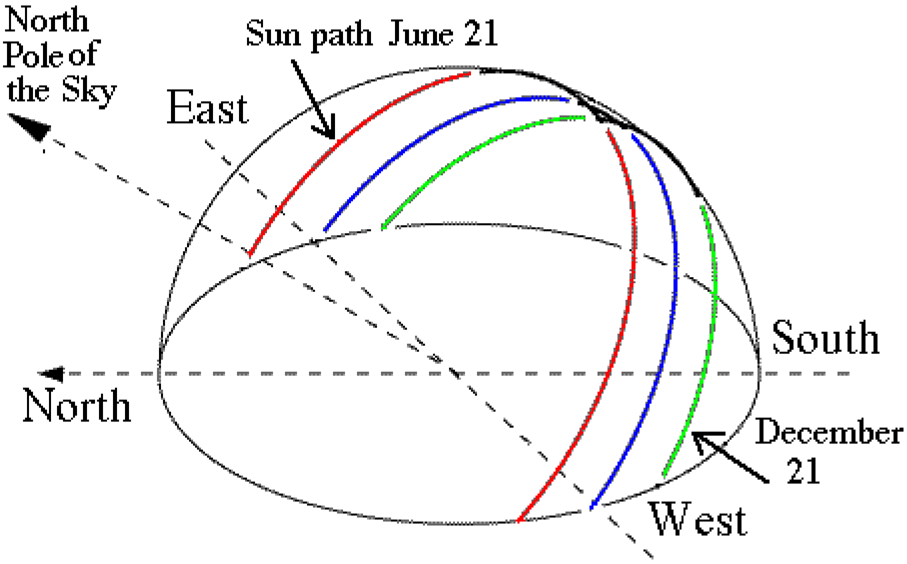


{View these images from left to right to left and you get the whole year’s cycle}

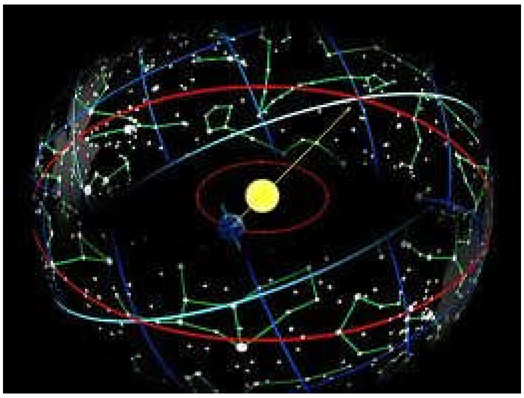
The sun also rises/sets more northerly or southerly during the year:



So the whole annual movement relative to the observer’s horizon during the year looks like this:



What about the sun’s position *relative to the stars and constellations* during the year? The sun obviously does not stay in the same place – relative to the stars and constellations.



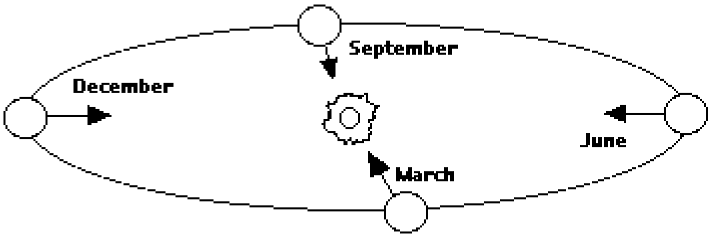
Imagine that you stand almost in the middle of this ring, on the blue planet representing the earth. You look in the direction of the yellow object which is the Sun. You see it projected against the sphere of the ‘fixed stars’ and constellations. They appear to revolve around you in a day moving from east to west.

The red line is the path which the sun appears to take – when projected against the celestial sphere - during the year, apparently moving eastward. This path is called the **Ecliptic** (Greek: ‘ekleipsis’ = Non-appearance (i.e. the plane where lunar or solar eclipses occur). On this path, the Sun appears to move through a series of constellations. These are the constellations of the **Zodiac** (your famous star signs used in horoscopes) - (Greek: ‘zodiakos kyklos’ = circle of animals). Now you can see in which constellation the sun is each month during the year:

The Sun in Constellations during the Year
(Note that when it is said that the sun is *in* X (in Leo for instance), what it really means is that the sun lies in the same direction of sight for us as the apparent configuration of stars which we call X (Leo). It does not mean at all that the sun forms a physical system with this constellation – which, in itself, is not for the most part a physical system either).

- Beginning of January in Saggitarius (Archer)
- Beginning of February in Capricornus (Goat)
- End of February in Aquarius (Water Bearer)
- End of March in Pices (Fishes)
- End of April in Aries (Ram)
- End of May in Taurus (Bull)
- Middle of June in Taurus (Bull)
- Beginning of July in Gemini (Twins)
- End of July in Cancer (Crab)
- Middle of August in Cancer (Crab)
- Beginning of September in Leo (Lion)
- Middle of October in Virgo (Virgin)
- Beginning of November in Libra (Balance)
- Beginning of December in Scorpius (Scorpion)

Roughly, you get the following picture:

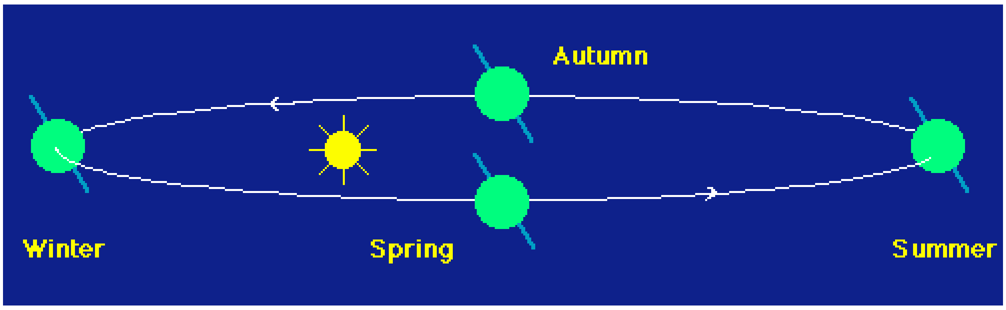


The Seasons Explained

Why is it that the sun appears to move up and down in the sky during the year? We all know a major effect of this motion: the annual seasons.

