

Chapter 1

Charting the Heavens

The Foundations of Astronomy

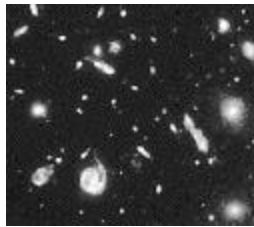


Chapter 1: Charting the Heavens

- **Scale: relative size and distance**
 - units
 - speed of light, distance, and time
- **Measuring distance and size**
 - triangulation
 - parallax
 - angular measurement
- **View from Earth**
 - celestial sphere
 - constellations and the zodiac
 - celestial coordinates and the ecliptic
- **The Earth, Moon, Sun, and Planets**
 - relative motions and time
 - lunar phases
 - eclipses
 - planetary configurations

Astronomy: The Oldest Science

- **Study of the universe**
 - all space, time, energy, and matter



Questions to ponder

- What is the tiniest object you have ever seen?
The largest?
- What was the longest time you ever spent doing one activity?
- How does that time compare to your lifetime?
- What is the longest distance that you have ever traveled?
- How does that distance compare to the size of the Earth?

Scale

- Scale - relative size and distance
- Astronomy scale ranges from atoms to the observable universe.

1:1,000,000,000,000,000,000,000,000,000,000,000,000,000,000,000

or

$1:10^{36}$

(scientific notation)

Video: *Powers of Ten* (9 minutes)

Large Numbers

- Large numbers all around us.
- # cells in human body
 - ~100 trillion or 10^{14}
- annual federal budget
 - ~\$1 trillion or 10^{12}
 - ~ number of stars in 10 galaxies

Metric System

- **Length** meter (m) ~ yard
 kilometer (km) = 1000 m 0.6 miles
 = 10^3 m
- **Mass** gram (gm) ~ Advil
 kilogram (kg) = 1000 gm 2.2 lbs.
 = 10^3 gm
- **Volume** m^3
 $cm^3 = 10^{-6} m^3$ sugar cube
- **Time** second (s)

Speed of Light

- EM energy or light travels through a vacuum with a constant speed.
- Speed of light = 300,000 kilometers/second
 = 3×10^5 km/s
- A light year is the distance traveled by EM energy (or light) in one year.
 - 1 Ly = 1×10^{13} km

Speed of Light: Calculation

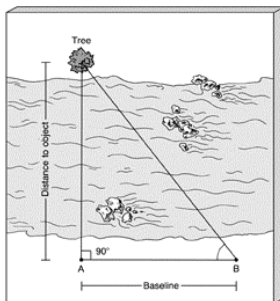
- **QUESTION**
 If the Earth is $\sim 150 \times 10^6$ km from the Sun, how long does it take light to travel from the Sun to the Earth?
- Distance = velocity x time OR $d = v t$
- $t = d/v = (150 \times 10^6 \text{ km}) / (300,000 \text{ km/s}) = 500 \text{ s}$
- 500 sec x (1 min/ 60 s) \sim 8 minutes

Measuring Distances and Size

- Common methods used in astronomy to determine distance to distant objects and their sizes are:
 - triangulation
 - surveying
 - parallax
 - pencil; depth perception
 - angular measure
 - penny

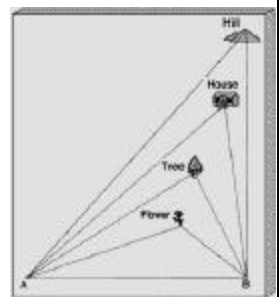
Triangulation: Measuring Distances

- Surveyors often use simple geometry and trigonometry to estimate the distance to a faraway object.
- To use triangulation to measure distances, a surveyor must be familiar with trigonometry, the mathematics of geometrical angles.



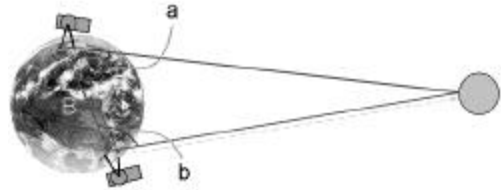
Triangulation: Angles and Baselines

- A triangle of fixed baseline (distance between points A and B) is narrower the farther away the object.
- Since planets are quite distant, a large baseline and an accurate means to measure small angles is needed.



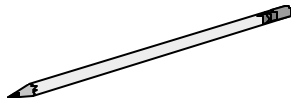
How are distances and sizes measured in astronomical applications?

Measuring Solar System Distances



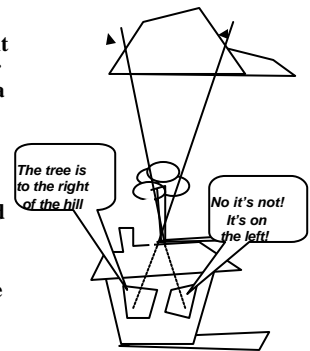
Triangulation gives the distance: measure angles (a & b) and distance (B) between the observation points. Derive the distance to the nearby object.

