Drexel-SDP GK-12 ACTIVITY

Activity Template

Subject Area(s): Sound

Associated Unit: None

Associated Lesson: None

Activity Title: Where is that sound coming from?

Grade Level: 9 (7-9)

Activity Dependency: None

Time Required: 120 minutes

Group Size: 3-4 students

Expendable Cost per Group: US $0.00

Summary:
In this activity, students will determine the direction of arrival of sound waves in the horizontal plane in an acoustic environment as the waves propagate and calculate the speed of the sound waves based on the time taken for the sound to travel each of the receivers (ears). As a result of the activity, students will learn how humans determine where a sound is coming and how a computer would mathematically attempt to perform the same task. This activity will give students a brief introduction to the calculations involved in this process, including computation of rates, angles and distances using supplied formulas.

Engineering Connection:
Engineers with jobs that focus on localizing a sound source are concerned with the time difference of arrival of sound waves, or, more simply, the time difference between when the same sound arrives at two or more sensors. This time information provides engineers with the knowledge needed to attempt to determine the location of a sound source. For example, if an

engineer hears a sound in his left ear before his right ear, then the sound originated somewhere to the left of the engineer. Further exploration into the exact direction of the sound source requires a more detailed mathematical algorithm that is based on the time difference of arrival of the sound waves and the distance between the sensors (generally two sensors meant to model the human anatomy). The direction of arrival is often employed as a key component in several other audio related tasks, such as sound source separation or determining the room impulse response of an acoustic environment. Sound source separation involves engineers attempting to separate one audio clip containing multiple sounds occurring simultaneously into individual clips containing just one sound source each. For example, engineers would take a recording of multiple people talking at a party and try to separate each voice into an individual audio clip. The room impulse response provides information about how audio is modified by the room environment, such as the difference between speaking in an empty room and a carpeted room with couches, paintings, etc. in the room. The direction of arrival of sound waves are also important in automated systems such as robots in the military that attempt to determine the direction of an approaching enemy. All of these applications use algorithms based on the general approach presented in this activity, but with much more detail and sophistication.

Keywords: sound, acoustics, interaural time difference, angles, rate

Educational Standards
Science: 3.4 – Physical Science, Chemistry and Physics
Math: 2.9 – Geometry
  2.10 – Trigonometry
  2.3 – Measurement and Estimation

Learning Objectives
After this lesson, students should be able to:
- Explain how humans localize a sound source
- Understand why it is important for humans to have two ears
- Determine the direction (in the horizontal plane) from which a sound originates
- Calculate the speed of a sound given the time taken for sound wave to reach the receiver

Materials List
Each group needs:
- Protractor
- ruler
- pencil
- calculator
- copy of the lab worksheet

Introduction / Motivation

The topic of determining the direction of arrival of received sound waves has many practical applications for engineers specializing in automated systems, robotics and other electronic devices. Engineers in the robotics field employ sound source localization algorithms to provide robots with functionality similar to everyday human behavior. This may enable robots to track a moving object that is producing sound or possibly make the robot face a person with which it is trying to communicate. In the future, as algorithms for localizing sounds mature, vehicles could come equipped with devices to determine where the sound of a crash is coming from in order to help the driver avoid an accident. In the military defense field, robots can be used as the front line instead of human soldiers for reconnaissance missions or as early warning devices for approaching enemies with detailed information about the approaching direction of the enemy vehicles. All of these examples demonstrate the benefit of sound source localizing algorithms and the need complex algorithms to provide specific information about the location of a sound source.

Vocabulary / Definitions

| Word	Definition
azimuth	the horizontal angle measured clockwise starting with 0 degrees straight ahead
sound source	the object producing a sound
interaural time difference	the difference in arrival times of a sound wave at each sensor or ear

Procedure
Background
Sound source localization is a human ability that is believed to be learned as sound is experienced with knowledge of the direction of arrival of the sound waves. The main component of the knowledge is based on how the pinna or outer ear filters the sound waves as they reach the ear. Depending on the direction of arrival, the pinna modifies the sound waves slightly to create distinct characteristics that are perceived by brain to determine where the sound originated. Localizing a sound source is something that humans can perform quite easily, but teaching a computer to do the same is not so simple. In this activity, students will perform sound source localization calculations, but at a very crude and low precision level with much more information provided than would be given to engineers.