We all know that the Earth rotates daily on its own axis. However, its axis is tilted by 23.5 degrees relative to the ecliptical plane but always (forgetting about Precession for a moment) points in the same direction in space. This rotating Earth orbits the sun in a year. Due to its tilting axis the Northern hemisphere in summer is oriented more to the sun (it *seems* to nod so that the sun moves higher in the sky) than in the rest of the year. In winter it is oriented less to the sun (it *seems* to raise its face up high when the sun moves lower in the sky). During the equinoxes Northern and Southern hemispheres appear to be exposed to the sun at equal amounts. (Of course, the Earth does not nod *really* or raise its face since the polar axis does not move!).

When you look at the drawing, you also notice that the Earth is actually closer to the sun in winter than in summer! Nonetheless, this does not make our winters warm or the summers cold.



Something seemingly odd with solar motion: Equation of Time

Just as the old Connemara farmers using a stick as an indicator of time when they were working on the bog, let us continue to use it for a while – with one exception only. Let us also use our wristwatch and compare the time indicated by a gnomon with the time indicated by your wristwatch. Furthermore, let us assume that we compare the time of midday (12.00 o'clock on your watch) and the time indicated by the gnomon.

Supposing you do this every day of the year, you will notice that at some days of the year 12am on your watch equals12am indicated by the gnomon (roughly middle of April, middle of June, beginning of September, last third of December). However, at most days of the year the time indicated by your stick (or sundial, because that's what it is) will either be too slow (roughly up to 14 minutes middle of February) or too fast (roughly up to 16 minutes at the end of October/beginning of November). Everyone putting up a sundial in the garden will have to be aware of this. It is a phenomenon that you can really observe. Again: it has taken people more than 2000 years to explain why this is the case! The main reason is that the earth does not orbit the sun in a perfect circle – in which case its motion might be uniform allowing for uniform time measurement. It orbits the sun in an elliptical orbit such that the sun is in one of its two foci (an ellipse has two rather than one focus or "centre"), accelerates when it approaches the sun (**perihelion** early in January) and decelerates when it recedes to its greatest distance from the sun (**aphelion** early in July). Kepler's first two laws explain this. For the time being it suffices to know that this is a characteristic feature of apparent solar motion during the year. The time indicated by your watch is **mean solar time**, whereas the time indicated by a gnomon is **true solar time**. They are not the same.

Let us change the subject and continue to concentrate on what we can see.

Our next neighbour in the sky is the Moon. We all know that it has phases – as the most obvious phenomenon we can observe. But how can we make sense of them using our eyes only? Here is the answer:

Apparent Motions of the Moon

Daily motion of the Moon

All of us love to look at the Moon. It is the Earth's closest companion. ***It should be your first celestial object to observe with binoculars or your telescope*. Never look at the Sun with your binoculars or your telescope unless you have solar filters especially designed for this purpose!!!**

It is easy to find the Moon. It also has a tremendous amount of surface detail to identify and puzzle about. Also: when using a telescope for the first time, it may be difficult to find a specific star/planet/nebula even though your finderscope may be perfectly aligned. The Moon, however, is a big blob in the sky which is difficult to miss.

Use the *Virtual Moon Atlas* (computer freeware) or Antonin Ruekl's *Atlas of the Moon*, edited by G. Seronik, Sky Publishing Company, Cambridge,Mass. 2004 as your celestial guides.

We can see the Moon rise in the East and set in the West - when it shines and clouds don't obstruct the view. We can also see that it waxes or wanes in regular cycles. When it is fully visible we call it **Full Moon**, when it is only half visible we call it **Half Moon**, when it does not shine at all we call it **New Moon**.

We can also see, provided that we pay a bit of attention to its motion during a night, that it moves eastward in relation to its nearby background stars (or a planet), although it follows their general daily movement from east to west.

Another practical task

Find a bright star relatively close to the East of the Moon. Using the method of measuring angular distance with your index finger described in Lesson One choose a star about 2 – 3 degrees East of the Moon. Remember its position. Return about two hours later and judge the distance between the star and the Moon by using the tip of your middle finger. You will notice that the Moon has moved in the direction of the star by one degree. Of course, both the Moon and your star have moved also with the westward daily rotation of the earth. If you wait long enough, you may even see that the star gets occulted by the Moon and – after some time – will return on the Western side of it.

If you measure the rate of angular speed of the Moon moving *eastward* you will notice that it moves by 0.5 degrees per hour! The sun moves eastward only by about one degree per day! This eastward motion of the Moon relative to the stars will cause it to rise by about 50 minutes later than it did on the previous day (Check it!). The Moon will complete this eastward motion *relative to the stars* in about 27 days. This is called a **sidereal month** (lat.:'sidus' = star).The Sun is much slower (further away) than the Moon; it takes a whole year, by which time the moon has finished about 13 runs around the zodiacal stars.

A sidereal month, however, is not what we commonly call 'a month'. What we call 'a month' is related to the cycle of lunar phases from New Moon to New Moon which has a period of 29days, 12 hours, 44 minutes and 3 seconds. This is called the **synodic month** (Greek: 'synodos' = companion of a journey, but also meeting). It is New Moon when it stands roughly in line (same azimuth) between the Earth and the Sun, i.e. when it shows us its un-illuminated night-side. (It only stands exactly in line on the occasion of a solar eclipse).

For advanced beginners:

How can the difference in time between the sidereal month and the synodic month of about 2-1/6 days be explained? Here is the answer. For its illumination the Moon depends on the Sun – just as the Earth and the rest of the planets.

The sun apparently moves eastward along the ecliptic by about 1 degree with respect to the stars because in reality this is the earth's motion orbiting the Sun. So here you have one apparent orbital motion.

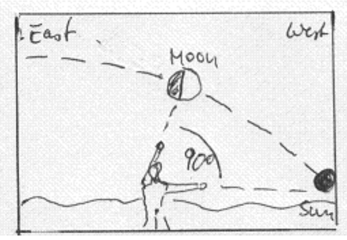
The Moon apparently moves eastward much faster. It takes roughly 27 days to complete a full cycle relative to the stars. Here you have a second apparent orbital motion.

