Exam 02: Chapters 02–09

Formulas and Constants

1 AU = 150×10^6 km

1 ly = 9.5×10^{12} km

1 pc = 3×10^{13} km
1 pc = 3.26 ly = 206265AU

Kepler's Third Law: $P^2 = a^3$

Newton #2: $F = ma$

Law of Gravity: $F = G\frac{m_1 m_2}{r^2}$

Wave speed: $v = \lambda f$

Wave energy: $E = hf$

Speed of light: $c = 3\times10^8 \frac{\text{m}}{\text{s}}$

Wien's Law: $T(\text{K}) = \frac{0.29}{\lambda(\text{cm})}$

Stefan's Law: $F = \sigma T^4$

Light gathering power: $\frac{A_1}{A_2} = \frac{r_1^2}{r_2^2}$

Angular separation:

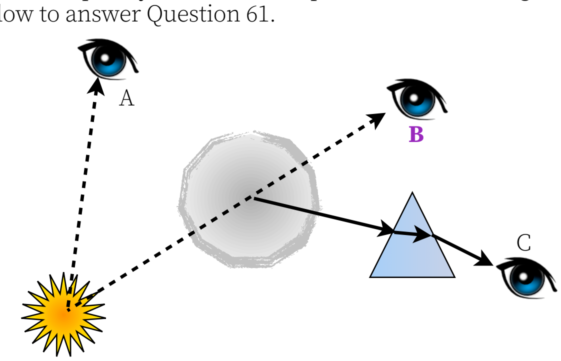
$$\theta(\text{arc min}) = \left[\frac{s(\text{m})}{d(\text{km})}\right]\left(\frac{10.8}{\pi}\right)$$

Diffraction-limited angular resolution:

$$\alpha(\text{arcsec}) = (0.25)\left(\frac{\lambda(\mu\text{m})}{d(\text{m})}\right)$$

1. A bright-line **emission** spectrum will form when
   A) protons absorb electrons in the nucleus of an atom. The result is a very bright nuclear explosion.
   B) a photon emits an electron when a nucleus decays into a smaller nucleus.
   C) Answer B) is backwards: a photon absorbs an electron when a nucleus decays into a smaller nucleus.
   D) an electron in a higher energy orbit emits a photon having a specific amount of energy and returns to a lower energy orbit.
   E) an electron in a lower energy state absorbs a specific quantum of energy and jumps to a higher energy orbit.

Three observers (on completely different planets orbiting completely different stars; definitely not drawn to scale!) are viewing a cloud of interstellar gas, and recording the data spectroscopically. Use the multiple choices on the figure below to answer Question 61.



2. Which observer records a dark-line **absorption** spectrum? B
   D) Each records the same absorption spectrum.
   E) None of the observers sees an absorption spectrum.

3. Hydrogen, mercury, argon, and krypton all have a blue emission line at **λ = 435 nm**. How can this happen?
   A) It can't! The above statement must be false, because no two different elements will have emission lines at identical wavelengths.
   B) Coincidence! It may happen that more than one element has a line at 435 nm. But when you compare the other spectral lines, no two differing elements will have the same overall pattern.
   C) *Every* element will have a line at 435 nm, not just the ones listed above. This is the fundamental spectral line for all atoms, where an electron transitions from a full to an empty orbital shell.
   D) Shrug. It's a mystery. There are still a lot of things which remain unknown about atomic spectra.

4. When the source of a wave **recedes away** from a stationary observer, what does the observer perceive?
   A) The observer perceives a decrease in frequency, but the source has not changed the frequency it emits.
   B) The observer perceives a decrease in frequency because the source emits a lower frequency as it gets closer.
   C) The observer perceives an increase in frequency. This is because the source actually will emit a higher frequency as it gets closer.
   D) The observer perceives an increase in frequency, but the source has not changed the actual frequency it is emitting.
   E) The observer perceives the same frequency as the source is actually emitting. Being in motion (source or observer) has nothing to do with it.

