

Answer Key for Challenge Problems

Challenge 1 – Working with Geographic Coordinates

Problem 1
A) New York City, Statue of Liberty: 74.04465 West 40.6893 North
B) Kennedy Space Center: 80.6817 West, 28.5235 North
C) Golden Gate Bridge: 122 : 28 : 41.9 West 37 : 49 : 7.7 North,
D) Chaco Canyon Ruins : 107 : 57 : 22.0 West 36:05:53 North

Problem 2
A) Latitude 35° : 28' : 15.5"
B) Longitude 115° : 15' : 33.2"

Problem 3 - Convert all coordinates to decimal degrees to get Washington (38.905°, 77.037°) and Portland (45.544, 122.654). Find the mid-point between the Latitudes: (38.905+45.544)/2 = 42.225 or 42° : 13’ : 30” North. Find the mid-point between the longitudes: (77.037+122.654)/2 = 99.846 or 99° : 50’ : 46” West. The location of the midway station is at (42° : 13’ : 30” North, 99° : 50’ : 46” West). This is 35 miles south of Ainsworth, Nebraska!

Problem 4
A) Convert to decimal degrees and subtract them: 39.84 – 41.12 = 1.28°.
B) A full 360-degree great circle has a circumference of 40,000 km, so 1.28° corresponds to 40000(1.28/360) = 142 kilometers.

Problem 5
A) Convert to decimal degrees and subtract them: 101.71 – 94.64 = 7.07°.
B) 7.07° corresponds to 7.07 * 86 = 608 kilometers.
C) 7.07 x 38 = 269 kilometers or less than half the distance!

Challenge 2 – X Marks the Spot

Problem 1
Intersection near Longitude 89.27 West, 37.64 North.

Problem 2 - About 10 kilometers southwest of Carbondale.

**Challenge 3 – X Marks the Spot**

<table>
<thead>
<tr>
<th>Eclipse Date</th>
<th>Eqn for 2017</th>
<th>Eqn for Eclipse</th>
<th>Crossing Point</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Longitude</td>
</tr>
<tr>
<td>March 27, 1503</td>
<td>$y = -0.0647x + 36.8672$</td>
<td>$y = +0.1557x + 63.3460$</td>
<td>-120.1397</td>
</tr>
<tr>
<td>July 20, 1506</td>
<td>$y = -0.4728x - 4.4130$</td>
<td>$y = +0.2608x + 57.4857$</td>
<td>-84.3826</td>
</tr>
<tr>
<td>February 3, 1562</td>
<td>$y = -0.0660x + 36.7095$</td>
<td>$y = +0.5038x + 105.2234$</td>
<td>-120.229</td>
</tr>
<tr>
<td>July 21, 1618</td>
<td>$y = -0.0980x + 32.9103$</td>
<td>$y = -0.3112x + 8.1419$</td>
<td>-116.192</td>
</tr>
<tr>
<td>October 23, 1623</td>
<td>$Y = -0.4960x - 6.3555$</td>
<td>$Y = +0.1808x + 49.3526$</td>
<td>-82.306</td>
</tr>
<tr>
<td>April 10, 1679</td>
<td>$Y = -0.2165x + 19.8103$</td>
<td>$Y = +0.4931x + 94.2527$</td>
<td>-104.899</td>
</tr>
<tr>
<td>Date</td>
<td>Fitting function</td>
<td>Crossing Point</td>
<td></td>
</tr>
<tr>
<td>-----------------------</td>
<td>-----------------------------------</td>
<td>----------------</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Longitude</td>
<td>Latitude</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(° ' &quot; West)</td>
<td>(° ' &quot; North)</td>
</tr>
<tr>
<td>May 22, 1724</td>
<td>Y=-0.1932x + 22.2864</td>
<td>-106.622</td>
<td>42.880</td>
</tr>
<tr>
<td>June 24, 1778</td>
<td>Y=-0.5030x - 6.9270</td>
<td>-81.8694</td>
<td>34.256</td>
</tr>
<tr>
<td>June 16, 1806</td>
<td>Y=-0.3496x + 6.5846</td>
<td>-93.8733</td>
<td>39.406</td>
</tr>
<tr>
<td>November 30, 1834</td>
<td>Y=-0.2231x + 19.1221</td>
<td>-104.233</td>
<td>42.378</td>
</tr>
<tr>
<td>July 29, 1878</td>
<td>Y=-0.2911x + 11.4790</td>
<td>-109.789</td>
<td>43.446</td>
</tr>
<tr>
<td>January 1, 1889</td>
<td>Y=-0.1598x + 25.8940</td>
<td>-111.717</td>
<td>43.752</td>
</tr>
<tr>
<td>May 28, 1900</td>
<td>Y=-0.4978x - 6.503</td>
<td>-81.6964</td>
<td>34.1694</td>
</tr>
<tr>
<td>June 8, 1918</td>
<td>Y=-0.0954x + 33.2274</td>
<td>-116.48</td>
<td>44.3338</td>
</tr>
<tr>
<td>March 7, 1970</td>
<td>Y=-0.5105x - 7.5342</td>
<td>-80.0959</td>
<td>33.3539</td>
</tr>
<tr>
<td>April 8, 2024</td>
<td>Y=-0.4129x + 0.787</td>
<td>-89.2655</td>
<td>37.6433</td>
</tr>
<tr>
<td>May 11, 2078</td>
<td>Y=-0.5024x - 6.8741</td>
<td>-81.6446</td>
<td>34.1432</td>
</tr>
</tbody>
</table>

