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Topic Guide:

The Celestial Sphere

GCSE (9-1) Astronomy

Pearson Edexcel Level 1/Level 2 GCSE (9-1) in Astronomy (1AS0)

The Celestial Sphere

Contents

Specification Points

6.7 Understand the meaning of the terms:

- a celestial sphere
- b celestial poles
- c celestial equator

6.8 Understand the use of the equatorial coordinate system (right ascension and declination)

6.9 Understand the use of the horizon coordinate system (altitude and azimuth)

6.10 Understand how the observer's latitude can be used to link the equatorial and horizon coordinates of an object for the observer's meridian

6.11 Understand how the observer's meridian defines local sidereal time and an object's hour angle

6.12 Be able to use information on equatorial and horizon coordinates to determine:

- a the best time to observe a particular celestial object
- b the best object(s) to observe at a particular time

6.13 Understand, in relation to astronomical observations, the terms:

- a cardinal points
- b culmination
- c meridian
- d zenith
- e circumpolarity

6.14 Understand the diurnal motion of the sky due to the Earth's Rotation

6.15 Be able to use a star's declination to determine whether the star will be circumpolar from an observer's latitude

6.16 Understand the apparent motion of circumpolar stars, including upper transit (culmination) and lower transit

6.17 Be able to use information about rising and setting times of stars to predict their approximate position in the sky

6.18 Be able to find the latitude of an observer using Polaris

The Astronomy

The Celestial Sphere is an imaginary sphere surrounding the Earth on which all celestial objects are 'placed'.

Ecliptic: This great circle is the path which the Sun is observed to take through the celestial sphere in one year. It is inclined at 23.5° to the celestial Equator due to the axial tilt of the Earth. The Sun always lies on the ecliptic by definition but the planets will also be located near to this line and the ecliptic passes through the 12 constellations of the Zodiac (and Ophiuchus, a 13th constellation not included in the original Zodiac).

Equatorial coordinates

These coordinates are like Earth's latitude and longitude and are referred to as declination and Right Ascension.

Declination (equivalent to lines of latitude on Earth, abbreviated as dec or δ) is a projection of latitude onto the celestial sphere. The North Celestial Pole (NCP) is a projection of Earth's north pole and the celestial equator is a projection of the Earth's equator onto the celestial sphere.

Declination is measured in degrees (°), arc minutes (') and arc seconds ("). The NCP has a declination of +90°; the celestial equator a declination of 0°. The symbols + or – are used instead of N or S, so any object south of the celestial equator has a negative declination. The South Celestial Pole has a declination of -90°.

Right Ascension (equivalent to lines of longitude on Earth, abbreviated as RA or α). The Greenwich Meridian cannot be projected onto the Celestial Sphere because the Earth's daily rotation would result in this line continually moving around the Celestial Sphere. Therefore, a new 'prime meridian' for Right Ascension was defined as the point at which the ecliptic crosses the celestial equator. This occurs twice, and Right Ascension is measured from the Vernal Equinox or 'First Point of Aries' when the Sun crosses the celestial equator from south to north. (The Sun is therefore on the prime meridian of Right Ascension on 21 March +/- 1 day) Note that the First Point of Aires now lies in the constellation of Pisces due to the Earth's precession!

There are 24 major lines of Right Ascension measured eastwards from the First Point of Aries (each separated by 15°). These are referred to as hours ('h') of Right Ascension and further subdivided into minutes ('m') and seconds ('s'). One hour of RA is equal to 15^0.

