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The Moon's Motion and Phases

The Moon orbits the Earth in a period with respect to the stars (its **sidereal period**) of 27.3 days. It is illuminated by the Sun and, when viewed from the Earth at different positions in this orbit, shows the various **phases**. The cycle of lunar phases is described in Section 3-1 of Kaufmann and Freedman, *Universe*, Fifth Ed.

In this monthly cycle, the Moon appears first as a very thin crescent in the western sky, quite close to the Sun. It then proceeds to show more of its illuminated side to Earth as it moves farther from the Sun in the sky, passing in this **waxing**, or growing, half of the cycle through **crescent**, **first quarter**, and **gibbous** phases before reaching **full moon**. At this point, the Moon is opposite the Sun in our sky. Its distance from the Sun, measured across the sky, then begins to decrease, and it enters the **waning**, or diminishing, half of the cycle, proceeding through **gibbous**, **third quarter**, and **crescent** phases before reaching new moon again.

Because of the orbital motion of the Earth–Moon system around the Sun, the period between successive full moons (its **synodic period**) is longer than the Moon's actual orbital period by more than 2 days, a full lunar phase cycle taking 29.5 days. This effect is illustrated in Figure 3-5 of *Universe*.

In this exercise, we will demonstrate the motion of the Moon against the background stars and estimate its angular speed. We will also show the phases of the Moon and relate them to the position of the Moon with respect to the Sun in the sky.

PART 1: Moon's Motion Across the Sky and it's Angular Speed

A. Screen Set-up

1. After starting the program, check the icon/location box to see that the field of view is 100° (if this box is not visible on the screen, you can activate it by clicking Show Floating Palettes in the Window menu). If the field of view is not 100°, then click on the house button to reset the field of view to 100°.

2. Set the location to Chicago (Settings/Viewing Location/North America/United States/Chicago, IL/Set Location).

3. If your viewing direction is not already toward the south (S), then click the S button on the button bar near the top of the screen. If this button bar is not visible, activate it by clicking Toolbar in the Window menu. After the screen adjusts direction, you should see the symbol S on the horizon near the bottom of your screen.

4. Stop the time by clicking the time-stop button in the date/time box (if this box is not visible on the screen, activate it by clicking Time in the Window menu); then
   a. set the date to July 27, 1999 (7/27/1999 AD);
   b. set the time to 11:45:00 PM; at this time, the Moon is close to its full phase;
   c. set the time interval in the date/time box to 1 sidereal day.

   Using a time interval of one sidereal day means that the background sky remains stationary as time is changed by single time steps.

5. Check that the Daylight Saving Time option is turned off. To do this, check the small sun icon to the left of the time in the date/time box. The sun icon is yellow with 8 rays if DST is activated, but background color with 4 rays if DST is not activated. If the icon is yellow, then click on it to deactivate DST.

6. The program can show the Moon as a small dot or as an enlarged image. For the initial run of this exercise, ensure that the enlarged image is activated. (Click Settings, then Preferences; if there is no check mark beside Enlarge Moon Size, then click on Enlarge Moon Size.)

B. Procedure

1. Because of the Earth's rotation, the whole sky, including the Moon, appears to move westward as time progresses. However, the Moon also moves independently because of its orbital motion around the Earth. We can see this motion of the Moon against the background stars if we step time in 1 sidereal day intervals, because then the background stars return to the same position night-by-night, but Moon will move past these stars from one night to the next.

   Demonstrate this motion by advancing time by several sidereal day steps. Note the direction of the Moon's motion. (It looks as though the stars do not move, but in fact the computer advances them through exactly one complete "rotation" around the Earth each time you click the button.)

2. To measure the Moon's angular speed against the background stars, we can change the date by sidereal-day steps and estimate how many days it takes the Moon to move across the full 100° width of the screen. To do this, step time backward in sidereal day steps until the date is July 24, 1999 (7/24/1999), at which point the time will be 12:00:44 AM. The Moon should be near the right-hand edge of the screen. Use the Grabber Tool to slide the sky over toward the right (to the West) until the Moon lies right at the edge of the screen.

   Advance the time in 1 sidereal day steps and count how many days it takes the Moon to reach the left edge of the screen, estimating the final fraction of a day that would be needed in order to just reach the edge. After each click of the button, the sky has "rotated" once around the Earth (or actually the Earth rotates once) until the stars are in exactly the same position as they were before the click. For this reason, the stars do not seem to move. However, the Moon moves in its orbit during that time, and this motion of the Moon in one sidereal day is visible against the background stars. Estimate the speed of the Moon by dividing 100° by the number of days it took to move across the 100° screen.