**Challenge 4 – X Marks the Spot with Quadratic Equations**

**Problem 1**

<table>
<thead>
<tr>
<th>Date</th>
<th>Fitting function</th>
<th>Crossing Point</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Longitude</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(° ' &quot; West)</td>
</tr>
<tr>
<td>August 21, 2017</td>
<td>y = -0.005792x^2 + 1.4425x - 44.968</td>
<td>89 16 38</td>
</tr>
<tr>
<td>March 27, 1503</td>
<td>y = -0.00441x^2 + 0.8998x + 0.1113</td>
<td>119 19 15</td>
</tr>
<tr>
<td>July 20, 1506</td>
<td>y = -0.003139x^2 + 0.2726x + 34.776</td>
<td>84 15 55</td>
</tr>
<tr>
<td>February 3, 1562</td>
<td>y = 0.029785x^2 - 7.6792x + 537.25</td>
<td>119 52 07</td>
</tr>
<tr>
<td>July 21, 1618</td>
<td>y = -0.009871x^2 + 2.6021x - 124.7</td>
<td>116 29 56</td>
</tr>
<tr>
<td>October 23, 1623</td>
<td>y = 0.005971x^2 - 1.1966x + 92.538</td>
<td>82 25 29</td>
</tr>
<tr>
<td>April 10, 1679</td>
<td>y = -0.00392x^2 + 0.3425x + 49.689</td>
<td>104 42 40</td>
</tr>
</tbody>
</table>
### Challenge 5 – Estimating the speed of the lunar shadow

Problem 1 - Speed = 232 km/0.0619 hours = 3750 km/hr

Problem 2 - Convert the times to decimal hours to get Carbondale: 18.3656 hours and Hopkinsville: 18.4342 hours. The time difference is then 0.069 hours. The speed is then Speed = 155 km/0.069 hours = 2450 km/hr

