Introductory Astronomy **NAME:**

Homework 3: The Moon: Orbit, Phases, Eclipses, and More: Homeworks and solutions are posted on the course web site. Homeworks are **NOT** handed in and **NOT** marked. But many homework problems ($\sim$ 50–70 %) will turn up on tests.

Answer Table

Name:

	a	b	c	d	e
1.	O	O	O	O	O
2.	O	O	O	O	O
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72.	O	O	O	O	O

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001 qmult 00007 1 4 1 easy deducto-memory: reading done 2

1. Did you complete reading the Introductory Astronomy Lecture before the **SECOND DAY** on which the lecture was lectured on in class?

   a) YYYessss!   b) Jawohl!   c) Da!   d) Sí, sí.   e) OMG no!

   SUGGESTED ANSWER: (a),(b),(c),(d)

   Wrong answers:

   e) As Lurch would say AAAARGH.

   Redaction: Jeffery, 2008jan01

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003 qmult 00100 1 4 2 easy deducto-memory: satellite Moon

2. “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

   SUGGESTED ANSWER: (b)

   It is remotely possible I suppose that there are some tiny, unknown natural satellites of the Earth. Their orbits would probably not too stable since almost anything could perturb them.

   Wrong answers:

   a) The Sun cannot be considered a satellite of the Earth since the Earth orbits the Sun physically: i.e., the Sun’s frame is more inertial than the Earth’s.
   c) Cruithne is a 5-kilometer-diameter asteroid that orbits close to the Earth and interacts gravitationally with the Earth. It has sometimes been called the “2nd Moon,” but this is not correct since it is not gravitationally bound to the Earth.
   d) This is an artificial satellite.
   e) Superman’s home planet is not in our Solar System.

   Redaction: Jeffery, 2001jan01

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003 qmult 00250 2 5 3 moderate thinking: intercalary month

3. 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 lunisolar calendar before you need to insert a 13th lunar month in a year (an intercalary month) in order to keep the lunisolar calendar roughly consistent with the solar year (i.e., keep the months in the seasons they are supposed to be in)?

   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

   SUGGESTED ANSWER: (c)

   Note that the difference between 12 lunar months and a solar year is about $365.24 - 354.37 = 10.87$, and so after 3 years the discrepancy is about 32.61 or 33 days.

   Many societies tried to keep a 12 lunar month calendar and a solar calendar at the same time: i.e., a lunisolar calendar. Since 12 mean lunar months is 354.367 days and the solar (i.e., tropical) year is about 365.2421897 days (Cox-15), the 12-lunar-month year would run a head of solar time in year count by about 32.6254 days every 3 years. In order to keep the months from moving out of their seasons, a 13 month (an intercalary month) had to be inserted into the calendar a bit more frequently than every 3 years. In fact, if you have 12 12-lunar month years and 7 13-month years (i.e., 235 lunar months equal to 6939.69 days) in 19 tropical years (6939.60 days), then the lunar and solar time-keeping stay consistent for a very long time: a discrepancy of only about a tenth of day adds on every 19-year cycle. The 19-year cycle is called the Metonic cycle after the Athenian astronomer Meton (late 5th century BCE) who may have been the first to discover it (Ne-7).

Most early societies didn't have any scientific rule. The relevant officials just inserted an intercalary month whenever it seemed necessary.

Fortran Code

```
      print*
      xlunar=29.53059  ! Cox-16
      xsolar=365.2421897 ! Cox-15
      xlyear=12.*xlunar
      dif=3.*(xsolar-xlyear)
      xlun=12.*12.*xlunar+7.*13.*xlunar
      xsol=19.*xsolar
      print*,'xlyear,dif,xlun,xsol'
      print*,xlyear,dif,xlun,xsol
* 354.367    32.6254    6939.69    6939.60
```

Wrong answers:

a) As Lurch would say: "Aaaarrh."

Redaction: Jeffery, 2001jan01

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003 qmult 00320 2 4 5 moderate deducto-memory: Moon distance

4. 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.

