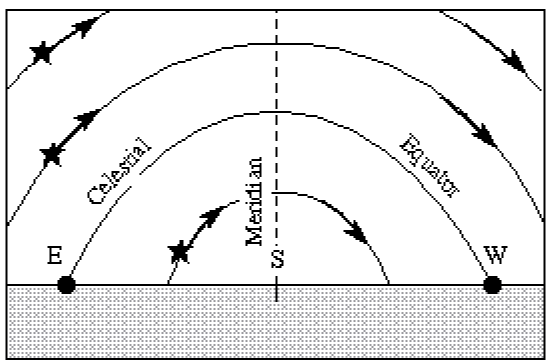
Overview

You will be measuring the position of the Moon over the course of the semester as a means to measure its orbital period around the Earth. By recording the date, time, and phase of the Moon of each observation you will be able to predict the Moon phase on the last day of class (or on any other day). This is accomplished by determining the angle between the Moon and the Sun. This angle is called the Moon's elongation angle. By observing how the elongation angle and the Moon phase changes over the semester you will gain an understanding of the relationship between these quantitates.

Orientation of the Night Sky

Visualize the sky in terms of the celestial sphere; remember, we're inside it. Imagine that you're facing south, looking up at the sky. Each day or night, celestial objects rise in the east (to your left), cross the sky along the curved paths shown in the figure below, and set in the west (to your right). Of course this behavior is really caused by Earth's eastward rotation.

Figure 1:



The sketch in the above figure represents a huge curved view. The top edge is almost at the zenith (straight overhead) and the eastern and western horizons are directly to your east and west, respectively. Stars and other celestial objects follow the curved paths parallel to the celestial equator as they move across the sky each night or day.

ASTRONOMICAL MERIDIAN

This is an invisible line extending North-South across the sky, from the south point on the horizon and passing straight overhead. Stars cross the meridian from left to right if you're facing south. A star is highest in the sky at the time when it is on the meridian. Another way of thinking of meridian is this: It is the projection of the longitude line which passes through your zenith nd is projected out into space.

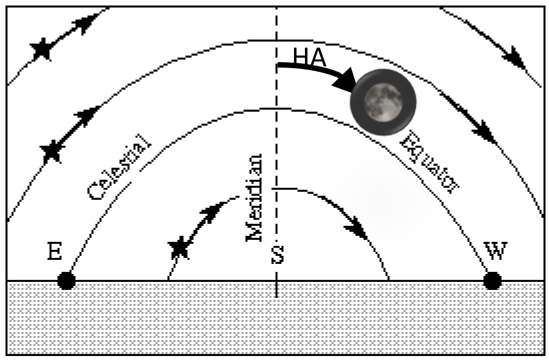
CELESTIAL EQUATOR

The celestial equator is the projection of the Earth's equator out into space. This is similar to the concept of astronomical meridian (see above). Our view of the celestial equator's location in the sky is also shown in Figure 1. It extends from directly east on the horizon to directly west on the opposite horizon. As seen from Laramie, the celestial equator is tilted upward at an angle of 49° (90°-41°) from the southern horizon.

MOON'S HOUR ANGLE and SUN'S HOUR ANGLE

In this project we'll try to estimate the Moon's orbital rate more accurately, in more or less the same way that ancient astronomers did. We will need to relate the daily motion of the Moon across our sky to its elongation. To do this we will measure the angle on the sky between the Moon and meridian (remember we are imaging the arc across the sky from the imaginary North-to-South line, or Meridian). The Moon's rotation angle from the meridian is called Hour Angle or H.A., see Figure 2.

Figure 2:



If you stand and wait a while, you will notice the Moon appears to move across the sky to the West. Thus, the H.A. of a star, planet, the Sun, or the Moon continuously increases by about 15 degrees per hour (360° in 24 hours due to Earth's rotation) as it moves westward across the sky. We define hour angle to be negative (backwards in time) on the left side of the meridian, i.e., in the eastern half of the sky and positive (forwards in time) on the right side of the meridian, i.e., in the western half of the sky where celestial objects set. It is this parameter, the H.A. of the Moon you will be measuring.

