Lesson 202:

THE DOPPLER EFFECT

The Doppler Effect is another type of illusion that led scientists to discover that the Universe is expanding.

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Fundamental Questions

Attempting to give thorough and reasonable answers to the following questions will help you gauge your level of understanding this lesson. Students that can confidently answer these questions have mastered the concepts of this lesson.

1. Why is the Doppler Effect so important to astronomers?
2. What have astronomers learned about the universe by observing the Doppler Effect?
3. When can a person hear the Doppler Effect?
4. When can a person see the Doppler Effect?
5. Which is more affected by the Doppler Effect: light or sound?
6. What do radio waves appear as if the object emitting the radio waves moves away from the observer?
7. What do gamma rays appear as if the object emitting the gamma rays moves toward the observer?
8. If you look at a violet star that is moving toward you at a high speed, the light will blue-shift and appear as ultraviolet light. Will you go blind by looking at this light?
9. How is Doppler radar used to show where it is raining?

Lesson Objectives

At the end of this lesson, students should have mastered the objectives listed below.

1. Students understand the significance of the Doppler Effect and Hubble's Law to astronomy.
2. Students understand that the Doppler Effect is an apparent change because the observer is separate from the source of the light/sound.
3. Students understand that an object's temperature and chemical composition determine what wavelengths of light that the object will emit.
4. Students can determine if an object is moving toward or away from the observer based the Doppler shift of the object's spectrographic signature.
5. Students understand the relationship between a sound's frequency and its pitch.
6. Students can describe what happens to the waves of light/sound when the object moves toward or away from the observer.
7. Students are familiar with the differences between blue shift and red shift.
8. Students can name the type of electromagnetic radiation that a light source will appear to change to when the source of the light/sound moves toward or away from the observer.
9. Students understand that the extent of Doppler shift will depend on how fast the object emitting the light/sound is moving.
10. * Honors students can compute doppler shifts in frequency using fObserved = fSource [v/(v-vSource)].

Important Terms

The following terms are some of the vocabulary that students should be familiar with in order to fully master this lesson.

1. Spectroscope
2. spectrograph
3. prism
4. Doppler Effect
5. blue shift
6. red shift
7. pitch
8. continuous spectrum
9. absorption spectrum
10. emission spectrum
11. Hubble's Law
12. Edwin Hubble

Assessment Questions

The following are examples of questions that students should be able to answer. These or similar questions are likely to appear on the exam.

1. What is a spectrograph?
2. How are spectrographs used to determine Doppler shifts?
3. What is Hubble's Law and why is it important to astronomy?
4. How is Doppler radar used to show where it is raining?
5. * An ambulance is driving down Main Street at a speed of 80 kilometers per hour. You are standing on the sidewalk and the ambulance drives by you while beeping its horn. The normal pitch of the horn has a frequency of 290 Hz when the ambulance is not moving. The speed of sound is 340.29 meters per second. What will the frequency of the horn change to as the ambulance gets closer to you and then what will the frequency change to as the ambulance drives away from you?
6. Explain how light can "blueshift" but not appear to be blue.

7. Why isn't possible to detect doppler shifts in continuous spectra?
8. If an object is emitting infrared radiation and the object moves toward the observer at a speed close to the speed of light, what will the observer see?
9. If an object is emitting green light and the object moves away from the observer at close to the speed of light, what will the observer see?
10. How is the temperature of an object related to the light that the object emits?
11. Who is Edwin Hubble?
12. * A galaxy is moving away from Earth at a speed of 50,000 kilometers per second. Part of the normal wavelengths of the galaxy should be 500 nanometers when the galaxy is not moving. What will the frequency of the light change to as the galaxy gets moves away from Earth?
13. Why is it easier to hear the Doppler Effect than it is to see the Doppler Effect?
14. Define the Doppler Effect.
15. * How fast would a source of green light (565 nm) need to travel to make the light look red (600 nm)?
16. * A lunatic is running down Franklin Street at a speed of 10 kilometers per hour. You are standing on the sidewalk and he runs by you screeching a high-pitched sound. The pitch he is screeching has a frequency of 20 kHz when he is not moving. The speed of sound is 340.29 meters per second. What will the frequency of the screech change to as the lunatic gets closer to you and then what will the frequency change to as the lunatic runs away from you?
17. If an object is emitting violet light and the object moves toward from the observer at close to the speed of light, what will the observer see?

Related Web Sites

The following are some web sites that are related to this lesson. You are encouraged to check out these sites to obtain additional information.