SUGGESTED ANSWER: (e)

It's one of the numbers students should memorize.

Wrong answers:

c) This can be eliminated since that is the Earth-Sun distance.
d) This is meaningless answer unless the context is specified.

Redaction: Jeffery, 2001jan01

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003 qmult 00322 1 4 5 easy deducto-memory: Earth focus of ellipse

5. 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.

SUGGESTED ANSWER: (e)

Two isolated gravitationally bound bodies orbit in ellipses with their mutual center of mass at one of the foci of the ellipses. If one body is much more massive than the other, it is effectively at the center of mass. In the Earth-Moon system, the Earth is very much the dominant mass, and the Earth's center is nearly at the center of mass relatively speaking. So it makes sense in many cases to say the Moon orbits the Earth with the Earth at one focus of the elliptical orbit. But if one is dealing with the Earth's tides, one does have take into consideration the Earth's orbiting the center of mass.

Wrong answers:

a) A geometrical center is not a focus.
b) Elliptical, not ecliptical. The similarity of these two words is sometimes confusing, but their meanings are distinct.
c) The Earth is not in two places at once.

d) The Earth is never at the perigee of the Moon's orbit; the Moon, however, is there once per orbit.

Redaction: Jeffery, 2001jan01

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003 qmult 00324 2 4 1 moderate deducto-memory: Moon inclination to ecliptic

6. The plane of the Moon's orbit is:

a) at an inclination of about 5° from the **ECLIPTIC PLANE**.
b) at an inclination of about 5° from the **ECLIPTIC POLE**.
c) at an inclination of about 50° from the ecliptic plane.
d) in the ecliptic plane.
e) parallel to, but far above, the ecliptic pole.

SUGGESTED ANSWER: (a)

This can be answered as straight fact question. But the answer can also be deduced. To be more exact, the inclination is 5.145°.

Wrong answers:

b) This would make the Moon's orbit and the ecliptic nearly perpendicular which is from casual observation very unlikely.
c) Again unlikely from casual observation.
d) If this were so, we would have solar and lunar eclipses monthly.
e) We would never have eclipses.

Redaction: Jeffery, 2001jan01

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003 qmult 00330 1 4 2 easy deducto-memory: lunar sidereal month

7. "Let's play *Jeopardy*! For \$100, the answer is: A lunar time period that is 27.321661 days long."

What is the ____________, Alex?

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

SUGGESTED ANSWER: (b)

See Cox-16 for the various lunar time periods.

Wrong answers:

c) The anomalistic month is the time from perigee to perigee: mean value 27.55455 days (Cox-16).
d) The draconitic month is time from a node to the same node: mean value 27.21222 days (Cox-16).
e) I just made this up.

Redaction: Jeffery, 2001jan01

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003 qmult 00332 1 3 1 easy math: lunar angular speed synodic

8. 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°.

SUGGESTED ANSWER: (a)

It can also be straight memory question. The student must realize that a complete lunar month takes the Moon through 360° relative to the Sun: i.e., new moon to new moon. Then

$$360^\circ/29.531\text{ days} = 12.19^\circ\text{ per day.}$$

Wrong answers:

b) This is the angular velocity relative to the fixed stars.
c) This number looks suspiciously over-familiar.

d) This number looks suspiciously fast.
e) This has wrong units.

Redaction: Jeffery, 2001jan01

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003 qmult 00340 2 4 4 moderate memory: nodes of Moon's orbit

9. 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.

SUGGESTED ANSWER: (d)

Wrong answers:
e) If they were, there would be total lunar and solar eclipses every month.

Redaction: Jeffery, 2001jan01

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003 qmult 00380 2 5 3 moderate thinking: low-Earth-orbit satellite rising west

10. 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 $\sim 4^\circ$ 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 $\sim 360^\circ$ 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 $\sim 4^\circ$ per minute. It **RISES WEST AND SETS EAST**.
d) Its angular speed is $\sim 360^\circ$ 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 $\sim 0.25^\circ$ per minute. It **RISES EAST AND SETS WEST** like all other astronomical bodies due to the daily rotation of the Earth.