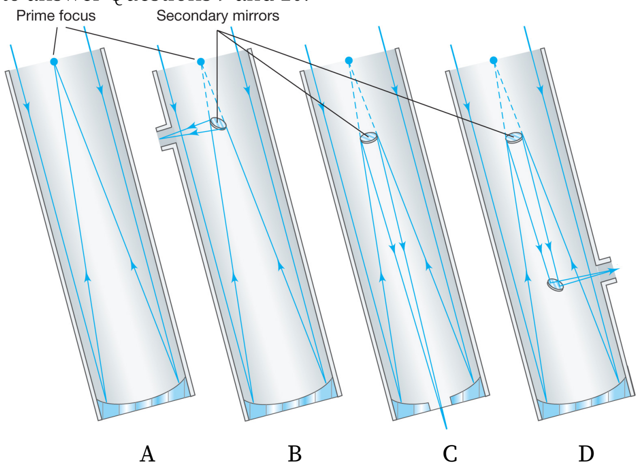
5. The e·m spectrum of an object in motion **toward** a stationary observer will be
   A) blue-shifted. The entire spectrum is shifted to the blue, or shorter wavelengths.
   B) blue-shifted. Only the blue-violet and ultraviolet lines are shifted, though. Longer wavelength lines are not affected.
   C) red-shifted. The lines in the orange-red and infrared part of the spectrum are shifted. Any other lines are unaffected.
   D) red-shifted. All of the spectral lines will be shifted by the same amount in the direction of longer wavelength.

6. The Doppler shift can tell you several things about the motion of an object, but it **cannot** tell you anything about the object's
   A) rotational speed.
   B) rotational direction.
   C) tangential (or transverse) velocity.
   D) distance (increasing or decreasing).

7. Galileo is credited with being the first person to use a telescope to make astronomical observations. What type of telescope did he make for himself?
   A) A reflecting telescope using a curved primary mirror.
   B) A simple refracting telescope using a single primary lens and an eyepiece.
   C) A compound refractor using a system of precisely ground achromatic primary lenses coupled with a high-powered eyepiece.
   D) Trick question. Galileo never used a telescope, but made all of his observations using a sextant and cross-staff.

8. Who is credited with inventing the reflecting telescope?
   A) Aristotle.
   B) Copernicus.
   C) Tycho Brahe.
   D) Johannes Kepler.
   E) Galileo.
   F) Isaac Newton.

The picture below illustrates different types of telescope configurations. **Use the multiple choices listed on the figure** to answer Questions 9 and 10.



9. Which of the reflecting telescopes pictured above is a Coudé type? D
   E) None of them are Coudé.

10. Which type of telescope pictured above is the Hubble Space Telescope (HST)? C
    E) None of them represent the HST.

11. True or false: The two most important properties of a telescope are its light gathering power and image magnification.

12. When it sees first light in about 2022, how big will the European Extremely Large Telescope actually be?
    A) Not actually all that big. About 10 meters, similar to the Keck telescopes on Mauna Kea.
    B) Pretty big, about 20-22m, which is why they are opening in 2022. Get it?
    C) The European ELT is a perfect twin to the US's TMT, and both will have 30m primary mirrors.
    D) The primary will be as wide as half a football field. Seriously, it's pretty extreme: a 40m primary mirror.

13. You are a billionaire philanthropist, and your best friend is an evil genius. Together, you have almost all the money in the world, and you have decided to form a Superhero Stargazer's Club. You need an awesome observatory/hideout. Where would you site your scope?
    A) The Upper Peninsula of Michigan, deep in the woods.
    B) Downtown Los Angeles, because, duh, that's where all the stars are!
    C) On a remote mountaintop, preferably near the equator.
    D) Any of these sites would work equally well. Figuring out where to put a telescope just isn't that hard.

14. You are at the Telescope Store comparing a couple of backyard telescopes. The sales associate helpfully informs you that the 10-inch reflector you have your eye on has twice the light gathering power of the less expensive 5-inch reflector.
    A) The sales associate is quite right. If you double the diameter of the primary mirror, you will double the telescope's light gathering ability.
    B) The sales associate is not quite right. Light gathering power depends on the area of the mirror, not the diameter. The 10-inch telescope will actually have four times the light gathering ability of the 5-inch.
    C) The sales associate is quite wrong. Increasing the size of a telescope's primary mirror has no effect on light gathering. It increases the magnification, but not the amount of light collected.
    D) The sales associate is quite persuasive. Not only did you buy the bigger telescope, but you left with a set of Zeiss eyepieces, a tripod with precision motorized equatorial mount, a subscription to Astronomy Today, a genuine moon rock autographed by Buzz Aldrin, a bumper sticker that reads **ASK ME ABOUT MY CASSEGRAIN**, and a t-shirt with glow in the dark letters that says *I ♥ STARS!*

15. You are driving down a long straight stretch of the interstate, and see a car coming towards you in the distance. If the vehicle is a distance **d = 3 km** away, and a pair of headlights is typically about **s= 1 m apart**, what is the angular separation of the headlights?
    A) θ = 0.115 arcmin   C) θ = 11.5 arcmin
    B) θ = 1.15 arcmin   D) θ = 1.15°

16. At that distance of 3 km, can you (with a typical human eye having 2' resolution) resolve the individual headlights? Do you see two separate lamps, or a single smeary blur?
    A) Smeary blur.   B) Two separate lights.