To figure out the Sun's Hour Angle, note the following:

- The Sun crosses the meridian (H.A. = 0) at a time called "astronomical noon" or "local apparent noon". This is somewhat different than normal Civil Noon, but we will be using Civil Noon instead of astronomical noon because that is what our clocks show us.
- The Sun's hour angle increases by 15 degrees per hour.

A simple formula that agrees with both of these facts is:

$$\text{Sun's H.A} = (\text{ MST in hours} - 12 \text{ (noon)}) * 15°/\text{hour}$$

- Note that the Sun's H.A. is negative (East) before noon and a positive value (West) after noon.
- Example: What is the Sun's hour angle at 9:30 a.m. (daylight savings time; MDT)?
- 9:30 MDT is 8:30 MST
- 8:30 MST or 8.5 hours. Therefore the Sun's H.A. at the specified time is
(8.5 h - 12 h) × 15° = - 3.5 × 15° = -53°

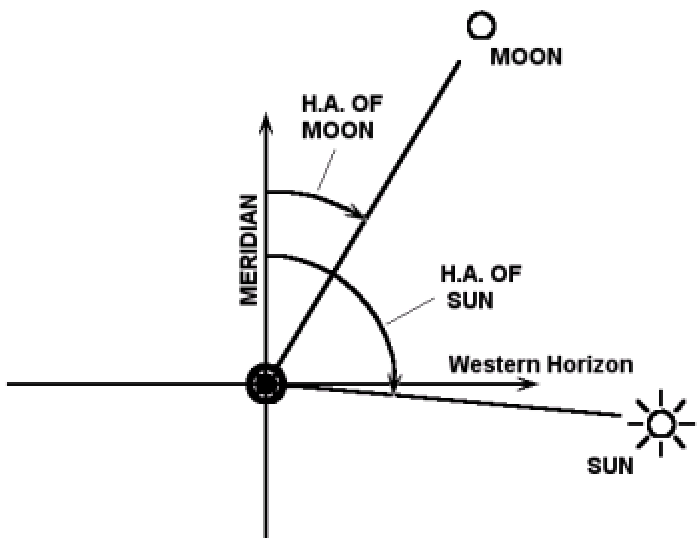
- The negative sign indicates that the Sun is east of the meridian. In other words, if you were looking directly South at 8:30 AM on July 4, the Sun would be 53° East (to your left) of the meridian along the ecliptic.
- BEWARE of daylight savings time! By moving the clocks forward (adding an hour), the Sun is no longer on the Meridian at noon! It is on the Meridian at 1 p.m. To get an accurate angle between the Moon and the Sun, we have to subtract 1 hour from your recorded time:

MST = MDT – 1 hour

ELONGATION

Standing on the Earth, you could measure the H.A. of both the Moon and the Sun. The difference between these two angles must be the Elongation angle of the Moon. This can be seen more clearly in Figure 3.

Figure 3:

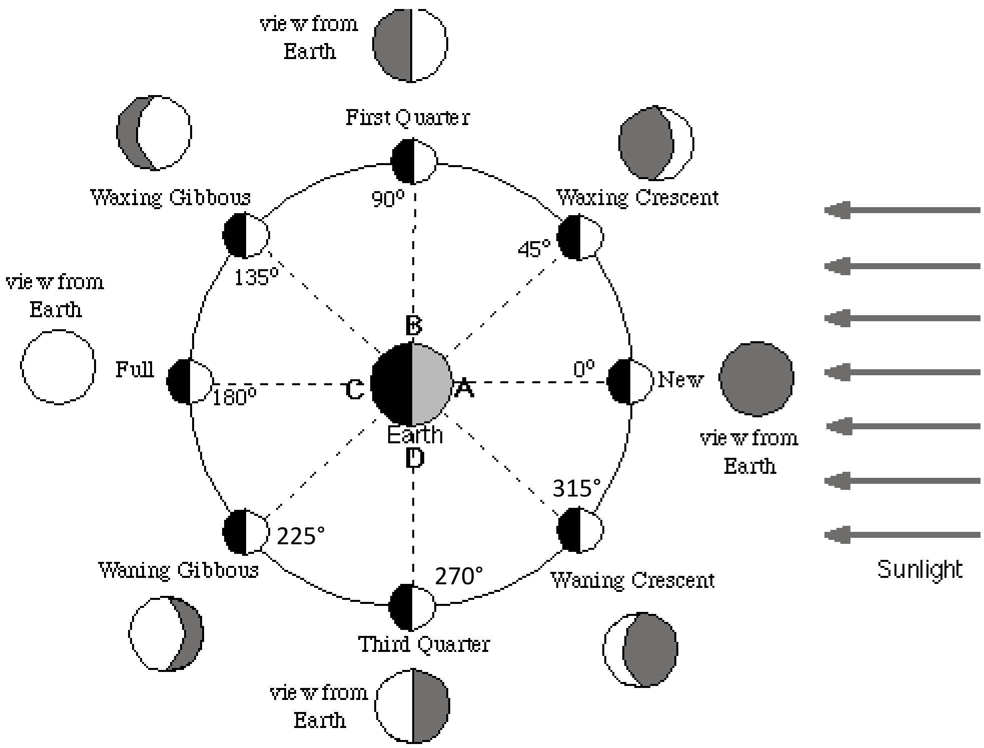


In Figure 3 we have chosen the time of day to be just after Sunset so that the Sun's hour angle is about +95 degrees and we placed the Moon at +30 degrees. Note that the Moon's elongation, the angle between the Sun and the Moon, is the difference between these two hour angles. If you get a negative number, just add 360 degrees.

Moon's Elongation = H.A. of the Sun - H.A. of the Moon

This formula can be used to find the Moon's elongation (angular distance from the Sun), even at night when we cannot see the Sun. This is possible because we know where the Sun is because we know the time of day. At midnight, for example, the Sun is on the other side of the Earth (H.A is about 180°), out of view. At sunset the Sun is on the Western Horizon (H.A. is about 90°). We can easily calculate its hour angle at any given time!

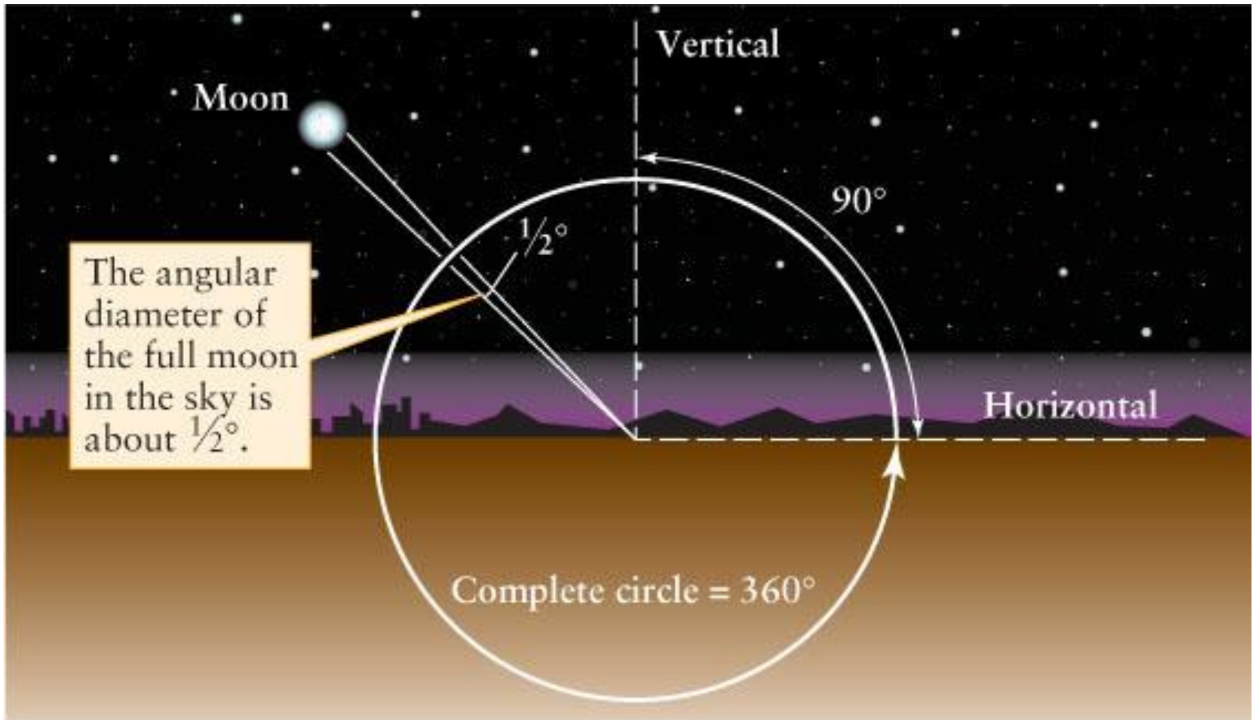
Another way of interpreting elongation is this: The Moon's elongation is the Moon's orbital position around the Earth from a bird's eye (top-down) view fixing the Sun to a single spot; to the right in this case:



Making Angular Measurements on the Sky

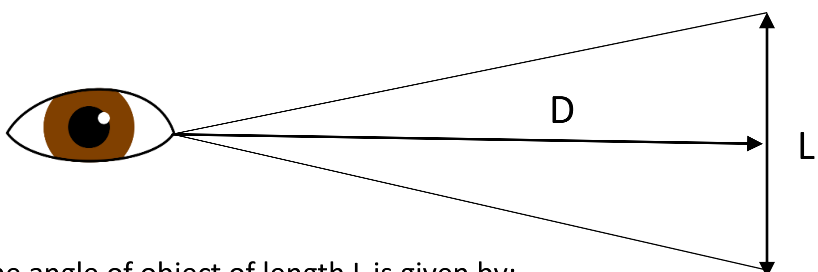
An important part of this project is identifying your location and making sure face **DUE SOUTH**. Two ways to do this is to use a map and find a street that is aligned North-South or use a compass. Most streets in Laramie marked N-S are actually a few degrees off of actual N-S, so using a compass is the most accurate.

Apparent “distances” on a star map or in our view of the sky are arcs on the celestial sphere. These represent angles subtended at Earth just as if you measured the angle between two lines on a piece of paper with a protractor. However, angles on the sky are a little harder to measure.



(a) Measuring angles in the sky

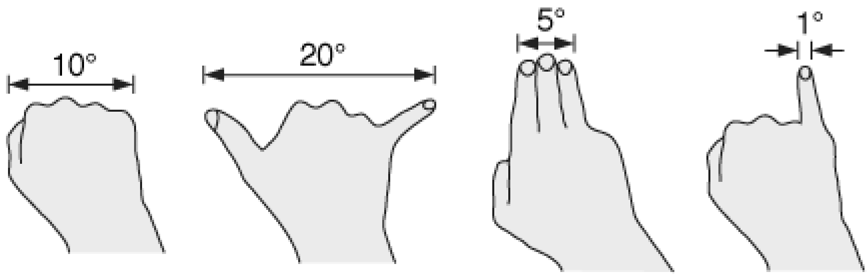
One method to measure angles on the sky is to hold an object length L at a distance D from your eye:



, then the angle of object of length L is given by:

$$\boldsymbol{Angle\ (degrees) = 57.3\ \left(\frac{degrees}{radian}\right) * \frac{L}{D}}$$

Where the parenthesis indicate units, the 57.3 factor is a conversion between radians (a standard unit of an angle) and L/D is the ratio of length of an object to the distance it is away. This formula is accurate if D is at least twice as large as L. A convenient angle measuring device like this is your hand. Holding your clenched fist at arm’s length and using the equation above, provides the means to measure angles on the night sky. For most people, the angular distance of your fist is 10 degrees and the angular distance of your pinky finger is 1 degree as shown by:

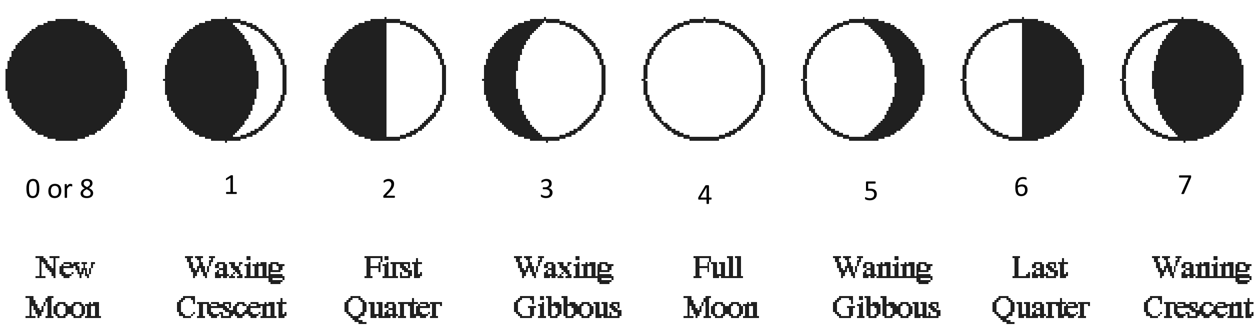


This a general rule for **most people**, but may not be accurate for all people. Every person can calibrate their hand using the following steps:

1. Stand at a place where two distant directions 90 degrees apart are easy to identify; perhaps at the intersection of two long, straight sidewalks or walls that are perpendicular to each other.
2. Hold out your fist at an arms distance and carefully rotate your body, keeping your arm stiff, to exactly how many fist-widths fit into the 90 degree angle.
    a. Example: Say it takes 8 of my fists to cover the 90 degree angle. Then we have: 90/8 = 11 (degrees/fist)
3. Repeat the measurement to see how reliable it is.

Moon Phase Measurement

The phase of the Moon is decribed by the portion of the Moon which is illuminated. You will observe he phase and relae it to a numbering scheme referred to as the “phase number.” Record the appearance of the moon on a scale of 0 to 8, referring to the figure below. Intermediate values are necessary for accuracy. For instance, a moon phase of 1.5 would describe a crescent that’s fatter than number 1 in the diagram.



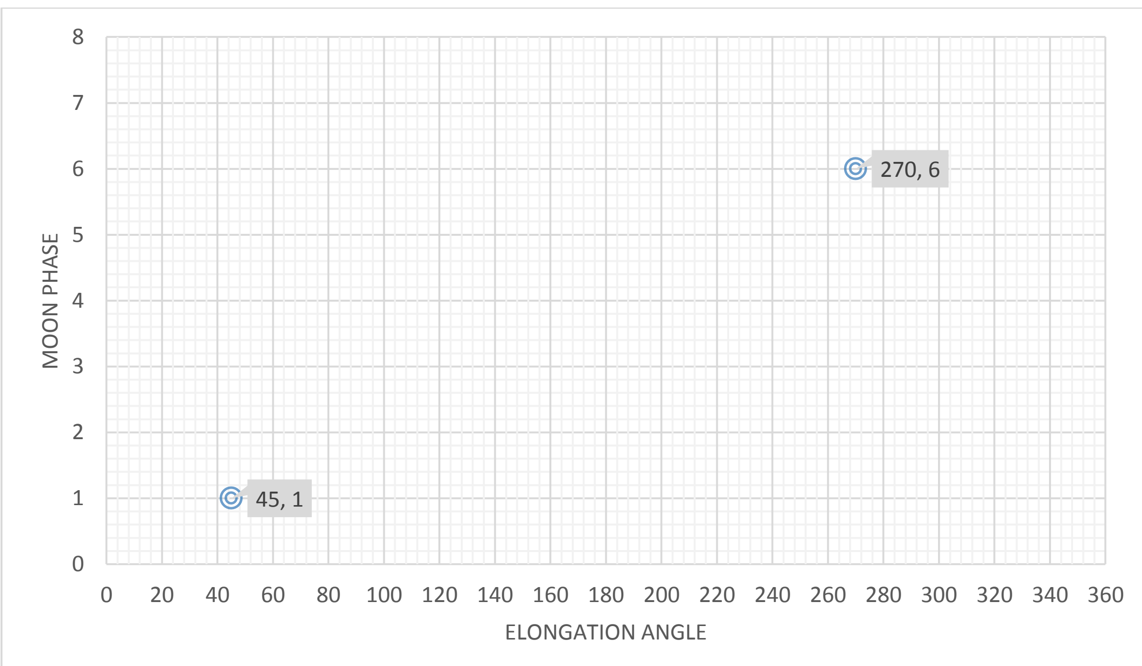
Making Graphs

The end goal of this project is to see for yourselves if the Moon phase is a consequence of the Moon's elongation angle (aka the illumination of the Moon given the relative Earth-Moon-Sun geometry). A relationship between the Moon's elongation and the Moon's phase can be verified if the data form a straight line (not all relationships require a linear description; a straight line). You will plot each of your observation's elongation angle and Moon phase to verify this relationship. You will also plot day number and elongation angle to predict the moon phase on the last day of class.