Parallax and Pencils



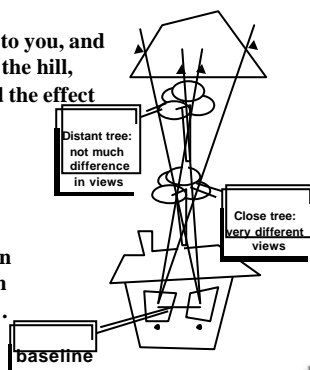
demo: pencil

- If you took a photo out of one window of your house, you might see a tree to the right of a distant hill ...
- ... but if you move through the house and take a photo out of another window, you may see the tree to the left of the hill instead.
- This is called parallax.

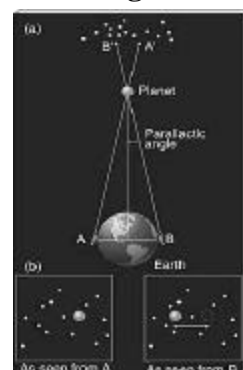


- The closer the tree is to you, and the further it is from the hill, the more pronounced the effect will be.

- The distance between your two observation points is the baseline.



Parallax: Measuring Cosmic Distances

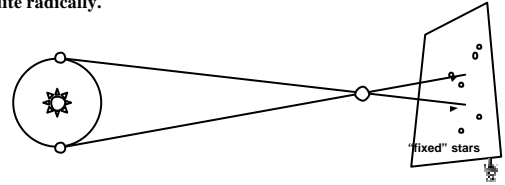


Improving Accuracy

- To improve accuracy, we need
 - large baseline
 - and
 - accurate angular measurements.
- How can we increase baseline?

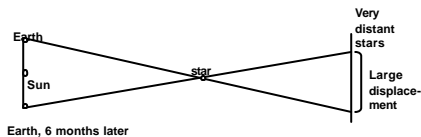
Earth's Revolution and Measuring Distances

- Apart from the fact that if it didn't orbit the Sun the Earth would plummet to a spectacular and fiery doom, the way the Earth spends its time moving quietly from one side of the solar system to the other is extremely useful.
- Twice every year our point of view of distant objects changes quite radically.



Parallax in Practice

- The apparent displacement of a star against a backdrop of “fixed” stars is measured many times, over many half-years.
- If a star seems to have a large displacement compared to other stars, then the star's position
 - (A) is relatively near Earth,
 - (B) is relatively far from Earth,
 - (C) cannot be determined from information given.



Angular Measurement

- Angles are measured in degrees, minutes and seconds of arc.
- A circle is divided into 360 equal slices, each representing one arc degree.
 - Circle = $360^\circ = 360$ arc degrees
 - 1 arc minute = $1' = 1/60$ arc degree
 - 1 arc second = $1'' = 1/60$ arc minute = $1/3600$ arc degree

Angular Measure Compared to Time Measure

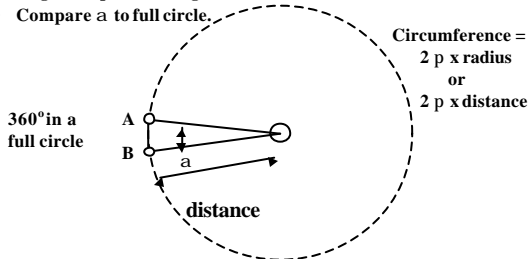
Part of a Circle	Angular Measure	Time Measure
Full	360°	24 ^h
Half	180°	12 ^h
Quarter	90°	6 ^h
1/32	1.5°	1 ^h
1/30	1°	1/15 ^h = 4 ^m
1/1440	$1/4^\circ$ or $15'$	1/60 ^h or 1 ^m

Measuring Angles and Distance

- One method for measuring distance involves measuring
 - the angular size (angular diameter) of a known object measured at a known distance to
 - the angular size of an object of unknown diameter.

Distances from Parallax

- Want to know the distance to a planet.
- Distance from A to B = baseline on Earth.
- Angle a = parallax angle observed from Earth.
- Compare a to full circle.

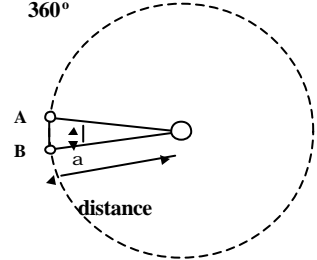


- Compare baseline to full circle circumference.