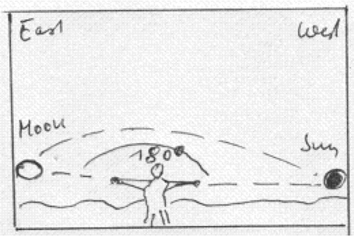
But here comes the crunch. The cycle of New Moon to New Moon implies that Moon and Sun meet again on the same line. However, when the Moon has completed a full cycle relative to the stars in a sidereal month, the sun, of course, has not stood still. It has also moved on eastward. The moon needs another 2-1/6 day to catch up with it in order to meet up.

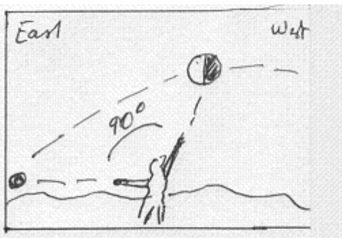
Phases of the Moon during a month

All of us know that the Moon shows phases: The amount of its surface which is illuminated by the Sun increases or decreases in a regular sequence. We also know that the Moon is invisible to us when it is not illuminated by the Sun. A few days after this New Moon, we can see its very thin crescent appearing in the west shortly after sunset. When you imagine the Sun just below the western horizon, the Moon appears to be relatively near it still. Each day from this time on, shortly after sunset, you can see the Moon in a more eastward position in the sky, further away from the position of the sun (which you cannot see but guess below the horizon). Also, the Moon increases its illuminated surface area day by day, moving from

- New Moon (angular distance between the Sun and Moon minimal), to
- First Quarter (waxing) Moon (angular distance of the Moon from the Sun is roughly 90 degrees and the Moon is *East* of the Sun), to
- Full Moon (angular distance of the Moon from the Sun is 180 degrees and the Moon is in **opposition**), and then
- Third Quarter (waning) Moon (angular distance of the Moon from the Sun is roughly 90 degrees *West* of the Sun), to
- New Moon (see above)







First Quarter Full Third Quarter

(to be continued)

Second Session Part 2

Eclipses of the Sun

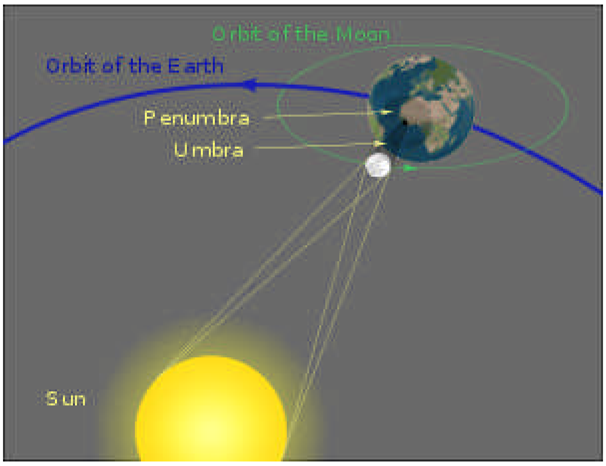
Eclipses are some of the most spectacular events in nature! Don’t miss them when you are able to see them.
Eclipses between the end of 2010 and 2012 are:

21.12.2010	Total Lunar eclipse
04.01.2011	Partial Solar
01.06.2011	Partial Solar
15.06.2011	Total Lunar
01.07.2011	Partial Solar
25.11.2011	Partial Solar
10.12.2011	Total Lunar
20.05.2012	Annular Solar
04.06.2012	Partial Lunar
13.11.2012	Total Solar
28.11.2012	Penumbral Lunar

Both lunar and solar eclipses are caused by the motion of the Moon. A **solar eclipse** (lat.: ‘sol’ = sun) occurs when the Moon – as seen from your location on Earth - passes *in front* of the Sun. The Moon passes between Earth and Sun. It may occult the solar disk either partly (**partial solar eclipse**), almost entirely or entirely (**total** or **annular solar eclipse**). Remember that you measured the solar and the lunar disk with the tip of your middle finger and found that both of them have an apparent angular diameter of ½ degrees. That is why the Moon can occult the Sun. The Moon occults the Sun entirely when both of them are exactly lined up. This event does not take more than a few minutes.

Of course, if the orbital plane of the Moon were to lie exactly on the ecliptical plane, an eclipse would happen every 14 days. However, this is obviously not the case. The orbital path of the Moon in relation to the orbital path of the Sun is tilted by 5 degrees. You can see this in the sky: The Moon is sometimes to be seen low in the sky - up to 5 degrees below the (invisible but imagined) line of the ecliptic - and sometimes up to five degrees above the ecliptic, high up in the sky. From our perspective on Earth, both orbital paths apparently intersect in two points (**nodes** {from lat.: ‘nodus’ = node, knot}) which means that Sun and Moon can stand in the same ‘place’ in the sky. This can only happen during a New Moon. That is when an eclipse can occur. Hence, an eclipse can occur only when the Sun is at or near one of these nodes of their orbits. If the Moon is almost in the same place but not near enough, then you get a New Moon but no solar eclipse.

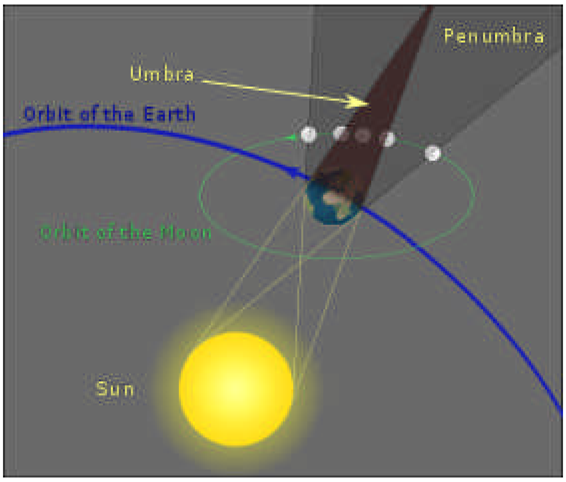
During a total solar eclipse, the Moon throws a fast moving shadow on Earth, only a few hundred kilometres wide. If you happen to observe the Sun just when this shadow passes your location, you will see a total solar eclipse. If you stand outside the band of the lunar shadow, you will only experience a partial eclipse.