Elongation vs. Moon Phase

Example: the figure below is a plot of elongation angle and Moon phase. This figure has 2 observations plotted onto it:

1. Elongation angle=45 & Moon phase=1
2. Elongation angle=270 & Moon phase=6

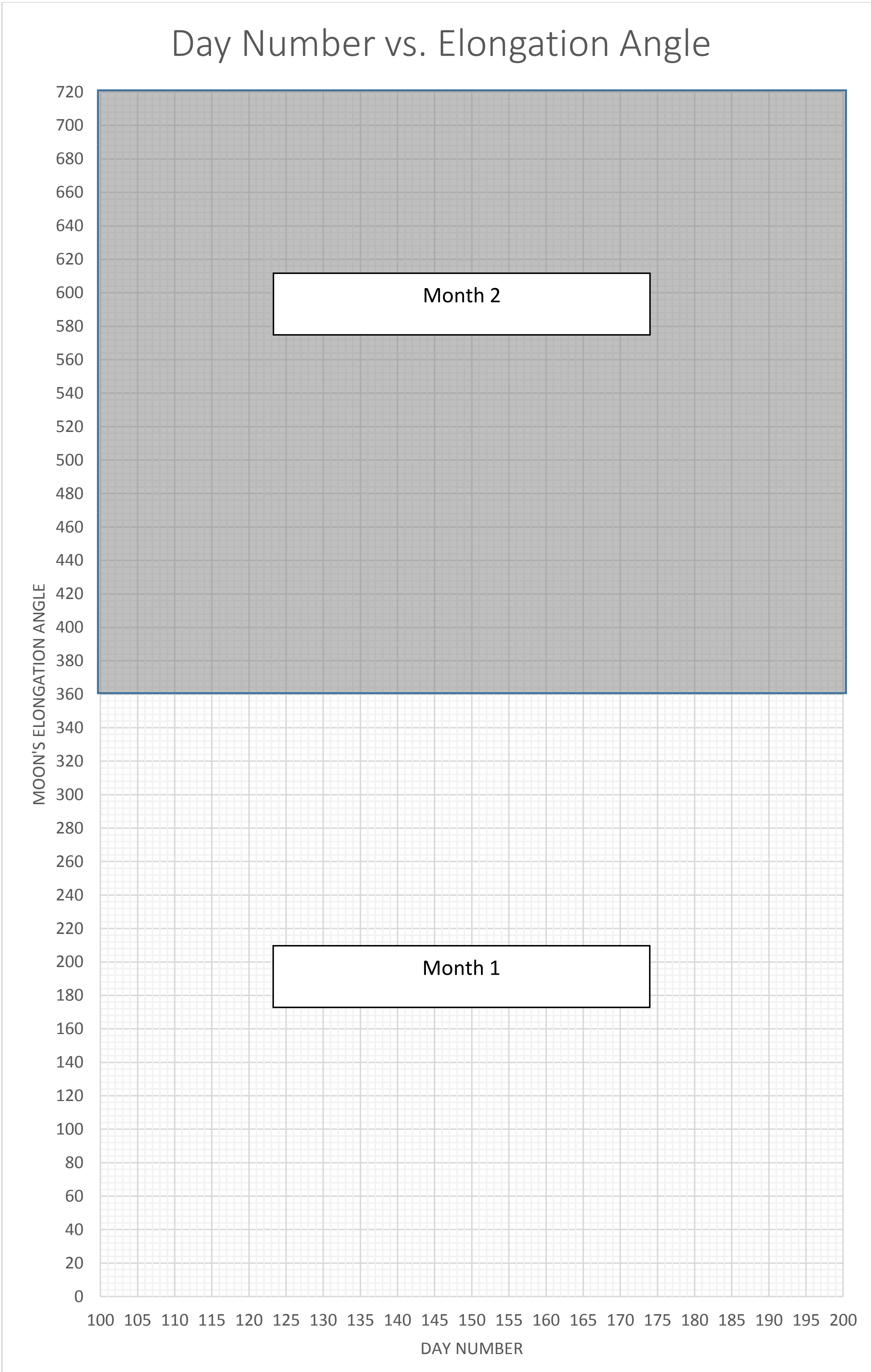


Elongation Angle vs. Day Number

In a similar method to Moon phase vs. elongation angle, you will plot the day of the year vs. the Moon elongation angle. You will discover that there is also a linear relationship between day number and elongation angle for each orbital period (each month). For this graph you will plot the day of the year (between 0 and 365 days). During the first month of observations the elongation angle will have linear relationship with the day number. However, after the moon starts a new orbit (lunar cycle), this relationship will start over and you will need to add 360 degrees to your elongation angles. This is shown in the example day number vs. elongation angle figure below.

Day Number vs. Elongation Angle

Day	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
1	1	32	60	91	121	152	182	213	244	274	305	335
2	2	33	61	92	122	153	183	214	245	275	306	336
3	3	34	62	93	123	154	184	215	246	276	307	337
4	4	35	63	94	124	155	185	216	247	277	308	338
5	5	36	64	95	125	156	186	217	248	278	309	339
6	6	37	65	96	126	157	187	218	249	279	310	340
7	7	38	66	97	127	158	188	219	250	280	311	341
8	8	39	67	98	128	159	189	220	251	281	312	342
9	9	40	68	99	129	160	190	221	252	282	313	343
10	10	41	69	100	130	161	191	222	253	283	314	344
11	11	42	70	101	131	162	192	223	254	284	315	345
12	12	43	71	102	132	163	193	224	255	285	316	346
13	13	44	72	103	133	164	194	225	256	286	317	347
14	14	45	73	104	134	165	195	226	257	287	318	348
15	15	46	74	105	135	166	196	227	258	288	319	349
16	16	47	75	106	136	167	197	228	259	289	320	350
17	17	48	76	107	137	168	198	229	260	290	321	351
18	18	49	77	108	138	169	199	230	261	291	322	352
19	19	50	78	109	139	170	200	231	262	292	323	353
