Introductory Astronomy

Homework 3: The Moon: Orbit, Phases, Eclipses Not to be handed in. Homework solutions are posted already.

1. "Let's play *Jeopardy*! For $100, the answer is: It is the Earth's only known natural satellite."

   What is ____________, Alex?

   a) the Sun b) the Moon c) Cruithne d) the International Space Station (ISS) e) Krypton

2. Describe the Moon phase on 1999 January 20. **HINT:** You could look up the answer (except in a test mise en scène, of course), but do you really have to?

   a) Waning crescent in the western sky at sunset.
   b) Waxing crescent in the western sky at sunset.
   c) A new moon in opposition.
   d) A full moon in the western sky at sunset.
   e) Waning gibbous moon in the eastern sky at sunrise.

3. At sunset you see the Moon in the western sky. It is

   a) a waning crescent. b) a waxing crescent. c) a full moon. d) a gibbous moon. e) partially eclipsed.

4. The Moon is 90° degrees from the Sun on the sky and it is sunset. The Moon is a/an:

   a) waning gibbous moon. b) waxing half moon. c) waxing crescent moon. d) new moon. e) old moon.

5. The Sun is setting; the Moon is 180° away from the Sun on the sky. The Moon is:

   a) setting too. b) half-full. c) a crescent. d)being eclipsed. e) rising and it is full.

6. The Moon is rising, the Sun is setting. The Moon is:

   a) a crescent. b) a waning crescent. c) about to be eclipsed. d) full. e) blue.

7. The mean distance from the Earth to the Moon is:

   a) 66 Earth radii. b) 40 Earth radii. c) 1 astronomical unit. d) negligible. e) 60 Earth radii.

8. "Let's play *Jeopardy*! For $100, the answer is: A lunar time period that is 27.322 days long."

   What is the ____________, Alex?

   a) lunar month b) lunar sidereal c) lunar anomalistic month d) lunar draconitic month e) lunar pathetic month

9. The mean lunar month is 29.53059 days. How many days are there in a year of 12 mean lunar months and approximately how many years on a luni-solar calendar before you need to insert a 13th lunar month in a year (an intercalary month) in order to keep the luni-solar calendar roughly consistent with the Sun and seasons?

a) 29.53059 days and every twelfth of a year.
b) 365.25 days and every 3 solar years.
c) 354.367 days and every **3 SOLAR YEARS**. Note you won't get perfect consistency with an every 3 solar year insertion since your luni-solar calendar will be short about **33 DAYS** after 3 solar years and a mean lunar month is only 29.53059 days.
d) 365.25 days and every 300 years.
e) 354.367 days and every **4 SOLAR YEARS**. Note you won't get perfect consistency with an every 4 solar year insertion since your luni-solar calendar will be short about **33 DAYS** after 4 solar years and a mean lunar month is only 29.53059 days

10. The mean lunar month is 29.53059 days. The angular velocity of the Moon relative to the Sun (**NOT** relative to the fixed stars) is

    a) 12.19° per day. b) 13.18° per day. c) 29.531° per day. d) 360° per day. e) 12.19°.

11. The sidereal period of a low Earth-orbit satellite is about 90 minutes. Say we have such a satellite and it is orbiting the Earth in basically an eastward direction relative to the fixed stars. What is its angular speed relative to the fixed stars? Where does it rise and set?

    a) Its angular speed is 4° per minute. It **RISES EAST AND SETS WEST** like all other astronomical bodies due to the daily rotation of the Earth.
    b) Its angular speed is 360° per minute. It **RISES EAST AND SETS WEST** like all other astronomical bodies due to the daily rotation of the Earth.
    c) Its angular speed is 4° per minute. It **RISES WEST AND SETS EAST**.
    d) Its angular speed is 360° per minute. It **RISES WEST AND SETS EAST**. This retrograde motion is simply because the satellite revolves faster to the east than the Earth rotates east.
    e) Its angular speed is 0.25° per minute. It **RISES EAST AND SETS WEST** like all other astronomical bodies due to the daily rotation of the Earth.

12. Why is the lunar month (i.e., the synodic period of the Moon) longer than the lunar orbital period relative to the fixed stars (i.e., the lunar sidereal period)? **Hint:** draw a diagram of the top (i.e., looking-down-from-north) view of the Earth-Moon-Sun system.