1. http://en.wikipedia.org/wiki/Doppler_effect
2. http://www.youtube.com/watch?v=Kg9F5pN5tlI
3. http://hyperphysics.phy-astr.gsu.edu/hbase/sound/dopp.html
4. http://www.physicsclassroom.com/class/waves/u10l3d.cfm
5. http://archive.ncsa.illinois.edu/Cyberia/Bima/doppler.html
6. http://www.acs.psu.edu/drussell/Demos/doppler/doppler.html
7. http://formulas.tutorvista.com/physics/doppler-shift-formula.html

Related Book Pages

The following are the pages from your book that correspond to this lesson.

Comprehensive E.S. Book	Intensive/Honors E.S. Book	Meteorology/GIS Book
pp. 677, 718	pp. 315, 818-819	

Massachusetts Standards

The following are the Massachusetts Framework Standards that correspond to this lesson.

Earth Science Learning Standard(s) 4.1

What's Next?

Notes

V. The Doppler Effect

A. Scientists use **spectroscopes** to study visible light

spectroscope - instrument that uses a prism to break visible light into its characteristic rainbow colors (Roy G. Biv)

B. All materials that give off visible light can be viewed through a spectroscope.

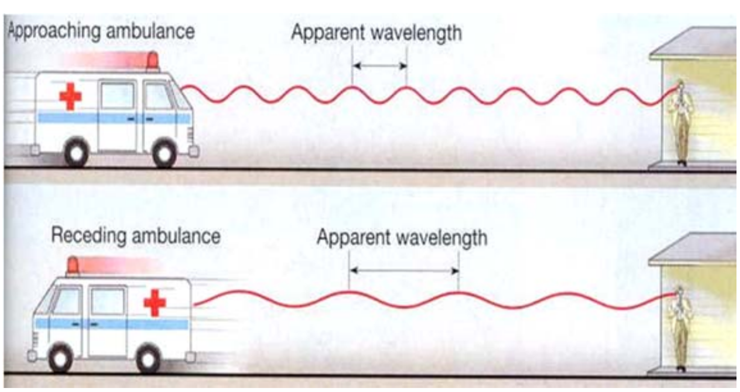
1. The type of material that is emitting the light and the temperature of the material dictates what pattern of colors will be seen in the spectroscope
2. Different materials emit different wavelengths of light

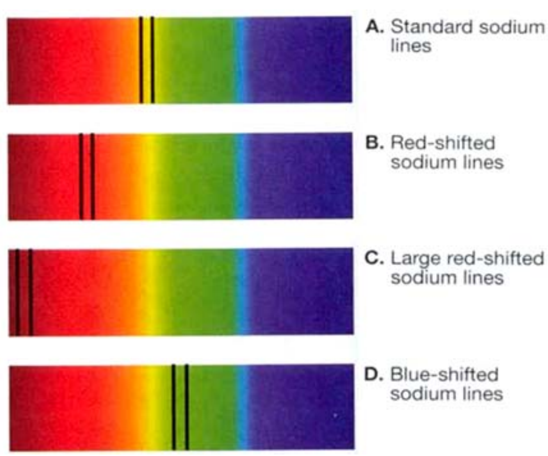
C. **Doppler Effect** - an *apparent* change in the wavelength of light or sound that occurs when the object that is emitting the light/sound is moving toward or away from the observer

1. **blue shift** - when an object that is emitting light/sound is *approaching* the observer, wavelengths shorten and color of light will shift towards blue (violet) end of spectrum or pitch of sound will become higher
2. The faster an object is moving toward you, the bluer the light will be or the higher the pitch will become.
3. **red shift** - when an object that is emitting light/sound is *moving away* from the observer, wavelengths stretch and color of light will shift towards red end of spectrum or pitch of the sound will become lower
4. The faster an object is moving away from you, the redder the light will be or the lower the pitch will become.
5. The Doppler Effect *does not work* when the object is *moving perpendicular* (i.e. sideways) to the observer.
6. Doppler shifts can be calculated using the formula

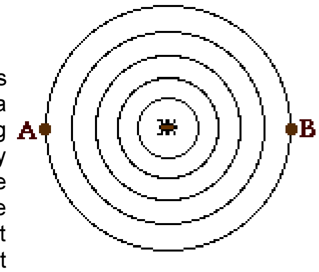
$$f_{observed} = f_{source} [v/(v-v_{source})],$$

where $f_{observed}$ is the new Doppler-shifted frequency, f_{source} is the frequency emitted when the object is at rest, v is the velocity of light/sound, and v_{source} is the velocity of the object that is emitting the light/sound.



