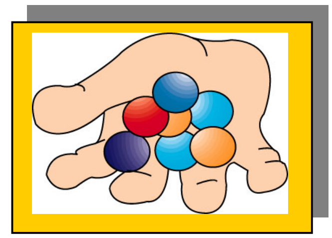
Cosmic Chemistry: Cosmogony

Doppler Effect—Are You Coming or Going?

TEACHER GUIDE

BACKGROUND INFORMATION



The measurement of cosmic distances often utilizes the Doppler effect, which is familiar enough in everyday life on a qualitative basis. It is usually illustrated by calling students' attention to the variable pitch observed in the whistle of a locomotive as it approaches and then recedes. More commonly, students may have observed the effect by listening to emergency vehicle sirens or the whine of racecar engines instead of train whistles.

In the case of sound, the phenomenon is easy to understand. The change in pitch arises from the fact that the number of sound waves striking the eardrum per second changes because of the source's motion relative to that of the observer. Note that what is called pitch really is the frequency of the sound wave, the number of cycles per second (Hertz, abbreviated Hz).

The Doppler effect applies to all wave phenomena (water waves, sound waves, or light rays). In the case of light, the effect is difficult to demonstrate without using sophisticated instrumentation, owing to the very high speed with which light moves. Therefore, while light is the wave of interest to astronomers, this activity will focus primarily on simulations and sound to demonstrate the Doppler effect. Once students understand the principles, they will interpret some astronomical data.

In Part 1, the students will observe marbles rolling down a sloped track from the source (top of the track) and calculate the "frequency" of the marbles by counting how many they collect at the end of the track during a given time interval. The marbles simulate wave crests. They then will determine how the "frequency" changes when they collect marbles while slowly walking toward the source and then away from the source. This activity simulates the effect of a sound receiver moving with respect to a sound source.

In Part 2, the students will construct a device that will allow them to hear easily the change in pitch (frequency) of a sound as it approaches and then recedes.

In Part 3, the students will interpret some astronomical data involving electromagnetic radiation and Doppler shifts.

NATIONAL SCIENCE STANDARDS ADDRESSED

Grades 5-8

Science As Inquiry
- Understandings about scientific inquiry

Physical Science
- Motions and forces
- Transfer of energy

Science and Technology
- Understandings about science and technology

History and Nature of Science
- Nature of science and scientific knowledge
- History of science and historical perspectives

Grades 9-12

Science As Inquiry
- Understandings about scientific inquiry

Earth and Space Science
- The origin and evolution of the universe

Physical Science
Interactions of energy and matter
Science and Technology
Understandings about science and technology
History and Nature of Science
Nature of science and scientific knowledge
Historical perspectives

(View a full text of the National Science Education Standards.)

MATERIALS

For each student:
- Copy of Student Activity: "Are You Coming or Going?"
- Copy of Student Text: "Doppler Effect"

In addition, for Part 1:
- A 15 ft. long (minimum) track along which balls can be rolled. This might be a section of ¾ x ¾ -inch wooden corner protector (or corner moulding), available in 16 ft. lengths at any store that sells lumber. A plastic interior wall corner protector might also work, as long as it is supported so that it is straight. Other tracks also will work, including gutter material, chalkboard trays, etc. You simply need to use something open on the top that will contain spherical objects as they roll down the track. The longer the track, the better.
- Approximately 20 marbles or other spherical objects, such as ball bearings, that are consistent with the track that you are using. Golf balls might work well in a gutter. The Student Activity, "Are You Coming or Going?" is written as if marbles will be used. If this is not the case, advise the students of the change that you have made.
- A stopwatch.
- Area where the track can be placed at waist to chest height of the students and supported on both ends and elsewhere, as necessary, to make it straight. A ring stand support attached to the upper end would be very helpful in making adjustments in height.
- Copy of Part 1 of Reporting/Data Sheet for "Are You Coming or Going?" for each team.

In addition for Part 2:
- An old sock.
- A small and inexpensive, but loud, battery operated buzzer. (Radio Shack offers several different models.) Models that require either 1.5 or 3 volt batteries are preferred.
- Battery for operating the buzzer.
- A piece of strong cord about 10 feet long.

