Astronomy 1140 Quiz 2 Review

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Light

1. What is light?
   - Light is electromagnetic energy.
   - It is both a particle (photon) and a wave.
2. How is light created and what can light interact with?
   - Light is created by moving electric charges, like electrons.
   - Light can only interact with particles that have an electric charge, like electrons.
3. How is the wavelength of light related to its frequency?
   - $c = \lambda f$, where c is the speed of light ($c = 300,000,000$ m/s), λ is the wavelength, and f is the frequency.
4. What are the units for frequency and wavelength?
   - Frequency is measured in hertz (Hz), which are inverse seconds $1/s$.
   - Wavelength is measured in many units of distance depending on how big it is, from angstroms (Å, 1 Å = 10^{-10} m) to nanometers (nm, 1 nm = 10^{-9} m) to millimeters, centimeters, or even meters or kilometers for very long waves. Mostly we're interested in light with wavelengths the size of a few thousand angstroms, like visible light.
5. What is the speed of light? Can anything move faster than light?
   - Roughly $c = 300,000,000$ m/s. Nothing can travel faster than light.
   - This means when we see the Sun's light, since the Sun's light takes 8 minutes to make it to Earth, we see the Sun as it was 8 minutes ago, not as it is now.
6. List the electromagnetic spectrum from highest energy to lowest energy. Note that this is also the list from shortest wavelength to longest wavelength.
   - Gamma rays, X-rays, ultraviolet, visible, infrared, microwaves, radio waves.
7. What wavelength range is visible light?
   - 4000Å(blue) to 7000Å(red) is visible, but the human eye is most sensitive in the somewhat reduced range of 5000Å to 6000Å.
8. How does the energy of a photon relate to other properties of light?
   - $E = hf = hc/\lambda$, where E is the energy of a photon, f is its frequency, λ is its wavelength, c is the speed of light, and h is Planck's constant.

- Since the speed of light is constant, that this means that knowing a photon's energy, wavelength, or frequency is equivalent to knowing the other two.
- A higher energy corresponds to a shorter wavelength and a larger frequency. A longer wavelength is a lower energy and smaller frequency.

Atoms and Spectroscopy

1. What subatomic particles make up the atom?
    - Protons and neutrons in the nucleus, electrons in "orbits" around them.
2. How many protons, electrons, and neutrons does a hydrogen atom have?
    - One proton and one electron, no neutrons. A neutral atom (an atom without any charge) always has equal numbers of protons and electrons.
    - The number of protons in the nucleus, known as the "atomic number", separates distinct atoms. Hydrogen has 1 proton. Helium, the second element, has 2 protons.
3. Can electrons be anywhere around the nucleus? Why do they orbit the nucleus?
    - No. Electrons *must* be in specific orbits around the nucleus with specific amounts of energy. They cannot be in arbitrary orbits!
    - Electrons orbit the nucleus because they are negatively charged, whereas the nucleus is made of positively charged protons.
4. What happens when an atom emits light? What is the energy of that light?
    - An atom can emit light when one of its electrons is in a large, high-energy orbit around the nucleus, and then the electron moves to a smaller, lower-energy orbit. The energy of the photon that is emitted is *exactly* equal to the energy difference between the two orbits that the electron moved between.
5. What happens when an atom absorbs light? Can an atom absorb light of any energy? Combined with the last question, what does this imply about the wavelengths of absorption and emission for a given gas?
    - An atom can absorb light by moving one of the electrons to a higher-energy orbit than it was originally in. The energy difference between the two electron orbits *must* be equal to the energy of the light, so an atom can't absorb every energy of light. It can only absorb light with the correct energy that matches the energy difference between electron orbits.
    - Since any absorption and emission must be equal to the energy required for an electron to move up or down orbital states, the emission lines of a gas occur at the exact same wavelengths as its absorption lines. Each gas, however, is unique in what its energy levels are, so based on a group of absorption and emission lines, you can determine what a gas is made of from its spectrum alone.
6. What does an emission spectrum look like, in general, for a single element?
    - An emission spectrum will be mostly dark with bright emission lines at the specific energies where the atom can emit light. These energies are equal to energy differences between different electron orbits in the atom. An emission spectrum occurs when a gas is heated (thus exciting the electrons to higher orbits) and tries to cool itself down by emitting photons (as the electrons drop to lower energy orbits).
7. What does an absorption spectrum look like, in general, for a single element?