17. As the car continues to approach you,
    A) the angular separation of the headlights increases.
    B) the angular separation of the lights decreases.
    C) the angular separation remains the same.

18. What does the "seeing" refer to?
    A) Clouds. The seeing is poor when the sky is cloudy.
    B) Light. In an urban area with a lot of street lights, the seeing is limited.
    C) Air. Even on a clear, dark night the seeing might be poor due to humidity and/or the movement of the air itself.
    D) Interstellar dust, which prevents us from seeing planets.

19. Compare the diffraction-limited resolution of the **10m Keck** to the **30m TMT**. For observations made at the same wavelength, the TMT will theoretically have
    A) 3x better resolution.   C) 30x better resolution.
    B) 9x better resolution.   D) 90x better resolution.

20. Why is it impossible for ground-based telescopes to achieve their diffraction-limited resolution?
    A) Light pollution. Too many bright lights from too many cities interfering with the telescopes.
    B) Dust pollution. The more dust and smog in the air, the dirtier the mirrors get. And they can't really be cleaned with Windex and a paper towel, you know.
    C) Noise pollution. Because sound waves are vibrations, they cause the mirror to shake.
    D) Atmospheric blurring. The motion of molecules in the air distorts the incoming light, resulting in a twinkling effect.

21. At a wavelength of **550nm** (right in the middle of the visible), the TMT should have a diffraction-limited resolution of **α = 0.005arcsec**. When the telescope sees first light in 2021, you will expect
    A) it to be awesome! Ground-based telescopes have no problem achieving resolutions equal to the diffraction limit.
    B) to be disappointed. There is no way to construct a ground-based telescope to get a resolution better than about 1°, so building a bigger dish is kind of pointless.
    C) amazing resolution, though not as low as the diffraction limit. Current predictions stand at about 0.015 arcsec resolution limit.
    D) it to be underwater, what with all the global climate change and rising sea levels and all.

22. How do **adaptive optics** improve the resolution of ground-based optical telescopes?
    - A) Adaptive optics applies Einstein's theory of relativity to the incoming light, and predicts which direction you should point the secondary (and tertiary) mirrors.
    - B) Adaptive optics do not improve the resolution of a telescope, it increases the light gathering power and image magnification.
    - C) By splitting off a portion of the incoming signal, the wave can be analyzed and the dynamic mirror can be adjusted to compensate for atmospheric blurring.
    - D) Adaptive optics is a fancy way to say "glasses." It is the equivalent of prescribing a pair of glasses to a nearsighted person. A lens is placed in front of the primary mirror to focus the light.

23. The Very Large Array (VLA) consists of 27 radio telescopes, each having a primary dish 25m across. Why such big dishes?
    - A) Radio waves are very high energy, and without a big surface area, they will just bounce right back out of the dish.
    - B) Radio waves have a very short wavelength, so they are hard to catch. You want a big dish to maximize your chances.
    - C) Because you will use the same manufacturing process as you use to make large mirrors, so you might as well make them big. There is no physical reason they have to be that large.
    - D) Radio waves have long wavelength and low energy. There also are not many of them. Because it's "drizzling" radio waves and not "pouring," you want the biggest "bucket" you can get to collect them in.

24. Space telescopes: *why*?
    - A) It is impossible to observe much of the e·m spectrum using ground-based telescopes. Space telescopes are necessary view the entire spectrum.
    - B) They are easy to build, inexpensive to launch, and cheap to maintain. It is far more cost-effective to design and deploy space telescopes than ground-based telescopes.
    - C) It's not about observing the entire e·m spectrum, and it's not about saving money. It's about aliens. We are placing scopes in space to demonstrate our obedience to our alien overlords.