Eclipses of the Moon

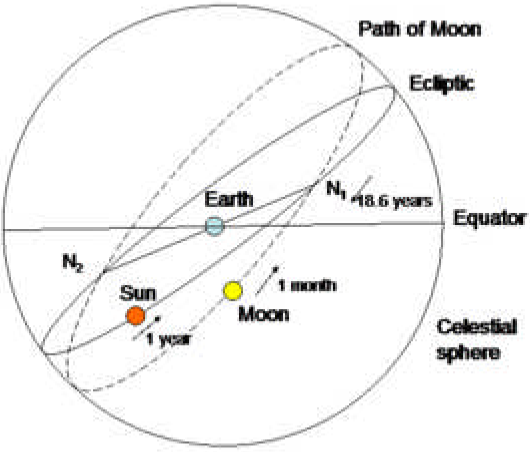
A **lunar eclipse** (lat.: ‘luna’ = moon) occurs when the Moon passes through the cone of the Earth’s shadow (**umbra**, lat.: ‘umbra’ = shadow) which cuts the Moon off the sunlight that normally illuminates it. (The dim illumination the Moon gets at a total lunar eclipse is sunlight reflected from the Earth’s atmosphere and scattered by it; hence the Moon appears reddish-orange!) As seen from the Sun, the Moon passes behind the Earth. The Earth is situated between the Sun and the Moon. This can only take place at Full Moon, because then Sun, Earth and Moon lie precisely (or almost precisely) on a line. This event may last for a few hours and can be seen from anywhere on Earth where it is night time.

Lunar eclipses can be total or partial, depending on whether the Moon passes the central cone of the earth’s shadow entirely or only a part of it. Its speed is about 1 km/ second. If it passes the fringe area of the central cone (**penumbra**), the Moon is still visible in its full glory although its light is slightly dimmed.



In spite of the fact that the ancient Babylonians already knew it about 3000 years ago, it would take us a long time to discover by our own observation that eclipses of the Sun and the Moon occur in cycles. This is a major reason why they can be predicted. The **Saros Cycle** is a cycle of 18 years, 11 days and 1/3 of a day at which almost identical eclipses occur.

We know by now that for a solar eclipse to occur the (full) Moon must pass between Earth and Sun; for a lunar eclipse to occur, the Earth must pass between the Sun and the (full) Moon, provided that these three bodies are aligned roughly or exactly. Furthermore, for the same eclipse to occur, Sun, Earth and Moon must also be almost at the same distance from each other and Sun and Moon must be at the same node. None the less, during the same period of the Saros cycle about 40 other eclipses will occur, yet have a different geometry.

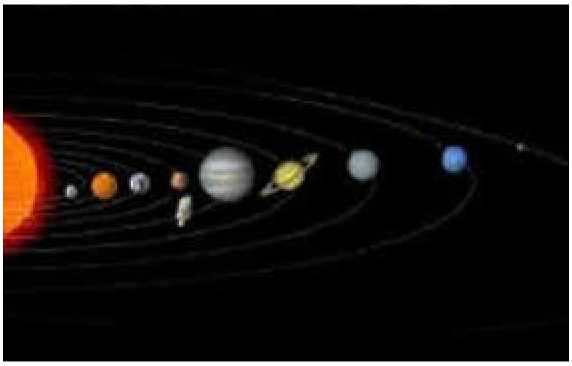


Motion of the Planets

Supposing you are out stargazing on several nights in a row. You may see some ‘stars’ (in the zodiac) which move quite differently from the rest of the ‘fixed’ stars within constellations. They seem to wander from east to west, and also move slowly eastward – like the Sun and the Moon - relative to the fixed stars. You can observe this over a period of several days. However, they also appear to stand still occasionally before moving eastward or westward again. Moving seemingly oddly, they even describe ‘loops’ relative to their starry background. They also dim or get brighter during this journey. Furthermore, they do not appear to twinkle like the rest of the stars. When you use a telescope, you can see that they are little disks rather than mere points of light. These are planets (Greek sing.: ‘planetes’, derived from ‘planes’ = wanderer).

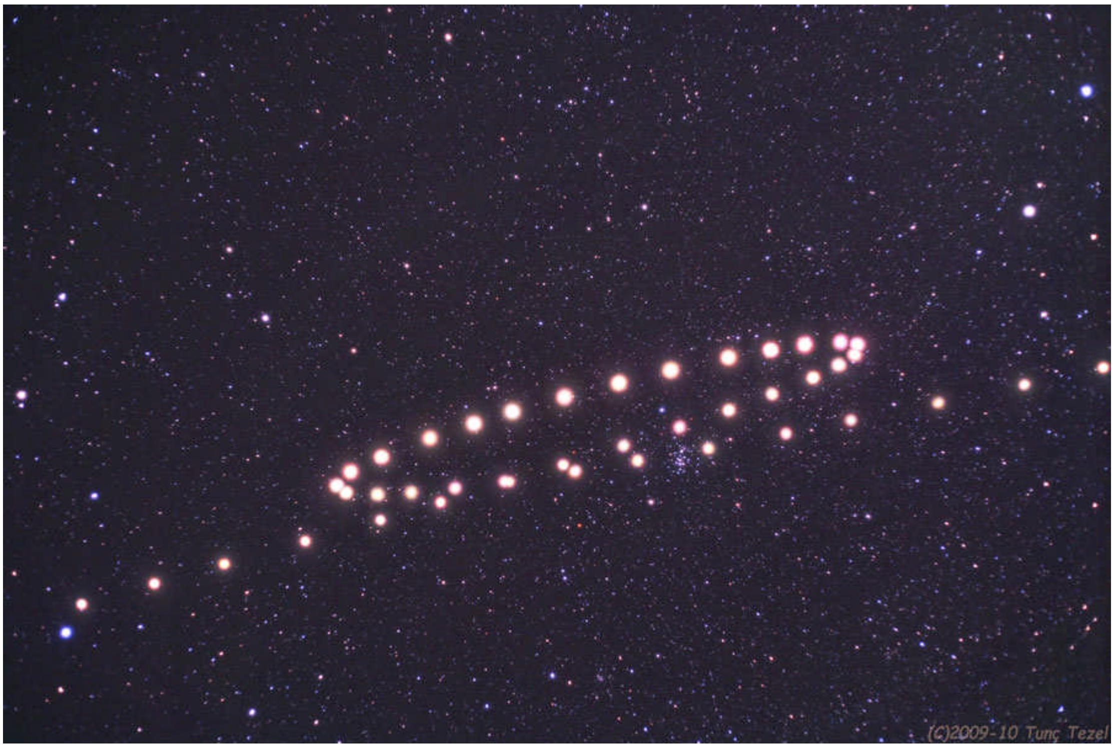
You may be patient enough to observe the planet Mars each night, for instance, for several months after you heard that it shines brightest. It appears brightest roughly every two years when it comes closest to the Earth. Initially, you will notice that over a few days Mars has slowly moved eastward (forget for the moment that it also moves westward every day due to the Earth’s rotation). This eastward motion is its apparent proper (**direct** or **prograde**) motion. However, it seems to stop after a while, and then, after about three months’ rest, moves westward related to the background stars (it is in **retrograde motion**). But then it stops again! Thereafter, it resumes its prograde eastward motion.