SUGGESTED ANSWER: (c)

The angular speed is

$$\frac{\Delta\theta}{\Delta t} \approx \frac{360}{90} = 4^\circ/\mathrm{min} \ .$$

In this case, the period of the satellite is much shorter than the period of the Earth's diurnal rotation, and so the satellite must rise in the west and set in the east. Note Martian moon Phobos also revolves eastward so quickly that it rises west and sets east.

Actually, one should make the comparison to the Earth's sidereal day (i.e., a day relative to the fixed stars), not the 24 hour solar day. But the difference between the two days is small since the Earth doesn't move far around the Sun during a sidereal day.

Some more detail beyond the scope of the course: The solar day (i.e., synodic day) is noon to noon: the time it takes for the Earth to return to the same orientation relative to the Sun. The sidereal day is the time it takes the Earth to return to the same orientation relative to the fixed stars.

Because the Earth revolves eastward about the Sun and turns eastward, the synodic day must be longer than the sidereal day. We really need to have the sidereal day for a mathematical calculation of the angular speed of the satellite relative to the Earth.

Now $360^\circ + \delta\theta = \dot{\theta}_{\mathrm{sid}} t_{\mathrm{syn}}$ where t_{syn} is the solar day, $\dot{\theta}_{\mathrm{sid}} = 360^\circ/t_{\mathrm{sid}}$, and $\delta\theta = (360^\circ/t_{\mathrm{year}_{\mathrm{sid}}})t_{\mathrm{syn}}$. The quantity t_{sid} is the sidereal day and $t_{\mathrm{year}_{\mathrm{sid}}}$ is the sidereal year. The $\delta\theta$ is the extra amount relative to the fixed stars that the Earth has to rotate to bring it back to noon and $t_{\mathrm{year}_{\mathrm{sid}}}$ is the sidereal year. The expression for $\delta\theta$ follows from a little geometry and a diagram of the Earth revolving about the Sun.

Solving for t_{sid} gives

$$t_{\mathrm{sid}} = \frac{t_{\mathrm{syn}}}{1 + t_{\mathrm{syn}}/t_{\mathrm{year}_{\mathrm{sid}}}} \ .$$

For the Earth $t_{\mathrm{sid}} = 1/(1 + 1/365.25)$ approximately. Thus for many purposes t_{sid} can be approximated as t_{syn} for the Earth. We will do that here.

Now angular speed of the satellite relative to Earth is:

$$\dot{\theta}_{\text{sat}_{\text{rel}}} = \dot{\theta}_{\text{sat}} - \dot{\theta}_{\text{sid}} \approx 360^\circ/(90\,\text{min}) - 360^\circ/(1440\,\text{min}) \ .$$

Clearly the relative angular speed of the satellite is positive (i.e., eastward). Thus the satellite rises in the west and sets in the east.

Wrong answers:
a) Nope. The satellite rises west sets east as wrong answer (d) explains.
b) The speed is 4° per minute. Satellites and space shuttles don't whip around the Earth once per minute.
d) Wrong speed, but the reasoning for the rising west and setting east is correct. The trick is that the right reasoning is given in wrong answer.
e) 0.25° per minute is actually the angular speed of the Earth's rotation relative to the Sun, but this is approximately the same as its angular speed relative to the fixed stars.

Redaction: Jeffery, 2001jan01

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003 qmult 00382 2 4 4 moderate deducto-memory: lunar synodic sidereal

11. 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., high-northern-celestial-sphere) 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. 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. 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. 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.