    a) The gravitational attraction of the Sun causes the Moon to slow down when it is nearest the Sun. The stars are too remote to have such a gravitational effect.
    b) The difference has no known explanation. It was just established by the unknown initial conditions of the solar system.
    c) Both the Earth and the Moon revolve **COUNTERCLOCKWISE** when viewed from the **NORTH ECLIPTIC POLE**: the Earth about the Sun and the Moon about the Earth (and the Sun too, but that's another story). Say we think of new moon, when the Moon is in the line between Sun and Earth (i.e., is in conjunction with the Sun). One sidereal period later the Moon has done a complete orbit with respect to the fixed stars. But the Sun relative to the Earth has moved further in the **CLOCKWISE DIRECTION** due, of course, to the Earth's **COUNTERCLOCKWISE MOTION**. Thus the Moon has to travel a bit farther than 360° relative to the fixed stars in order to come back into alignment with the Sun-Earth line and complete a lunar month. Traveling this extra bit takes more time, of course, and thus the lunar month is longer than the Moon's sidereal period.
    d) Both the Earth and the Moon revolve **COUNTERCLOCKWISE** when viewed from the **NORTH ECLIPTIC POLE**: the Earth about the Sun and the Moon about the Earth (and the Sun too, but that's another story). Say we think of new moon, when the Moon is in the line between Sun and Earth (i.e., is in conjunction with the Sun). One sidereal period later the

Moon has done a complete orbit with respect to the fixed stars. But the Sun relative to the Earth has moved further in the **COUNTERCLOCKWISE DIRECTION** due, of course, to the Earth's **COUNTERCLOCKWISE MOTION**. Thus the Moon has to travel a bit farther than 360° relative to the fixed stars in order to come back into alignment with the Sun-Earth line and complete a lunar month. Traveling this extra bit takes more time, of course, and thus the lunar month is longer than the Moon's sidereal period.

e) Both the Earth and the Moon revolve **CLOCKWISE** when viewed from the **NORTH ECLIPTIC POLE**: the Earth about the Sun and the Moon about the Earth (and the Sun too, but that's another story). Say we think of new moon, when the Moon is in the line between Sun and Earth (i.e., is in conjunction with the Sun). One sidereal period later the Moon has done a complete orbit with respect to the fixed stars. But the Sun relative to the Earth has moved further in the **COUNTERCLOCKWISE DIRECTION** due, of course, to the Earth's **COUNTERCLOCKWISE MOTION**. Thus the Moon has to travel a bit farther than 360° relative to the fixed stars in order to come back into alignment with the Sun-Earth line and complete a lunar month. Traveling this extra bit takes more time, of course, and thus the lunar month is longer than the Moon's sidereal period.

13. The Earth is at:

a) the geometrical center of the Moon's **ELLIPTICAL** orbit.
b) the geometrical center of the Moon's **ECLIPTICAL** orbit.
c) both foci (i.e., focuses) of the Moon's elliptical orbit.
d) the perigee of the Moon's orbit.
e) one of the foci (i.e., focuses) of the Moon's elliptical orbit.

14. A lunar eclipse can occur only when the Moon is:

a) a crescent. b) half full. c) gibbous. d) full. e) waning gibbous.

15. The nodes of the Moon's orbit are:

a) the foci (i.e., focuses) of the orbit. b) the perigee and apogee of the Moon's orbit. c) at the solstice positions. d) where the Moon's orbit crosses the ecliptic plane. e) always aligned with the Earth-Sun line.

16. From the umbra of the Earth the:

a) Sun's disk cannot be seen. b) Moon cannot be seen. c) stars cannot be seen. d) planets cannot be seen. e) Sun is partially visible. It appears as a bright crescent.

17. Given clear skies everywhere, from what part of the Earth is a lunar eclipse visible?

a) From almost the entire day side. b) From a small region near the equator. c) From half of the night side. d) From almost the entire night side. e) It is not visible at all.

18. The Moon in a total lunar eclipse tends to be darkest when the Moon:

a) goes through the center of the Earth's umbra.
b) goes through the edge of the Earth's umbra.
c) doesn't go through the Earth's umbra at all.
d) doesn't go through the Earth's penumbra at all.
e) eclipses the Sun at the same time.

19. When totally eclipsed, the Moon often appears reddish or coppery. Why?

a) Reddish is the Moon's natural color. When the glaring white light of the Sun is removed, we see this natural color.
b) Some sun light is **REFLECTED** from the Earth's atmosphere and re-directed toward the Moon. Light reflected by the atmosphere tends to be reddish. Thus the atmosphere reflected light gives the Moon its reddish color. The direct white light from the Sun completely (or almost completely) washes out any reddish color when the Moon is not totally eclipsed.
c) Some sun light is **REFRACTED** from the Earth's atmosphere and toward the Moon. (Refraction bends light beams toward the normal to the media interface when the medium the light is entering has a higher index of refraction. In the case of the Earth's atmosphere, refraction tends to bend the light beams around the Earth.) The atmosphere preferentially scatters blue light (hence the blue of the day-time sky) and transfers red light (hence the red color of the Sun at sunrise and sunset when more of the blue has been scattered out of the line of sight). Thus, the refracted light is reddish. This reddish light is reflected by the Moon, and hence we see the Moon as reddish. The direct white light from the Sun completely (or almost completely) washes out any reddish color when the Moon is not totally eclipsed.
d) The reddish color is an optical illusion caused by the human eye's tendency to see as red that which is not green.
e) The Moon is actually red hot: i.e., it is emitting red light due to high surface temperature. The eclipsed face of the Moon is after all the day side of the Moon, and we all know about day-time temperatures on the Moon. The direct white light from the Sun completely (or almost completely) washes out any reddish color when the Moon is not totally eclipsed.

