Astronomy
Discovery Sheet #1

The Earth

Creating a globe with great circles

With a small Styrofoam sphere (about the size of a baseball), do the following

- *The Axis*. Carefully push a (brass) rod through the sphere. This represents the axis of the earth.
- *The Equator*. Place a orange rubber band around the sphere that represents the equator.
- *Your Location*. I will tell you what angle above the equator to place a thumbtack. This represents where you are on the earth.
- *The (extended) Horizon*. From your location on the sphere, place a purple rubber band to represent the horizon (from the perspective of being far above your location).
- *The Zenith Circle*. Place a green rubber band that represents the zenith circle.
- *The Meridian Circle*. Place another rubber band that represents the meridian circle.

Questions:

1. What is the angle between the axis and the horizon?
2. What is the angle between the axis and the equator?
3. What is the angle between the horizon and the zenith circle?
4. What is the angle between the horizon and the meridian circle?
5. What is the angle between the meridian and zenith circles?
6. What is the angle between the horizon and the equator?
7. What is the angle between the zenith circle and the equator?
8. What is the angle between your location and the equator?
9. What properties have you noticed about these angles?
10. Spin the globe on its axis. Describe carefully what happens to the (a) equator; (b) your location; (c) the horizon; (d) the zenith circle; (e) the meridian circle.
11. Now go outside. Look at the celestial sphere. As with your Styrofoam globe, imagine the equator, the horizon, the meridian, and the zenith circle relative to your location on the earth. Now, in your imagination, extend these four circles from the earth onto the celestial sphere.
    a. Describe where the axis of the earth is (assuming that it is an infinitely long line) relative to your position.
    b. Describe where the zenith circle (on the celestial sphere) is relative to your position on the earth.
    c. Describe where the meridian circle (on the celestial sphere) is relative to your position on the earth.
    d. Describe where the celestial equator is relative to your position on the earth.
    e. As the earth spins on its axis (i.e., as the day progresses) how do the four circles move according to your perspective on earth?
    f. What does move according to your perspective on earth?
12. Given what you have learned on this sheet, how would it be possible to look up into sky and determine your latitude?

Astronomy
Discovery Sheet #2

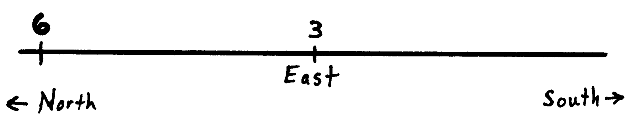
The Sun

The Sun's Rising Spot on the Horizon

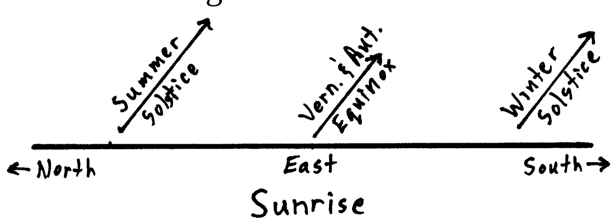
Only twice per year does the sun rise exactly in the east, and set exactly in the west.

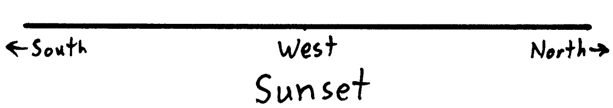
We will start with the facts that on the vernal equinox (first day of spring, March 20) the sun rises due east and on the summer solstice (June 21) it rises (in Boulder) at about 30° north of east.

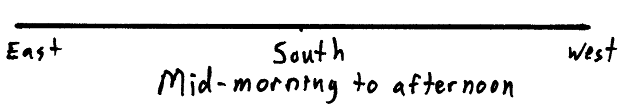
1. I have marked these two rising on the below horizon with numbers to represent months (therefore "10" represents October 21). Fill in the rest of the rising points of the months with tick mark and the numbers 1-12. Also add smaller tick marks to represent the half-month risings between the numbers. (This gives a total of 24 rising points.)