25. The Hubble Space Telescope has a 2.4m primary mirror. The James Webb Space Telescope will have a primary just over 6m across. Spitzer has a primary only 0.85m in diameter. Why are all these space telescopes so small?
    - A) Because the size of the primary mirror of a telescope does not matter.
    - B) Because these telescopes are in space, they do not have to contend with atmospheric blurring. A smaller mirror can yield better resolution.
    - C) These telescopes are all observing gamma rays, which have a very small wavelength and therefore can be seen using a small primary.
    - D) Large mirrors are always better, but they are expensive to launch. Space telescopes are small because of the cost, which is why the resulting images are always so terrible.

26. The Spitzer Space Telescope
    - A) observes using visible light, and the resulting images appear exactly as you would see them.
    - B) observes short wavelength UV, which is why the images you see are always blue and purple.
    - C) observes in the infrared range of frequencies. The images must be presented in false color, since your eyes are not sensitive to IR.
    - D) is a radio telescope, which means that the images are not images at all, they are actually sounds. You have to listen, as opposed to look.

For Questions 27–32, use the following set of multiple choices. You may use responses more than once!

- A) This characteristic is most typical of the **terrestrial** planets.
- B) This characteristic is most typical of the **jovian** planets.
- C) This characteristic is most typical of a **comet**.
- D) This is a general characteristic shared by **both terrestrial and jovian** planets.
- E) This is **not typical** of any planet *or* comet found in the solar system!

27. Small size but high density: A
28. Low eccentricity orbit: D
29. Metallic core containing iron and nickel: A
30. Undifferentiated rock/ice internal structure: C
31. Rings and moons: B
32. High orbital inclination with respect to the ecliptic: C

33. If you are looking for asteroids, where would you **least** expect to find them?
    - A) In low-eccentricity, prograde orbits between Mars and Jupiter.
    - B) In highly eccentric orbits which take them inside the orbit of Mercury at perihelion, and farther out than Pluto at aphelion.
    - C) In the same orbit as Jupiter, clustered at the LaGrange points L4 and L5, leading and trailing Jupiter by 60°.
    - D) All three of the above locations are typical places you find large numbers of asteroids.

34. The density of the **Earth** is **5,500 kg/m^3**. The density of **Saturn** is only **700 kg/m^3**. Individual objects in the asteroid belt will have different compositions and densities, but on average the densities are closest to
    - A) 700 kg/m^3. Asteroids are almost identical to the gas giant planets in composition.
    - B) 1,000 kg/m^3. This is the density of water. Asteroids are made of pure water ice.
    - C) 3,000 kg/m^3. Asteroids may have some metal, and may have some ice, but are generally rocky.
    - D) 5,500 kg/m^3. The asteroids are identical to the Earth in composition, just smaller.
    - E) 7,800 kg/m^3. This is the density of iron, and the asteroids are overwhelmingly made of 100% pure iron.

35. Ceres is located in the asteroid belt, but it gets classified as a **dwarf planet**. Why?
    - A) It is made of mostly water ice and bits of rock, similar to other dwarf planets like Pluto.
    - B) It is large enough to have assumed a spherical shape, but not large enough to clear its orbit.
    - C) Because it is the largest remnant of a much larger planet that used to exist between Mars and Jupiter. Until it exploded. Stupid aliens.
    - D) Because it was given a name, not just a numerical designation. Once you give an object an actual name, it becomes a planet.

36. True or false: There is no record or evidence of any kind to suggest that asteroids ever did, or ever will, collide with the Earth.

37. Distinguish between a **meteoroid** and a **meteorite**.
A) No distinction. Different words, same thing.
B) Meteorites are old, meteoroids are young.
C) A meteoroid in space will become a meteorite if it survives the fiery passage through the Earth's atmosphere and lands on the planet!
D) When you see a shooting star blazing across the sky, it is a meteorite. The meteoroid is what hits the ground (if anything is left).

38. What are comets made of?
A) Creamy vanilla soft serve studded with chunks of delicious chocolatey sandwich cookies.
B) A comet will typically have a solid iron core surrounded by a rocky mantle.
C) Comets are, like the whole rest of the universe, 90% pure hydrogen, 9% helium, and 1% everything else.
D) Comets are predominantly made of water ice, with small amounts of other ices. Embedded in the ice will be random bits of rocky material, ranging from specks of dust to the size of boulders.

39. Which of the following is **not** characteristic of a comet's orbit?
A) A comet will have a very high orbital eccentricity.
B) Comets may orbit the sun in either the pro- or retro-grade direction.
C) The orbital inclination of a comet might be large, tilting out of the plane of the ecliptic.
D) Comets take only weeks, or at most several months, to complete a single orbit around the sun.