20	20	51	79	110	140	171	201	232	263	293	324	354
21	21	52	80	111	141	172	202	233	264	294	325	355
22	22	53	81	112	142	173	203	234	265	295	326	356
23	23	54	82	113	143	174	204	235	266	296	327	357
24	24	55	83	114	144	175	205	236	267	297	328	358
25	25	56	84	115	145	176	206	237	268	298	329	359
26	26	57	85	116	146	177	207	238	269	299	330	360
27	27	58	86	117	147	178	208	239	270	300	331	361
28	28	59	87	118	148	179	209	240	271	301	332	362
29	29	---	88	119	149	180	210	241	272	302	333	363
30	30	---	89	120	150	181	211	242	273	303	334	364
31	31	---	90	---	151	---	212	243	---	304	---	365



Day Number vs. Elongation Angle
MOON'S ELONGATION ANGLE
DAY NUMBER
Month 2
Month 1
0
20
40
60
80
100
120
140
160
180
200
220
240
260
280
300
320
340
360
380
400
420
440
460
480
500
520
540
560
580
600
620
640
660
680
700
720
100
105
110
115
120
125
130
135
140
145
150
155
160
165
170
175
180
185
190
195
200

How to Fill Out Your Observation Sheet

Date column:

- This is the date that you recorded for each observation. It is very important so do not forget to write it down when you make an observation.

Clock Time column:

- This is the time that you record for each observation according to your watch (which you should make sure is correct). You must write down A.M. or P.M. If you don't, I will have no idea which one you are talking about. Do not make any adjustments for Daylight Time here, just write down the current official time.

Decimal Time column:

- For this you are required to have it on the 24-hour clock (military time). Therefore, if you observe at clock time of 9:30 p.m. you will have to convert. To do this, just add 12 to the hours after noon.

9:30 p.m. + 12 = 21:30 6:30 a.m. = 06:30 12:45 a.m. = 00:45

- You must make sure you are in standard time as well. When we are in Daylight Saving Time (starting 2 a.m. March 10), you have to subtract one hour from ALL OF YOUR TIMES (not just the ones you added 12 to).

