Astronomy 1143 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?
   - 4000 Å(blue) to 7000Å(red) is visible, but the human eye is most sensitive in the somewhat reduced range of 5000Åto 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.

- Note 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, and this causes it to have a certain temperature.
    - 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.
   - 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.
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.

Our Universe

1. Is the universe expanding, contracting, or staying the same? How do we know this?
   - The universe is expanding. We know this because the further away an object is from us, the redder it appears to be. Because of the Doppler Effect, we know this means it must be moving away from us, and objects further from us are moving away faster.
2. What is Hubble's Law?
   - $v = H_0 d$, where v is the velocity of a galaxy (which we can determine from the redshift), d is the distance to that galaxy, and H_0 is Hubble's constant.
3. Using Hubble's law, how can we determine the age of the universe?
   - Since the universe is expanding and must have had a beginning, then $1/H_0$ is the time it took for galaxies to get where they are now.
4. What is the Cosmic Microwave Background?
   - The CMB is radiation left over from the Big Bang. It's a blackbody with a uniform temperature of 2.73 Kelvin pretty much everywhere, except it has some small variations due to the presence of matter right after the Big Bang.
5. How do we know there's dark matter?
   - Stars rotate about galaxies with a speed determined by the mass of the galaxy and how far those stars are from the galaxy's center. This speed should decrease with distance, but we see that it doesn't. Therefore, there must be more mass in galaxies than we can see, so there must be dark matter.
6. What are the most abundant elements in the universe?
   - Hydrogen and helium.

Stars

1. What is a star?
   - A ball of gas with temperatures high enough at the center for hydrogen to be converted into helium via nuclear fusion, which converts mass into energy.
   - The higher temperature is needed because normally two protons do not want to form a helium nucleus due to their repulsion, both being positive charges.
   - Remember, mass is equivalent to energy by $E = mc^2$!
2. How hot is the surface of the Sun?
   - The surface of the Sun is about 5700 Kelvin, and the center is much hotter!

- For comparison, room temperature is about 300 Kelvin.

3. What is the H-R Diagram?
   - The Hertzsprung-Russell Diagram is a plot of stars' luminosity (brightness) vs. temperature. Stars with higher temperatures have higher luminosities. Note that the temperature axis is reversed: higher temperature is on the left, lower temperature on the right (but higher luminosity is still toward the top and lower toward the bottom).
4. How are the luminosity, radius, and temperature of a star related?
   - $L = 4\pi\sigma R^2 T^4$, where L is luminosity, R, is radius, and T is temperature. σ is the Stefan-Boltzmann constant.
   - This means a star is more luminous if it is (a) hotter or (b) larger. A small but very hot star can be more luminous than a cooler but much larger star!
   - Note that the flux, or brightness, you measure from an object depends on how far away you are from it.
5. What other properties of a star increase when the star's mass increases? What decreases?
   - Luminosity, temperature, and size all increase.
   - The star's lifetime decreases because it expends its fuel faster since it has a stronger gravity to counterbalance.
6. What determines the color of a star?
   - Its temperature: hotter stars are bluer and colder stars are redder.
   - Remember blackbody radiation. Hotter stars have a shorter peak wavelength, which means they appear bluer (as blue is shorter wavelength than red).
7. How do we classify stars?
   - Using the spectrum of a star, we can determine its temperature and color, and stars are organized in this way. Stellar types from hottest to coolest are: O, B, A, F, G, K, M, L.
8. Which layer of a star is the part that we see?
   - The photosphere. This is easy to remember because it's almost has "photon" right there in the name!