

OpenStax Astronomy, Ch.5: WS Solutions (Apr-2021)

Solutions

1. What distinguishes one type of electromagnetic radiation from another? What are the main categories (or bands) of the electromagnetic spectrum?

The different bands of the spectrum each have a characteristic wavelength or frequency range. In order from lowest to highest frequency, the main bands are: radio, microwave, infrared, visible, ultraviolet, X-ray, and gamma ray.

2. Explain how emission lines and absorption lines are formed. In what sorts of cosmic objects would you expect to see each?

Emission lines are formed when an atom's electron moves from a higher to a lower energy level, and that atom then emits a photon with a particular wavelength that corresponds to the energy difference between the two levels. You can see this in a low density gas cloud heated by light from a nearby star. Absorption lines are caused when light passes through a cloud and some photons with energies corresponding to differences in energy levels in a given element are "consumed" by atoms to push their electrons to higher energy states. This can occur when observing a continuous light source through a gas cloud or a planetary atmosphere that intercepts some of the photons that pass through it.

3. What kind of motion for a star does not produce a Doppler effect? Explain.

Transverse (sideways) motion (perpendicular to your line of sight to the object) does not produce a Doppler shift since there is no motion either toward or away from the observer.

4. Explain why light is referred to as electromagnetic radiation.

Light is an example of electromagnetic radiation, which encompasses a broad spectrum of waves. Light is a traveling wave of oscillating electric and magnetic fields.

5. Explain why astronomers long ago believed that space must be filled with some kind of substance (the "aether") instead of the vacuum we know it is today.

Astronomers thought that light, like other waves, needed some medium through which to propagate (like sound moves through air, water, or solids), and since we get light from distant planets and stars, they thought space must therefore be filled with a substance like the aether to be a medium for traveling light waves. We now know light does not require a medium to propagate.

6. Explain what the ionosphere is and how it interacts with some radio waves.

The ionosphere is a layer of charged particles at the top of our atmosphere, mostly ionized by interactions with sunlight and the solar wind. Some longer wavelength radio waves (such as AM radio) cannot penetrate this region and so the ionosphere scatters these waves in many directions. Under the right conditions, the ionosphere sometimes acts like a radio mirror, reflecting these waves back to the surface (hence the reason you can hear some powerful AM radio stations from more than 1,000 miles away at night).

7. Explain why we have to observe stars and other astronomical objects from above Earth's atmosphere in order to fully learn about their properties.

While we can see the visible light of planets, stars, and galaxies from the ground, much of the electromagnetic radiation emitted by these objects is not emitted in the visible part of the spectrum. Some of the radiation is emitted in a part of the spectrum that doesn't penetrate Earth's atmosphere easily (like ultraviolet, X-rays, gamma rays, and some parts of the infrared and radio bands of the spectrum). In order to observe the radiation emitted at all different wavelengths by astronomical objects, we have to also observe them from above the atmosphere.

8. Explain how we can deduce the temperature of a star by determining its color.

According to Wien's law, the peak wavelength of a blackbody spectrum is inversely related to its temperature. The color of a star is indicative of where the peak wavelength of its spectrum is located, so color can indicate to us the temperature of a star. Bluer stars are hotter, whereas red stars are cooler.

9. Explain why glass prisms disperse light.

When light passes through one edge of a prism, it goes from the air into glass, bending the light. The light bends (refracts) differently for different wavelengths, dispersing the colors. When the light comes out of the other side of the prism, it goes from glass into air, but since the other side of the prism is at a different angle, the dispersing effect continues. So the prism refracts different wavelengths of light at different angles, and "white light" is turned into a rainbow.

10. Explain how we use spectral absorption and emission lines to determine the composition of a gas.

As light passes through a gas, each specific element (or type of molecule) in a gas will leave a unique pattern of absorption lines. Likewise, if a gas is heated, each specific element will emit a unique pattern of emission lines. We know which patterns go with which elements (or molecules) and so we can use these "spectral fingerprints" to deduce the composition of the gas.

11. Is it possible for two different atoms of carbon to have different numbers of neutrons in their nuclei? Explain.

Yes, what determines the element is the number of protons in the nucleus, so any nucleus that has six protons is carbon, regardless of whether it has six, seven, or eight neutrons.