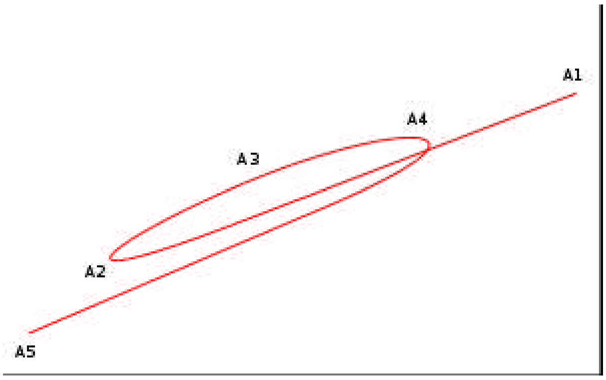
All planets (not the Sun or the Moon, since they are not planets) perform this motion, yet not all of them display these ‘loops’ simultaneously. These are the planets:



From left to right: Sun, Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus, Neptune, (Pluto). Of course, you cannot see retrograde motion of Earth since this is your own observer’s position. A Martian could see it!

This is an example of retrograde motion:





A1: prograde motion to A2; A2: standstill; A3: retrograde motion; A4: standstill; A5: prograde motion

Here is a (rough) table of retrograde motions of planets visible for the naked eye:

Planet	**Period around ecliptic**	**Duration of retrog.**	**Time between retr.**
Mercury	~ 1 year	22 days	116 days
Venus	~ 1	42	584
Mars	~ 2	72	780
Jupiter	~ 12	120	399

Saturn	~ 30	138	378

It took mankind thousands of years (up to Copernicus in 1543 AD) to understand what lies behind this ‘wandering’ motion of the planets. Here is the simple solution. Again, it depends on relative motion and how to explain it. As a start, I am taking superior (outer) planets as examples. Mars, Jupiter, Saturn are visible superior planets because their orbit lies beyond the space between Earth and the Sun.

Imagine, you are an observer on Earth (E in the next drawing). We know now that the Earth orbits the Sun (S) anticlockwise in a year. You observe planet Mars (P) from your moving Earth as it is projected against the starry background (Sphere of stars in the drawing). Of course, Mars also orbits the sun in two years. Hence, its apparent angular orbital speed is about half the speed of the Earth. It is much slower than your own planet.

When you begin to observe – let us say in January – you are in position E1, looking at Mars – which is in position P1. However, *you see* it projected on the sphere of stars in 1.

You wait with your next observation until February. The Earth has moved. Hence, you are in position E2. Mars has also moved, only more slowly. It is in position P2. However, you see it in Position 2 projected on the sphere of the stars. You see that it has moved in *prograde* motion from position 1 to position 2.

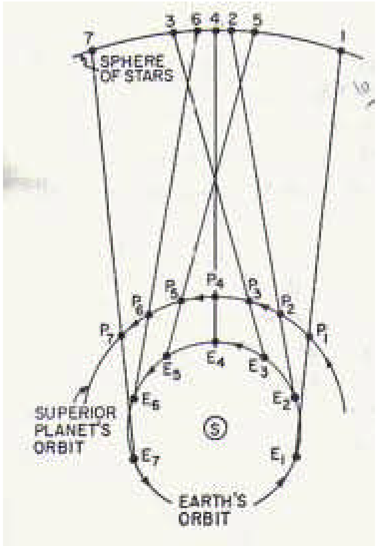
You resume your observations in March. The Earth has moved to E3; Mars has moved to P3. You see it in Position 3 projected on the sphere of the stars. You see that it has moved in *prograde* motion from position 2 to position 3.

You resume your observations in April. The Earth has moved to E4; Mars has moved around the sun to P4 without changing its direction. *But you see* Mars in Position 4 projected on the sphere of the stars. That’s odd: Mars appears to have stopped its retrograde motion somewhere between position 3 and 4 and started moving *retrograde*!

You resume your observations in May. Earth has moved to E5; Mars has moved around the sun to P5 without changing its direction. *But you see* Mars in Position 5 projected on the sphere of the stars. Mars appears to continue to be moving *retrograde* between position 4 and position 5!

You resume your observations in June. Earth has moved to E6; Mars has moved around the sun to P6 without changing its direction. For you, Mars is in Position 6 now, because you see it projected on the sphere of the stars. But what has happened? Mars appears to have stopped its retrograde motion somewhere between position 5 and 6 and started moving *prograde* again!

You resume your observations in July. Earth has moved to E7; Mars has moved around the sun to P7 without changing its direction. For you, Mars is in Position 7 now, because you see it projected on the sphere of the stars. Mars apparently continues to be moving *prograde* between position 6 and 7.



The ‘loops’ which you observe are obviously caused by the relative motion of Earth and Mars around a joint centre of motion when the observer is located on one of the moving planets (Earth in our case).

Obviously, the superior planets which do not orbit the Sun within the space between Earth and Sun can be in the line of sight (for us on Earth) with the Sun. In that case they are in **conjunction** with the Sun. However, they may also be in line of sight with the Earth – as seen from the Sun. In that case, they are in **opposition** to the Sun. You can observe relatively easily when they are in opposition:

In opposition, planets are opposite the Sun in the sky. When you know where the Sun is, stretch out your arms by 180 degrees, point your right arm to the sun (or where you think it is) and your left arm will point in the direction of the planet. If the Sun has just vanished below the western horizon, your planet in opposition will be in the eastern horizon. (It is like Full Moon). Superior planets reach opposition in the middle of their retrograde motion when they are also closest to Earth and, hence, shine brightest!