Problem 3 –

<table>
<thead>
<tr>
<th>Location</th>
<th>Latitude</th>
<th>Longitude</th>
<th>Time</th>
<th>Distance (km)</th>
<th>Speed (km/h)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Newport</td>
<td>44.8</td>
<td>-124.0</td>
<td>17:16:58</td>
<td>0</td>
<td>3750</td>
</tr>
<tr>
<td>Madras</td>
<td>44.7</td>
<td>-121.1</td>
<td>17:20:41</td>
<td>232</td>
<td>3480</td>
</tr>
<tr>
<td>Weiser</td>
<td>44.4</td>
<td>-117.0</td>
<td>17:26:21</td>
<td>328</td>
<td>2930</td>
</tr>
<tr>
<td>Idaho Falls</td>
<td>43.8</td>
<td>-111.9</td>
<td>17:34:14</td>
<td>417</td>
<td>2800</td>
</tr>
<tr>
<td>Riverton</td>
<td>43.2</td>
<td>-108.2</td>
<td>17:40:24</td>
<td>301</td>
<td>2360</td>
</tr>
<tr>
<td>Casper</td>
<td>42.8</td>
<td>-106.3</td>
<td>17:43:51</td>
<td>161</td>
<td>2480</td>
</tr>
<tr>
<td>Stapleton</td>
<td>41.5</td>
<td>-100.5</td>
<td>17:55:21</td>
<td>507</td>
<td>2330</td>
</tr>
<tr>
<td>St Joseph</td>
<td>39.8</td>
<td>-94.9</td>
<td>18:07:45</td>
<td>512</td>
<td>2480</td>
</tr>
<tr>
<td>Columbia</td>
<td>38.8</td>
<td>-92.3</td>
<td>18:13:57</td>
<td>247</td>
<td>2360</td>
</tr>
<tr>
<td>Carbondale</td>
<td>37.6</td>
<td>-89.1</td>
<td>18:21:56</td>
<td>313</td>
<td>2340</td>
</tr>
<tr>
<td>Hopkinsville</td>
<td>36.9</td>
<td>-87.5</td>
<td>18:26:03</td>
<td>161</td>
<td>2480</td>
</tr>
<tr>
<td>Anderson</td>
<td>34.6</td>
<td>-82.6</td>
<td>18:39:12</td>
<td>511</td>
<td>2360</td>
</tr>
<tr>
<td>Columbia</td>
<td>33.9</td>
<td>-81.1</td>
<td>18:43:10</td>
<td>156</td>
<td>2370</td>
</tr>
<tr>
<td>McClellanville</td>
<td>33.1</td>
<td>-79.5</td>
<td>18:47:30</td>
<td>172</td>
<td>2380</td>
</tr>
</tbody>
</table>
Worked example: Between Weiser and Idaho Falls, the distance is 417 kilometers, and the time difference is \( (17:34:14 - 17:26:21) = 17.5706 \text{h} - 17.4392 \text{h} = 0.1314 \text{h} \), so speed = \( \frac{417 \text{ km}}{0.1314 \text{ h}} = 3173 \text{ km/hr} \), which rounded to three significant figures becomes 3170 km/hr.

Problem 4 - Add up the distances in column 5 to get 4019 kilometers.

Problem 5 - At Newport, totality starts at 17:16:58 and at McClellanville it starts at 18:47:30, a difference in time of \( 18.7917 - 17.2828 \text{ or } 1.51 \text{ hours} \). The average speed is then \( 4019 \text{ km}/1.51 \text{ hours} = 2661 \text{ km/hour} \), and rounded to three significant figures this becomes 2660 km/hr.

Challenge 6 – As the crow flies on a spherical planet

Problem 1 - \( \text{Lat1} = 44.8439 \quad \text{Long1} = 124.051 \quad \text{Lat2} = 33.0354 \quad \text{Long2} = 79.4869 \)

Then
\[
\cos(X) = \sin(44.8439)\sin(33.0354) + \cos(44.8439)\cos(33.0354)\cos(124.051-79.4869)
\]
\[
\cos(X) = 0.7052 \times 0.5452 + 0.7090 \times 0.8383 \times 0.7125
\]
\[
\cos(X) = 0.8079
\]
So \( X = 36.1^\circ \) and the distance is then 40000 (36.1/360) = 4,011 kilometers.