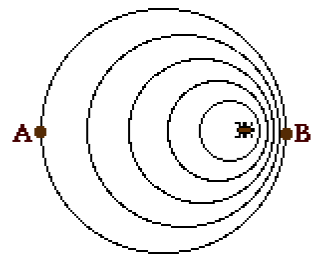


The Doppler Effect



A stationary bug producing disturbances in water.

Suppose that there is a happy bug in the center of a circular water puddle who is periodically shaking its legs in order to produce disturbances that travel through the water. If these disturbances originate at a point, then they would travel outward from that point in all directions. Since each disturbance is traveling in the same medium, they would all travel in every direction at the same speed. The pattern produced by the bug's *shaking* would be a series of concentric circles as shown in the diagram at the right. These circles would strike the edges of the water puddle at the same rate. An observer at point A (the left edge of the puddle) would observe the disturbances to strike the puddle's edge at the same frequency that would be observed by an observer at point B (at the right edge of the puddle). In fact, the frequency at which disturbances reach the edge of the puddle would be the same as the frequency at which the bug produces the disturbances. If the bug produces disturbances at a frequency of 2 per second, then each observer would observe them approaching at a frequency of 2 per second.

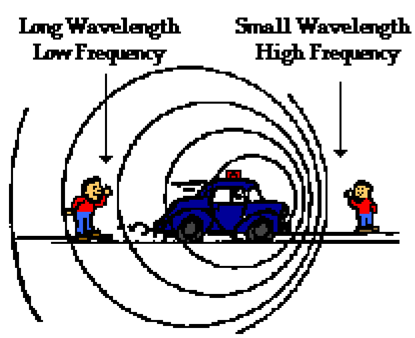


A bug moving to the right and producing disturbances.

Now suppose that our bug is moving to the right across the puddle of water and producing disturbances at the same frequency of 2 disturbances per second. Since the bug is moving towards the right, each consecutive disturbances originates from a position which is closer to observer B and farther from observer A. Subsequently, each consecutive disturbance has a shorter distance to travel before reaching observer B and thus take less time to reach observer B. Thus, observer B observes that the frequency of arrival of the disturbances is higher than the frequency at which disturbances are produced. On the other hand, each disturbance has a further distance to travel before reaching observer A. For this reason, observer B observes a frequency of arrival which is less than the frequency at which the disturbances are produced. The net effect of the motion of the bug (the source of waves) is that the observer towards whom the bug is moving observes a frequency which is higher than 2 disturbances/second; and the observer away from whom the bug is moving observes a frequency which is less than 2 disturbances/second. This effect is known as the Doppler effect.

The Doppler effect is observed whenever the source of waves is moving with respect to an observer. The **Doppler effect** can be described as the effect produced by a moving source of waves in which there is an apparent upward shift in frequency for observers towards whom the source is approaching and an apparent downward shift in frequency for observers from whom the source is receding. It is important to note that the effect does not result because of an actual change in the frequency of the source. Using the example above, the bug is still producing disturbances at a rate of 2 disturbances per second; it just appears to the observer whom the bug is approaching that the disturbances are being produced at a frequency greater than 2 disturbances/second. The effect is only observed because the distance between observer B and the bug is decreasing and the distance between observer A and the bug is increasing.

The Doppler effect can be observed for any type of wave - water wave, sound wave, light wave, etc. We are most familiar with the Doppler effect because of our experiences with sound waves. Perhaps you recall an instance in which a police car or emergency vehicle was traveling towards you on the highway. As the car approached with its siren blasting, the pitch of the siren sound (a measure of the siren's frequency) was high; and then suddenly after the car passed by, the pitch of the siren sound was low. That was the Doppler effect - an apparent shift in frequency for a sound wave produced by a moving source.

