# Summary Sheet #1 for Astronomy Main Lesson

## From our perspective on earth

- The earth appears flat.
- We can see half the celestial sphere at any time.
- The earth's axis is always perpendicular to the equator. Close to the North Pole, the axis is high and the equator is low. Close to the equator, the axis is low and the equator is high.
- At any moment in time, the horizon, zenith, and meridian are all great circles on the celestial sphere. They are all at right angles to each other and divide the celestial sphere into 8 equal sections.
- The *celestial equator* is the earth's equator extended out to the celestial sphere. You can imagine tracing the *Celestial Equator* with your finger by painting a circle on the celestial sphere that goes from directly east on the horizon, rising to a height of your complementary latitude (50° in Boulder), and then ending up directly west on the horizon.
- The celestial horizon and the celestial equator intersect directly east and directly west of where you are.
- From our perspective on earth, the four above great circles don't appear to move; they are always in the same place – all day long and all year long.

## From the perspective of a spaceman looking down from far above at the earth:

- The earth orbits the sun counter-clockwise. The earth rotates on its axis counter-clockwise.
- The axis is 23.4° off perpendicular from the orbital plane.
- As the earth spins, the equator does not appear to move, but the horizon (of a person standing in Colorado) appears to "wobble" (as seen by the spaceman).

## Effects of the tilt of the earth's axis:

- On the equinox (3/20 & 9/21)…
  - The axis is tilted to the side (not toward nor away from the sun).
  - The sun rises *east* no matter where you are on earth.
  - The sun's path is *on* the celestial equator.
  - In Boulder (latitude 40°) the sun is 50° (the complementary latitude) above the horizon at midday.
- On the summer solstice (6/21)…
  - The axis is tilted *toward* the sun.
  - The sun rises *north of east* no matter where you are on earth.
  - In Boulder, the sun's path is *parallel* to the celestial equator, but higher in the sky.
  - In Boulder, the sun is 73.4° (50+23.4) above the horizon at midday.
- On the winter solstice (12/21)…
  - The axis is tilted *away from* the sun.
  - The sun rises *south of east* no matter where you are on earth.
  - In Boulder, the sun's path is *parallel* to the celestial equator, but lower in the sky.
  - In Boulder, the sun is 26.6° (50–23.4) above the horizon at midday.

# Summary Sheet #2 for Astronomy Main Lesson

The Path of the Sun through the sky at different places on the earth:

- In the tropics (between the *Tropic of Cancer*, 23.4°N, and the *Tropic of Capricorn*, 23.4°S), the sun passes directly overhead twice per year. On the equator, these two days are on the equinoxes. On the *Tropic of Cancer*, the sun passes overhead on June 21. On the *Tropic of Capricorn*, the sun passes overhead on December 21.
- Further north than the tropic of Cancer (23.4°N), the sun at noon is in the south every day of the year, and it travels through the sky from left to right.
- Further south than the tropic of Capricorn (23.4°S), the sun at noon is in the north every day of the year, and it travels through the sky from right to left.
- In the tropics (between 23.4°N and 23.4°S), the sun at noon is sometimes in the north, sometimes in the south, and can appear to be traveling from left to right or from right to left, all depending on the time of year, time of day, and what direction you are facing.
- On the Arctic Circle (66.6°N, which is 90–23.4) the sun never sets on June 21; it touches the north horizon at midnight. Further north, there are more never set days in the year. At the North Pole, the sun never sets half of the year, and never rises half the year.

From the perspective of a person on the earth:

- You are on the "top" of the earth. It seems that you are on a flat plane looking up at the celestial sphere. On a clear night without obstruction, you can see exactly half of the stars at any given moment.
- *The ecliptic* is the great circle along the celestial sphere on which the sun travels over the course of one year against the background of the fixed stars.
- The planets and the moon also travel (closely) along the elliptic.
- Everywhere on the earth, the sun travels along the celestial equator on the equinox, and on every other day travels along a path that is parallel to the celestial equator, either above or below it.
- The celestial equator, axis, celestial horizon, zenith circle, and meridian circle never move. However, the ecliptic "wobbles" over the course of the day. In other words, at certain times of the day or night the ecliptic appears to be above the celestial equator, and at other times ecliptic appears to be below the celestial equator.
- The celestial equator and the ecliptic intersect (always) in the constellations of Pisces and Virgo.
- The sun is in the following constellations at these times of the year:
  - Summer Solstice: in between Taurus and Gemini (with Gemini to the east/left of Taurus).
  - Autumnal equinox: Virgo
  - Winter solstice: Sagittarius
  - Vernal equinox: Pisces
  - Orion is on the celestial equator located directly underneath Taurus and Gemini.
- Looking toward the north in the Northern Hemisphere, the stars appear to rotate counterclockwise around the North Star. Looking toward the south in the Southern Hemisphere, the stars appear to rotate clockwise around the (non-existent) South Star. On the equator, the stars appear to rotate counter-clockwise around the North Star if you are facing north, or clockwise around the Celestial South Pole if you are facing south.