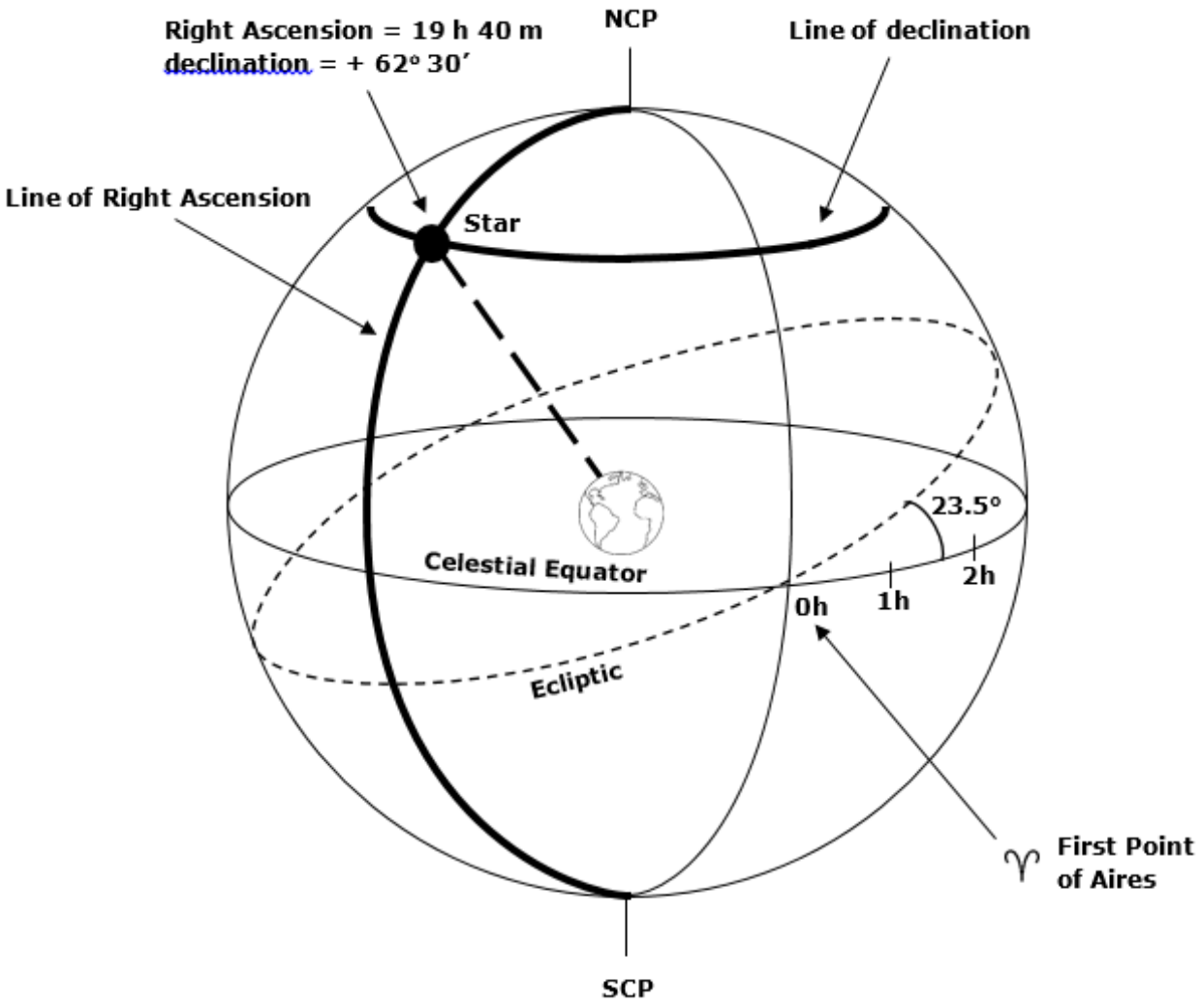

Figure 1 – Celestial Sphere showing a star at δ = + 62° 30′ and α = 19 h 40 m

Horizon Coordinates

This system is based on the observer, so an object's coordinates are dependent on the observer's location and the time of the observation. An object's horizon coordinates are continually changing with time.

Altitude is the angle of the object measured upwards from the observable horizon (neglecting trees and hills). It can range from 0° (the horizon) to 90° (the observer's zenith). If an altitude is calculated as an angle greater than 90°, then this should be measured from the opposite horizon (less than 90°) e.g. a star with an altitude of 98° from the northern horizon should be given as an altitude of 82° from the southern horizon.

Azimuth is the bearing of an object taken from true north moving round in an easterly (clockwise) direction. It can range from 0° (N) to 360°. The cardinal points (N, E, S and W) can also be used; so South is Azimuth 180°.

Meridian – this observer-based line runs from due north on the horizon, up through the zenith and finally down until it reaches the horizon due south of the observer.

