Module 5: Red Recedes, Blue Approaches

Objectives/Key Points

Students will be able to:
1. match the direction of motion of a source (approaching or receding) with the apparent sensory effect (color, pitch) and the change in wave properties (higher/lower frequency, shorter/longer wavelength). To facilitate this goal, students will memorize the mnemonics “red is receding” and “low is long.”
2. use the language of redshift and blueshift.
3. identify the extra mathematical term that distinguishes the Doppler shifted wavelength from the wavelength emitted by the source.
4. apply the Doppler shift formula (derived together) to determine either the motion of objects or the change in the observed wavelength/frequency, when given one or the other.

Unit Home

Waves

Prerequisites

Students should be familiar with waves, both sound and electromagnetic, but need not have been exposed to Doppler shifts. The preparatory homework for this class introduces the Doppler shift equation.

Time: (20 min. prep; can be homework +) 60 min (+ 20 min enrichment)

Materials

video found at *http://www.youtube.com/watch?v=imoxDcn2Sgo*
if doing enrichment, can use gas tubes and gratings/spectrometers
copies of advance homework worksheet and in-class worksheet

Sticking Points

1. Students tend to confuse higher/lower pitch with louder/softer sound and thus closer/further.

Pre-Lesson

Advance Preparation for Lesson: Have students complete appended worksheet as homework. Remind them of terminology of “factor” and “ratio” before giving it. At the start of the main class, go over concept checks at the end of this homework then complete appended quiz.

Main Lesson

1. Fire truck video revisited and discussed with chart below (teacher helps with left column, students try right column then discuss). Teacher mention mnemonics and put on blackboard: “red is receding” and “low is long.” Go over quiz/homework problem 1.

In-Class Worksheet

Fire Truck Approaching	**Fire Truck Receding**
Drawing	Drawing
The pitch of the siren is ___________________. (higher/lower)	The pitch of the siren is ___________________. (higher/lower)
The frequency is _________________, and therefore the wavelength is ________________. (higher/lower), (longer, shorter)	The frequency is _________________, and therefore the wavelength is ________________. (higher/lower), (longer, shorter)
If this were a light wave, the light wave would be ____________________________. (red shifted/blue shifted)	If this were a light wave, the light wave would be ____________________________. (red shifted/blue shifted)

Equation Derivation Space

Independent Practice

2. Students complete the following individually in class. Teacher reinforces mnemonics “red is receding” and “low is long.”

Sensory Effect on Observer (lower/higher pitch or redshifted/blueshifted color)	*Motion (approaching, receding)*	*Wavelength/Frequency (longer or shorter/lower or higher)*
lower pitch	______	*longer/_____*
______ *pitch*	*Approaching*	_____/_____
______ *pitch*	______	_____*/lower*
pitch getting ______er	*receding faster and faster*	*getting _____er/_____er*
Redshifted	*Receding*	_____/_____
Blueshifted	______	_____/_____
______	______	*longer/_____*
______	______	_____*/higher*

Presentation & Concept Checks (integrated)

3. Teacher derives Doppler shift formula on blackboard reiterating handout in Socratic style and also taking questions. This derivation is a review of the material in the homework, so the students should be able to help lead it. Class goes over homework/quiz problem 2.

4. Teacher role models application of formula by going over homework problem 3.

Independent Practice (can become Homework if time runs out)

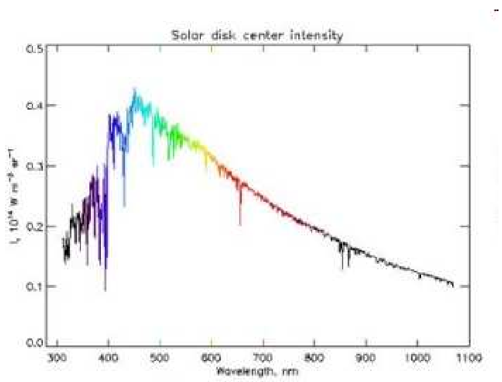
5. Try the following problems in class with teacher circulating.

a) Suppose the observed wavelength of an approaching star changes by a factor of 1.0001. Write an equation relating $\lambda_{observed}$ to $\lambda_{original}$, thinking about whether the observed wavelength increases or decreases. Using the Doppler shift equation, what is the velocity of the star? Is the sign of the velocity you derived correct and why? Is this a redshift or a blueshift?

b) Suppose a star is receding at a velocity of 100 m/s. Calculate the change in the ratio of $\lambda_{observed}$ to $\lambda_{original}$. Is this a redshift or a blueshift? Is your ratio consistent with a receding star, and why?