2. The first below diagram shows the path of the sun in Boulder shortly after sunrise on the first day of each season. Fill in the next two diagrams in a similar fashion.







3. The sun's daily path through the sky lies on a plane. (This plane is always parallel to the celestial equator and determines the angle at which the sun rises and sets.) At what angle does this plane intersect the horizon, if…
   a. …you are on the equator?
   b. …you are in Boulder (40° latitude)?
   c. …you are in Hawaii (21° latitude)?
   d. …you are in Oslo, Norway (60° lat.)?
   e. …you are at the North Pole?

4. Describe how the daily path of the sun varies over the course of the year if…
   a. …you are on the equator.
   b. …you are in Boulder.
   c. …you are in Hawaii.
   d. …you are in Oslo, Norway.
   e. …you are at the North Pole.

Astronomy
Discovery Sheet #3

The Sun – Part II

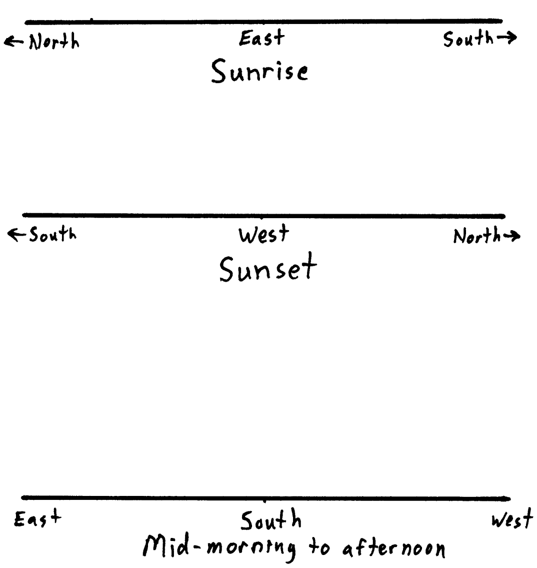
1. Fill out all of the below table.

The Daily Path of the Sun

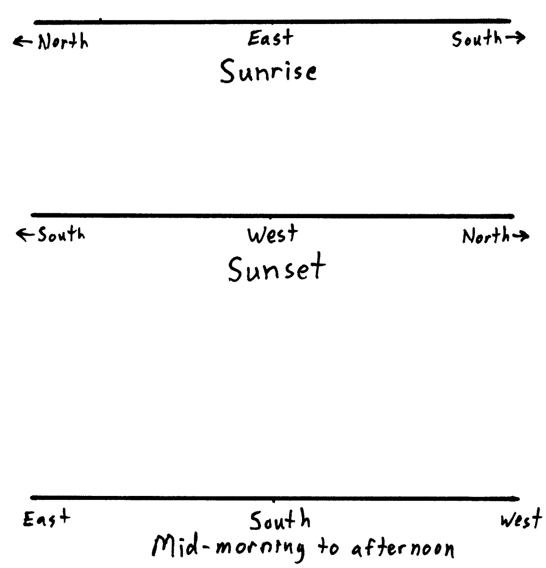
Location	Latitude	Rising			Midday			Setting			Comment
		6/21	Equinox	12/21	6/21	Equinox	12/21	6/21	Equinox	12/21	
Boulder	40°N	NE	E	SE	73.4°S	50°S	26.6°S	NW	W	SW	
Oslo	60°N										
Cairo	30°N										
Quito	0°										
Goa	15°N										
Adelaide	35°S										
San José	10°N										
Lima	12°S										
Sao Paulo	23.4°S										
North Pole	90°N										

Directions: For each of the remaining problems, complete the diagram (as was done on the previous sheet) in order to show the daily path of the sun for the location indicated. For each time of day, you should show the path during the winter solstice (in blue), the summer solstice (in red), and the equinoxes (in green).