Problem 2 - \( \text{lat1}=38.9 \quad \text{long1}=77.05 \quad \text{lat2}=34.00 \quad \text{long2}=81.05 \)

Then
\[
\cos(X) = \sin(38.9)\sin(34.0) + \cos(38.9)\cos(34.0)\cos(81.05-77.05)
\]
\[
\cos(X) = 0.628 \times 0.559 + 0.778 \times 0.829 \times 0.998
\]
\[
\cos(X) = 0.995
\]
so \( X = 5.9^\circ \) and so the distance is \( 40000 \times (5.9/360) = 660 \text{ kilometers} \).

Challenge 7 – Exploring the lunar shadow cone.

Problem 1 - The sun is 151.39 million km from the center of Earth and the moon is 372,027 km from the center of Earth, so the distance from the center of the sun to the center of the moon is \( 151,390,000 - 372,000 = 151,018,000 \text{ km} \), then

\[
\frac{696,300}{151,018,000 + X} = 1737
\]
\[ X = \frac{151,018,000}{696,300 - 1737} \]

\[ X = 377,673 \text{ km.} \]  
To 4 significant figures:  \( X = 377,700 \text{ km} \)

Now the moon is 372,027 km sunwards of the Earth's center (USNO), so the vertex of the shadow cone is 377,700 – 372,027 = 5,673 km (to 4-SF) from the center of Earth opposite the sun or 6378-5673 = 705 km below the surface of Earth!

Problem 2 –

\[ \frac{696,300}{228,000,000 + X} = \frac{25}{X} \]

\[ X = \frac{228,000,000 (25)}{696,300 - 25} \]

\[ X = 8,186 \text{ km.} \]

The vertex of the shadow cone is located 9300-8186 = 1,114 km from the center of Mars. The radius of Mars is 3,396 km, so the vertex is located 3,396-1,114 = 2,282 km below the surface of Mars.

**Challenge 8 – Exploring angular diameter**

Problem 1  Angular diameter = \( 206265 \times 1392600/151384000 = 1897 \text{ arcseconds} \).

Problem 2  Angular diameter = \( 206265 \times 3474/365600 = 1960 \text{ arcseconds} \).

Problem 3  -  Angular diameter = \( 206265 \times 3474/377,700 = 1897 \text{ arcseconds} \).

This is the same as the angular diameter of the sun, and so at the vertex the disk of the moon exactly covers the disk of the sun for a total solar eclipse. At the surface of Earth, however, the angular diameter of the moon is 37 arcseconds smaller than the sun, so the dark lunar disk will not appear to fully cover the sun.
**Challenge 9 – Lunar shadow size on Earth’s surface**

Problem 1 The diameter is about 110 km, so it will take 110 km / (2600 k/h) = 0.042 hours or about 2.5 minutes from start to finish. After that time, the limb of the sun will brighten enormously and darkness will become daylight again. This does not leave much time for photographers to set up their equipment correctly and snap a few pictures!

Problem 2 \[ H = \frac{(8186-9300 + 3396) \times 12.5}{8186} = 3.5 \text{ km} \]

The angular diameter of Phobos would appear to be significantly smaller than the sun so there would be no total solar eclipse.

**Challenge 10 – Shadow speed and Earth’s rotation**

Problem 1 The Surface is moving eastward at a speed of \( 1674 \cos(42.8) = 1228 \) km/hr so the true shadow speed is \( 2,800 + 1,200 = 4,000 \) km/hr.

Problem 2

A) \( V_{\text{rot}} = 1674 \cos(19) = 1600 \) km/h. True speed = 2,200 km/h + 1600 km/h = 3,800 km/h. The speed relative to the Concorde, which is sharing Earth’s rotation, is just \( 2,200 \text{ km/h} - 2,100 \text{ km/h} = 100 \text{ km/h} \).

B) Total duration of the eclipse was about 250 km / (100 km/h) = 2.5 hours. If you were on the ground, the maximum duration would have only been about 7 minutes! The actual time the astronomers were able to get after meeting up with the shadow and maneuvering to keep pace with it was about 1.5 hours!