- An absorption spectrum is mostly bright, with dark absorption lines where light is missing at the specific energies where the atom can absorb light. These energies are equal to the energy differences between different electron orbits in the atom. Here, the incoming light excites the gas by providing light at the proper energies to bump electrons to higher orbits.

8. What are some of the most well-known emission and absorption series of lines of hydrogen, and what part of the electromagnetic spectrum are they in?
   - The Lyman series: the electron transitions from higher-energy orbits to the lowest-energy orbit, seen in ultraviolet light.
   - The Balmer series: the electron transitions from higher-energy orbits to the second lowest-energy orbit, seen in visible light.
   - The Paschen series: the electron transitions from higher-energy orbits to the third lowest-energy orbit, seen in infrared light.
9. What can you learn from looking at the spectrum of a star?
   - You can learn its temperature based on the wavelength where it emits the most energy because of blackbody radiation.
   - You can learn what elements make up its photosphere based on the absorption lines present, since each element has its own distinct pattern of emission and absorption.
   - You can learn how fast it's moving toward or away from us (Doppler effect: see section below).
10. What is a blackbody?
    - A blackbody is a perfect absorber and emitter of radiation. It emits exactly as much radiation as it absorbs.
    - A blackbody has a very distinct emission pattern. From its spectrum, you can directly determine its temperature based on the wavelength of peak emission.

Doppler Effect

1. What causes the Doppler effect?
   - Wavelengths get "squished" when the object emitting them is moving toward you, because the object starts to "catch up" with the wave while it continues to emit. "Squished" here means they get a shorter wavelength/higher frequency. For sound, this means higher pitched. For light, it gets bluer.
   - Wavelengths get "stretched" when the object emitting them is moving away from you, because the object is moving away from the wave while it continues to emit. "Stretched" here means they get a longer wavelength/lower frequency. For sound, this means lower pitched. For light, it gets redder.
2. What kinds of waves exhibit the Doppler effect?
   - All kinds! We observe the Doppler effect in light and sound. In everyday life, it's much easier to observe in sound (think police car siren zooming by you) because sound travels MUCH slower than light. This makes it easier for the object to "catch up" or "leave behind" its sound wave. Objects moving very fast, like stars, have detectable Doppler shifts in the light they emit. Technically even slow-moving objects, like a person walking toward or away from you, exhibit Doppler shifts in the light coming from them, but it's such a small change because walking speed is such a small fraction of the speed of light that you can't detect it with your eye.

3. If a star has an emission line at a particular wavelength λ, will the observed wavelength be longer or shorter if the star moving away from us? What color will this emission line be shifted toward?
    - The wavelength of the star's emitted light will be longer if it's moving away from us. Since red light has longer wavelengths than blue light, this light is shifted toward red, and we say that it is "redshifted."
    - If the star was moving toward us, the light would be "blueshifted" and have shorter wavelength than usual.