From the perspective of a spaceman looking down on the solar system (above our north pole):

- The celestial sphere has all of the stars on it, and the spaceman can see all of the celestial sphere. The earth is at the center, with the sun, moon, and planets close by.
- The sun, moon and planets are not on the celestial sphere – only the stars are. The stars don't appear to move.
- The planets all rotate counter-clockwise around the sun on elliptical (almost circular) orbits. All of the planets lie on (nearly perfectly) the same orbital plane.
- The moon rotates around the earth. The moon's orbital plane is tilted about 5 degrees with respect to the plane of the earth's orbit.
- The ecliptic is where the (extended) orbital plane of the earth intersects the celestial sphere.
- The celestial equator is the earth's equator (which is tilted by about 23.4° from the ecliptic plane) extended out to the celestial sphere, i.e., where the plane of the earth's equator intersects the celestial sphere. The celestial equator doesn't move.

# Summary Sheet #3 for Astronomy Main Lesson

From the perspective of a person on the earth:

- From our perspective on Earth, the sun has a *daily path* and an *annual path.*
- The *daily path* of the sun across the sky takes exactly 24 hours. This path is always parallel to the celestial equator. We can easily see this every day.
- The sun moves a bit more slowly through the sky than do the stars, so it appears that the sun moves from right to left (west to east) against the background of the stars of the zodiac.
- The sun is always on the ecliptic – i.e., one of the constellations of the zodiac is always behind the sun.
- Because we cannot see the stars behind the sun, it takes careful observation combined with thinking to understand the sun's annual path.
- The *annual path* of the sun takes one full year for the sun to move through the ecliptic/zodiac.
- On average, it takes one month for the sun to move from one zodiac constellation to the next.

From the perspective of a spaceman looking down on the solar system (above our north pole):

- *One day*. From the perspective of a spaceman looking down at the solar system, the earth spins around once every 23 hours and 56 minutes. (Why isn't this 24 hours?)
- *One year*. The earth makes one complete rotation around the sun in about 365¼ days, but makes 366¼ rotations during that time. (Why?)

The Movement of the Ecliptic.

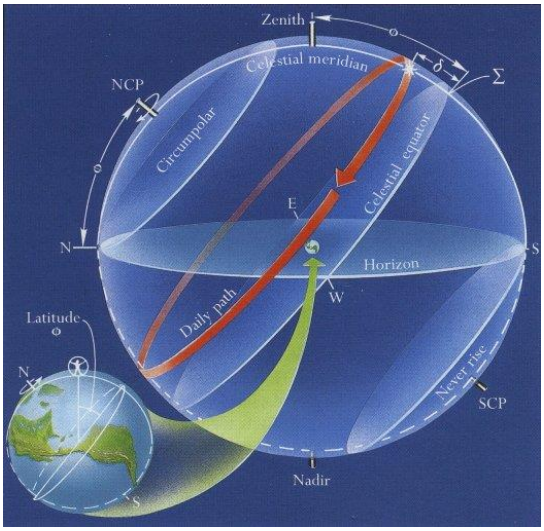
- There are two places where the celestial equator and the ecliptic intersect: in the constellation Virgo (where the sun is at the autumnal equinox) and the constellation Pisces (where the sun is at the Vernal equinox).
- Every day these two constellations travel along the celestial equator, dragging the wobbling ecliptic along with it.
- Taurus and Gemini (where the sun is at the summer solstice) mark the highest point that the ecliptic is above the celestial equator – 23.4° above.
- Sagittarius (where the sun is at the winter solstice) marks the lowest point that the ecliptic is below the celestial equator – 23.4° below.

The Movement of the Stars

- Any given star moves across the sky following a path parallel to the celestial equator, travels along this same exact path every day of the year, and takes 23 hours and 56 minutes to reach the same point in the sky from one day to the next. In other words, any given star (that does rise) rises 4 minutes earlier each day.
- Any given star always rises in exactly the same place and follows the same path through the sky (parallel to the celestial equator), no matter what the time of year – although we cannot see it rise if it rises during the day.
    - Example: Orion's belt rises due east, travels right along the celestial equator, and sets due west. It does this every day.
    - Example: Sirius (the brightest star in the sky), always rises to the south of east. It has a declination of -17 degrees, which means it travels through the sky parallel and 17° south of the celestial equator. In Boulder, this means that Sirius reaches a maximum height (looking south) in the sky of 33° (which is 50-17) every day.
- The daily rising and setting locations of the sun and the moon along the horizon *change every day*.