20. Why did Aristotle (384–322 BC) conclude that lunar eclipses prove that the Earth was a sphere?

a) Based on the duration of total lunar eclipses Aristotle was able to deduce the diameter of the Earth.
b) From the reddish color of some total lunar eclipses, Aristotle deduced that the a circular limb of the Earth's atmosphere was refracting light onto the Moon. Since the limb was circular, it was reasonable that the whole atmosphere and Earth was spherical.
c) The shadow (i.e., the umbra) of the Earth on the Moon is always circular. Only a sphere casts a circular shadow in all cases.
d) Only perfect bodies can cause eclipses. Spherical bodies are perfect. Ergo only spherical bodies can cause eclipses.
e) We don't know. The argument was given in a lost work: *De Caelo* (*On the Heavens*).

21. For eclipses (any of partial, total, annular, or penumbral) to occur, the Moon's orbital nodes do **NOT** have to be exactly on the Earth-Sun line: i.e., the line drawn through the centers of Earth and Sun. This is because the light-emitting body, the eclipsing body, and the eclipsed body all have finite size. The eclipse season is the period during which nodes are sufficiently close to an alignment that an eclipse is possible. The eclipse season for the Moon (only partial and total, not penumbral) is about 22 days: 11 days before exact aligment and 11 days after. Why is there **NOT** a partial or total lunar eclipse during every lunar eclipse season?

a) Lunar eclipses can only happen very near exact **FULL MOON**. If the Moon is just past an eclipsable **FULLISH MOON** when a lunar eclipse season begins, it will only get back to an eclipsable **FULLISH MOON** only somewhat less than **29.5 DAYS** later and so miss the eclipse season. Consequently, there doesn't have to be either of a total or partial lunar eclipse in every lunar eclipse season albeit usually there **IS**.
b) Lunar eclipses can only happen very near exact **NEW MOON**. If the Moon is just past an eclipsable **NEWISH MOON** when a lunar eclipse season begins, it will only get back to an eclipsable **NEWISH MOON** only somewhat less than **29.5 DAYS** later and so miss the eclipse season. Consequently, there doesn't have to be either of a total or partial lunar eclipse in every lunar eclipse season, and, in fact, there usually **IS NOT**.

c) Lunar eclipses can only happen very near exact **NEW MOON**. If the Moon is just past an eclipsable **NEWISH MOON** when a lunar eclipse season begins, it will only get back to an eclipsable **NEWISH MOON** only somewhat less than **22 DAYS** later and so miss the eclipse season. Consequently, there doesn't have to be either of a total or partial lunar eclipse in every lunar eclipse season albeit usually there **IS**.
d) Lunar eclipses can only happen very exact **FULL MOON**. If the Moon is just past an eclipsable **FULLISH MOON** when a lunar eclipse season begins, it will only get back to an eclipsable **FULLISH MOON** only somewhat less than **29.5 DAYS** later and so miss the eclipse season. Consequently, there doesn't have to be a either of a total or partial lunar eclipse in every lunar eclipse season, and, in fact, there usually **IS NOT**.
e) The Bos Domesticus effect in which the Sun sort of dodges the Earth happens frequently near nodal alignment. This often prevents lunar eclipses.

22. For eclipses (any of partial, total, annular, or penumbral) to occur, the nodes do not have to be exactly on the Earth-Sun line: i.e., the line drawn through the centers of Earth and Sun. This is because the light-emitting body, the eclipsing body, and the eclipsed body all have finite size. The eclipse season is the period during which nodes are sufficiently close to an alignment that an eclipse is possible. The eclipse season for the Sun (total, annular, and partial) is about 34 days: 17 days before exact aligment and 17 days after. Will there be solar eclipse of some kind in every solar eclipse season?

a) Solar eclipses can only happen at nearly exact **NEW MOON**. If the Moon is just past an eclipsing **NEWISH MOON** when a solar eclipse season begins, the Sun misses an eclipse just at the start of the season. The Moon will get back to new moon in a lunar month of about 29.5 days. This is less than the eclipse season, and thus a solar eclipse will occur. Clearly if the Moon enters the solar eclipse season at any other phase, a solar eclipse **MUST HAPPEN** as well.
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d) Solar eclipses can only happen at nearly exact **FULL MOON**. If the Moon is just past eclipsing **FULLISH MOON** when a solar eclipse season begins, the Sun misses an eclipse just at the start of the season. The Moon will get back to new moon in a lunar month of about 29.5 days. This is less than the eclipse season, and thus a solar eclipse will occur. Clearly if the Moon enters the solar eclipse season at any other phase, a solar eclipse will **NOT** occur.
e) The Bos Domesticus effect in which the Sun sort of dodges the Moon happens frequently near nodal alignment. This often prevents solar eclipses.