In addition for Part 3:
- Copy for each student of Student Handout: "Spectral Data"
- Copy for each student of Part 3 of Student Reporting/Data Sheet "Are You Coming or Going?"

Teaching Tip

An activity that provides an elementary introduction to the Doppler Effect by using a vacuum cleaner hose and a slinky can be found at the URL:

http://near.jhuapl.edu/Education/lessonDoppler.

PROCEDURE

1. Before class make copies of the following:
   Student Activity, "Are You Coming or Going?"
   Student Text, "Doppler Effect"
   Reporting/Data Sheet, Parts 1 and 3, for "Are You Coming or Going?"
   Student Handout, "Spectral Data"

PART 1

2. You can divide the class up into teams of three and designate one team member as a "source," another as a "timer/recorder," and the third as a "receiver." Alternatively, you may wish to have the class select a "source," a "timer/recorder" and an initial "receiver" and then have each student collect his/her own data, each acting in turn as a moving receiver. In the latter case, you might also wish to rotate the "source" and "timing" responsibilities among the class so that everyone gets to collect a set of data. The exact procedure will depend on the class or how this activity fits into your schedule.

3. The "source" end of the track should be about 1 ft. higher than the "receiver" end. Students should have easy and clear access to one side of the track. Tie or otherwise clamp the track in place at the "source" end to hold the open side up.

4. It should take about 40-50 seconds to roll 20 marbles down the track when they are placed on it at roughly one-second intervals. Adjust the height of the "source" end as necessary to achieve this time frame.

5. Students should walk along the track as moving "receivers" by taking baby-steps so that they cover roughly two-thirds of the length of the track in the 10 second receiving time specified. This may require them to practice a few times before collecting data. Be aware that some hand-eye coordination is required to both walk along the track slowly and pick marbles up off the track as they pass by. It may be easier for some students to use golf balls instead of marbles. If students miss a marble and it does not get counted, they probably should start over again. The number of marbles collected while moving up and down the track does not change dramatically during the 10 second collecting period. Hence, any missed marbles can introduce significant error into the experiment.

> **Teaching Tip**
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> A mechanical analog to the Doppler effect has been published in the following reference: Herbert T. Wood, "The Physics Teacher" 30, 340 (1992). This activity might provide an interesting additional project for the students to pursue. The author also points out that he has had limited success illustrating the Doppler Effect with water droplets falling uniformly beside a vertical ladder. The students collect drops as they climb and descend the ladder, much like they collect marbles in the activity described in this module. Another technique is to use an escalator, with students going up and down the escalator to illustrate changes in frequency depending on the direction in which the students are walking.

6. Distribute copies of the Student Activity, "Are You Coming or Going?" and a copy of the Reporting/Data Sheet to each student.

7. Instruct the students to carry out Part 1 of the student activity. Collect their Reporting/Data Sheets.

8. Start the next period by showing tabulated student results on an overhead projector or on newsprint. Follow up with a discussion of their observations, posing questions like the following:
   a) In what way does the "frequency" of the marbles simulate the frequency of a sound wave?
   b) How does the "frequency" of the marbles compare to the frequency of real sound waves?
   c) Can the "frequency" of the marbles be altered? Can the frequency of real sound waves be altered?
   d) How does the marble "frequency" change (higher or lower) as the receiver moves to and from the source?
   e) Why did not all students observe the same "frequency" changes?
   f) How would the results change if the source were moving and the receiver were stationary?

9. Instruct the students to read the Student Text, "Doppler Effect" and return their Reporting/Data Sheets to them.

PART 2— Thanks to Professor Don Foster for this suggestion!

10. For this part of the activity, you will need a lot of room. A clear, circular space having a diameter of at least 20 ft. is needed, with room outside of the circle for students to stand and listen to the tone of the buzzer. A gymnasium is well suited to this part of the activity.

11. Connect the battery to the buzzer, and insert both into the sock. Tie the open end of the sock to the strong cord. MAKE SURE IT IS SECURELY TIED.