Distances from Parallax

- Then, comparing to a full circle,

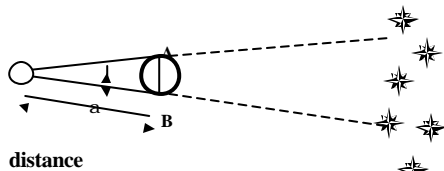
$$\frac{\text{baseline}}{2 \text{ p x distance}} = \frac{\text{parallax angle}}{360^\circ}$$



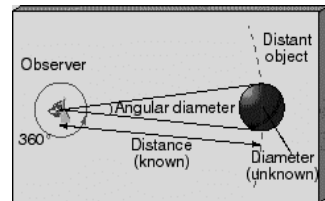
$$\text{Distance} = (\text{baseline} \times 360^\circ) / (2 \text{ p x parallax angle})$$

Size Measurements

- If distance to an object is known, then it is simple to calculate the object's size by measuring its angular diameter.



Measuring Size of Object



$$\frac{\text{Diameter}}{2 \text{ p x distance}} = \frac{\text{angular diameter}}{360^\circ}$$

Re-arranging yields the **small-angle formula**:

$$\text{Diameter} = \text{distance} \times (\text{angular diameter} / 57.3^\circ)$$

Chapter 1: Problem 10

- Given that the angular size of Venus is $55''$ when the planet is 45,000,000 km from Earth, calculate Venus's diameter (in km).
- The small-angle formula relates angular diameter, distance, and size (diameter)

$$\text{diameter} = \text{distance} \times (\text{angular diameter} / 57.3^\circ)$$

- So, for this problem
- angular diameter = $55'' = 55'' \times (1'/60'') \times (1^\circ/60') = 0.015^\circ$
- distance = 45,000,000 km
- diameter = 45,000,000 km $\times (0.015^\circ / 57.3^\circ) = 12,000$ km

The View from Earth



What do you see in the sky?

- What do you see during the day? night?
- Does what you see change over time?
 - Within hours, days, months, years?
- Can you predict the changes?
- How would you communicate what you see in the sky to a friend living in Maine?
- Do you see the same things if you are in Australia looking at the sky?

Describe the sky.

- From Earth,
 - the sky appears to be a hollow, spherical shell with the Earth at the center.
 - The Sun, Moon, and stars rise and set as the Earth turns within this imaginary shell.
- How do the Sun, Moon and stars appear to move across the sky when viewed from Texas?
 - Sun and Moon rise in the east, move smoothly across the sky, and set in the west.
 - Stars follow a similar pattern.

Modeling the View from Earth

- Early Greeks - Celestial Sphere
 - unaware of Earth's rotation
 - imagined that a celestial sphere rotated about axis through Earth, carrying a fixed pattern of stars.
 - Sun, Moon, and wandering stars (planets) change position (wrt fixed stars) on day-to-day basis.
- Model developed still used today as a convenient tool for locating objects in the sky as seen from Earth.

The Celestial Sphere



Coordinate Systems

1. TERRESTRIAL COORDINATE SYSTEM
 - Latitude and Longitude
2. CELESTIAL COORDINATE SYSTEM
 - This coordinate system is an extension of the terrestrial system on to the celestial sphere.
3. THE ECLIPTIC SYSTEM
 - Based on the Earth's orbit around the Sun.
4. THE HORIZON SYSTEM
 - A completely local system that is based on an observers latitude and longitude and the time.

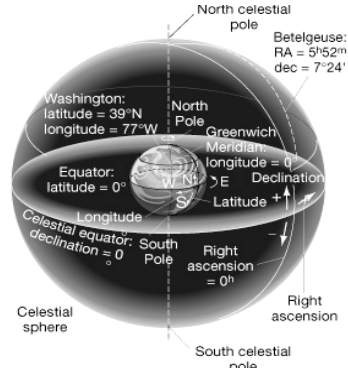
TERRESTRIAL COORDINATE SYSTEM

- Latitude = north/south measurement (degrees).
 - Latitude is based on a scale of 90° at poles and 0° at the equator.
- Longitude = east/west measurement (degrees).
 - Longitude is based on 0° at Greenwich and 180° at International Date Line.

CELESTIAL COORDINATE SYSTEM

- This coordinate system is an extension of the terrestrial system on to the celestial sphere.
- Declination = north/south measurement
 - Units of degrees.
 - Based on 90° at poles and 0° at the equator.
- Right Ascension = east/west measurement
 - Units of time.
 - Based on 0^h at March Equinox point in the sky.
 - Measured continuously from 0^h to 24^h .

Celestial Coordinates



THE ECLIPTIC SYSTEM

- Based on the Earth's orbit around the Sun.
- Ecliptic is the plane of the Earth's orbit projected on to the celestial sphere.
 - The 12 zodiac constellations are located in a band following the ecliptic.
 - The Sun, Moon, and planets are found on or near the ecliptic.
 - The ecliptic is tilted 23.5° with respect to the celestial equator.