3. It is of interest to track the Moon s motion with respect to the **ecliptic**, which is the path of the Sun against the background stars. Switch on the ecliptic (click Ecliptic in the Guides menu, or press CTRL+3), and step time backward so that the Moon retraces its path back to the right edge of the screen. The Moon's orbit is inclined at about 5° to the ecliptic plane, hence the Moon is seen to follow a path across the sky that is close to the ecliptic, but does not exactly follow it. The Moon's path crosses the ecliptic plane at two points, known as the **nodes** of its orbit, one of which should be visible in the part of the path you have watched on the screen. To display the Moon's orbit, click Planets in the Window menu to display the planet box, and look to see if there is a list of planets; if not, click on the triangle next to the Sun to display the planet names. Then look to see if the Moon is listed underneath the Earth; if not, click on the triangle to the left of the Earth to display the Moon. Finally, click on the "Orbit Column" next to the Moon. Clicking here again will remove the Moon's orbit from the screen. Clicking on the X at the top of the box will remove the box from the screen. The orbit of the Moon is described in Section 3-2 and Figure 3-6 of *Universe*.

Questions

1. In which direction does the Moon move night-by-night against the background stars?

2. At what speed does it move across the sky?

3. What path does the Moon take (curved, straight, along the ecliptic . . .)?

PART 2. The Phases of the Moon

To demonstrate the phases of the Moon, we must observe the sky at different times of the night on different days. For example, the best time to observe the waxing phases is just after sunset, when the Moon appears in the western sky. The phases around full moon are best observed near midnight, while the waning phases can be most effectively seen in the dawn sky.

A. Waxing Phases

Screen Set-up

1. Check that the location is Chicago, IL, USA.
2. Set view direction to W.
3. Set the date to July 13, 1999 (7/13/1999 AD).
4. Check that Daylight Saving Time is OFF.
5. Set the time to 7:30:00 PM, just after sunset on this day.
6. Check that Daylight is ON. If it is not, click on Daylight in the Display menu.
7. Set the time step to 1 solar day (the unit should be days, not sidereal days, in time-step box).
8. Check that "Enlarge Moon Image" is still activated. This gives a false view of the size of the Moon but is illustrative of the movement and phase of the Moon during this part of the exercise.

Procedure

If your set-up is correct, you will see the Sun just below the horizon and the Moon appearing as a faint disk just to the east of it, in the twilight. You can see that the unilluminated side of the Moon is visible at this time, which is why the Moon looks like a faint disk and not just as a thin crescent. This is a result of earthshine, the effect of sunlight reflected from the surface of the Earth illuminating the Moon. This was referred to in earlier times as "the old moon in the new moon's arms."

Advance the time by 1-day steps, and watch the motion of the Moon away from the Sun. The Moon will pass a bright object, which you can identify as Venus with the Object Identification Tool (the arrow icon in the icon/location box; if this box is not visible on the screen, activate it by clicking Show Floating Palettes in the Window menu). To remove the "Venus" label that appears when this tool is used, click again on blank sky. Advance time in 1-day steps to watch the Moon grow from crescent toward quarter moon as it moves in its orbit.

Change back to the Grabber Tool (click on the hand icon in the icon/location box). It is advisable at this stage to move your viewpoint around the horizon with the Grabber Tool to place the Moon in the center of the screen, since the enlarged moon image is distorted when it moves close to the edge of the screen. You can now advance time again by several days to July 27, using the Grabber Tool to move the screen westward (toward the right) as necessary to keep the Moon in view. You will see the full transformation from crescent through quarter to gibbous and then to full moon.

The full moon will appear in the East at sunset and will just be rising as the Sun is setting. The reason for this is that, in order for us to see a fully illuminated Moon, the Sun must be behind us when we face the Moon; that is, the Sun must be in the opposite part of the sky from the Moon.

It is perhaps instructive to repeat this procedure with the ecliptic illuminated (Guides/Ecliptic or CTRL+3), to follow the Moon's path with respect to the Sun's track across our sky. Again, you will see that the Moon's path does NOT follow precisely that of the Sun, but crosses it twice per orbit at the nodes.

B. Waning Phases

Screen Set-up

1. Change the time to midnight, 12:00:00 AM. Make sure you set AM rather than PM.
2. Advance the date to July 28, 1999 (7/28/1999 AD).
3. Move your viewpoint to S.

Procedure

Again, advance time in 1-day steps and follow the Moon through the waning phases of its cycle, using the Grabber Tool to move along the horizon as necessary to keep the Moon in the center of the screen. You will note that the Moon passes Jupiter on August 4 (8/4/1999) as it approaches the eastern horizon.

To watch the late phases of this cycle, advance the time to dawn, 4:45:00 AM, move your viewpoint to E, and advance time in 1-day steps again. During this phase, the Moon will rise before dawn. You can show that the new moon occurs on about August 11.

Questions

1. How many days elapse between
   a. new moon and first quarter?
   b. new moon and full moon?
   c. new moon and the next new moon?

2. In which way do the "horns" of the crescent moon point in the early phases, with respect to the direction to the Sun?

3. In which way do the "horns" of the crescent moon point in the late lunar cycle phases, with respect to the direction to the Sun?

4. Above which horizon do we see the full moon at its highest in the sky?

PART 3. Setting of the Sun and Crescent Moon

It is perhaps instructive to show a sunset sequence with a new crescent moon nearby. This is one of the finest sights that occurs every month: The thin crescent, with the rest of the Moon faintly illuminated, slowly slides below the horizon in a dark blue twilight.