However, planets which orbit the Sun between Earth and Sun (**inferior planets** (see next section)) can never be in opposition to the Sun since the Earth is never in line *between* the Sun and an inferior planet! However, they can be in conjunction with it.

Motion of the Inferior (Inner) Planets

Unlike the rest of the planets which we can see with our unaided eyes, two of them appear to be always close to the Sun. They never wander too far away from it. We can see them – if we see them - either directly after sunset in the western part of the sky or shortly before sunrise in the eastern part. They are Mercury (which is difficult to see because it mostly appears to be very close to the Sun) and Venus. They are the **inferior** (or **inner**) **planets** because they follow their orbits between Earth and Sun, yet never outside this space. The rest are called **superior** (or **outer**) **planets** because they orbit the Sun at some considerable distance from Earth, yet never between Earth and Sun.

You can use your outstretched arm, hand, fist or fingers again to determine how far separated they appear to be from the Sun (**elongation**). You only have to guess fairly correctly how far below the horizon the Sun might be either at sunset or at sunrise when you try to determine their angular separation.

Venus and Mercury are ‘evening stars’ when they appear east of the Sun. They are ‘morning stars’ when they are west of the Sun.

Take Venus, for instance, which may be a very bright object in the evening sky. (Somebody rang me up, one evening, and asked me if there was a bright, yellowish UFO hovering over the Aran Islands). Supposing you are patient enough and the weather is exceptionally good over a longer period.

You may observe that Venus as ‘evening star’ (1) increases its angular distance from the Sun day by day, apparently moving *eastward*, further and further away from the Sun, until (2) it reaches a maximum angular distance, where it appears to stand still (**maximum eastern elongation**), before it begins (3) to decrease its angular distance from the Sun. After a period of invisibility (4) in the sky (because it is too close to the Sun which means that it is in **conjunction** with the Sun) it suddenly turns up (5) in the morning before the Sun rises, i.e. in a position west of the Sun.

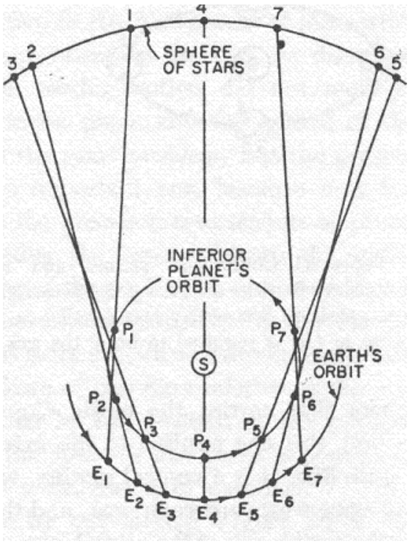
You may also observe that Venus as ‘morning star’ (6) increases its angular distance from the Sun day by day, apparently moving *westward* in relation to the Sun, until (7) it reaches a maximum angular distance, when it appears to stand still (**maximum western elongation**), before it begins (8) to decrease its angular distance from the Sun again.

For Venus, the average maximum elongation is 46 degrees (measure it with your hand!), for Mercury it is 23 degrees – which may vary, however - and reach a maximum of 28 degrees (use your hand again as instrument!).

You may observe that Venus increases its angular distance from the Sun day by day, apparently moving eastward, until it reaches a maximum angular distance, when it appears to stand still (**maximum eastern elongation**), before it begins to decrease its angular distance from the Sun.

Obviously, the diameter of the orbit of Venus is larger than that of Mercury when you compare the angular distance from the Sun and time between their maximum western and eastern elongations!

You can reconstruct the whole dance of the inferior planets by applying the instructions for reconstructing retrograde motion for superior planets, using this drawing:



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Second Session Part 3

The Celestial Sphere II (Equatorial System)

Co-ordinates on Earth

Nowadays we take it for granted that the Earth rotates in daily rotation. This rotation determines its North and South poles and its polar axis (forget about magnetic North and South or other kinds of poles for a moment). We also know that the Earth is roughly a globe (a bit flattened at the poles due to rotation – some say that it looks like a roundish (spheroid) potato). The greatest geometrical circle around this globe is called the equator.

How can we identify a location on this globe? We identify it with the aid of a co-ordinate system. We say that a place such as Galway has a latitude and a longitude (for Galway: Lat.: 53 degrees, 16 minutes and 29 seconds North of the Equator; Long.: 9 degrees, 3 minutes and 4 seconds West of Greenwich). Latitude and longitude are measured in degrees, minutes, seconds of arc. Their intersection defines any place on Earth geometrically. What are latitude and longitude?

Starting from the equator and ending at the north (or south) pole(s) you can divide this angular distance on the globe by further circles going ‘across’ the globe, ranging from 0 degrees at the equator up to +90 degrees at the north pole and -90 degrees at the south pole. These circles are **latitude** (lat.: 'latitudo' = breadth) lines.

Starting from the north pole and ending at the south pole you can imagine lines 'along' the globe. They are called **longitude** (**meridian**) (lat.:'longitudo' = length) lines. Longitude is either measured in degrees (360 degrees in total) or in hours, minutes and seconds, relating these lines to the Earth's rotation. Hence, 360 degrees equals 24 hours; 1 hour equals 15 degrees.

Whereas it is relatively clear from where to start measurement in the case of latitude lines, it is not clear in the case of longitude lines. There has to be a zero line from which to start measuring. But there is no natural zero line. It was decided in the 19th century that this line should be the line going from North to South through Greenwich Observatory. This is the **Zero Meridian Line** or **Prime Meridian.**

We live in Galway**,** nine degrees west of Greenwich. Let us assume that the Sun crosses the Meridian line at Greenwich at midday (12 o'clock GMT) (GMT means Greenwich Mean Time. Astronomers mostly call it UT = Universal Time). When we look at the meridian in Galway at 12 o'clock GMT – that's roughly the time on our wrist watch, we notice (forgetting about Equation of Time and time zones for the moment) that the Sun we see has not yet crossed our local meridian (remember the gnomon). It is not midday for us yet according to true solar time. It will be midday according to true solar time 36 minutes later, after the earth has rotated another 9 degrees east. For us who observe the Sun in the sky, the Sun appears to have moved 9 degrees west, of course.