2. Cairo, Egypt



3. Oslo, Norway



4. Adelaide, Australia

← North East South →

Sunrise

← South West North →

Sunset

East South West

Mid-morning to afternoon

5. Goa, India

← North East South →

Sunrise

← South West North →

Sunset

East South West

Mid-morning to afternoon

6. Sao Paulo, Brazil (Tropic of Capricorn)

← North East South →

Sunrise

← South West North →

Sunset

East South West

Mid-morning to afternoon

7. Quito, Ecuador (Equator)

← North East South →

Sunrise

← South West North →

Sunset

East South West

Mid-morning to afternoon

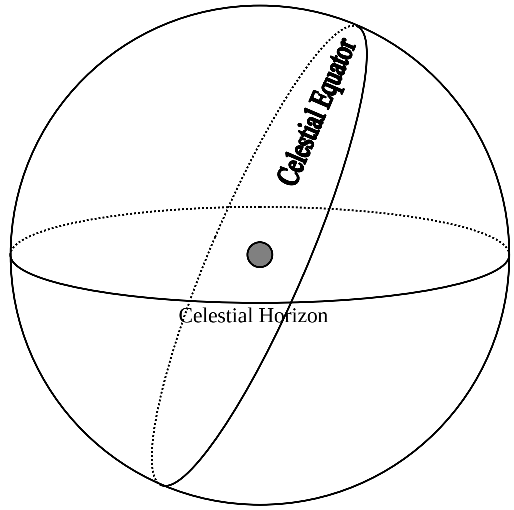
Astronomy
Discovery Sheet #4

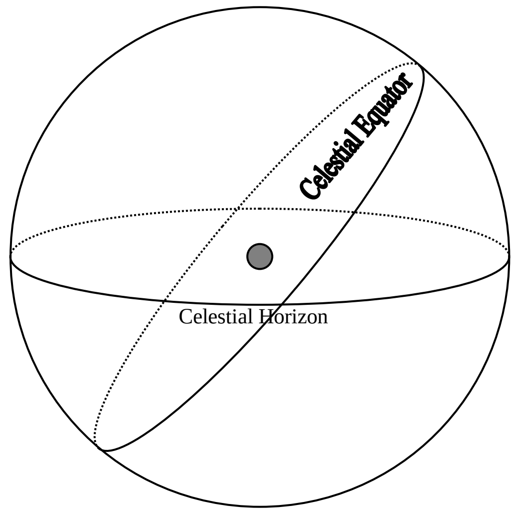
The Stars

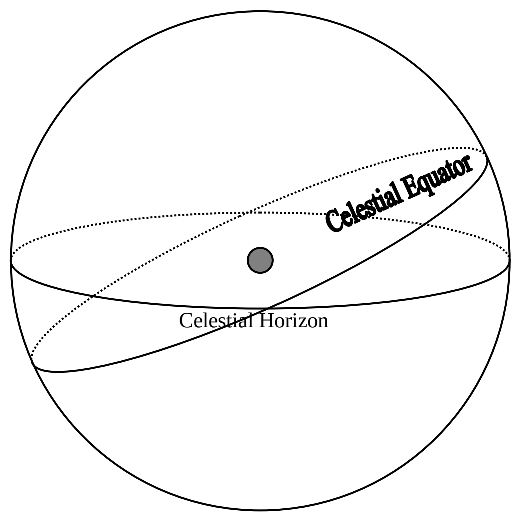
Relative distances

Fill in the blanks:

1. For an observer (5’ 7” tall) standing on perfectly flat ground the horizon is about ____ miles away.
2. The “furthest sight distance” one can possibly see on a very clear day is about ____ miles.
3. The circumference of the earth is about ____ times further than that.
4. The distance to the moon is about ____ times further than that.
5. The distance to the sun is about ____ times further than that.
6. The distance from the sun to Neptune (the furthest planet) is about ____ times further than that.
7. The nearest star is about ____ times further away than that.
8. The diameter of the Milky Way Galaxy is about ____ times further than that.
9. Andromeda galaxy (the nearest galaxy) is about ____ times further than that.
10. The diameter of the “observable universe” is about ____ times greater than that.
11. The celestial spheres on the right are for Oslo, Hawaii, and Boulder, but not in that order.
    a. With each sphere, mark the observer’s location with an “X”, and state the location (Hawaii, Boulder or Oslo).
    b. Draw in the axis of each sphere.
    c. Draw two circles (which should look like ellipses) for the “never set” stars and the “never rise” stars.