THE HORIZON SYSTEM

- The horizon system is a completely local system that is based on an observer's latitude and longitude and the time.
 - Altitude = vertical measurement.
 - Altitude is based on, 0° at horizon and 90° at the zenith.
 - Zenith is the point in the sky directly over the observer.
 - Azimuth = direction measurement.
 - Azimuth is based on:
 - north = 0° , east = 90° , south = 180° , west = 270° .
 - The meridian is a vertical circle that runs due N/S.
 - When celestial objects transit the meridian, they are highest in the sky.

Handy Tools

- A helpful tool for using any method of finding your way around is found conveniently at the end of your arm.
- By extending your hand at arm's length, you can approximate a many degree measurements.
 - Apparent width of one finger at arm's length is about 1°
 - A fist covers about 10° .
- With a star map, a working knowledge of the coordinate systems, and a few waves of the hand, any observer can find almost any object visible.

Pennies and Angles

Distance from eye to penny	Angle subtended by penny
1 meter	1 arc degree = 1°
60 meters	1 arc minute = $1'$
3.6 km	1 arc second = $1''$

To Try at Home

- At a distance of about 1 meter, a penny subtends an angle of 1° .
- Some night (preferably near full moon), hold a penny at arms length from your face and estimate the following (in degrees):
 - (1) the Moon's diameter,
 - (2) the angular distance between the pointer stars of the Big Dipper,
 - (3) the angular distance between the stars in Orion's belt.

The Sky from Denton: 33.5° N

- North Celestial Pole is 33.5° above northern horizon.
- Celestial Equator is 56.5° above southern horizon.
- Circumpolar stars lie within 33.5° of N-Celestial Pole.
- Rising & setting stars are visible from 33.5° away from South Celestial Pole.
- Stars within 33.5° of South Celestial Pole are never visible from Denton.

The Earth's Rotation

- The Earth's west to east rotation causes the celestial sphere to appear to rotate from east to west in 24 hrs.
- LOOKING SOUTH
 - The Sun, Moon, planets, and stars appear to rise in the east, cross the meridian due south, and set toward the west.
 - Celestial objects are said to transit when they cross the celestial meridian in the southern sky.
 - This is when they are highest in the sky.
- LOOKING NORTH
 - The stars appear to circle around the North Celestial Pole (near Polaris) once in 24 hours.
 - Stars within the angle of the observer's latitude away from the North Celestial Pole never rise or set. They are always above the horizon (circumpolar stars).

What's in the Night Sky?

Summer Sky

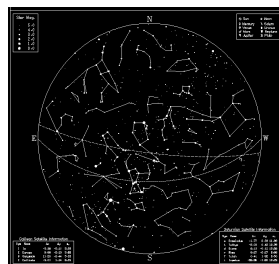


Winter Sky



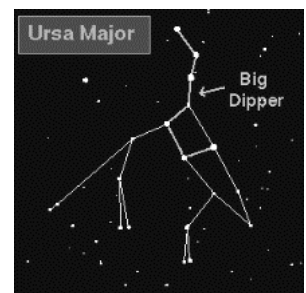
Constellations

- **Constellations:** groupings of stars that outline the shape of something (something usually with mythological significance).
- 88 recognized constellations.
- Names trace back to as long as 5000 years ago.



Groupings of Stars

- The Big Dipper is a familiar grouping of stars, but it is NOT a constellation.
- The Big Dipper is part of a larger grouping called the Big Bear or Ursa Major that is a constellation.



The Constellation Orion

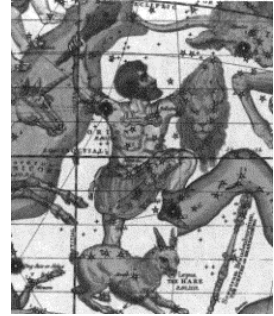
One of the most easily recognizable star fields in the winter nighttime sky is the familiar constellation Orion.

This field of view spans roughly 100 light-years, or 10^{15} kilometers.



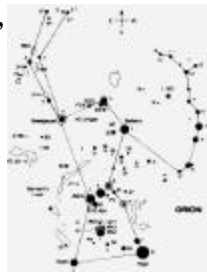
Orion: Historical View

- The picture at the left is an ornate star chart printed in 1835 showing the great hunter Orion.
- Orion is holding a lion's head instead of his traditional bow or shield.
- He has an eager look in his eye as he stalks Taurus, the Bull.
- Behind him, is faithful dog, Canis Major, is chasing Lepus, the Hare.



Orion: Star Chart View

- When you look in a sky atlas, you might see diagrams like that shown to the right.
- Obviously, this is very different from the photo.
- This type of schematic draws the stars as different sizes to represent different brightnesses.



Constellations: Apparent vs. Real Positions of Stars



- Apparent groupings of stars into constellations seen on celestial sphere are not true, physical groupings.
 - Stars in constellations are often at different distances from us.
 - They appear to be grouped because they lie in approximately the same direction.

