Answers to EMR & Telescopes Homework

Selected Answers

1. For a given medium the speed of a wave remains constant and the wavelength decreases as the frequency increases. The wavelength is inversely proportional to the frequency.
2. a. 1480 m/s
   b. 1.34 m
3. a. 303 m
   b. 3.22 m
4. a. 6.0×10^{14} Hz, g
   b. 4.3×10^{14} Hz, r
   c. 5.1×10^{14} Hz, y
5. a. Visible light and other types of EMR (radio, microwave, infrared, ultraviolet, X-ray, gamma) are all transverse waves with a medium consisting of electric and magnetic fields. All of these phenomena travel through a vacuum at the same speed.
   b. Visible light is simply the particular EMR range of frequencies and wavelengths that the human eye is capable of detecting.
6. a. The key RIVUXG indicates the type of EMR used to create the image.
   b. RIVUXG = radio, infrared, visible, ultraviolet, X-ray, gamma
   c. RIVUXG is in order of increasing frequency and energy per photon and decreasing wavelength.
7. 2.5×10^{16} Hz, 12 nm
8. 0.60 μm to 29 μm: some visible light (orange and red) and infrared
9. a. The colors of a rainbow are produced by reflection, refraction, and dispersion. The light from the Sun refracts (bends) when it enters a raindrop, reflects off of one side of the raindrop and emerges and refracts again, exiting the raindrop moving in nearly the reverse direction (back toward the observer). The colors are due to dispersion upon entering and exiting the raindrops – more or less bending due to refraction depending on the wavelength and color of the light.
   b. Multi-path distortion and degradation of a radio signal is the result of destructive interference and reflection. The radio receiver gets two waves – one from the broadcast tower, and another that has reflected off a building or landform. If the two waves arrive at the receiver out of phase and out of sync then the resulting signal strength is decreased.
10. a. The radio window means that Earth's atmosphere is transparent to this type of wave. It is a "window" in the sense that the atmosphere is opaque to other types of waves and so absorbs and prevents certain EMR from reaching the ground.
    b. The optical window allows visible light and some (but not all) infrared to reach the ground.
11. a. Blackbody radiation is the natural emission of energy from any object or substance. It is more pronounced the warmer the object is.
    b. As the temperature increases the wavelength of the emitted blackbody radiation shifts toward shorter wavelengths and greater frequencies.
    c. As the temperature increases the intensity of the emitted blackbody radiation increases at all wavelengths and frequencies.

12. Rigel has a pronounced bluish color and Betelgeuse has an orange-red appearance. As such, Rigel has a greater temperature – its spectrum is shifted toward shorter wavelengths and greater frequencies, which is the blue/violet side of the visible spectrum. Betelgeuse's lower temperature has the opposite effect.
13. 5900 K
14. a. 3.1×10^{15} Hz, UV
    b. 3.1×10^{14} Hz, IR
15. 9.4×10^{-6} m, 3.2×10^{13} Hz, IR
16. a. The Doppler effect is the change in frequency and wavelength caused by motion of the source of a wave and/or the observer of a wave.
    b. Redshift is an increase in wavelength and decrease in frequency of EMR observed coming from a source that is moving away from the observer.
    c. Blueshift is an decrease in wavelength and increase in frequency of EMR observed coming from a source that is moving toward from the observer.
17. a. The radar signal that bounces off a baseball has the same speed before and after the reflection. However because the baseball is approaching the radar gun the reflected signal exhibits the Doppler effect – an increase in frequency, decrease in wavelength compared to the original signal.
    b. Because it is a shift toward higher frequency lower wavelength it is called "blueshift" even though the radar signal is at no point in the visible spectrum and so is never actually "blue" in color.
18. a. Spectroscopy is one of the main ways that astronomers can "decode" and "extract" information coming from objects that are extremely far away in space.
    b. The prism or diffraction grating causes the separation of incoming radiation into identifiable wavelengths and frequencies – a spectrum. For example white light is separated into the range of colors ROYGBIV.
19. The emission spectrum of a certain element has lines that occur at the exact same wavelengths as the absorption spectrum of the same element. In other words it is the same pattern of lines (except dark instead of bright). This is because each unique bright line is caused by an electron moving from a higher orbital to a lower orbital resulting in a photon of particular energy and wavelength being emitted. If the exact same energy photon is absorbed by the atom it can cause the reverse change of the electron from the same lower orbital back to the same higher orbital.
20. In order to be absorbed photons would have to have the correct amount of energy that equals a particular jump up in orbitals for some of the atoms in the gas. And, there must be at least some electrons that are in the particular "lower orbital" that are "ready" to be boosted to the higher orbital.
21. a. The continuous spectrum of the Sun is the blackbody radiation coming from its denser central parts (its "main body"). This is the "sufficiently dense gas" mentioned in Kirchoff's law regarding continuous spectra.
    b. The absorption spectrum of the Sun is due to absorption of certain photons – this is occurring in the less dense parts of the Sun's outer layer (its "atmosphere"). This is a "thin, low density" and relatively cool gas mentioned in Kirchoff's law regarding dark line spectra. Although the gas is actually quite hot it is cool relative to the lower layers of the Sun.
22. In order for hydrogen atoms to absorb at the "alpha line" there must be electrons located in the second energy level – the alpha line correlates to transitions between orbitals 2 and 3. If