Astronomy
Discovery Sheet #5

The Stars, Part II

Using the Celestial Globe

1. *Summer Solstice.* Move the sun so that it is at the summer solstice. Answer the following questions:
   a. The sun is in what constellation? (It should be on the ecliptic.)
   b. Rotate the earth so that it is midday in Colorado. Is the sun above or below the celestial equator as viewed from Colorado?
   c. Rotate the earth so that it is midnight in Colorado. What constellation lies near the meridian (due south) and on the ecliptic as viewed from Colorado?
   d. What other prominent constellations can be viewed from Colorado at midnight?
   e. Where are Virgo and Pisces in the sky as viewed at midnight from Colorado?

2. *Winter Solstice.* Move the sun so that it is at the winter solstice. Answer the following questions:
   a. The sun is in what constellation?
   b. Rotate the earth so that it is midday in Colorado. Is the sun above or below the celestial equator as viewed from Colorado?
   c. Rotate the earth so that it is midnight in Colorado. What constellation lies near the meridian (due south) and on the ecliptic as viewed from Colorado?
   d. What other prominent constellations can be viewed from Colorado at midnight?
   e. Where are Virgo and Pisces in the sky as viewed at midnight from Colorado?

3. *Vernal Equinox.* Move the sun so that it is at the vernal equinox. Answer the following questions:
   a. The sun is in what constellation?
   b. Rotate the earth so that it is midday in Colorado. Is the sun above or below the celestial equator as viewed from Colorado?
   c. Still looking to the south at midday, does the ecliptic cut *down* to the right through the celestial equator, or *up* to the right?
   d. Rotate the earth so that it is midnight in Colorado. Looking to the south, does the ecliptic cut down to the right through the celestial equator, or up to the right?

4. *Autumnal Equinox.* Move the sun so that it is at the autumnal equinox. Answer the following:
   a. The sun is in what constellation?
   b. Looking to the south at midday, does the ecliptic cut *down* to the right through the celestial equator, or *up* to the right?
   c. Rotate the earth so that it is midnight in Colorado. Looking to the south, does the ecliptic cut down to the right through the celestial equator, or up to the right?

Using the Celestial Umbrella

By looking at the celestial umbrella…

5. At what constellations do the celestial equator and the ecliptic intersect?
6. Which constellation along the ecliptic (zodiac) is *closest* to the celestial north pole?
7. What is special about this constellation?
8. Which constellation along the ecliptic (zodiac) is *furthest* from the celestial north pole?
9. What is special about this constellation?
10. Hold the umbrella above your head, and spin it counter-clockwise while looking upward. If someone is looking down at the umbrella from above, would they say it is turning clockwise, or counter-clockwise?
11. Now, have someone hold the umbrella above you without it spinning. While looking up, spin yourself so that the movement of the stars on the umbrella appear to be spinning in the same direction as before. If someone is looking down at you from above, would they say you are turning clockwise, or counter-clockwise?
12. In the northern hemisphere, the stars appear to rotate around the celestial north pole in a ___________ direction.
13. In the southern hemisphere, the stars appear to rotate around the celestial south pole in a ___________ direction.

Fill in the Blanks

14. The ecliptic is also called the _________.

15. The ecliptic is where the _________ intersects the celestial sphere.

16. On *Winter Solstice* in Boulder, the sun is in _________, and at midnight, the zodiac constellation in the south is________.

17. On *Summer Solstice* in Boulder, the sun is in _________, and at midnight, the zodiac constellation in the south is ________.

18. On *Vernal Equinox* in Boulder, the sun is in _________, and at midnight, the zodiac constellation in the south is ________.