The equatorial co-ordinate system

Astronomers use a corresponding system of co-ordinates to locate positions of objects in the starry sky which, in turn, they interpret as a gigantic sphere. (They use other co-ordinate systems as well but the one I am going to describe is the commonest among amateurs and professionals). This celestial sphere *appears* to rotate from east to west around a north – south axis which seems to hinge on a celestial north- and south pole (**Celestial North Pole** very close to the star Polaris, the **Pole Star**). However, *we know* that this is really the Earth's rotation from west to east and the celestial axis is really the Earth's axis, only prolonged up to the celestial sphere.

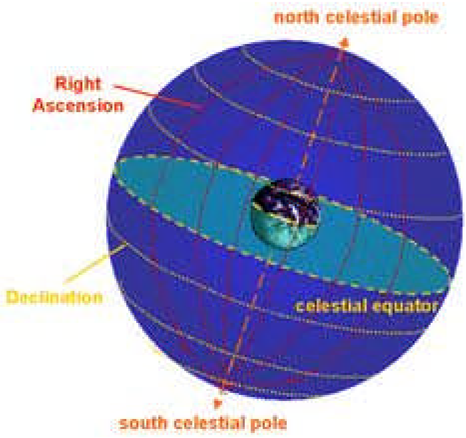
For us here in Galway, the axis of this sphere appears to be tilted by roughly 53 degrees. This corresponds to the latitude from which we are observing. If we were observing at the north pole, the sphere would not appear tilted because the celestial pole would be directly above us in the zenith! If we were observing at the equator, the celestial north pole – including Polaris, would appear just in line with the horizon! Try to figure out how different the night sky must look in these parts of the world.

Let us concentrate on the geometry of the celestial sphere itself. As we can imagine a north- and south poles on Earth, so we can imagine them as projected onto the celestial sphere as Celestial North- and South.

Just as we can imagine an equator on the Earth's globe, so we can equally imagine its projection onto the celestial sphere as the **Celestial Equator**.

Starting from the celestial equator and ending at the celestial North (or South) pole(s) you can imgagine that this angular distance on the celestial sphere can be divided by further circles going 'across' the sphere, ranging from 0 degrees at the equator up to +90 degrees at the north pole and -90 degrees at the south pole. These circles are lines of **declination (**lat.: ‘declinatio’ = a turning away), abbreviated **Dec** . Their distance is measured in degrees, minutes and seconds of arc.

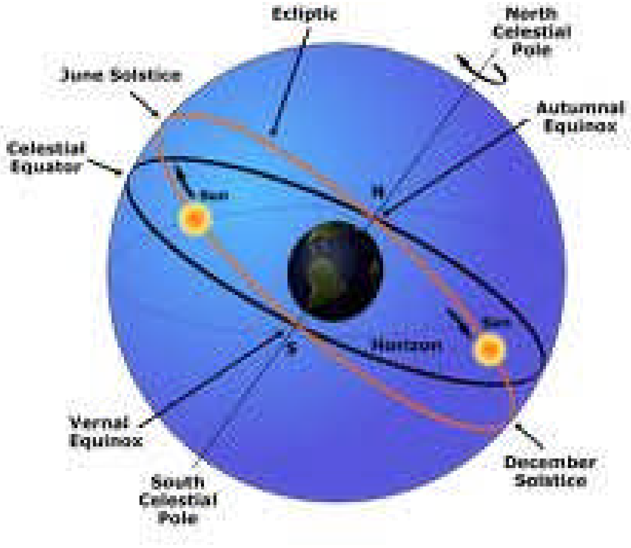
Starting from the celestial north pole and ending at the celestial south pole you can imagine lines ‘along’ the sphere. They are called lines of **Right Ascension**, abbreviated **RA**. Right Ascension is measured in hours, minutes and seconds, relating these lines to the celestial sphere’s apparent daily rotation. Hence, a whole rotation equals 24 hours.



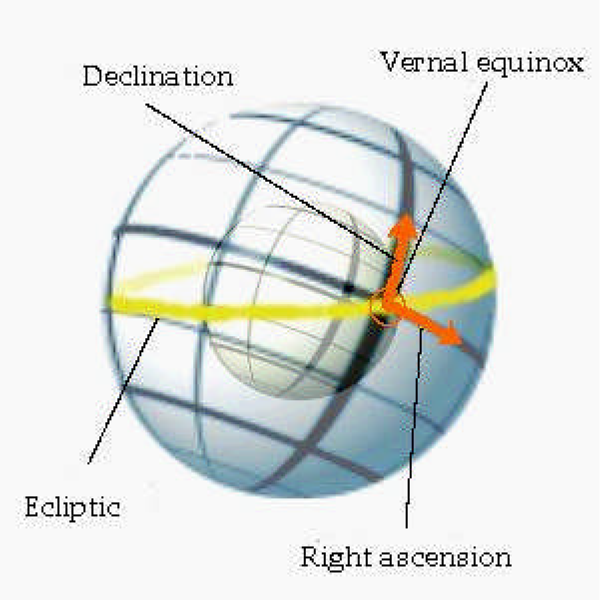
Whereas it is relatively clear from where to start measurement in the case of lines of declination (the celestial equator having 0 degrees Dec), it is not clear in the case of lines of right ascension (RA). There has to be a zero line of RA from which one can start measuring. There has to be a **Celestial Meridian**. Where do we find it?

You remember that we talked about the **vernal** or **spring equinox** before**.** It is one of the two points on the celestial sphere where the celestial equator and the ecliptic intersect (the other point of intersection is the **autumn equinox**), since the ecliptic is tilted by 23 1/2 degrees relative to the celestial equator. This ‘point’ of intersection represents the moment in time when the Sun in spring crosses the celestial equator. It has 0 degrees declination. If you could see the stars behind the Sun at this time of year, you could see that nowadays it is in the constellation of the Fishes (Pisces). From this moment on, it will culminate higher and higher in the sky (its declination will increase) during summer - until summer solstice.

Now we can determine the celestial meridian: The Celestial Meridian (with RA = 24 h) is the line starting from the Celestial North Pole, going through the point of vernal equinox to the Celestial South Pole. Consequently, an object with a right ascension of 12 h has the same RA as autumn equinox.