SUGGESTED ANSWER: (d)

Wrong answers:
a) A specious answer. The Sun does have some subtle effects on the Earth-Moon system, besides, of course, the unsubtle effect of causing it to orbit the Sun. But even assuming the statement the "Sun slows down the Moon when the Moon is nearest the Sun" was right (and I have no

idea), then the slow-down effects both the length of lunar month and sidereal period by the same amount since it's the same Moon on the same path.

b) Unknown initial conditions get the blame for a lot of things in the Solar System. But in this case, we don't ask for the origin of a particular arrangement, but only why two descriptions of it differ.

c) If the Earth moves counterclockwise relative to the Sun, then the Sun moves counterclockwise relative to the Earth. Draw a diagram.

e) It's counterclockwise (or eastward or prograde) when viewed from the north ecliptic pole.

Redaction: Jeffery, 2001jan01

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003 qmult 00400 1 4 5 easy deducto-memory: lunar phase defined

12. "Let's play *Jeopardy*! For \$100, the answer is: It is the appearance of the sunlit portion of the Moon as seen by an observer usually located on the Earth."

What is ____________, Alex?

a) the terminator   b) lunar month   c) the leaping rabbit   d) a mare   e) lunar phase

SUGGESTED ANSWER: (e)

Wrong answers:

c) The leaping rabbit.

Redaction: Jeffery, 2013jan01

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003 qmult 00424 1 1 2 easy memory: named full moons

13. Full moons occuring at particular times of the year often have traditional names associated with them that varying with culture. A folkloric (or maybe pseudo folkloric) name for a full moon in or near January is:

a) June Moon   b) Wolf Moon   c) Juney Moon   d) Green Cheese Moon
e) Waning Moon

SUGGESTED ANSWER: (b) Actually this name may just have been made up by the *Farmers' Almanac* in the 20th century. See Wikipedia: Full Moon.

Wrong answers:

a) A nonsense answer.

Redaction: Jeffery, 2013jan01

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003 qmult 00440 2 5 2 moderate thinking question: Moon phase 1999jan20

14. Describe the Moon's 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.

SUGGESTED ANSWER: (b)

A moderate thinking question.

Wrong answers:

a) There are no waning crescents east of the Moon at sunset. A waning crescent is west of the Moon at sunrise.

c) New moons are in inferior conjunction with the Sun, not in opposition. Conjunction: aligned with the Sun as seen from the Earth; the body can be in front of or behind the Sun. Opposition: opposite the Sun on the sky.

d) A full moon is in opposition, not near the Sun.

e) A waning gibbous moon would be in the western sky at sunrise.

Redaction: Jeffery, 2001jan01

003 qmult 00450 1 4 2 easy deducto-memory: Moon phase sunset

15. 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.

    SUGGESTED ANSWER: (b)

    Wrong answers:
    e) As Lurch would say: "Aaaaah."

    Redaction: Jeffery, 2001jan01

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003 qmult 00452 1 4 5 easy deducto-memory: Moon phase sunrise

16. At sunrise, you see the Moon in the eastern sky. It is:

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

    SUGGESTED ANSWER: (e)

    Wrong answers:
    a) As Lurch would say: "Aaaaah."

    Redaction: Jeffery, 2001jan01

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003 qmult 00456 2 4 5 moderate deducto-memory: full Moon opposition

17. 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.

    SUGGESTED ANSWER: (e)

    Wrong answers:
    d) It could be eclipsed, but it "aint necessarily so."

    Redaction: Jeffery, 2001jan01

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003 qmult 00458 1 4 4 easy deducto-memory: Moon phase full

18. 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.

    SUGGESTED ANSWER: (d) The Moon is in opposition to the Sun. Therefore we are on the Moon-Sun line and in front of the Moon. Therefore its full illuminated face is toward us.

    Wrong answers:
    c) This could happen, but it's not usually the case.

    Redaction: Jeffery, 2001jan01

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003 qmult 00460 1 4 2 easy deducto-memory: Moon phase horned

19. The Moon is a crescent—the horned Moon. Which way, in a rough sense, do the horns point relative to the Sun?

    a) Toward the Sun. b) Away from the Sun. c) They can have any orientation depending on the time of year. d) They can have any orientation depending on the time of day. e) Perpendicular to the line from the Moon to the Sun.