19. On *Autumnal Equinox* in Boulder, the sun is in _________, and at midnight, the zodiac constellation in the south is ________.

20. Every day Taurus and Gemini reach a maximum height in the Boulder sky of about ____ degrees. The path of these constellations is ________ to the celestial equator, but _______ in the sky.

21. Every day Sagittarius reaches a maximum height in the Boulder sky of about ______ degrees. The path of this constellation is ________ to the celestial equator, but _______ in the sky.

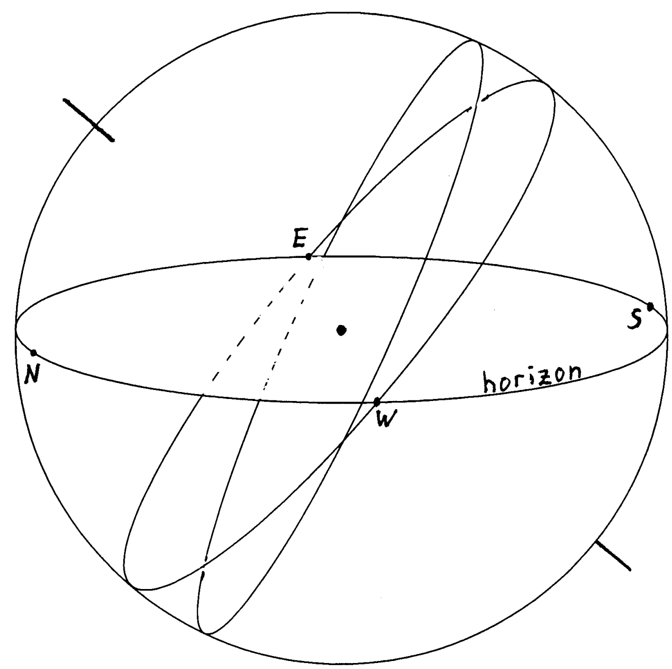
22. Every day Virgo and Pisces (where the sun is during the equinoxes) travel approximately ________ the celestial equator.

23. *Every star* (which rises and sets) always travels on a daily path through the sky which is _________ to the celestial equator.

Filling out the Celestial Sphere

The below drawing is intended to represent the view of the sky in Boulder slightly after midnight on the winter solstice.

24. Label the ecliptic and the celestial equator.
25. Label the vernal and autumnal equinoxes.
26. Label today's approximate locations of the sun, moon, and five visible planets.
27. Label the approximate locations Orion, Gemini, Taurus, Sagittarius, Pisces, and Virgo.



28. How would the drawing be different if it were instead at noon on the winter solstice?

29. How would the drawing be different if it were instead at noon on the summer solstice?

Astronomy
Discovery Sheet #6

The Moon

How the Moon Works

1. Around winter solstice in Boulder, the full moon rises to the _______ of east, and sets to the ______ of west. On that day, the full moon follows the same path in the sky that the sun does on ________________. It reaches a maximum height in the sky of about ______ degrees, and is in the sky for a total of about _____ hours.

On the winter solstice, the sun rises in Boulder around 7:20am, sets around 4:40pm, and midday is at 12:00 noon. (With the below questions, assume that daylight savings time didn't exist.)

Around what time is sunrise and sunset in Boulder…

2. on the summer solstice?

3. on the vernal equinox?

4. on the autumnal equinox?

On the winter solstice, around what time is moonrise and moonset in Boulder…

5. if it is a new moon?

6. if it is a waxing half moon?

7. if it is a full moon?

8. if it is a waning half moon?

For each lunar phase, give the times (relative to sunset and sunrise) that the moon can best be viewed in the night sky.