The Stars on the Celestial Sphere fall into three categories
(See the drawing at the right, which is for 40° latitude, like Boulder):

- The stars that "never set". These are the circumpolar stars, which, in Boulder (40° latitude), comprise about 12% of the stars on the celestial sphere.
- The stars that "never rise". For us in Boulder, these are the stars that circle the southern celestial pole – again, about 12% of the stars on the celestial sphere.
- The stars that rise and set *every day*. Where we are in Boulder, these stars are about 76% of the stars on the celestial sphere. Therefore, in Boulder, we get to we get to see (at some point in the year) about 88% of the stars on the celestial sphere.

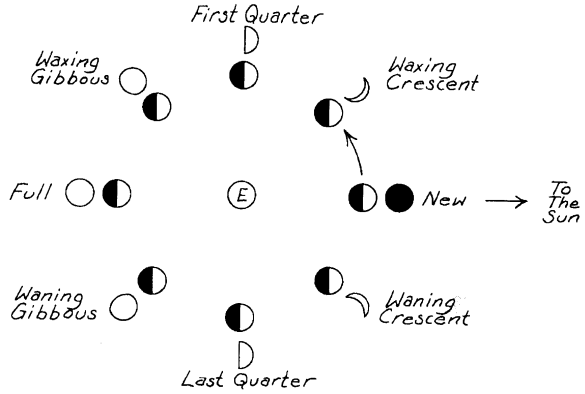



The Zodiac.

- *Tropical Zodiac*. The (original) tropical zodiac originates with Babylonian astronomy nearly 3000 years ago. The zodiac signs were assigned according to where the sun was at that time, and divided them evenly into 12 segments starting with Aries on the first day of spring.
- *Sidereal Zodiac*. The (modern) sidereal zodiac is shifted from the tropical zodiac by about 25 because the sun is now in a different position in the zodiac. Due to the procession of the equinox the zodiac dates move about one day every 70 years.
- *Astronomical Zodiac*. The astronomical zodiac shows where the sun is in each constellation without dividing it equally. Note that there are 13 constellations on the ecliptic, but that Ophiuchus is left out of the zodiac.
- *Precession of the Equinox*. This is the "wobbling" of the earth. It takes about 25,800 years for the earth to make one full gyroscopic precession. This is why the tropical and sidereal zodiac dates are about 25 days out of sync.
- *An Astrological Age*. This corresponds to which zodiac the vernal equinox falls on. It takes approximately 2,150 years (25,800 ÷ 12) to move from one age to the next.

# Summary Sheet #4 for Astronomy Main Lesson

- *The Phases of the Moon*. (See drawing at right.)
  - Note that the inner drawings of the moon represent the view of the moon from a spaceman's perspective, and the outer drawing is as it appears from standing on the earth.




- From a spaceman's perspective, the orbit of the moon is about 5% titled from the earth's orbital plane.
- The sun takes 24 hours to make its daily cycle through the sky.
- Any star takes about 23 hours and 56 minutes to make its daily cycle through the sky.
- The moon takes about 24 hours and 50 minutes to make its daily cycle through the sky.
  *The moon moves through the sky more slowly than the sun.*
- Vocabulary:
  - *New*. The moon is "new" when the moon is passing in its cycle closest to the sun in the sky, which is when the moon is (almost) not illuminated at all.
  - *Full*. The moon is "full" when the moon is passing in its cycle furthest away from the sun in the sky, which is when the moon is (almost) completely illuminated.
  - *Crescent*: When the moon is less than half.
  - *Gibbous*: When the moon is more than half
  - *Waxing*: When the moon is in a phase of growth.
  - *Waning*: When the moon is in a phase of shrinking.
- The moon completes a cycle (i.e., from full moon to full moon again) in about 29½ days, but from spaceman's perspective, the moon takes about 27.3 days to orbit the earth one time.
- On the full moon, the moon and the sun are on opposite sides of the sky. For example, near the winter solstice, at the moment that the sun is setting to the south of west, the moon is rising to the north of east. The full moon follows a path through the sky that is (nearly) the same as the sun's path at the opposite time of the year. For example, on the winter solstice, the full moon follows (nearly) the same path through the sky that the sun travels on the summer solstice.
- In the northern hemisphere, when the moon is waxing, it is to the left of the sun in the sky, and falling further to the left of the sun each day. Why is this? Because it moves through the sky more slowly than the sun does. Additionally, we can observe that it is the right side of a waxing moon that is illuminated. In other words, the illuminated portion "points" to the sun. With a waning moon, the moon is "falling" toward the sun each day, and the left side of the moon is illuminated.