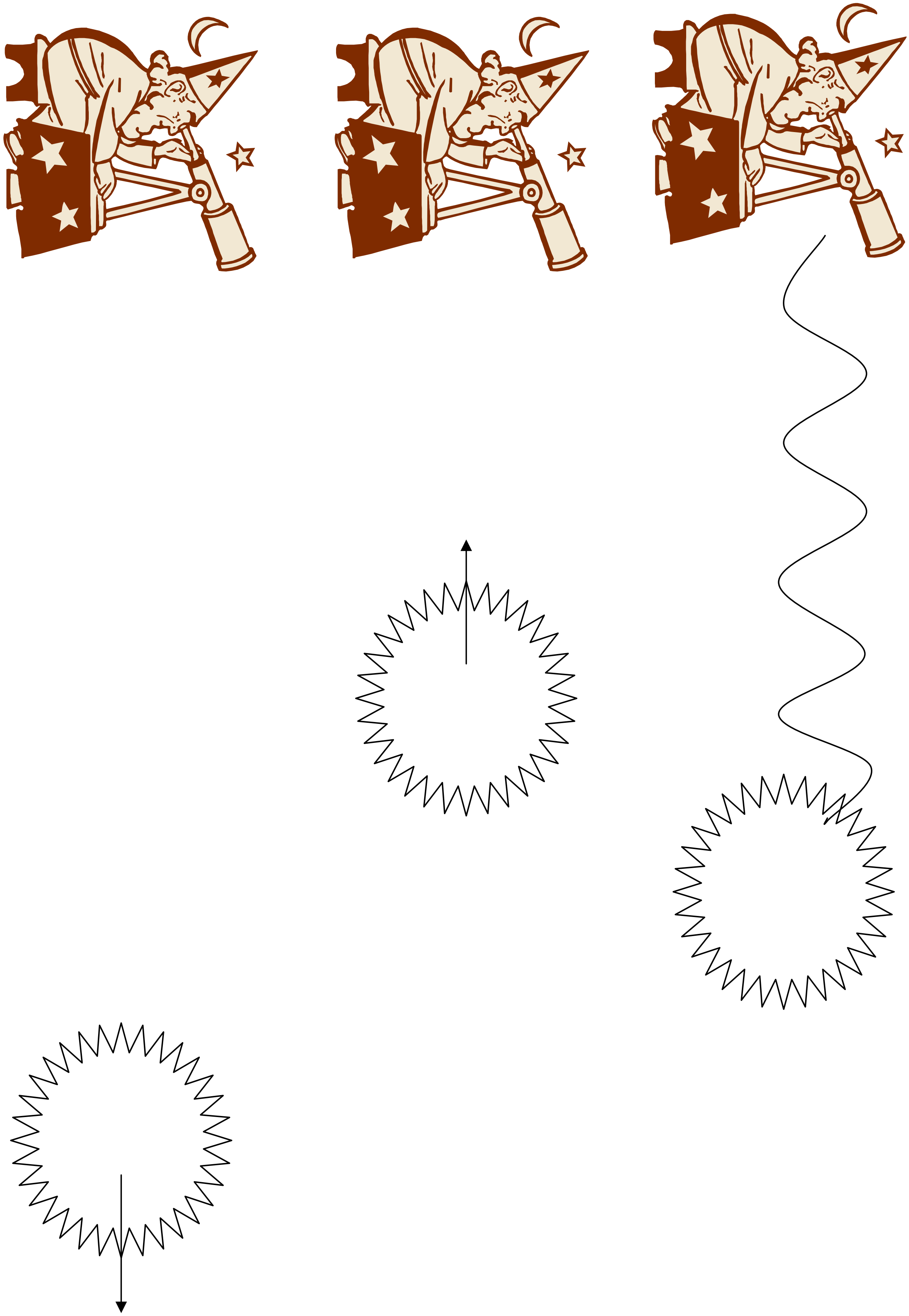


The Doppler Effect for a moving sound source

The Doppler effect is of intense interest to astronomers who use the information about the shift in frequency of electromagnetic waves produced by moving stars in our galaxy and beyond in order to derive information about those stars and galaxies. The belief that the universe is expanding is based in part upon observations of electromagnetic waves emitted by stars in distant galaxies. Furthermore, specific information about stars within galaxies can be determined by application of the Doppler effect. Galaxies are clusters of stars which typically rotate about some center of mass point. Electromagnetic radiation emitted by such stars in a distant galaxy would appear to be shifted downward in frequency (a "red shift") if the star is rotating in its cluster in a direction which is away from the Earth. On the other hand, there is an upward shift in frequency (a "blue shift") of such observed radiation if the star is rotating in a direction that is towards the Earth.

Taken from http://senseti.ddart.net/science/physics/physics_tutorial/Class/waves/U10L3d.html.

Red Shift Blue Shift No Motion



A If B is moving <u>away</u> from you (red shift), the light first becomes…	B **Type of Light**	C If B is moving <u>toward</u> you (blue shift), the light first becomes…
?	Radio Waves	
	Gamma Rays	?