The North Celestial Pole (NCP) always lies on the meridian and its altitude is equal to the observer's latitude.

altitude of NCP (and approximately Polaris) = observer's latitude

Diurnal Motion is the apparent motion of an object due to the daily rotation of the Earth. Looking North, stars appear to rotate anticlockwise in the sky about the NCP with a period of 23h 56m (one sidereal day).

If an object is located close to the NCP, it will not set below the observer's horizon and is said to be **circumpolar**. A star is circumpolar if the

star's declination > 90° - observer's latitude

OR

δ > observer's co-latitude

where *'co-latitude' = 90° – latitude*

Circumpolar stars cross the meridian twice a day; upper and lower transit of the meridian.

altitude of a star at upper/lower transit

= observer's latitude ± (90° – stars declination)

OR

altitude of a star at upper/lower transit

= observer's latitude ± stars co-declination

where *'co-declination' = 90° – declination* (and can also be referred to as the stars **polar distance**).

Upper transit is when the star is culminating.

Culmination – the star is at its greatest altitude and therefore highest in the sky (potentially the best time to observe).

altitude of star at upper transit (culmination)
= observer's latitude + co-declination

Looking South, stars will all rise and set apparently moving clockwise from East to West as the Earth moves anticlockwise. Stars culminate due South on the meridian.