21:30 - 1 = 20:30 06:30 - 1 = 05:30 00:45 - 1 = 23:45

As you can see, observations made between midnight and 1 a.m. "wrap around" the 0/24 hour mark back to 23 hours.

- You MUST also convert your minutes into decimals - this will help you when you make calculations. I'll give you a few examples:

20:30 will be 20.5 (as 30/60 = 1/2 = 0.5) 00:45 will be 00.75 (as 45/60 = 0.75)
06:10 will be 06.17 (as 10/60 = 0.167)
(max of 2 digits after decimal!)

Phase Sketch column:

- Draw what you saw. Try to be as accurate as possible of what percentage of the moon is lit (crater detail is not needed, only illumination).

Phase Number column:

- I highly encourage you to use decimal phase numbers for the 'in-between' phases. By doing this, you will end up with better results on the graphs you will do for your final project.

the moon is not quite full = phase 3.8
the moon has just passed 3rd quarter = phase 6.1

Hands/Fists column:

- Don't know how to take an observation? Either check back to Observing project Lab.

- Write down how many fists East (left) or West (right) of South you measured the Moon's position.

- Make VERY sure that you record the direction you went - either to the right or the left of south (left [East] = negative)

Moon's H.A. column:

- The Moon's HA column should have the number of degrees the moon is away from south. To convert:

my hand spans 15 degrees, my fist 10 degrees
observation 1: moon 4.0 hands right (West) of south -->
4.0 hands * 15 degrees per hand = 4 * 15 = 60 degrees
observation 2: moon 2.3 hands left (East) of south -->
-2.3 hands * 15 degrees per hand = -2.3 * 15 = -34.5 degrees

Day Number column:

- This is the number of days from the beginning of the year (i.e. January 1st). For example, Jan 1 = Day 1, Jan 2 = Day 2, Jan 31 = Day 31, Feb 1 = Day 32, etc...

Sun's H.A. column:

- Sun's Hour Angle is where the sun is in relation to 0 degrees South (just like the moon). Therefore, if the Sun's H.A. is 0, the time is 12 noon

- The equation goes as this: [(MST) - 12.0] * 15 = SUN'S H.A.

You have CST from your observations. It MUST be in the 24 hour clock AND THE MINUTES MUST BE IN DECIMALS (see the third point in the 'MST column' section). If the minutes are not in decimals, your future calculations WILL BE WRONG (and points deducted).
ex: observed at 9:30 pm (MDT) so,

MST = 20.5, and 20.5 - 12.0 = 8.5, so Sun's HA = 8.5 * 15 = 128
ex: observed 6:30 am (MDT) so, MST = 5.5 and 5.5 - 12.0 = -6.5 , so Sun's HA = -6.5 * 15 = -98
ex: observed 12:59 am (MST) so, MST = 0.98 and 0.98 - 12.0 = -11.02, so Sun's HA = -11.02 * 15 = -165
example of WRONG: obs at 12:59 am (MST) ~~ so then I (wrongly) say MST = 0.59, so 0.59 - 12.0 = -11.41, so Sun's HA = -11.41 * 15 = -171 -- WRONG

Elongation column:

- The equation goes as this: (Sun's H.A.) - (Moon's H.A.) = ELONGATION

- You have the Sun's H.A. from above and the Moon's H.A. is what you calculated from your hands/fists. REMEMBER, if Moon's H.A. is negative, keep it that way and when you subtract a negative number, it turns positive.

ex: Sun's H.A. = 128, Moon's H.A. = -13 ~~ Elongation = 128 - (-13) = 128 + 13 = 141
ex: Sun = -5, Moon = -90 ~~ Elongation = -5 - (-90) = -5 + 90 = 85
ex: Sun = -128, Moon = -13 ~~ Elongation = -128 - (-13) = -128 + 13 = -115

- This brings up a situation: ELONGATION MUST BE POSITIVE. If you get a negative number for elongation, then add 360 degrees until you get a number between 0 and 360 (sometimes you may come up with a rather large negative number). Do NOT just change the - sign to a + sign. This rule doesn't apply to H.A.'s, only the elongation.

ex: Elong = -115, so -115 + 360 = 245 degrees