9. Full moon

10. Waning gibbous

11. Waning half

12. Waning crescent

13. New moon

14. Waxing crescent

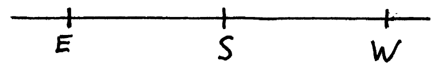
15. Waxing half

16. Waxing gibbous

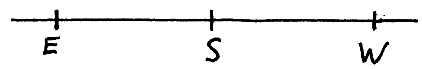
Drawing the Moon

For each lunar phase, draw a fairly accurate picture of moon in the night sky either just before sunrise, or just after sunset. Indicate also the position of the sun. (The illuminated portion of the moon should be shaded in with a lead pencil.)

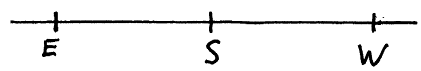
17. Waning half



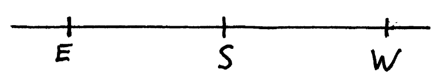
18. Waning crescent



19. Waxing crescent



20. Waxing half



How an Eclipse Works

21. Draw a diagram, from a spaceman's perspective, showing the positions of the earth, moon and sun during a solar eclipse.

22. Draw a diagram, from your perspective on Earth, showing the positions of the moon and sun during a solar eclipse.

23. Draw a diagram, from a spaceman's perspective, showing the positions of the earth, moon and sun during a lunar eclipse.

24. Draw a diagram, from your perspective on Earth, showing the positions of the moon and sun during a lunar eclipse.

25. Where do you have to be on the earth in order to see a lunar eclipse?

26. Where do you have to be on the earth in order to see a solar eclipse?

27. Why is it more rare to be able to view a solar eclipse than a lunar eclipse?

Astronomy
Discovery Sheet #7

The Planets

Planet	Orbital Radius (AU)	Orbital Period [1]	Axial Tilt	Rotation Direction	Rotation Period [2]	Rotations Per Orbit [3]	(Solar) Days Per Orbit	Day Length [4]
Mercury	0.387	0.241	0°	Cntr-clock	58.7	1.50	0.50	176.1
Venus	0.723	0.615	3°	Clockwise	243	0.924	1.924	116.7
Earth	1.000	1.000	23.5°	Cntr-clock	0.997	366.3	365.3	1.000
Mars	1.52	1.881	25°	Cntr-clock	1.027	669	668	1.029
Jupiter	5.20	11.86	3°	Cntr-clock	0.414	10463	10462	0.414
Saturn	9.58	29.46	27°	Cntr-clock	0.440	24455	24454	0.440
Uranus	19.2	84.01	82°	Clockwise	0.718	42736	42737	0.718
Neptune	30.0	164.8	30°	Cntr-clock	0.671	89667	89666	0.671
Pluto	39.4	248	72°	Clockwise	6.39	14176	14177	6.39

[1] Orbital Period is measured in "earth years". [2] Rotational Period and Day Length are measured in "earth days"

[3] Rotations per Orbit = $\frac{\text{Orbital Period}}{\text{Rotational Period}}$ [4] Day Length = $\frac{\text{Rotations per Orbit}}{\text{Days per Orbit}} \cdot \text{Rotational Period}$

Use the above table to answer the following questions:

1. Explain how the seasons, days and years are different for Venus as compared to the earth.

2. Explain how the seasons, days and years are different for Saturn as compared to the earth.

3. Explain how the seasons, days and years are different for Mercury as compared to the earth.

4. Explain how the seasons, days and years are different for Uranus as compared to the earth.

5. A planet orbits around a star in a counterclockwise direction and rotates on its axis in a counterclockwise direction. It's orbital period is 5.86 (earth) years, and it rotational period is 53.4 (earth) days.
   a. Find its (average) orbital radius.
   b. Find the number of rotations per orbit.
   c. Find the solar days per orbit.
   d. Find the length of a day (on this planet).

6. A planet orbits around a star in a counterclockwise direction and rotates on its axis in a clockwise direction. It's (average) orbital radius is 0.61 AU, and it rotational period is 53.4 (earth) days.
   Find the length of a day (on this planet).

7. Which planets can be seen (ever) in the sky close to a small crescent moon? Explain.

8. Which planets can be seen (ever) in the sky close to a full moon? Explain.