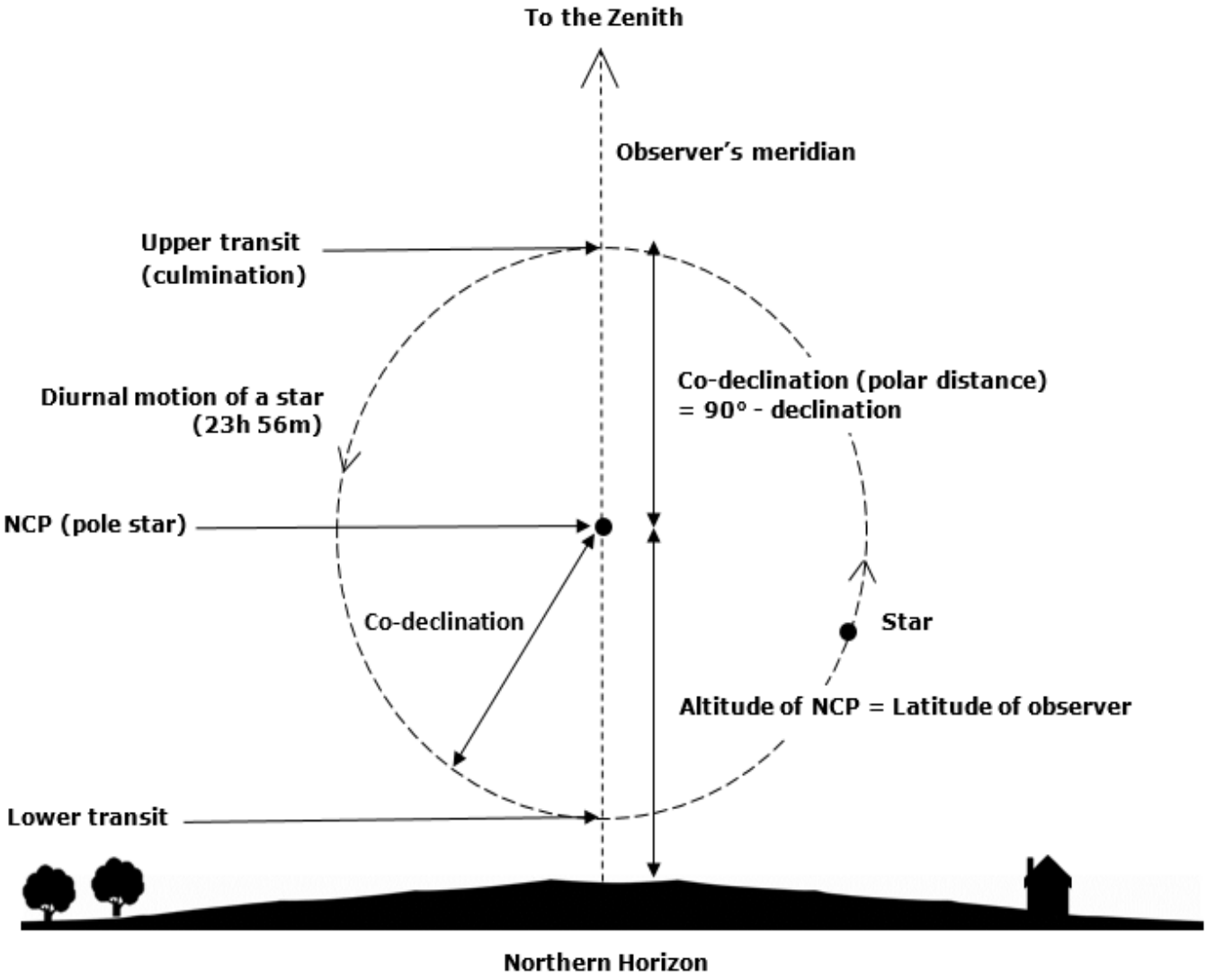

Figure 2 – Motion of a circumpolar star around the North Celestial Pole

Motion of a circumpolar star (looking West)