    SUGGESTED ANSWER: (b) The illuminated face of the Moon always points toward the Sun. Therefore the bow of the crescent must be toward the Sun and the horns away.

    Wrong answers:
    a) This would look really weird.

    Redaction: Jeffery, 2001jan01

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003 qmult 00720 1 4 4 easy deducto-memory: lunar eclipse

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

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

SUGGESTED ANSWER: (d) The Moon can't be in the Earth's shadow unless it's opposite the Sun: i.e., it's full.

Wrong answers:

b) When half full the Moon is at a right angle to the Sun as seen from Earth.

Redaction: Jeffery, 2001jan01

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003 qmult 00730 2 1 1 moderate memory: Earth umbra

21. From the umbra of the Earth, the:

a) Sun's photosphere 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.

SUGGESTED ANSWER: (a)

I'm assuming that atmosphere-refracted light doesn't count as seeing the Sun.

Wrong answers:

b) The Moon can be seen from here, but not at all times. For example, on the night side of the Earth, one is in the umbra. If the Moon hasn't risen, one can't see it.

e) Even if students were tempted to say they see the refracted light of the Sun, and so see the Sun. They wouldn't see a crescent, just a red ring around the Earth

Redaction: Jeffery, 2001jan01

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003 qmult 00740 2 5 1 moderate thinking: lunar eclipse seasons

22. For lunar 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 sizes. The eclipse season is the period during which nodes are sufficiently close to an exact nodal alignment that an eclipse is possible. The eclipse season for the Moon (for partial and total eclipses, and **NOT** including penumbral eclipses) is about 24 days: 12 days before exact nodal alignment and 12 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.

SUGGESTED ANSWER: (a)

According to *Wikipedia: Eclipse season: Details*, the total eclipse season is 31 to 37 days (with average 34 days). There must at least one solar and one lunar eclipses of some type in either order. There can be at most three eclipses (solar, lunar, solar or vice versa). But Mo-128 (i.e., Motz & Duveen, p. 128) give the lunar total and partial eclipse season as 24 days (from 12 days before to 12 days after exact nodal alignment). Se-47 gives 22 days and that is closer to my own calculation. But since I no longer have Seeds nor my own calculation, I'll trust Mo-128.

I think one can see the reasoning for the right answer from the question and right answer themselves.

Wrong answers:

b) The Moon has to be behind the Earth not in front of it for a lunar eclipse. Thus lunar eclipses happen at full moon, not new moon.
c) Full moon again. Also the lunar month is about 29.5 days.
d) In order to miss a lunar eclipse, the Moon has to enter the lunar eclipse season in the period from just a hairs-breath after full to about 5.5 days after full moon. There is only about a 5.5/29.5=1/5 chance of this if lunar phase and nodal alignment are uncorrelated which over the long haul I think is more or less true. Usually then there will be a lunar eclipse, partial or total.
e) High diddle, diddle, the cat and a fiddle, the . . . . According to the Oxford English Dictionary, the domestic cow is Bos Taurus, but Bos Domesticus sounds better.

Redaction: Jeffery, 2001jan01

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003 qmult 00750 1 4 4 easy deducto-memory: lunar eclipse seen

23. 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.

SUGGESTED ANSWER: (d)

The eclipsed Moon is a full Moon and so opposite the Sun, in fact nearly exactly opposite given that it is eclipsed. Thus it can be seen from the dark side. An object infinitely far from the Earth and opposite the Sun could be seen by anyone on the night side in the idealized case. Even those on the day-night border could see it on their horizon. Well the Moon is rather far from the Earth, but not effectively infinitely far. So there may be marginal regions close to the day-night border where it can't be seen. But practically it should be visible from most of the night side.

Wrong answers:

e) Surely not.

Redaction: Jeffery, 2001jan01

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003 qmult 00760 2 5 1 moderate thinking: eclipsed Moon darkest

24. 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.