the atoms in the gas have electrons mainly in the "ground state" orbital 1 then the alpha line cannot occur. Nor can it occur if the atoms in the gas have electrons mainly located in orbitals 3 or higher.

23. A molecule has unique energy states that correspond to vibration or rotation, whereas a monatomic substance does not.
24. a. If the same lines appear then the two stars must possess the same elements identified by the particular patterns of lines.
    b. Greater width of star B's lines can be caused by higher temperature (thermal broadening) and/or greater rate of spinning (rotational broadening).
25. As temperature increases emission lines may grow broader due to the Doppler effect – faster moving atoms have significant redshift and blueshift away from the central wavelength of the line. Also some lines may increase in intensity while other lines in the emission spectrum may decrease in intensity. At higher temperatures the excited atoms would tend to have electrons present in higher orbitals. This may decrease the likelihood of some lines but increase the likelihood of others.
26. Greater diameter telescopes allow for increased light gathering capabilities and hence greater sensitivity and ability to detect and image very dim and distant objects. Also, greater diameter decreases the relative effect of diffraction. The diffraction limit is decreased, which means that it is possible to get increased resolution provided that the telescope design and manufacture is good enough.
27. Refractors use a lens as the primary optical element, whereas reflectors use a mirror. Reflectors are less expensive and easier to manufacture for a given size. Reflectors do not suffer from chromatic aberration like refractors do. Reflectors are more efficient at handling light – absorption cannot occur like it can with a refractor, and so a greater percentage of the incoming light makes it to the eyepiece or detector.
28. a. Aberration refers to inability to produce an exact focus of light.
    b. Incorrect shape of the lens or mirror is generally referred to as "spherical aberration" because a spherical shape is not ideal.
    c. Chromatic aberration can cause false color because it means that light of different wavelengths and colors focus at different locations.
29. Radio telescopes need to be very large because radio emission by astronomical objects is usually quite weak so great "light gathering ability" and sensitivity is required. Also, because the wavelength of radio is relatively long the effect of diffraction is more pronounced. In order to decrease the diffraction limit on the resolution a very large diameter is needed.
30. a. The atmosphere causes blurring due to the turbulence and layers of air.
    b. Because HST is in space it is extremely inconvenient and expensive to repair or maintain. Also space is a harsh environment and relaying information back and forth is challenging.
31. a. Digital images are better because the detector chips used to capture the image are much more sensitive to light than film. Also digital images are convenient for processing on a computer. For example "stacking" multiple images of the same object allows astronomers to reduce the blurring effect of the Earth's atmosphere.
    b. Digital images are subject to the same technological glitches and shortcomings as any electronic file. Images can be lost or erased or corrupted. Also file formats can become obsolete and "lost" such that older images may be unreadable.

32. a. Adaptive optics is a system where the mirror of a telescope has an adjustable shape. The shape is continuously adjusted by a computer to counteract the blurring effect of the Earth's atmosphere and maintain a sharp focus.
    b. Earth's atmosphere is opaque to some wavelengths. Adaptive optics is no help in this case. Therefore it is still necessary to make some observations from above the atmosphere.
33. a. 35 times
    b. 15 times
34. 17 mm
35. 12 inches (0.30 m)
36. a. 0.25″
    b. 0.01″
37. a. 0.003″
    b. 0.005″
38. a. 6000 km
    b. 300 km
    c. 6 km
39. a. 1650 times
    b. 0.74″
40. 8.2 times as sensitive
41. 6.67 minutes (6 m), 1.67 minutes (2 m)
42. 4 minutes