Announcements

Some sample moon problems from Lecture 10:
1. If you wake up at 3 am and see the moon rising, what is its phase?
   Ans. At 3 am the sun is below eastern horizon, full-moon position is opposite at about sun's 3 pm position and moon is well past there so is waning. Moon is nearer sun than opposition so answer is waning crescent.

2. Same problem only it's 9 pm and you see the moon transiting.
   Ans. At 9 pm sun is below western horizon and full moon position is at sun's 9 am position and the moon has not yet reached there so is waxing. Moon is nearer opposition than the sun so answer is waxing gibbous.

Artists are often careless about the moon. Remember the horns of the crescent moon always point away from the sun. The full moon can never be near sunset in the west. Venus can never be near the quarter moon. The dark side of the moon is the unlit side.

Moon's motions

1. Revolution. A sidereal month = once around with respect to the stars
   \[ = \frac{27d7h43m11.5s}{27} + \frac{7h}{27} = 27 \frac{1}{3} \text{ days} + 7 \text{ h on average} \]

   A synodic month = complete cycle of phases, e.g. new moon to new moon = 2 days after a sidereal month due to earth's motion
   \[ = \frac{29d12h44m2.8s}{12h} + 12h = 29 \frac{1}{2} \text{ days} + 12 \text{ h} \]

   The reason for the huge variation is that both earth and moon move non-uniformly. (This is reminiscent of the calendar problem: which month to use as the basis?) So in addition to rising and setting (the diurnal motion due to earth's rotation) the moon moves eastward against the stars due to its revolution around earth
   \[ 360^\circ/\text{month} = \frac{360^\circ}{30 \text{ d}} = \frac{12^\circ}{12 \text{ d}} = 1^\circ/12 \text{ h} = 1/2^\circ/\text{hour} \]

   Since the moon's angular size is $1/2^\circ$ it moves its own diameter every hour to the east (counterclockwise as you look down from north celestial pole). An occultation is when the moon (or other dark object) passes in front of a star. These are very useful for amateurs to time using WWV accurate time signals. The moon makes an excellent shutter since it has no atmosphere:
   - for double stars, each winks out separately even if unresolved telescopically
   - especially for radio sources poorly resolved, successive lunar occultations can be used

2. Rotation. Does the moon rotate?
   We always see the same face of the moon (with the same features: man-in-the-moon, bunny or whatever). This means the moon rotates exactly once as it revolves around the earth, synchronous rotation which is also true for some 60 satellites in the solar system (virtually all except Jupiter's outer 8 [captured asteroids], Saturn's Phoebe & Hyperion and Neptune's Nereid). Once synchronised there's no further change for the moon except it is slowly braking earth's rotation .002 s/century (evidence in fossil corals and 2000 year old eclipse tracks) and the moon-
earth distance is increasing by a few mm/year.

3. Libration = wobble

Libration in latitude. Due to inclination of moon's orbit (by 6.5°) to ecliptic, we see over N. pole sometimes and 2 weeks later under S. pole so extra features are seen beside the usual man-in-the-moon.

Libration in longitude. The rotation of the moon is very regular like earth's, but its revolution is not so uniform (faster at perigee than at apogee). The consequence is that rotation and revolution get out of step. At perigee revolution gets ahead and you see part of the following limb; at apogee revolution gets behind and you can see some of the preceding part.

The total effect is that we can see a total of 59% of the moon, half at a time. 41% can never be seen from earth; the first glimpse of this was in October 1959 when Lunik III transmitted data back.

Thumbnail review of Apollo results. In brief there are 4 major findings:
1. all returned rocks were formed by cooling of molten rock; no shale, limestone, sandstone, as formed on earth under water.
2. no trace of embedded water in moon rocks (earth rocks contain at least 1 to 2% water).
3. moon rocks include crystals of pure iron, no oxidation present (vs on earth the iron has long since rusted or oxidized).
4. same elements are found on moon but the distribution is different. In general moon rocks have high temperature melting points (Ca, Al, Ti) vs earth has more low melting point elements like Na, K. This implies that at some time lunar temperatures were higher than for earth.

Theories of lunar origin.
1. fission theory (daughter)—split off of earth (no, it has the wrong composition and this predicts too high angular momentum)
2. accretion theory (sister)—condensed out of leftovers when earth condensed out of dust cloud. Again, chemical composition inconsistent here.
3. capture theory (spouse)—originated elsewhere (so different composition OK) but was captured into present orbit. (No, dynamics too improbable)

Conclusion: there's no satisfactory theory to explain moon's origin. More recently there's a compromise that looks acceptable (?):
4. large impact theory: earth is struck by Mars-sized projectile ejecting mantle material into space where volatiles were lost before final condensation into moon, whereas original projectile ends up inside earth's core. Accounts for both similarities and differences comparing composition of earth and moon.