23. The solar corona:

a) is a thin surface layer of the Sun seen as a thin pink ring surrounding the totally eclipsed Sun. The corona often has eruptions of gas called solar prominences.
b) is the outermost part of the atmosphere of the Sun. It is a very hot, rarefied gas. Although very hot (of order 10^6 K), the corona is very **FAINT** because of it's low density. In **TOTAL SOLAR ECLIPSES** it becomes visible to the human eye. It has a milky white color and appears rather wispy. Magnetic field lines extending out from the Sun tend to concentrate corona gas into filaments.

c) is the outermost part of the atmosphere of the Sun. It is a very hot, rarefied gas. Although very hot (of order 10^6 K), the corona is very **BRIGHT** because of it's low density. In **TOTAL SOLAR ECLIPSES** it becomes visible to the human eye. It has a milky white color and appears rather wispy. Magnetic field lines extending out from the Sun tend to concentrate corona gas into filaments.

d) is the outermost part of the atmosphere of the Sun. It is a very hot, rarefied gas. Although very hot (of order 10^6 K), the corona is very **FAINT** because of it's low density. In **TOTAL AND ANNULAR SOLAR ECLIPSES** it becomes visible to the human eye. It has a milky white color and appears rather wispy. Magnetic field lines extending out from the Sun tend to concentrate corona gas into filaments.

e) was a **CROWN** awarded to the preeminent astronomer of ancient Greece. Poets have their laurel wreath; astronomers have their crown. Demosthenes (384?–322 BC), defying tryanny, argued in his oration *On the Crown* that it should not be given to Alexander (356–323 BC) for discovering that the Sun at sunrise in India is not a hundred times larger than in Greece. Later Ptolemy (circa 100–175 AD) was awarded the crown.

24. Why is the corona visible to the unaided eye only during a total solar eclipse?

a) It is behind the disk of the Sun ordinarily, and thus cannot be seen ordinarily.
b) The Moon's shadow usually hides it.
c) Only during total eclipses is it compacted by magnetic fields.
d) It is too faint to be seen when any significant part of the disk of the Sun is visible.
e) Only a total solar eclipse is long enough to let it stand out.

25. The solar system is not truly periodic and stable. Over billions of years the orbits and rotation rates even of the major planets and moons evolve. The motions of smaller bodies can evolve even more quickly in some cases. Nevertheless, the motions of the major bodies over long periods of time are periodic to a very high degree of accuracy. Therefore it is not surprising that the **relative positions of the Sun-Earth-Moon system** form a sequence in time that approximately repeats itself: i.e., the relative positions occur in a cycle. This cycle when used to describe the occurrence of eclipses is called the **Saros cycle**. (The use of the ancient Sumerian word saros for this cycle was a historical inaccuracy on the part of Edmund Halley [1656–1742] [Neugebauer, O. 1969, *The Exact Sciences in Antiquity,* p. 142]).

The **Saros cycle** is 6585.321 days long (Se-49). This is 18 calendar years and 10.321 days (5 leap year case) or 11.321 days (4 leap year case). (The two cases exist because 18 years can include 4 or 5 leap years depending on when the 18 year period begins. If the 18 year period includes a century year not whole number divisible by 4, then the 18 year period can include 3 or 4 leap years. In the 3 leap year case, the Saros period is 18 years and 12.321 days.) If a particular eclipse (i.e., total solar, annular solar, partial solar, total lunar, partial lunar, penumbral lunar) occurs on a given day, 6585.321 days later the same eclipse will occur again with Earth, however, rotated $\sim 120°$ degrees further east from where it was due the approximate third of day beyond an even number of days in the Saros period. For a particular total solar eclipse in the Saros cycle to occur in approximately the same location one has to wait how many Saros periods?

There was a total solar eclipse crossing Cornwall, England and Europe on 1999 August 11 (see, e.g., `http://sunearth.gsfc.nasa.gov/eclipse/solar.html`). When will this "Cornwall" eclipse recur on very approximately the same eclipse path?

a) 4 Saros periods and the "Cornwall" eclipse will re-occur in 2071 September.
b) 3 Saros periods and the "Cornwall" eclipse will re-occur in 2053 September.
c) 3 Saros periods and the "Cornwall" eclipse will re-occur in 2053 August.
d) 5 Saros periods and the "Cornwall" eclipse will re-occur in 2089 October.
e) 5 Saros periods and the "Cornwall" eclipse will re-occur in 2089 June.