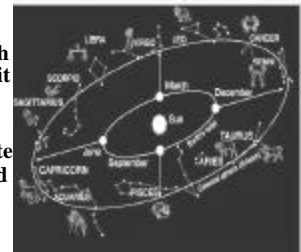
Apparent Motion of the Sun

Ecliptic - apparent path of the Sun on the celestial sphere

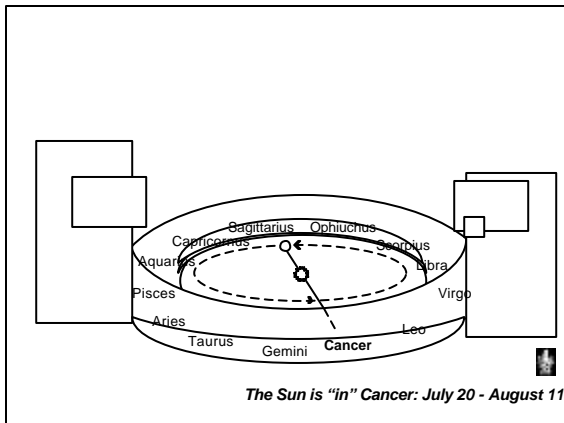
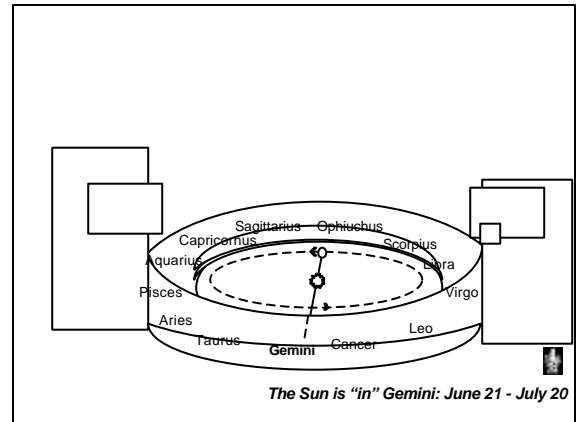
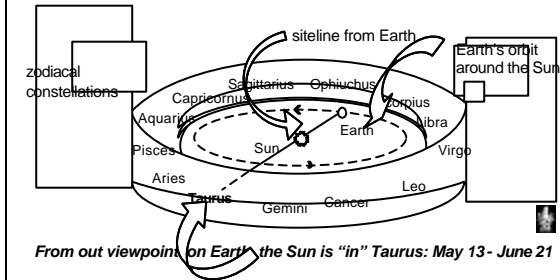


Zodiac Constellations

- **The zodiac:** collective name for the 13 constellations through which the Sun passes as it moves along the ecliptic.
- Time required for the constellations to complete one cycle around sky and return to starting points as seen from a given point on Earth is one *sidereal year*.

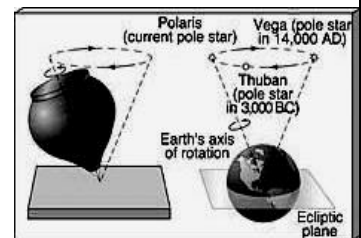


The following animations might help relate the zodiacal constellations to the way the Earth orbits the Sun each year.



Precession

- **Precession** : a slow change in the direction of the axis of a spinning object.
- Earth's axis changes its direction over time like a spinning top that rotates rapidly on its own axis while that axis slowly revolves about the vertical.



Earth's axis currently points toward the star Polaris.
12,000 years from now (~ halfway through one cycle of precession)
Earth's axis will point toward Vega.
Orion will become a summer constellation.

The Effects of Precession

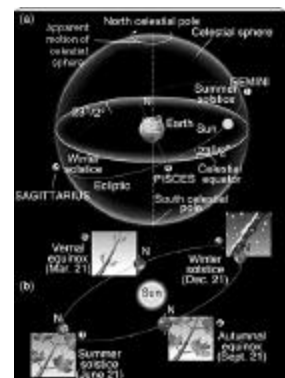
- **Causes the pole star to change.**
 - Thuban (in Draco) was the pole star in 3,000 B.C..
 - Polaris (in Ursa Minor) is the pole star now.
 - Vega (in Lyra) will be the pole star in 14,000 A.D.
- **Causes intersection point of ecliptic and celestial equator to shift.**
 - "Age of Aries" occurred 2,000 years ago.
 - "Age of Pisces" is now.
 - "Age of Aquarius" will begin about 400 years from now.

Motion of the Earth Relative to the Sun

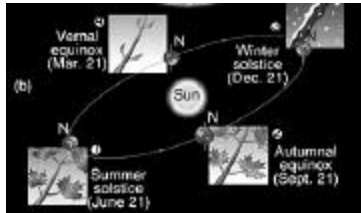
- (a) **Ecliptic** - apparent path of the Sun on the celestial sphere

- (b) **Actual relation to Earth's rotation and revolution.**

The seasons result from the changing height of the Sun above the horizon.