**Challenge 11 – Modeling Shadow Speed, Diameter and Duration along the Path of Totality**

Problem 1

A) Use the Quadratic Formula to determine the roots of the equation.

We see, at once that the discriminant \( b^2 - 4ac \) is negative so there are no crossing points where \( V \) is less than zero.

B) This is a parabolic curve that opens upwards and has a vertex at \( L = -b/2a = -179/(2 \times 1.06) = - 84.4 \), which is longitude 84.4 West. The point on the path of totality with this longitude has a latitude of 35.53 North and is located 90 kilometers northeast
of Chattanooga, Tennessee. The speed there is found from the formula for V as
\[
1.06(-84.4)^2 + 179(-84.4) + 9900 = 2,400 \text{ km/hr.}
\]

Problem 2
A) This is a parabola that opens downwards so its vertex is a maximum value for D(L). Using the Quadratic Equation, the two roots of the equation do not occur over the latitude range of the continental United States [-125.0, -65.0] so there are no locations in the continental United States for which the lunar shadow diameter is zero.

B) The vertex is located at \( L = -\frac{b}{2a} = -79.8 \) and has a maximum value of 114.7 kilometers.

Problem 3
A) Time = distance/speed so

\[
\frac{-0.0084L^2 - 1.3423L + 61.245}{1.06L^2 + 179L + 9900} \times (60 \text{ minutes/hr})
\]

B) See below

The eclipse will last about 2 minutes and 54 seconds near a longitude of -85. This is a location near Crossville, Tennessee.

Note: The actual location of maximum duration is 240 km northwest near Hopkinsville, IL (longitude -87.6) where the maximum duration is 2 minutes 40
seconds. The shape of the shadow is elliptical and so the actual function D(L) is more complicated than the one used, which overestimates the size of the shadow leading to longer eclipse times. A 10% change in the shadow diameter reduces the time by about 15 seconds, and moves the location of maximum eclipse further west towards Hopkinsville.

**Challenge 12 - A Physics-based Model for Estimating the Shadow Ground Speed**

**Problem 1**

<table>
<thead>
<tr>
<th>Location</th>
<th>Latitude (L)</th>
<th>Actual speed</th>
<th>Predicted</th>
<th>Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Madras, OR</td>
<td>44.7</td>
<td>3,750</td>
<td>2,380</td>
<td>1,370</td>
</tr>
<tr>
<td>Casper, WY</td>
<td>42.8</td>
<td>2,800</td>
<td>2,340</td>
<td>460</td>
</tr>
<tr>
<td>Carbondale, IL</td>
<td>37.6</td>
<td>2,350</td>
<td>2,240</td>
<td>110</td>
</tr>
<tr>
<td>McClellanville, SC</td>
<td>33.0</td>
<td>2,400</td>
<td>2,160</td>
<td>240</td>
</tr>
</tbody>
</table>

Answer B) The farther you are from the Atlantic Coast along the path, the more the model seems to underestimate the shadow speed. The differences vary from a high of 37% on the Pacific Coast to a low of 5% towards the Atlantic Coast. As a model, it matches the data to better than 15% east of Casper, Wyoming.

**Problem 2**

<table>
<thead>
<tr>
<th>Location</th>
<th>Latitude</th>
<th>( \theta )</th>
<th>Obs. Speed</th>
<th>Predicted</th>
<th>Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Madras, OR</td>
<td>44.7</td>
<td>34°</td>
<td>3,750</td>
<td>2,870</td>
<td>880</td>
</tr>
<tr>
<td>Casper, WY</td>
<td>42.8</td>
<td>23°</td>
<td>2,800</td>
<td>2,540</td>
<td>260</td>
</tr>
<tr>
<td>Carbondale, IL</td>
<td>37.6</td>
<td>9°</td>
<td>2,350</td>
<td>2,270</td>
<td>80</td>
</tr>
<tr>
<td>McClellanville, SC</td>
<td>33.0</td>
<td>0°</td>
<td>2,400</td>
<td>2,160</td>
<td>240</td>
</tr>
</tbody>
</table>

We see that the differences now range from 23% near Madras, to a maximum of 9% east of Casper. This is a significant improvement, but we still have the trend that points farther to the west of McClellanville are underestimating the speed.