12. Explain why astronomers use the term "blueshifted" for objects moving toward us and "redshifted" for objects moving away from us.

Objects moving toward us appear to have their light shifted to a shorter wavelength. In the visible spectrum, the short wavelength end of the spectrum is blue (or violet), so we use "blueshifted" as shorthand for "shifted to a shorter wavelength." The color red is at the longest wavelength end of the visible spectrum, so objects moving away from us that have their light shifted to longer wavelengths are similarly called "redshifted."

13. If spectral line wavelengths are changing for objects based on the radial velocities of those objects, how can we deduce which type of atom is responsible for a particular absorption or emission line?

We look for patterns of wavelengths associated with each element rather than a single specific line, so even if a particular line has been shifted in an unknown



direction, we look for other lines in the pattern that may be similarly shifted in order to identify an element or molecule.



14. With what type of electromagnetic radiation would you observe:

- A. A star with a temperature of 5800 K?
- B. A gas heated to a temperature of one million K?
- C. A person on a dark night?

A. visible light; B. X-ray; C. infrared; According to Wien's law, the wavelength in nanometers at which a blackbody emits its maximum energy is given by the relationship $\lambda_{\text{max}} = 3,000,000 \text{ nm K/T}$. Let's assume that each of the objects named behaves approximately like a blackbody. Then the star emits its maximum radiation at 517 nm, which corresponds to visible light (green) radiation. A gas with a temperature of 1,000,000 K emits its maximum radiation in the form of X-rays with a wavelength of 3 nm. A person at a normal temperature of 98.6 °F, or 310 K (see Appendix D or conversion from Fahrenheit to kelvin temperature scales) radiates maximum energy at 9680 nm, and so the infrared is the region in which to detect a person on a dark night.

15. Why is it dangerous to be exposed to X-rays but not (or at least much less) dangerous to be exposed to radio waves?

X-rays are much more energetic with wavelengths much smaller than most biological organisms, so they can do damage to cells and biological organisms. Radio waves are much longer than most biological organisms and much less energetic, so there is very little interaction between organic material and radio waves.

16. Go outside on a clear night, wait 15 minutes for your eyes to adjust to the dark, and look carefully at the brightest stars. Some should look slightly red and others slightly blue. The primary factor that determines the color of a star is its temperature. Which is hotter: a blue star or a red one? Explain.

Blue stars are hotter. Their radiation curve peaks at a shorter, more energetic wavelength or higher frequency.

17. Water faucets are often labeled with a red dot for hot water and a blue dot for cold. Given Wien's law, does this labeling make sense?

Given that bluer objects are hotter than redder for blackbodies, it is backward.

18. Suppose you are standing at the exact center of a park surrounded by a circular road. An ambulance drives completely around this road, with siren blaring. How does the pitch of the siren change as it circles around you?

The frequency (pitch) only changes if the motion of the siren is toward you or away from you. If the ambulance is driving in a circle around you, the pitch should remain constant since the motion is all transverse.



19. The greenhouse effect can be explained easily if you understand the laws of blackbody radiation. A greenhouse gas blocks the transmission of infrared light. Given that the incoming light to Earth is sunlight with a characteristic temperature of 5800 K (which peaks in the visible part of the spectrum) and the outgoing light from Earth has a characteristic temperature of about 300 K (which peaks in the infrared part of the spectrum), explain how greenhouse gases cause Earth to warm up. As part of your answer, discuss that greenhouse gases block both incoming and outgoing infrared light. Explain why these two effects don't simply cancel each other, leading to no net temperature change.

Only a small portion of the incoming radiation is in the infrared part of the spectrum. Most of the incoming energy is in the visible part of the spectrum, so only a small fraction of the incoming radiation is blocked by the atmosphere. For outgoing radiation from Earth, a large fraction is in the infrared part of the spectrum. Since this is blocked from escaping, there is a net gain in Earth's energy leading to a warming effect.

20. What is the temperature of a star whose maximum light is emitted at a wavelength of 290 nm?

$$\lambda_{\max} = 3 \times 10^6 \text{ nm K}/T, \text{ so } T = 3,000,000 \text{ nm K}/290 \text{ nm} = 10,350 \text{ K}$$