40. On August 11, you should be able to step outside and view the Perseids, a meteor shower.
A) Catch this if you can! Every meteor shower is a unique event, and if you miss it…well, I guess that's one thing you will never be able to cross off your bucket list.
B) This is the result of a predicted near-miss with an Earth-crossing asteroid. It might not even happen, we won't know until astronomers are able to better predict the path of the asteroid.
C) The Perseids are an annual event. Meteor showers in general are the result of the Earth crossing the debris field left behind by a comet.
D) The Perseids are the result of comet debris, but the shower does not happen annually. It only happens when the comet is close to the sun, which won't be for another 415 years.

41. All of the planets are spinning on their axes in the same direction, except Venus and Uranus.
A) The unusual rotations of these planets is evidence for violent collisions between the planets and other large objects early in the formation of the solar system.
B) Venus and Uranus evolved with retrograde rotation, which demonstrates the law of conservation of angular momentum.
C) The retrograde rotation of these planets is a clear *violation* of the law of conservation of angular momentum.
D) Not true. The direction of the spin of any planet is completely random, and cannot be used to form any hypotheses about planet formation.

42. The Kepler mission to detect extrasolar planets uses
A) the changing radial velocity of the star (wobble) as the planet tugs on the star while it orbits.
B) starlight reflected from the surface of the planet, or direct observation (just like we can directly observe Mars or Jupiter, for example).
C) the transit method: A planet passing in front of its parent star will block a small amount of the starlight every time it completes an orbit.
D) radio signals broadcast from the planet. A planet with intelligent life will be sending out radio and TV signals (like we have been doing for almost a century now).

43. True or false: Planetary systems seem to be fairly common, and over 3000 extrasolar planets have been discovered and confirmed since 1989.

44. True or false: Direct imaging is the most productive method for detecting extrasolar planets.

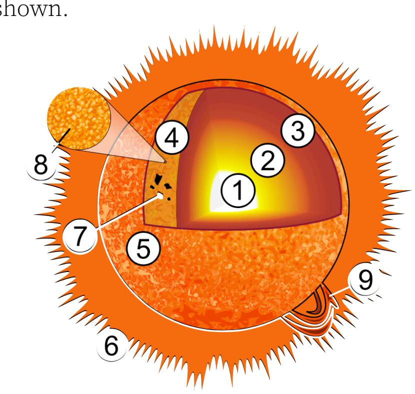
45. True or false: The easiest extrasolar planets to detect will be the largest planets, orbiting the closest to their parent star.

46. *Rogue Planet!*
A) Possibly a bad sci-fi movie from the 1950s?
B) The term astronomers use to describe a planet which orbits its star in a retrograde direction.
C) Any planet with an axial tilt greater than 20° is considered a rogue planet.
D) A planet (typically larger than Jupiter) which is not orbiting any star, but is hurtling through space.

47. If you were predicting what a planetary system surrounding a distant star might look like, which of the following features would you include?
A) Multiple planets.
B) Low eccentricity orbits.
C) One or more planets as large or larger than Jupiter.
D) Debris fields (similar to our own asteroid belt).
E) All of these features are reasonable, and have in fact been observed at least once.
F) *None* of these features are realistic; not one planetary system has been observed with *any* of these properties.

48. The Earth has a warm asteroid belt between Mars and Jupiter, and a cold outer belt of comet nuclei beyond Pluto.
A) This is very unique; no other star has been observed with features resembling these debris fields.
B) This is very common; just about every exoplanet discovered is part of an asteroid belt circling its parent star.
C) This is very similar to features observed surrounding the star Vega, but it remains unknown whether asteroid belts are a common occurrence.
D) Wait, what? No, the Earth does not have an asteroid belt. Neither does it have a belt of comet nuclei out beyond Pluto. Silly to even suggest it.

The figure below represents the sun, with 9 distinct features or areas labeled. Use the figure to identify each of the features shown.



49. Region 1:
A) Radiative zone.
B) Convective zone.
C) Core.
D) Photosphere.
E) Prominence.
F) Chromosphere.

50. Region 02:
    A) Radiative zone.
    B) Convective zone.
    C) Core.
    D) Photosphere.
    E) Prominence.
    F) Chromosphere.

51. Region 03:
    A) Radiative zone.
    B) Convective zone.
    C) Core.
    D) Photosphere.
    E) Prominence.
    F) Chromosphere.