**Problem 3**

<table>
<thead>
<tr>
<th>Location</th>
<th>Latitude</th>
<th>( \theta )</th>
<th>Elev</th>
<th>Obs</th>
<th>Predicted</th>
<th>Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Madras, OR</td>
<td>44.7</td>
<td>34°</td>
<td>42°</td>
<td>3,750</td>
<td>4,290</td>
<td>-540</td>
</tr>
<tr>
<td>Casper, WY</td>
<td>42.8</td>
<td>23°</td>
<td>54°</td>
<td>2,800</td>
<td>3,140</td>
<td>-340</td>
</tr>
<tr>
<td>Carbondale, IL</td>
<td>37.6</td>
<td>9°</td>
<td>64°</td>
<td>2,350</td>
<td>2,610</td>
<td>-260</td>
</tr>
<tr>
<td>McClellanville, SC</td>
<td>33.0</td>
<td>0°</td>
<td>61°</td>
<td>2,400</td>
<td>2,470</td>
<td>70</td>
</tr>
</tbody>
</table>

The predictions are now larger than the actual measurements and vary from 14% in Madras to 3% in McClellanville.
**Challenge 13 – The last total solar eclipse on Earth**

Problem 1
Answer:  
A) \( \theta = 206265 \times \left( \frac{1,392,000}{149,000,000} \right) = 1927 \text{ arcseconds} \)
B) 1927 arcseconds x (1 degree/3600 arcseconds) = 0.5 degrees

Problem 2  
\[ 0.0073 (4.5)^2 - 0.028 (4.5) + 0.98 = 1.00. \]
So 1392000 x 1.0 = current diameter of sun in kilometers.

Problem 3; The solar diameter in arcseconds is given by:

\[
\theta(T) = \frac{206265}{149,000,000 \text{ km}}
\]

\[
\theta(T) = 1927 \left( 0.0073 T^2 - 0.028 T + 0.98 \right)
\]

Problem 4 - In 1 billion years, the distance traveled will be 3.8 cm/yr x 1 billion years x (1 km/100000 cm) = 38,000 km, so the rate of increase is 38,000 km/billion years. The current perigee distance \( T=4.5 \) is 356,400 km, so the formula would be \( D = 38,000 T + 185,400 \text{ km} \) where \( T \) is the time in billions of years.

Problem 5 – At lunar perigee distance where the moon subtends its largest possible diameter:

\[
\theta(T) = \frac{3,474}{38000 \text{ T} + 185,400}
\]

\[
\theta(T) = 18857 / \left( T + 4.88 \right)
\]

Problem 6  Graph the two equations

\[
\theta(T) = 1927 \left( 0.0073 T^2 - 0.028 T + 0.98 \right)
\]
\[
\theta(T) = 18857 / \left( T + 4.88 \right)
\]
Answer: The two functions cross at an age of about $T=4.75$ billion years, which is 250 million years from today!

If we did not allow for the change in the solar diameter, the answer for when the last perigee total solar eclipse would occur would be

$$1927 = \frac{18857}{(T+4.88)}$$  so $T = 4.90$. This is 400 million years from today ($T=4.5$).

We could also allow for the difference in Earth’s orbital perihelion (147 million km) and aphelion (152 million km) distances to get the last perigee total solar eclipses under these conditions:

- **Aphelion:** Solar diameter $\theta(T) = 1889 \left(0.0073 T^2 - 0.028 T + 0.98\right)$
- **Perihelion:** Solar diameter $\theta(T) = 1953 \left(0.0073 T^2 - 0.028 T + 0.98\right)$

For a variable solar diameter, these give intersection times of $T = 4.9$ or 400 million years for the Aphelion case and $T=4.7$ or 200 million years for the Perihelion case.