When an engineer determines the direction of arrival of an incoming sound wave, he is generally concerned with the azimuth, or the horizontal angle relative to the front of the person's face. The azimuth begins with 0 degrees representing directly in front of the person, 90 degrees straight out from the right ear, 180 degrees directly behind the person, and 270 degrees straight out from the left ear. A diagram of this description is shown below.
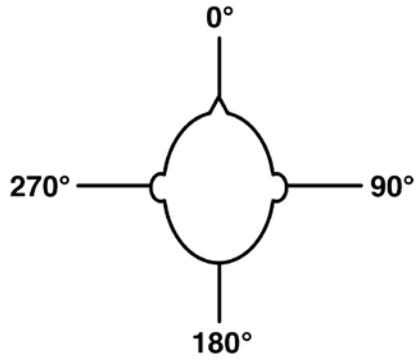
As an example, the figure below is a diagram with a sound source propagating sound waves to the person's ears. Notice the length of the path from the source to the left ear is shorter than that of the path from the source to the right ear. Therefore, the sound waves reach the left ear before the right ear, basically eliminating the possibility of the wave coming from 0-180 degrees.
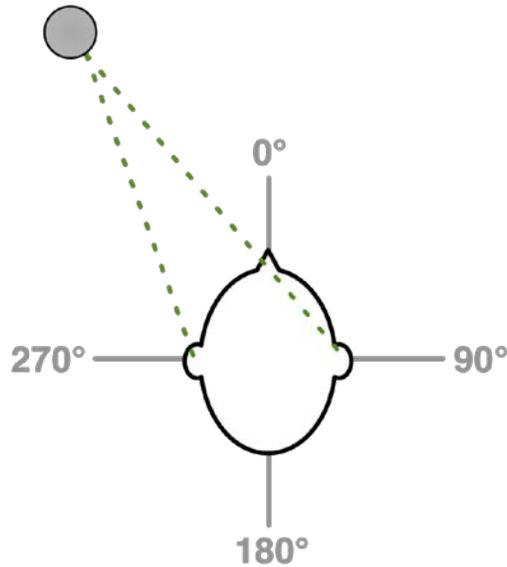
To calculate the exact angle of arrival, the angles and sides of the triangle created by the paths of the sound waves to each ear and the line between the ears must be determined. This description is displayed in the next two figures.
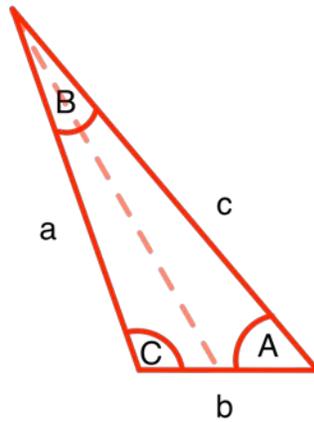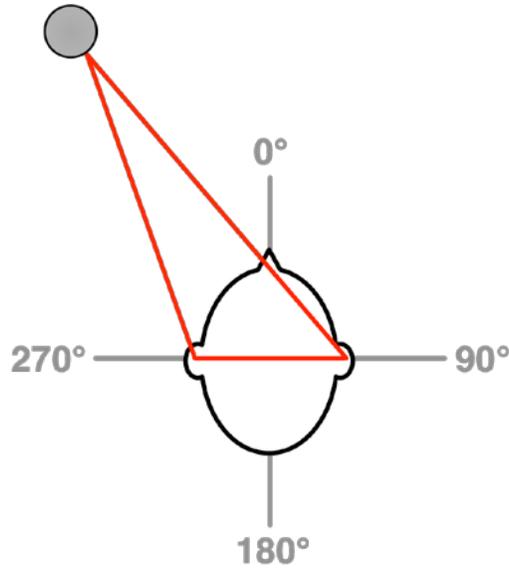
All angles and sides must first be calculated before attempting to determine the exact azimuth of the approaching sound waves. Next, a line can be drawn from side b (line connecting the two ears) up through angle B (sound source), displayed as the dashed line in figure above. This creates a new angle for B that is just half its previous value and a new angle for A that is the previous A plus half of the previous B. Remember a triangle's angles should add up to 180 degrees. The formulas for determining the sides and angles are shown below.

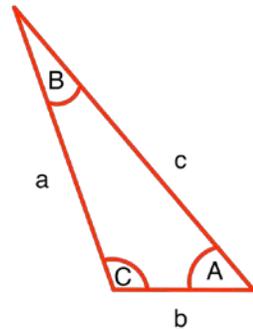$$A = \cos^{-1}\left(\frac{-a^2 + b^2 + c^2}{2bc}\right) \qquad a = \sqrt{b^2 + c^2 - 2bc\cos A}$$

$$B = \cos^{-1}\left(\frac{a^2 - b^2 + c^2}{2ac}\right) \qquad b = \sqrt{a^2 + c^2 - 2ac\cos B}$$

$$C = \cos^{-1}\left(\frac{a^2 + b^2 - c^2}{2ab}\right) \qquad c = \sqrt{a^2 + b^2 - 2ab\cos C}$$

Before the Activity
- Print out a copy of the lab worksheet for each group
- Prepare a set of supplies for each group in the class (ruler, protractor and calculator)

With the Students
1. Ask the students how they determine where a sound is coming from
2. Discuss how the brain is able to determine where a sound originates as described in the background section
3. Explain to the students that their job is to determine the direction of arrival of a sound wave
4. Have the students attempt to determine where a sound is coming from with their eyes closed
5. Provide a sample problem to go through with the students based off of the worksheet
6. Distribute the prepared supplies (ruler, protractor, calculator and lab worksheet without the challenge problem attached) to each group
7. Explain that the protractor is for checking the answers to the angle calculations to determine if their answer is close to the correct answer
8. Have the students attempt to complete the worksheet as a group and offer to check answers for each problem to make sure the students are comprehending
9. After the students have completed the worksheet as a group, have the students turn in the worksheet
10. Grade the worksheets and return them to the students the following day
11. Discuss the answers to clear up any misunderstandings

Attachments
- Determining the Direction of Arrival of Sound Waves Worksheet
- Determining the Direction of Arrival of Sound Waves Worksheet Answers

Safety Issues
- None

Troubleshooting Tips

When calculating angles using the graphing calculator, make sure the values returned for $\cos^{-1}$ are in degrees and not radians!