> **Teaching Tip**
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> Another activity that fits in here is to drive with students to a quiet and infrequently traveled road where they can tape record the sound of an automobile horn. Then have them record the sound as the auto approaches and recedes from them at 20, 30, and 40 miles per hour.

12. Tell the students to form a circle well outside of the diameter of the cord. Now, slowly start to swing the sock containing the buzzer around your head while letting out more cord. Try to reach the point where the buzzer is traveling around in a circle of radius 8-10 ft. at a high speed. Tell the students to listen to the buzzer as it approaches them, as it is right in front of them, and then as it swings on past and recedes from them. Try varying the speed of the sock and ask the students if they can detect any effects of the variation in the sock speed. If you feel comfortable doing so, you might let the students swing the apparatus. If you do so, make sure they understand that the battery/buzzer combination is heavy, and that it might injure observers if it were to strike them.

Teaching Tip

If you know the actual frequency of the buzzer, you might ask students to calculate what apparent frequency would be heard by the catcher if the buzzer were attached to a baseball thrown at 100 mph. They would have to use an equation from the Student Text, look up the speed of sound in air, and be careful with the units of speed. Alternatively, you might ask the students to calculate the speed at which the ball would have to be thrown to cause the pitch to double or triple.

13. Gather the students together for a discussion that focuses on the following questions:
    a) What is the relationship of the pitch of the buzzer to its frequency?
    b) Did they hear a change in pitch of the buzzer as it approached them and then as it receded from them?
    c) Why did the pitch change?
    d) Does the person in the middle swinging the apparatus hear a change in pitch?
    e) If they were to run in a circle around the person swinging the buzzer at the same speed as the buzzer, what pitch would they hear?
    f) Assume that the buzzer is in a fixed position and that you were swung around in the sock. What would you hear?
    g) Describe what changes would occur in the pitch of a "buzzing" baseball as it leaves the pitcher's hand, as it travels toward home plate, and then as it leaves the bat and sails over the center field wall (assuming the buzzer survives the encounter with the bat!). In this discussion, assume that you initially are playing first base, then second base, then third base, and then catcher. What changes in pitch would you hear from each of these positions? What would the pitcher hear?
    h) What additional information would be needed in order to calculate the actual speed of the buzzing baseball as it travels from the pitcher to home plate?

Teaching Tip

Ask a local police officer to bring some radar equipment to your class to show students how it works. This is the Doppler Effect in action. Radar waves bounced off a moving vehicle will have a different frequency than the source frequency because of the motion of the vehicle. The change in frequency can be correlated with vehicle speed.

Part 3 –

14. In this part of the activity, the students will interpret some spectral data, both simulated and actual, for astronomical objects. Distribute the Student Handout, "Spectral Data." It is suggested that they work individually on this part of the activity.

15. After they have turned in the Student Reporting/Data Sheets, gather the class and engage in a general discussion of the uses of the Doppler Effect. Questions that you might explore include the following:
    a) Does the Doppler effect apply to radio waves? Would a radio go "out of tune" if it were suddenly accelerated to a high velocity?
    b) Would a microwave oven continue to heat food if it were on a spacecraft moving at, perhaps, 2000 km/sec? This is a bit tricky. The students would need to recognize that this has nothing to do with the Doppler Effect. The source (oven) and receiver (food) are moving at the same speed, just as is the case here on Earth. There is no relative motion.
    c) Can they think of uses of the Doppler Effect in everyday life?
    d) If a track star were carrying a buzzer while running a 100 yd. dash, would there be any perceptible change in the pitch of the buzzer as she passed by you?
    e) Hydrogen has a 21 cm emission. This is the spectral position of the line, or a measure of energy that these photons have. This emission from the Andromeda galaxy can be observed on Earth. Would its wavelength be higher or lower than 21 cm? If this line from a distant object were observed on Earth at a wavelength of 21 cm, what would this imply about the object?

f) For fun—do red cars go faster than blue cars because of the Doppler effect?
g) Why is the Doppler Effect not useful for determining the speed of a “stealth” airplane?