Enrichment

If the spectrum of a star includes a full rainbow of colors, it is not easy to see the Doppler shift in the overall color of the star (which is just the brightest color range in a spectrum of colors). The overall color shift is only large enough to notice for distant galaxies that are expanding with the cosmic expansion of the Universe, moving much faster than nearby stars. So how do we tell that nearby stars have Doppler shifts? Discuss lines in spectra and how they can be used as signposts to actually measure wavelength shifts and therefore velocities of light-emitting objects.



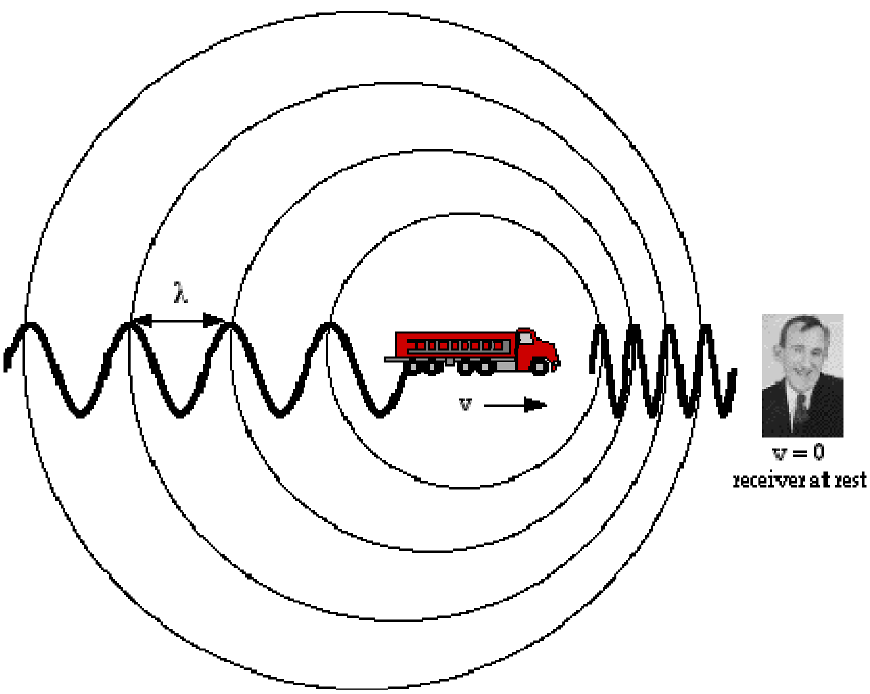
Homework (or can serve as Assessment)

1. What if a star is orbiting another star at a speed of 30 m/s; how will its Doppler shift change with time? How big is the change in wavelength? Assume the observer is watching the stars orbiting edge on, so that one star is going in front of and behind the other periodically.

Doppler Shifts: Advance Preparation Worksheet

Often, the information that we receive from objects (in the form of light or sound) is not true to the information that left the object. For example, let's think about the way a fire truck sounds to the person driving the truck versus a person standing on the side of the road as the truck drives by. To the person in the truck, the sound of the siren is a constant frequency. Therefore the driver hears a constant pitch, true to the actual pitch of the siren.

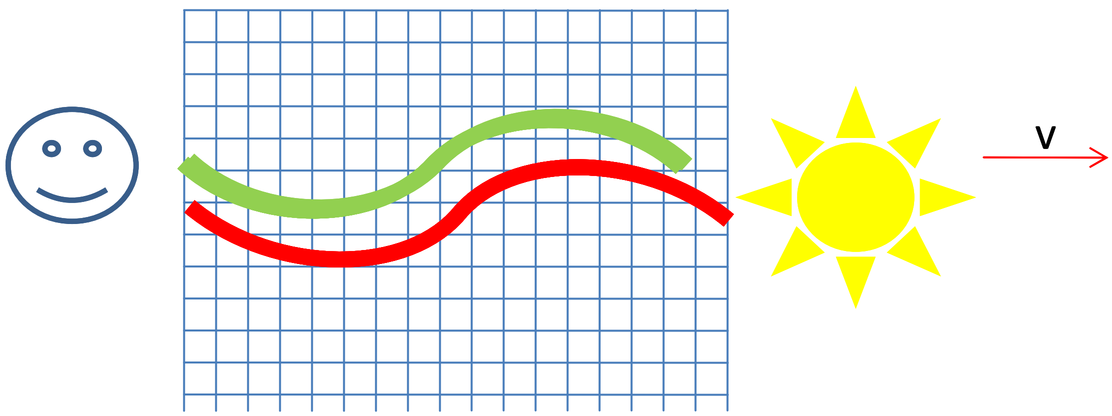
Now the person on the side of the road hears something a little different. Watch the video in class, which can also be found at *http://www.youtube.com/watch?v=imoxDcn2Sgo*. As the truck is coming towards the person on the side of the road, the frequency is being altered. The sound wave is moving with its initial speed as well as the speed of the truck. This causes the wave to be "shortened" making the frequency or pitch seem higher. As the truck is driving away from the person on the side, the opposite happens. The sound wave is moving with the initial speed minus the speed of the truck. Therefore, to the person on the side of the road, the sound wave seems to be "stretched" making the frequency or pitch seem lower. The change in the observed frequency (or equivalently, wavelength) of the wave compared to its emitted value is called a Doppler shift.