SUGGESTED ANSWER: (a)

It should be reasonable that the center would be darkest because that is where you are relying on the more refracted sunlight. The more the light refracts, the more Earth's atmosphere it has to pass through and thus the more extinquished it would be.

Wrong answers:

e) The Moon can't be eclipsed (a full moon event) and eclipse the Sun (a new Moon event) at the same time. But the Moon is very dark at during a solar eclipse. It only shines be reflected Earth light and this is very faint compared to the solar corona

Redaction: Jeffery, 2001jan01

003 qmult 00762 2 4 3 moderate deducto-memory: lunar eclipse coppery

25. 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.

SUGGESTED ANSWER: (c)

A moderate memory question. One just has to remember it is refraction of sun light in the Earth's atmosphere which causes the red color.

Wrong answers:

a) Actually a reflecting object's color is determined by its intrinsic properties and the spectrum of the light that is shining on it. Thus objects don't really have natural color. Of course, given that the light is always white light (which is basically what humans like to use usually) objects will have definite colors. Under white light, the Moon is sort of grey??? I think. The contrast with the dark sky makes it look white or even silvery at least in story and song: "by the li-i-i-ght of the silvery Mo-o-o-o-on, I want to cro-o-o-o-n ..."
b) Refracted not reflected.
d) I just made this up: unless I've made a lucky hit, it's total nonsense.
e) The day side of the Moon is hot (up to 130° C: see Se-445), but not red hot. Red hot is, well, hotter: like a glowing burner—however hot that is.

Redaction: Jeffery, 2001jan01

003 qmult 00780 1 4 3 easy deducto-memory: Aristotle, Earth's shadow

26. Why did Aristotle (384–322 BCE) conclude that lunar eclipses prove or at least strongly suggest 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) If you have parallel light beams (which is nearly the case for beams from the Sun at the Earth because of the Sun's remoteness), then the shadow they cause from sphere has a circular cross section for all orientations of source and sphere. The sphere shadow will tend to look circular on most objects on which it falls. Now the shadow (i.e., the umbra) of the Earth on the Moon is circular or nearly circular in all cases: i.e., for all times of day when the partial lunar eclipse is seen and all locations of the Sun on the celestial sphere. Ergo it seems that the Earth must be spherical, unless there is some strange other way to arrange a circular or nearly circular umbra on Moon's face.

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*).

SUGGESTED ANSWER: (c)

I think that roundness of the umbra is almost a definitive proof if one accepts that it is the Earth's umbra that causes lunar eclipses. Because of the rotation of the Earth (or as Aristotle would think the revolution of the Sun), the Earth can be in any rotation orientation region when the Moon crosses the umbra and the Moon can cross it high or low. If the Earth were an odd shape, then sometimes the shadow would not look round. But the fact that the umbra is bigger than the Moon, may make judging perfect roundness difficult.

Wrong answers:
a) He wasn't able to do this and the statement doesn't answer the question.
b) Aristotle didn't know (as far as we know) about atmospheric refraction although a later Greek discovered the effect. But if he had, a square atmosphere would also refract reddish light onto the Moon.
d) Even if we grant the two premises, the conclusion doesn't follow since non-spherical perfect bodies can cause eclipses too. Aristotle would never have made such an error in a syllogism.
e) We do know: it's (c). And *De Caelo* isn't lost. See North p. 80.

Redaction: Jeffery, 2001jan01

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003 qmult 00724 1 4 3 easy deducto-memory: annular eclipse

27. "Let's play *Jeopardy*! For $100, the answer is: In this kind of solar eclipse a ring of photosphere of the Sun is seen around the dark moon."

What is a/an ____________, Alex?

a) total solar eclipse b) partial solar eclipse c) annular solar eclipse d) ring eclipse
e) diamond ring eclipse

SUGGESTED ANSWER: (c)

Wrong answers:
a) A total eclipse is when the Moon is close enough to the Earth to cover the whole photosphere.
d) A sensible name since "annular" means ring-like, but these eclipses arn't called annular.
e) There is a diamond ring effect when the photosphere of the Sun just peeps through a valley or the like of the Moon just before/after totality.