52. Which of the numbered features illustrates the **granulation** on the solar photosphere? 8

53. Which of the numbered features or regions represents the **solar corona**? 6

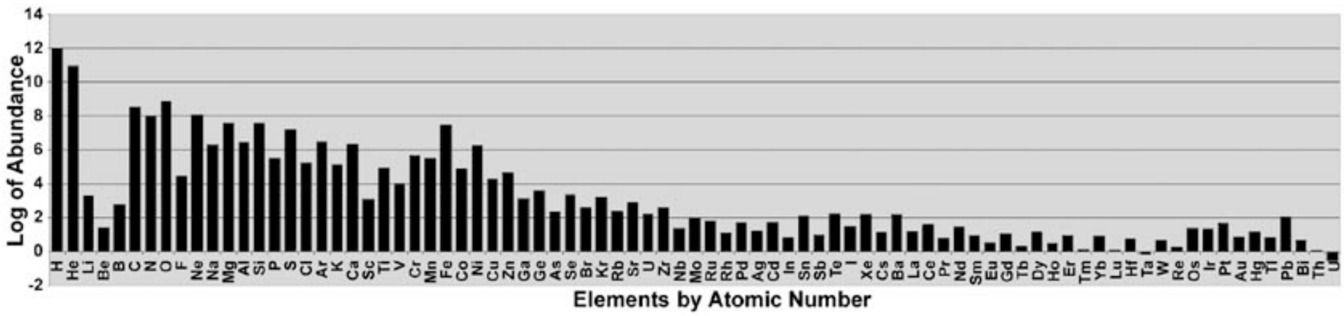
54. True or false: It is easily possible to send probes into the solar interior to directly determine its structure.

55. True or false: If you could stand at the very core of the sun, it would seem transparent (like the air we breathe).

56. True or false: It takes a very long time for energy to traverse the radiative zone (as long as 10,000 years!), because of repeated electron absorptions and emissions.

57. When a star, like the sun, is in a state of **hydrostatic equilibrium**, what counteracts the inward pull of gravity?
    A) Nothing. The star will continue to collapse due to gravity, gradually getting smaller and dimmer with time.
    B) The electrostatic repulsion of positively charged hydrogen nuclei pushing away from each other.
    C) Ironically enough, more gravity. Positive protons pull inwards, but this is balanced by the negative gravity of the negative electrons.
    D) Thermal pressure. As a gas heats up, the atoms move more rapidly, spreading out and creating an outward force opposing gravity.

Use the bar chart of solar abundances below to answer Questions 58 and 59.



58. What is the overall composition of the sun?
    A) 100% hydrogen. Nothing else.
    B) 12% hydrogen, 11% helium, 3% lithium, etc.
    C) 90% H, 9% He, and 1% everything else.
    D) Unknown. It is impossible to truly measure.

59. Compare the solar abundance of **hydrogen (H)** to **nitrogen (N)**. The ratio of **H:N** is *closest* to
    A) 1:1. Equal amounts of H and N.
    B) 12:8. Twelve H atoms for every 8 N atoms.
    C) 10^4:1. Ten thousand times more H than N.
    D) Unknown. Since the bar chart is pure speculation, there is no way to actually compare the H and N.

60. What color does the solar **chromosphere** appear?
    A) It doesn't. The chromosphere has no color.
    B) The sun appears yellow because the chromosphere is yellow.
    C) Molecules of iron oxide (literally, rust) form in the chromosphere, and appear reddish.
    D) The pink color is the result of the H-α emission line, which is red.

61. Why is the temperature of the solar corona so high (literally more than 10^6K) ?
    A) This is incorrect; the corona is the outermost, and therefore the coolest layer of the sun. Maybe 106K, but definitely not 10^6K!
    B) The solar corona is where hydrogen fuses into helium, and the resulting energy release heats up the corona dramatically.
    C) The temperature correlates to the kinetic energy of the solar particles. This coronal hydrogen is moving very fast–fast enough to escape the sun entirely.
    D) The solar corona is constantly absorbing the heat energy from the center of our Milky Way galaxy.

62. The sun is losing mass as particles are carried away by the solar wind. How much mass?
    A) About 1 million tons every second.
    B) About 1 million tons every day.
    C) About 1 million tons every week.
    D) Inconceivable! If the sun was losing mass that fast, it would have disappeared a long time ago!