Once the celestial meridian has been determined, the position of any celestial object can be identified by specifying its rate of right ascension and declination. RA indicates the object's distance from the celestial meridian in hours, minutes and seconds of arc. Dec indicates how distant the object is from the celestial equator in degrees of arc.



Some simple tasks

1. Take your Philips' Planisphere and determine RA and Dec for the following stars: Algenib (in Pisces), Mira (in Cetus), Aldebaran (in Taurus), Betelgeuse (in Orion), Procyon (in Canis minor). Does RA increase clockwise or anticlockwise?

2. Which stars (aequinoctium 2000) are in

RA: 14 h 15min 38 s
Dec: +19 deg 10 min 35 s

RA: 18h 36m 56s
Dec: +38deg 47min 04s

RA: 05h 16 min 41 s
Dec: +45deg 59 min 18s

3. Take a star atlas (like Norton's Atlas) or use *Stellarium* on your computer and identify the same objects.

4. Most importantly: Stand outside on a clear night and imagine the co-ordinate system as if it were drawn on the starry sphere which you can see. Imagine how the whole system turns during a night and during a full day. Repeat this exercise as often as you can and you get a real feel for stellar positions!

Precession of the Equinoxes

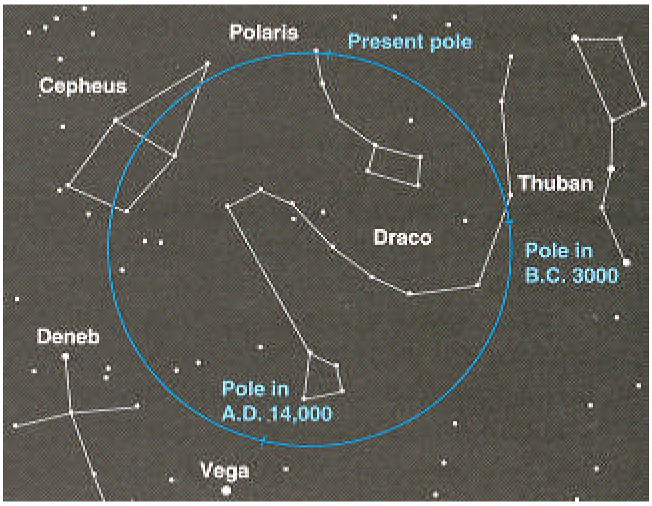
Some information for advanced beginners

We have learned just now that the whole celestial co-ordinate system has its zero point (0 degrees Dec; 24 h RA) in the point of vernal equinox. The Sun is in this position on the 21. March each year. If we could see the Sun projected against the background of the zodiac, we would see that it is in the constellation of Pisces. So it seems.

However, this was not always the case and will not always be the case. In 3.000 BC, for instance, the Sun at vernal equinox appeared in the Bull (Taurus), not in Pisces at all. Obviously, within 5.000 years the point of vernal equinox has moved from the constellation of Taurus through Aries into Pisces. It continues to move, very, very slowly indeed, into Aquarius and further on through the whole zodiac. The equinoxes **precess** and with them the whole system of celestial co-ordinates. To circuit the whole zodiac it will take roughly 25.800 years!

Furthermore, we have learned that the North Celestial Pole (abbreviated: NCP) is less than one degree distant from Polaris such that Polaris is a good indicator of the location of NCP. So it seems.

About 5.000 years ago, the NCP was near the star Thuban in the Dragon (Draco), not near Polaris at all. It will be near Vega in the Lyre (Lyra) in roughly 12.000 years.

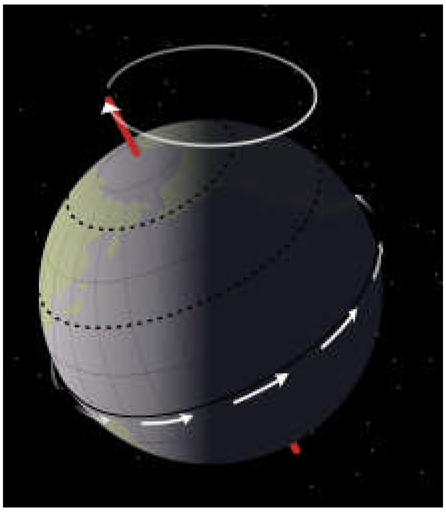


Why does this happen? It is because the Earth’s axis wobbles. It rotates just as a spinning top or a gyroscope does.

We know that the Earth spins fairly rapidly around its axis which is tilted by 23 ½ degrees. Its rotation causes the Earth to be flattened on its poles and to bulge out at the equator. As a consequence, the Earth’s longitudinal diameter from pole to pole is 21 kilometers less than its latitudinal diameter at the equator. The latitudinal bulge is oriented along the Earth’s equator.

The Moon and the Sun pull at this latitudinal bulge, but the Moon and (to a lesser degree) the Sun pull at it at an angle, because they pull from the ecliptic. This pull is an attempt to put the Earth and its axis into a more upright orientation.

However, we all know that spinning tops or gyroscopes tend to keep their orientation in spite of extraneous pushes or pulls. They begin to wobble, instead. This means that the direction of tilt changes. That’s what happens to Earth: Due to the pull by Moon and Sun the Earth’s direction of tilt changes but not the amount of tilt! It stays 231/2 degrees. Consequently, the Earth’s axis describes a circle relative to the fixed stars with a radius of 231/2 degrees which takes 25.800 years to complete.



Since the sky’s celestial pole also shifts relative to the stars due to precession, the entire co-ordinate system also shifts with relation to the stars. This is a problem for celestial atlases with seemingly fixed rates for RA and Dec for each celestial object. RA and Dec of a star are valid data only for a particular moment (**epoch**) of time. Hence, every star atlas which is in use at present will say that its data refer to the **epoch 2000**. In 50 years they will have to refer to the epoch 2050 to remain sufficiently precise. This shift should not worry you as an amateur astronomer. It should not prevent you, for instance, to use star charts with the epoch of 1950. The more precisely you are going to work with your high power telescope or future astrometric calculations, however, the more you will depend on exact charts or catalogues.

The next session will discuss how you can apply what you have learned so far to setting up your telescope and its use.

(to be continued)