Redaction: Jeffery, 2001jan01

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003 qmult 00870 3 4 2 tough deducto-memory: Sun corona defined 1

28. 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 unaided 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 unaided 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 unaided 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 BCE), defying tyranny, argued in his oration *On the Crown* that it should not be given to Alexander (356–323 BCE) for discovering that the Sun at sunrise in India is not a hundred times larger than in Greece. Later Ptolemy (circa 100–175 CE) was awarded the crown.

SUGGESTED ANSWER: (b)

Wrong answers:

a) That's the chromosphere: see Se-45.
c) Low density in gas tends to faintness, not brightness in gas emission. This can be understood by imagining density going to zero.
d) Annular eclipses are apparently too bright to allow the corona to be seen by eye.
e) Drivel. Some ancient person made an oration *On the Crown*, I think, but it wasn't about astronomy. Maybe it was Cicero. Of course, Alexander and his mates did find out that the Sun at sunrise was the same size in Greece and in India. But the Greek philosophers had assumed that for a long time. There were probably earlier reports too. Ptolemy is sometimes shown wearing a crown in Medieval pictures (see Se-59), but this was because Medievals thought he had to belong to the Ptolemaic dynasty—you know, Cleopatra, etc.

Redaction: Jeffery, 2001jan01

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003 qmult 00872 1 4 4 easy deducto-memory: visible corona

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

a) It is behind the photosphere 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 photosphere of the Sun is visible.
e) Only a total solar eclipse is long enough to let it stand out.

SUGGESTED ANSWER: (d)

Wrong answers:

a) Nah, it surrounds the Sun of which, of course, it is the outermost layer.
b) It's not in the Moon's shadow. It's far away from the Moon's shadow and much bigger too.
c) The magnetic fields of the Sun arn't affected by eclipses.
e) The corona is there all the time. If time alone was enough to see it, we would always see it.

Redaction: Jeffery, 2001jan01

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003 qmult 00882 3 5 2 hard thinking: Saros Cornwall

30. 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 significantly. 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 6585.3213 days long (Wikipedia: Saros). This is 18 Julian years (of 365.25 days each exactly) plus 10.8213 days. In calendar years, the period is trickier to report because of leap years. It is 18 calendar years plus 10.3213 days for the 5 leap year case and 18 calendar years plus 11.3213 days for the 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 cycle period is 18 years and 12.3213 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 cycle period. For a particular total solar eclipse in the Saros cycle to occur in approximately the same location one has to wait ____ Saros cycle periods.

There was a total solar eclipse crossing Cornwall, England and Europe on 1999 August 11. This "Cornwall" eclipse recur on very approximately the same eclipse path in ____________.

a) 4; 2071 September b) 3; 2053 September c) 3; 2053 August d) 5; 2089 October
e) 5; 2089 June

SUGGESTED ANSWER: (b)

A long, but very easy question. Note the "Cornwall" total solar eclipse may not re-occur in Cornwall at all. The eclipse path could be a 1000 km or more away from Cornwall—but I'm just guessing on this point. The Saros cycle is not a perfect, only approximate.

Wrong answers:

c) Well 3 Saros periods is right. But the eclipse will be shifted to September: 3 Saros periods is about 54 calendars years plus a month.

Fortran-95 Code

```
         print*
         sar=18d0*365.25d0
         saros=6585.3213d0
         diff=saros-sar
         sar3=3.d0*sar
         saros3=3.d0*saros
         diff3=saros3-sar3
         print*,'sar,saros,diff,sar3,saros3,diff3'
         print*,sar,saros,diff,sar3,saros3,diff3
!  6574.500000000000        6585.321299999996        10.821299999999610
!       19723.500000000000        19755.963899999999        32.463899999998830
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Redaction: Jeffery, 2001jan01