Note: The problem solved by SpaceMath@NASA, (See https://spacemath.gsfc.nasa.gov/moon/4Page28.pdf) which gave an answer of 565 million years from now was based on a slightly different set of assumptions.
**Challenge 14 The View from Mars: A matter of time**

Problem 1 - A Martian day is 24h 39.6 minutes long by Earth time-keeping, which in decimal value is equal to 24.66 so that means that a Martian hour is equal to 24.66/24 = 1.02749 Earth hours, and also that a Martian minute equals 1.02749 Earth minutes. In other words, a Martian minute equals about 62 Earth seconds.

Problem 2 - (August 30 – August 6) = 24 Earth Days. Since 1 Sol equals 1.02749 Earth days, that means 24 Earth days is the same as 24/1.02749 = Sol 23 on the Curiosity calendar.

Problem 3 - First calculate the number of Earth days between August 6, 2012 and August 21, 2017 including leap-days. You can use an online calculator to compute this, for instance, [http://www.timeanddate.com/date/duration.html](http://www.timeanddate.com/date/duration.html). The answer is 1842 Earth days. Next convert Earth days to Sols: Sols = 1842/1.02749 = 1792, so the Eclipse will happen on Sol 1792 at the Curiosity lander.

Problem 4 - First calculate the number of Earth days between August 6, 2012 and August 21, 2017 including leap-days. You can use an online calculator to compute this, for instance, [http://www.timeanddate.com/date/duration.html](http://www.timeanddate.com/date/duration.html). The answer is 1842 Earth days. Next convert Earth days to Sols: Sols = 1842/1.02749 = 1792, so the Eclipse will happen on Sol 1792 at the Curiosity lander.

**Challenge 15 Angular Size and the Earth-Moon System**

Problem 1 - It would appear in the sky to have an angular diameter of 1.9 degrees.

Problem 2 - The moon has a diameter of only 0.5 degrees, so Earth is about 4 times bigger in the sky as viewed from our moon!

Problem 3

\[
\frac{r}{X + D} = \frac{R}{X}
\]

Problem 4
### Problem 5

<p>| | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Moon</td>
<td>1750</td>
<td>6.2 million + 384,000</td>
</tr>
<tr>
<td></td>
<td></td>
<td>---------------</td>
</tr>
<tr>
<td>Earth</td>
<td>6378</td>
<td>6.2 million</td>
</tr>
</tbody>
</table>

\[
\frac{6.2 \text{ million} + 384,000}{6.2 \text{ million}} = 0.27 \times 1.06 = 0.28
\]

### Problem 6

#### A)\( X = 150 \text{ million} - 40 \text{ million} = 110 \text{ million from sun to Venus} \)

\[
\frac{12,700}{1.4 \text{ million}} = \frac{40 \text{ million} + 110 \text{ million}}{110 \text{ million}} = 0.0124
\]

#### B)\( D = 225 \text{ million} - 150 \text{ million} = 75 \text{ million km from Earth to Mars} \)

\[
\frac{12,700}{1.4 \text{ million}} = \frac{150 \text{ million} + 75 \text{ million}}{75 \text{ million}} = 0.027
\]

So from Mars, Earth will appear as a black dot on the face of the sun that is more than twice as big as Venus appeared during the 2012 Transit of Venus!

### Problem 7

\[
1 \quad 1750 \quad 1.6 \text{ million} + D
\]
2.9 \[6378\] 1.6 million

1.24 = 1 + \(D/1.6\) million

\[D = 384,000\] km.

**Problem 8**

The apparent diameter ratio of Phobos to the sun is 12:20 so

\[
\frac{12}{20} = \frac{25}{X + 225\text{ million}} = \frac{1.4\text{ million}}{X}
\]

\[X = 6,700\text{ kilometers.}\]