5.E: Radiation and Spectra (Exercises)

For Further Exploration

Articles

Augensen, H. & Woodbury, J. “The Electromagnetic Spectrum.” *Astronomy* (June 1982): 6.

Darling, D. “Spectral Visions: The Long Wavelengths.” *Astronomy* (August 1984): 16; “The Short Wavelengths.” *Astronomy* (September 1984): 14.

Gingerich, O. “Unlocking the Chemical Secrets of the Cosmos.” *Sky & Telescope* (July 1981): 13.

Stencil, R. et al. “Astronomical Spectroscopy.” *Astronomy* (June 1978): 6.

Websites

Doppler Effect: http://www.physicsclassroom.com/clas...Doppler-Effect. A shaking bug and the Doppler Effect explained.

Electromagnetic Spectrum: http://imagine.gsfc.nasa.gov/science...spectrum1.html. An introduction to the electromagnetic spectrum from NASA’s *Imagine the Universe*; note that you can click the “Advanced” button near the top and get a more detailed discussion.

Rainbows: How They Form and How to See Them: http://www.livescience.com/30235-rai...explainer.html. By meteorologist and amateur astronomer Joe Rao.

Videos

Doppler Effect: www.esa.int/spaceinvideos/Vid...ion_video_VP05. ESA video with Doppler ball demonstration and Doppler effect and satellites (4:48).

How a Prism Works to Make Rainbow Colors: https://www.youtube.com/watch?v=JGqsi_LDUn0. Short video on how a prism bends light to make a rainbow of colors (2:44).

Tour of the Electromagnetic Spectrum: https://www.youtube.com/watch?v=HPcAWNlVl-8. *NASA Mission Science* video tour of the bands of the electromagnetic spectrum (eight short videos).

Introductions to Quantum Mechanics

Ford, Kenneth. *The Quantum World.* 2004. A well-written recent introduction by a physicist/educator.

Gribbin, John. *In Search of Schroedinger’s Cat.* 1984. Clear, very basic introduction to the fundamental ideas of quantum mechanics, by a British physicist and science writer.

Rae, Alastair. *Quantum Physics: A Beginner’s Guide.* 2005. Widely praised introduction by a British physicist.

Collaborative Group Activities

1. Have your group make a list of all the electromagnetic wave technology you use during a typical day.
2. How many applications of the Doppler effect can your group think of in everyday life? For example, why would the highway patrol find it useful?
3. Have members of your group go home and “read” the face of your radio set and then compare notes. If you do not have a radio, research “broadcast radio frequencies” to find answers to the following questions. What do all the words and symbols mean? What frequencies can your radio tune to? What is the frequency of your favorite radio station? What is its wavelength?
4. If your instructor were to give you a spectrometer, what kind of spectra does your group think you would see from each of the following: (1) a household lightbulb, (2) the Sun, (3) the “neon lights of Broadway,” (4) an ordinary household flashlight, and (5) a streetlight on a busy shopping street?
5. Suppose astronomers want to send a message to an alien civilization that is living on a planet with an atmosphere very similar to that of Earth’s. This message must travel through space, make it through the other planet’s atmosphere, and be noticeable to the residents of that planet. Have your group discuss what band of the electromagnetic spectrum might be best for this message and why. (Some people, including noted physicist Stephen Hawking, have warned scientists not to send such messages and reveal the presence of our civilization to a possible hostile cosmos. Do you agree with this concern?)

Review Questions

1. What distinguishes one type of electromagnetic radiation from another? What are the main categories (or bands) of the electromagnetic spectrum?
2. What is a wave? Use the terms *wavelength* and *frequency* in your definition.
3. Is your textbook the kind of idealized object (described in section on radiation laws) that absorbs all the radiation falling on it? Explain. How about the black sweater worn by one of your classmates?
4. Where in an atom would you expect to find electrons? Protons? Neutrons?
5. Explain how emission lines and absorption lines are formed. In what sorts of cosmic objects would you expect to see each?
6. Explain how the Doppler effect works for sound waves and give some familiar examples.
7. What kind of motion for a star does not produce a Doppler effect? Explain.
8. Describe how Bohr's model used the work of Maxwell.
9. Explain why light is referred to as electromagnetic radiation.
10. Explain the difference between radiation as it is used in most everyday language and radiation as it is used in an astronomical context.
11. What are the differences between light waves and sound waves?
12. Which type of wave has a longer wavelength: AM radio waves (with frequencies in the kilohertz range) or FM radio waves (with frequencies in the megahertz range)? Explain.
13. 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.
14. Explain what the ionosphere is and how it interacts with some radio waves.
15. Which is more dangerous to living things, gamma rays or X-rays? Explain.
16. Explain why we have to observe stars and other astronomical objects from above Earth's atmosphere in order to fully learn about their properties.
17. Explain why hotter objects tend to radiate more energetic photons compared to cooler objects.
18. Explain how we can deduce the temperature of a star by determining its color.
19. Explain what dispersion is and how astronomers use this phenomenon to study a star's light.
20. Explain why glass prisms disperse light.
21. Explain what Joseph Fraunhofer discovered about stellar spectra.
22. Explain how we use spectral absorption and emission lines to determine the composition of a gas.
23. Explain the results of Rutherford's gold foil experiment and how they changed our model of the atom.
24. Is it possible for two different atoms of carbon to have different numbers of neutrons in their nuclei? Explain.
25. What are the three isotopes of hydrogen, and how do they differ?
26. Explain how electrons use light energy to move among energy levels within an atom.
27. Explain why astronomers use the term "blueshifted" for objects moving toward us and "redshifted" for objects moving away from us.
28. 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?

Thought Questions

1. Make a list of some of the many practical consequences of Maxwell's theory of electromagnetic waves (television is one example).
2. With what type of electromagnetic radiation would you observe:
   1. A star with a temperature of 5800 K?
   2. A gas heated to a temperature of one million K?
   3. A person on a dark night?
3. Why is it dangerous to be exposed to X-rays but not (or at least much less) dangerous to be exposed to radio waves?
4. 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
5. 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?

6. 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?
7. How could you measure Earth's orbital speed by photographing the spectrum of a star at various times throughout the year? (Hint: Suppose the star lies in the plane of Earth's orbit.)
8. Astronomers want to make maps of the sky showing sources of X-rays or gamma rays. Explain why those X-rays and gamma rays must be observed from above Earth's atmosphere.
9. 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.
10. An idealized radiating object does not reflect or scatter any radiation but instead absorbs all of the electromagnetic energy that falls on it. Can you explain why astronomers call such an object a blackbody? Keep in mind that even stars, which shine brightly in a variety of colors, are considered blackbodies. Explain why.
11. Why are ionized gases typically only found in very high-temperature environments?
12. Explain why each element has a unique spectrum of absorption or emission lines.

Figuring for Yourself

1. What is the wavelength of the carrier wave of a campus radio station, broadcasting at a frequency of 97.2 MHz (million cycles per second or million hertz)?
2. What is the frequency of a red laser beam, with a wavelength of 670 nm, which your astronomy instructor might use to point to slides during a lecture on galaxies?
3. You go to a dance club to forget how hard your astronomy midterm was. What is the frequency of a wave of ultraviolet light coming from a blacklight in the club, if its wavelength is 150 nm?
4. What is the energy of the photon with the frequency you calculated in the previous exercise?
5. If the emitted infrared radiation from Pluto, has a wavelength of maximum intensity at 75,000 nm, what is the temperature of Pluto assuming it follows Wien's law?
6. What is the temperature of a star whose maximum light is emitted at a wavelength of 290 nm?