A. Screen Set-up

1. Set date to July 14 (7/14/1999 AD) and the time to 7:15:00 PM, just before sunset.

2. Move your viewpoint to W.

3. Set the time interval to 1 minute.

4. Remove the trees from along the horizon by clicking on Settings, then on Options. Click on the down arrow to see a list of options, click on Horizon, click off the Scenery, and then click OK to return to the screen.

B. Procedure

Advance time continuously in 1-minute steps and watch the Sun and then the Moon slowly set over the western horizon. Venus can be seen easily and the star Regulus becomes visible as the twilight sky darkens through sunset. Return to 7:15:00 PM and re-run this sequence, stopping the motion and noting the times of setting of the Sun, the Moon, Venus, and Regulus.

Questions

1. What is the time of sunset on this date?

2. What is the time of moonset?

3. When does Venus set?

4. When does Regulus set?

PART 4. Lunar Occulation of a Star

One striking consequence of the lunar motion is the occasional passage of the Moon in front of a star, known as an occultation. This is an exciting event to watch through a telescope, particularly if circumstances are such that only the Moon's northern or southern polar regions pass over the star in what is known as a grazing occultation. In this case, the star is seen to wink out several times as it moves behind the mountains and crater walls of the polar regions of the Moon.

It is possible to simulate an occultation with the present configuration, though not a grazing event. This demonstrates strikingly the motion of the Moon against a star background.

A. Screen Set-up

1. Set your location to the North Pole (Settings/Viewing Location/Others/North Pole/Set Location).

2. Set the date to July 29, 1999 (7/29/1999 AD).

3. Set the time to 8:00:00 AM.

4. Set the time step to 1 minute.

5. Switch off daylight by clicking on Daylight in the Display menu.

6. Set the field of view to 4° using the Magnification Tool, as follows. Click on the magnifying glass icon in the icon/location box or press F8 to activate the Magnification Tool. Then place the magnifying glass near the center of the screen (you may find it interesting to place it on the Pleiades, the little cluster of stars near the center of the screen), and click the left mouse button several times while watching the field of view displayed in the icon/location box. Stop when the field of view is 4°. If you wish, at any time you may demagnify the image by holding the Control (CTRL) key on the keyboard while clicking the Magnification Tool.

7 Lock the field of view onto the Moon. To do this, highlight the Moon in the planets box (if this box is not already on the screen then click Window/Planets to activate it, and click on the triangles next to the Sun and the Earth if necessary to see the Moon in the list), and click on the Center and Lock button. Note that if you adjust the magnification using the Magnification Tool after this, you will need to re-engage this Center and Lock facility. However, if you change the field of view by clicking on the field-of-view number in the icon/location box, the Center and Lock condition will be maintained.

You can now see the Moon at its true size for this field of view, whether the "enlarge moon image" is set or not. You can also see a star to the left or lower left of the Moon.

If we had not locked onto the Moon, then if we were to advance time, even by a small amount, the whole scene would change drastically and the Earth's rotation would carry the Moon completely out of our field of view. Locking onto the Moon is like looking through a telescope that is steering so that the Moon stays centered in our field of view.

Setting our location to the North Pole means that our angle of tilt relative to the Moon remains constant as the Earth rotates. If we had not done this, then the sky (and Moon) would seem to rotate on the screen as time passed.

B. Procedure

Click the time-start button in the date/time box, and watch the occultation. The star is occulted by the southern part of the Moon.

As you watch the occultation, it may look as if the Moon is at rest and the stars are moving past the Moon; but remember that it is really the Moon that is moving past the stars. The illusion of moving stars arises because we have locked our field of view onto a moving Moon.

In real life stars are (almost) true points of light in the sky, and therefore they disappear almost instantly as the Moon's limb covers them. In fact, a star's angular size can sometimes be measured by the careful measurement of the disappearance time of a star during such an occultation! However, the simulation shows a small disk for the star, and a rather slow disappearance. You can reverse time and see the event several times, through the magic of the computer!

One other important measurement can be made using a grazing occultation of a star by the Moon. If several observers, spaced out at right angles to the shadow path of the Moon across the Earth, watch the occultation through telescopes and make careful timings of the disappearances and reappearances of the star, then these timings can be used to construct a detailed profile of the mountains along the Moon's limb.

A similar procedure can be used when an asteroid occults a star. Asteroids are too far away for us to be able to see them as much more than just points of light, even through the largest telescopes. However, occultation observers scattered across the shadow path of the asteroid on Earth see different parts of the asteroid passing in front of the star, so careful timings of the disappearance and reappearance of the star can tell us the shape and size of the asteroid. Occasionally, we see the star disappear a second time and then reappear, telling us that the asteroid has a companion moon orbiting it.

Answers

Moon's Motion

1. Toward the east.

2. At about 13° per night.

3. Curved, close to but not exactly along the ecliptic.

Phases

1. a. about 7 days; b. about 14 days; c. about 28 days.

2. The horns point away from the Sun.

3. The horns point away from the Sun.

4. The southern horizon.

Setting of the Sun and Moon

1. Sunset: 7:27 PM (standard time).

2. Moonset: 8:36 PM (standard time).

3. Venus sets: 9:12 PM (standard time).

4. Regulus sets: 9:15 PM (standard time).