Earth's Seasons



• Equinox - equal night
points where the ecliptic
intersects the celestial
equator

- Vernal - March 21
- Autumnal - Sept. 21

• Solstice - sun stand
point on celestial sphere
where the Sun reaches its
greatest distance N or S of
the celestial equator.

- Summer - June 21
- Winter - Dec. 21

The Earth's Orbital Motion: The Reason for the Seasons

- The Earth's orbital motion causes
 - the apparent eastward motion of the Sun along the ecliptic of about 1° per day.
 - the annual motion of the Sun through the 13 zodiac constellations.
 - the seasonal visibility of stars and constellations.
- The tilt of Earth's rotation axis by 23.5° causes
 - tilt of the ecliptic with respect to the celestial equator.
 - the Sun's declination to change during the year.
 - seasonal variations in the altitude of the midday Sun, length of day & night, and rising & setting directions of the Sun.

Measuring Time

- To establish a way of measuring time, people look for events which are both
 - recurring
 - predictable
 - universal
- Must choose a frame of reference.

The Earth's Motion and Time

- Earth
 - rotates on its own axis
 - The day is a measure of the rotational rate of the Earth rotating on its own axis.
 - The Earth rotates at a rate of 15° per hour.
 - $(360^\circ/24 \text{ hours} = 15^\circ/\text{hour})$
 - revolves about the Sun
 - The year is a measure of the orbital period of the Earth about the Sun.
 - The Earth orbits the Sun in 365 days.
 - The Earth moves through space $\sim 1^\circ$ per day.
 - $(360^\circ/\text{year} = 360^\circ/365 \text{ days} = 0.986^\circ/\text{day})$

Motion of the Moon

- The Moon revolves about the Earth in an elliptical orbit that tilts about 5° to the ecliptic.
 - orbital period about the Earth
 - synodic month (relative to the Sun) = 29.5 days
 - Moon moves $\sim 12^\circ$ per day across the sky
 - » $(360^\circ/29.5 \text{ days} = 12.2^\circ/\text{day})$
 - or its own diameter 0.5° in about an hour.
 - » $(12^\circ/\text{day} = 12^\circ/24 \text{ hours} = 0.5^\circ/\text{hour})$
- The Moon rotates on its axis with a period that is the same as its orbital period.
 - called “synchronous rotation”
 - result: same face of Moon always faces the Earth

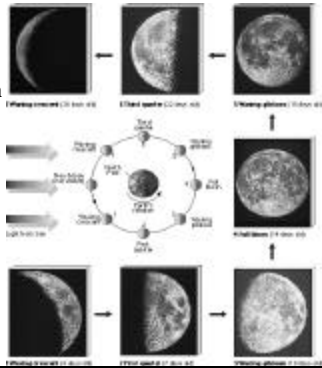
The Moon's Light

When viewed from space, it is clear that the phases of the Moon are due to our viewing varying proportions of sunlight & shadow from the Sun during each month.



Lunar Phases

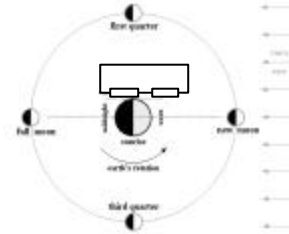
- Because the Moon orbits Earth, the visible fraction of the sunlit face that we see differs from night to night.
- The complete cycle of lunar phases takes ~29 days to complete.



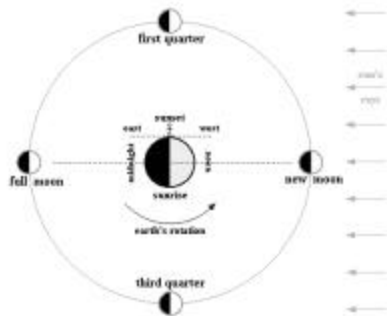
Question on Lunar Phases

The phase of the Moon is related to the time on moonrise and moonset.

At what time of day or night is the 1st quarter moon highest in the sky?

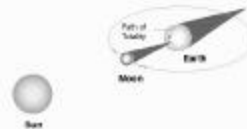


Answer: Sunset



Eclipse Geometries

- One consequence of the Moon's orbit about the Earth is that the Moon can shadow the Sun's light as viewed from the Earth or the Moon can pass through the shadow cast by the Earth.



solar eclipse:
the Sun's light is blocked from regions of the Earth by the shadow of the Moon.

lunar eclipse:
the Sun's light is blocked from the Moon by the Earth's shadow.

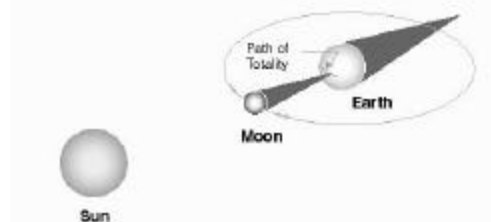


Recording Eclipses

- Oldest record of lunar eclipse >4000 years ago in Mesopotamia.
- Oldest record of solar eclipse a few hundred years later in China.
- Greeks understood cause of solar eclipses, but not lunar eclipses.