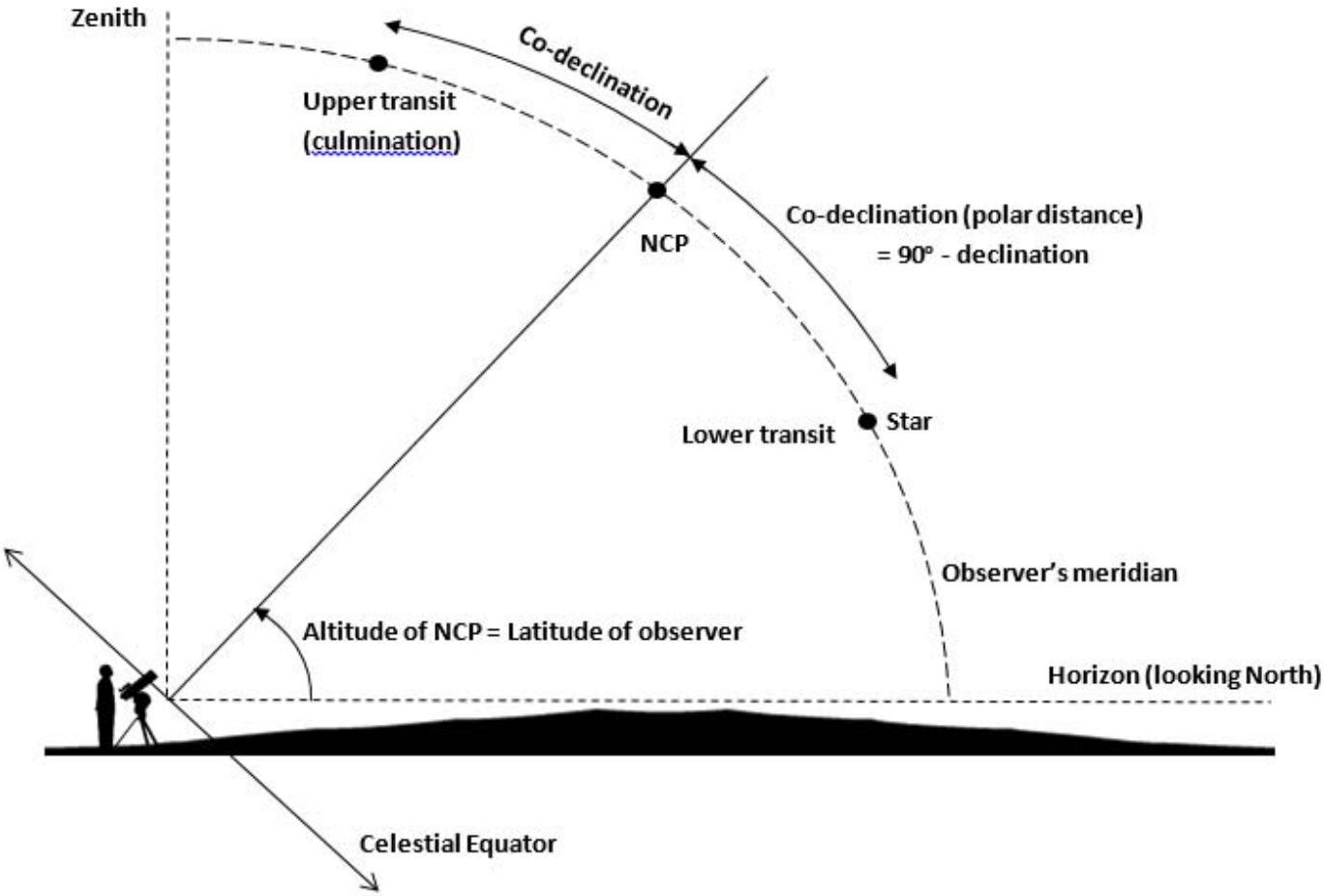

Figure 3 – Transits of the meridian

Local Sidereal Time (LST) is based on the sidereal day of 23h 56m (period of apparent rotation of stars) instead of the 24h solar day. It is therefore very useful when observing anything other than the Sun in the sky. LST is measured by the apparent diurnal motion of the Vernal Equinox (First Point of Aires), it is the Hour Angle of the Vernal Equinox. The daily motion of this point provides a measure of the rotation of the Earth with respect to the stars, rather than the Sun.

Hour Angle (HA) of a star (measured in h, m, s) is the time since that star last culminated on the meridian.

Hour Angle of star = Local Sidereal Time of the Vernal Equinox

Hour Angle of star = Local Sidereal Time – Right Ascension of star

HA = LST – RA

A negative Hour Angle indicates how long until the star will next cross the observer's meridian. A positive Hour Angle shows the time elapsed since the last culmination. If a star is crossing the observer's meridian and culminating, the hour angle of a star is 0 h.

Therefore,

A star culminates when Right Ascension = observer's local sidereal time

At culmination, RA = LST

This can be used to determine the best time to observe an object or alternatively which objects are currently culminating.

Teaching the celestial sphere requires 3D visualisation!

Resources could include:

- *a 'blow-up' beach ball celestial sphere*
- *an apple and orange with knitting needles stuck through them to represent the Earth, Sun, axial tilt and orbital mechanics*
- *Stellarium (a freeware program)*
- *apps for phones and tablets*
- *a laser pen to show key points and lines when night time observing*
- *star charts and planispheres*
- *look out for 'mobile' planetaria which can be hired*

Further support

One-minute Astronomer – Guide to the Night Sky and Basic Astronomy
http://oneminuteastronomer.com/stargazing-and-night-sky-guide/

Sky and Telescope – What are Celestial Coordinates?
http://www.skyandtelescope.com/astronomy-resources/what-are-celestial-coordinates/

Youtube – Basics of Astronomy: The celestial Sphere
https://www.youtube.com/watch?v=1Toya19H12w

Youtube – Introductory Astronomy: Positions on the celestial Sphere
https://www.youtube.com/watch?v=9XHoVF2G0j8

The One-minute Astronomer – Peterborough Astronomical Society (pdf)
http://www.peterborough-as.co.uk/documents/StargazingNorth_EBook_v2.pdf

Topic test questions

The following questions make reference to the stars tabulated below.

Star	Right Ascension	declination (degrees, °)	Hour Angle
α	01 : 00	+36	+12h 30
β	15 : 30	+49	-2h 00
γ	13 : 00	-17	
δ		+1	-5h 00

An observer is at a latitude of 51° N and their Local Sidereal Time is 13h 30m.

1. Complete the Right Ascension and Hour Angle columns.

2. Which star:
   a) lies nearest to the Celestial Equator?
   b) is located below the Celestial Equator?
   c) has a co-declination of 54°?
   d) is circumpolar from this latitude?
   e) has the highest altitude when it culminates?
   f) will cross the meridian in 2 hours?
   g) Has most recently culminated?
   h) is about to have its lower transit of the observer's meridian?

3. What is the altitude of:
   a) star α when it culminates?
   b) star α during a lower transit of the meridian?

4. How long does the observer have to wait until:
   a) star δ culminates?
   b) star α culminates?

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