Telescopes

1. Why do we use telescopes?
    - The apparent brightness of distant objects decreases with the square of the distance to them, so distant objects are extremely faint.
    - If we can build something that stares at something for a long time and can collect as much light as possible from that thing, then maybe we can see it.
2. What is the difference between a refracting and a reflecting telescope?
    - Refracting: light is bent and focused by passing through glass lenses.
    - Reflecting: light is bent and focused by bouncing off of mirrors.
3. What happens when light passes through a lens?
    - Light travels slower in glass than in air, so the path of light gets bent at the interface between glass and air.
    - Red light doesn't get bent as much as blue light, so there can be **chromatic aberrations** where the image separates into a red image and blue image.
    - This "bending" of light by altering its speed is used to focus a wide area of light down to a pinpoint.
    - Since light doesn't pass through a mirror to slow down, reflecting telescopes do not have chromatic aberrations.
4. Where is the best place to put a telescope?
    - Space! Then we don't have to deal with the Earth's atmosphere, which absorbs mostly UV light.
    - If we can't put a telescope in space, then any place where the atmosphere doesn't cause as many problems: dry, high, dark places.
5. How does the power of a telescope scale with its diameter?
    - Power $= \pi(D/2)^2$, where D is the diameter of the objective lens/mirror. So doubling the diameter will quadruple ($2^2 = 4$) the power. Ignoring atmospheric distortions, a telescope's usefulness is dictated by the power, so size is key.
6. What is the purpose of a telescope's eyepiece?
    - To magnify the focused image. The telescope itself does not magnify anything.
7. List a few of the important telescopes in use today.
    - Keck: Largest optical telescope with a 10 meter diameter, in Hawaii.

- Large Binocular Telescope (LBT): Owned by OSU, has two 8 meter mirrors, in Arizona.
- Hubble Space Telescope (HST): 2.4 meter, but huge advantage because it's in space and doesn't have to see through the atmosphere.
- Arecibo: In Puerto Rico, 1000 foot radio telescope.

8. Would it be wise to build a large UV telescope on a mountain?
   - No! The atmosphere absorbs most UV photons and higher energy photons before they reach the ground.
   - It's only efficient to build telescopes on the ground for types of light that can easily make it through the atmosphere, like optical, radio, and (some) infrared photons.

Relativity

1. What are the two postulates of relativity?
   - Light travels at the same speed for all observers, no matter how fast those observers are traveling, and this speed is the maximum speed anything can move.
   - All physical laws must be the same everywhere.
2. How is the energy of an object related to its mass?
   - $E = mc^2$ where E is the energy, m is the mass, and c is the speed of light.
   - This means there is equivalence between mass and energy. So much like we know all about a photon's energy and frequency from only its wavelength, we can give the energy of an object in terms of its mass (or vice versa) and it mean the same thing.
3. What is the important idea in general relativity?
   - Gravity is just acceleration! If you're traveling on an accelerating vehicle, it feels the same as gravity.
4. What are time dilation and space contraction?
   - Time dilation: Time moves slower for moving observers than for those who are stationary.
   - Space contraction: Objects appear shorter for moving observers than for those who are stationary.

Solar System

1. What are the terrestrial planets? The Jovian planets? What properties do they have in common with the members of their group?
   (a) The terrestrial planets are Mercury, Venus, Earth, and Mars. They are much smaller and closer to the Sun, with higher densities due to their rocky surfaces.
   (b) The Jovian planets are Jupiter, Saturn, Uranus, and Neptune. They are much larger and farther from the Sun than the terrestrial planets. They are also very gaseous and thus much less dense than the terrestrial planets.
2. How massive is Jupiter, the largest planet in our solar system, compared to the Sun?
   (a) Jupiter is about 1/1000th as massive as the Sun!
   (b) On the other hand, it is as massive as over 300 Earths!

3. Why do the Jovian planets have lighter elements in their atmospheres than the terrestrial planets?

   (a) During formation, they became so massive that their gravity was strong enough to maintain hydrogen, the most abundant but also lightest element, at their colder location in the solar system. This let them gather even more material.

   (b) Free hydrogen is much too light to be maintained by Earth's atmosphere because Earth is both less massive and much hotter, meaning the hydrogen would be moving faster. The fast-moving hydrogen can thus easily escape Earth's gravity. Jupiter, on the other hand, is much cooler, so the hydrogen moves much more slowly. Combined with Jupiter's higher mass and thus stronger gravity, nearby hydrogen was captured as the planet formed, making it more massive.