Solar Eclipses

As seen from Earth, a solar eclipse occurs when Moon's shadow blocks Sun's light from Earth.

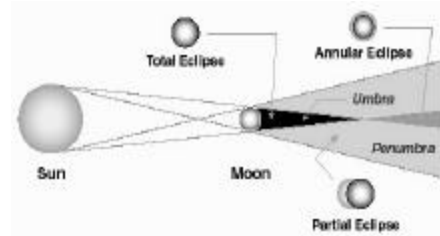


The Moon's Shadow



- The Moon's shadow averages 371,000 km in length.
- Average distance to Earth is 378,000 km, so shadow doesn't quite reach Earth most of the time.
- Moon's umbral diameter at Earth's orbit is < 270 km.
 - Path of Moon's shadow across Earth called eclipse track.
 - People on eclipse track see a total solar eclipse.
- Longest possible total eclipse lasts 7' 40" at any one spot (most see only 2-3 minutes).

Solar Eclipse Geometry

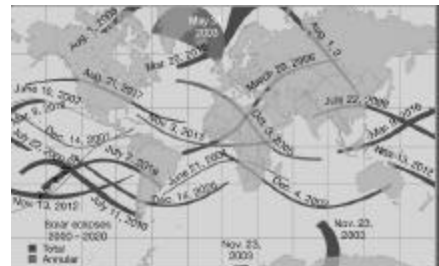


- The Moon's shadow on Earth during a solar eclipse consists of the *umbra*, where the eclipse is total, and the *penumbra*, where the Sun is only partially obscured.
- If the Moon is too far from Earth at the moment of the eclipse, there is no region of totality; instead, an *annular eclipse* is seen.

Umbra and Penumbra



Solar Eclipse Paths



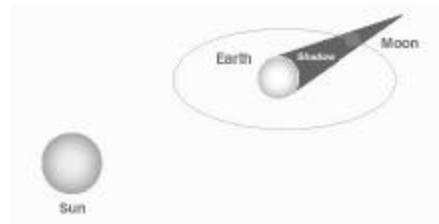
- Regions of the Earth that will see total or annular eclipses between 2000 and 2002.

Little Known Facts About Solar Eclipses

- The longest duration for a total solar eclipse is 7.5 minutes.
- A total solar eclipse is not noticeable until the Sun is more than 90 percent covered by the Moon. At 99 percent coverage, daytime lighting resembles local twilight.
- Eclipse shadows travel at 1,100 miles per hour at the equator and up to 5,000 miles per hour near the poles.
- The width of the path of totality is at most 167 miles wide.
- The maximum number of solar eclipses (partial, annular, or total) is 5 per year.
- There are at least 2 solar eclipses per year somewhere on the Earth.
- Total solar eclipses happen about once every 1.5 years.
- Every eclipse begins at sunrise at some point in its track and ends at sunset about half way around the world from the start point.
- Local temperatures often drop 20 degrees or more near totality.

Lunar Eclipse Geometry

One consequence of the Moon's orbit about the Earth is that the Moon can pass through the shadow cast by the Earth, causing a lunar eclipse.



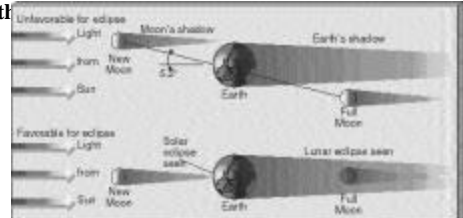
Earth's Shadow



- Earth's shadow averages 1,380,000 km in length and extends far beyond Moon's orbit.
- At average distance to Moon, Earth's shadow is 9,200 km across.
 - Moon's diameter = 3,476 km
- Moon crosses shadow in ~3 hours and can be completely within umbral shadow for ~100 minutes.
- People on night side of Earth can see lunar eclipse.

Tilt of the Moon's Orbit

- How often do solar and lunar eclipses occur?
- Solar and lunar eclipses occur less often than expected because of two factors:
 - the small tilt of the Moon's orbit with respect to the plane of the ecliptic and
 - the

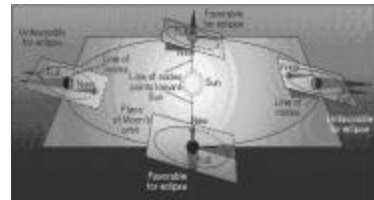


The Moon's Orbital Path



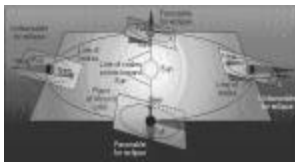
- The Moon's orbit about the Earth does not quite coincide with the ecliptic.
- The orbit is inclined at ~5° to the ecliptic plane.
- The 2 intersections of Moon's orbit with ecliptic are called the nodes of the Moon's orbit.