Now let's examine the Doppler shift for the light given off by a star that is moving away from an astronomer, which changes the color of the light. We know that the equation for the speed of a wave is given by $v = \lambda \cdot f$. For light, this equation becomes $c = \lambda \cdot f$.

The wavelength of light as emitted by the star is $\lambda_{original} = \frac{c}{f}$. Recall that one wavelength is the length between two wave crests. Therefore if $\Delta t = \frac{\lambda_{original}}{c}$ is the time between the emission of the crests, then the first crest to be emitted has traveled a distance $d_{wavemotion} = \lambda_{original} = c \cdot \Delta t$ in that time. From the point of view of the star, this is the only motion, so the second crest follows the first at distance $\lambda_{original}$ and the wavelength is what we expect. But from the point of view of the astronomer, the star has moved a distance $d_{starmotion} = v_{star} \cdot \Delta t$ so the second crest follows the first at distance $d_{wavemotion} + d_{starmotion} = c \cdot \Delta t + v_{star} \cdot \Delta t = \lambda_{observed}$.

Thus when we look at the star we find that the wavelength of light is actually "stretched" or longer than the original light wave emitted. Recalling that $\lambda_{original} = c \cdot \Delta t$ and $\Delta t = \frac{\lambda_{original}}{c}$, we have $\lambda_{observed} = \lambda_{original} + v_{star} \cdot \frac{\lambda_{original}}{c}$. The Doppler shift equation is then $\lambda_{observed} = \lambda_{original}\left(1 + \frac{v_{star}}{c}\right)$ where the velocity is defined as positive when receding.



In the picture above, the green wave represents the original light given off by the star. As the star moves away from the observer, the wave is stretched and the observer sees the wave as being red. This is what is known as a redshift. It tells us that an object is moving away from us. Using the above equation, we could figure out the relative speed between us and the star. Stars can also being moving towards us, similar to the fire truck example. Of course this would make the wavelength appear "shorter," making it appear bluer. This is referred to as a blueshift.

Concept Checks:

1. If a fire truck is moving __________ *(fill in toward or away from)* you, the pitch is increasing, which is analogous to a __________ *(fill in redshift or blueshift)* for starlight if the star is __________ *(fill in approaching or receding).*

2. The wavelength of light or sound observed from an approaching object (star, fire truck) will be ________ *(fill in longer or shorter).* If the velocity of approach is v_1 (a positive number), then what is the equation for the observed wavelength? ___________________ Circle the extra term that modifies the original wavelength. Should the extra term be positive or negative? _________

3. For a receding star, suppose the observed wavelength increases by a factor of 1.0001, i.e., $\lambda_{observed} = 1.0001\lambda_{original}$. Using the Doppler shift equation, what is the velocity of the star?

Quiz:

1. If a fire truck is moving __________ *(fill in toward or away from)* you, the pitch is decreasing, which is analogous to a __________ *(fill in redshift or blueshift)* for starlight if the star is __________ *(fill in approaching or receding).*

2. The wavelength of light or sound observed from a receding object (star, fire truck) will be ________ *(fill in longer or shorter).* If the velocity of recession is v (a positive number), then the equation for the observed wavelength is $\lambda_{observed} = \lambda_{original}\left(1+\frac{v_{star}}{c}\right)$. Circle the extra term that modifies the original wavelength. Should the extra term be positive or negative? _________

Answers to Concept Checks:

1. *toward, blueshift, approaching*
2. *shorter,* $\lambda_{observed} = \lambda_{original}\left(1-\frac{\mathrm{v}_1}{c}\right)$ *since the velocity is approaching, extra term is* $\lambda_{original}\left(-\frac{\mathrm{v}_1}{c}\right)$*, which should be negative in order to make the observed wavelength smaller (shorter/bluer) than the original*
3. *If* $\lambda_{observed} = 1.0001\lambda_{original}$ *then 1+v/c = 1.0001 for v defined as positive since the star is receding. Thus v = 0.0001c = 30 km/s.*

Answers to Quiz:

1. *away from, redshift, receding*
2. *longer, extra term is* $\lambda_{original}\left(\frac{v_{star}}{c}\right)$*, which should be positive in order to make the observed wavelength larger (longer/redder) than the original, since the object is receding*