Eclipses and the Phase of the Moon



- Inclination of Moon's orbit means that not every new or full Moon phase produces a solar/lunar eclipse.
- Eclipses occur only when the Moon is near one of the nodes of its orbit at the same time that it is new/full phase.
- Times when the line of nodes points nearly at the Sun are called eclipse seasons.

Eclipse Seasons



- Each eclipse season lasts about one month.
 - Seasons are separated by intervals of 5.7 months.
- Eclipse year is interval between successive times when same node is aligned with Sun
 - Eclipse year = 2 x eclipse season interval = 346.6 days

ECLIPSES

- The Moon's orbit is inclined about 5° to the ecliptic. That's why there are not eclipses every month.
- In order for an eclipse to occur, the Earth, Moon, and Sun must be nearly perfectly aligned.
- All eclipses occur when the Moon crosses the ecliptic.
 - Solar eclipses are possible only at the New Moon phase, when the Moon is crossing the Earth's orbital plane (ecliptic).
 - Lunar eclipses are possible only at Full Moon phase, when the Moon is crossing the ecliptic.

SOLAR AND LUNAR ECLIPSES

• Solar Eclipses

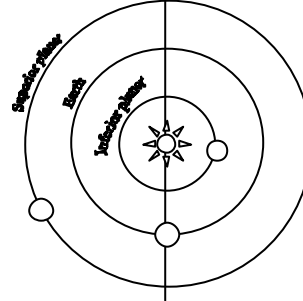
- Earth moves into the Moon's shadow.
- Occur only at the New Moon phase.
- Visible only over a narrow path across the Earth.
- Can be total, annular, or partial.
- Total solar eclipses are possible because the angular size of the Sun and Moon are very nearly equal.

• Lunar Eclipses

- Moon moves into Earth's shadow.
- Occur only at the Full Moon phase.
- Are visible over the entire night side of the Earth.
- Can be total, partial, or penumbral.
- A total lunar eclipse does not get completely black, because some light from the Sun is bent around the Earth by the Earth's atmosphere.

Planetary Configurations

In their orbital cycles, planets assume various configurations relative to the Sun-Earth line as viewed from Earth.

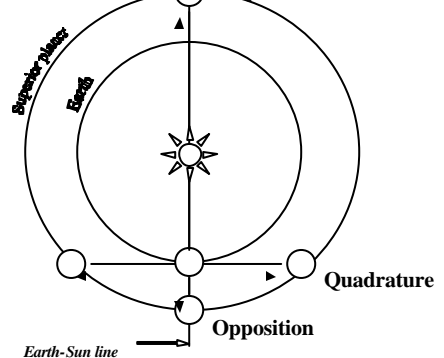


Planetary Configurations: Superior Planets

• For a planet farther from Sun than Earth:

- opposition - planet is closest to Earth and appears to be opposite the Sun (as viewed from Earth).
- conjunction - planet is farthest from Earth and Sun lies between planet and Earth
- quadrature - planet is 90° from the Sun-Earth line.

Superior Planet Configurations

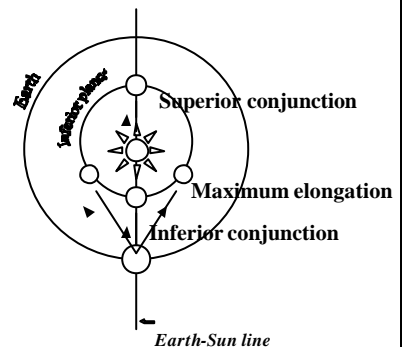


Planetary Configurations: Inferior Planets

• For the planets closer to the Sun:

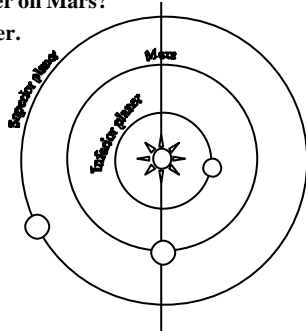
- inferior conjunction - closest to Earth
- superior conjunction - farthest from Earth
- maximum elongation - maximum angular distance from the Sun as seen from Earth.

Inferior Planet Configurations



Question

- Do these same definitions for planetary configurations apply to an observer on Mars?
- Explain your answer.
- Do they apply to observers on Venus?



Chapter 1: Charting the Heavens

- **Scale: relative size and distance**
 - units
 - speed of light, distance, and time
- **Measuring distance and size**
 - triangulation
 - parallax
 - angular measurement
- **View from Earth**
 - celestial sphere
 - constellations and the zodiac
 - celestial coordinates and the ecliptic
- **The Earth, Moon, Sun, and Planets**
 - relative motions and time
 - lunar phases
 - eclipses