Investigating Questions
- How do you determine which direction a sound is coming from when you can see the object making the sound?
- Can you close your eyes and try to follow my voice without looking at me?

Assessment

Pre-Activity Assessment
Class Discussion:
- Talk with the students about how they think their brain determines where a sound is coming from
- Explain how sound arrives at each ear at slightly different times, creating a large enough difference for their brains to determine which ear heard the sound first

Activity Embedded Assessment
Lab handout/worksheet: Have the students fill out the worksheet and review their answers as a measure of comprehension

Post-Activity Assessment
Similar Problems: As a final assessment, give the students a few examples of time differences and see if they can determine the general direction from which the wave originated and then create one final problem for each student to complete on his/her own, not in groups.

Activity Extensions
- The students could research interaural level difference and explain how that is related to the interaural time difference
- Have the students determine what frequency range the interaural time difference applies to (based on the spacing between the ears)

Activity Scaling
- For lower grades, the general direction can be obtained by just focusing on the amount of time it takes for the wave to reach each ear with answers more general, such as the sound originates more towards the left ear than the right

- For upper grades, students should calculate the interaural time difference more directly since it should truly be measured by the difference in arrival times of the waves, which would provide information about the lengths of the wave paths

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Determining the Direction of Arrival of Sound Waves Worksheet

Names: _____

Materials

- protractor (to check answers)
- ruler
- pencil
- calculator

Legend

Formulas

$$A = \cos^{-1}\left(\frac{-a^2 + b^2 + c^2}{2bc}\right)$$

$$a = \sqrt{b^2 + c^2 - 2bc \cos A}$$

$$B = \cos^{-1}\left(\frac{a^2 - b^2 + c^2}{2ac}\right)$$

$$b = \sqrt{a^2 + c^2 - 2ac \cos B}$$
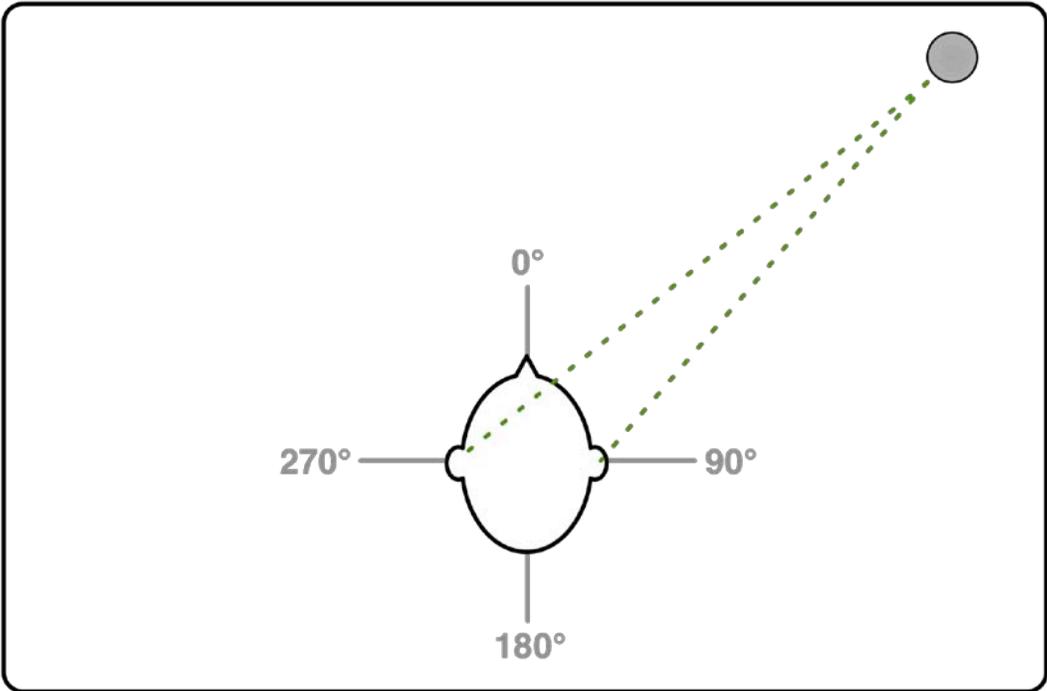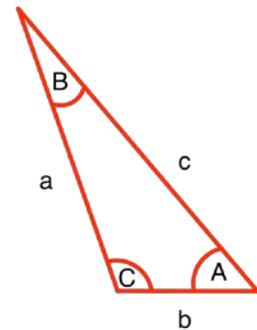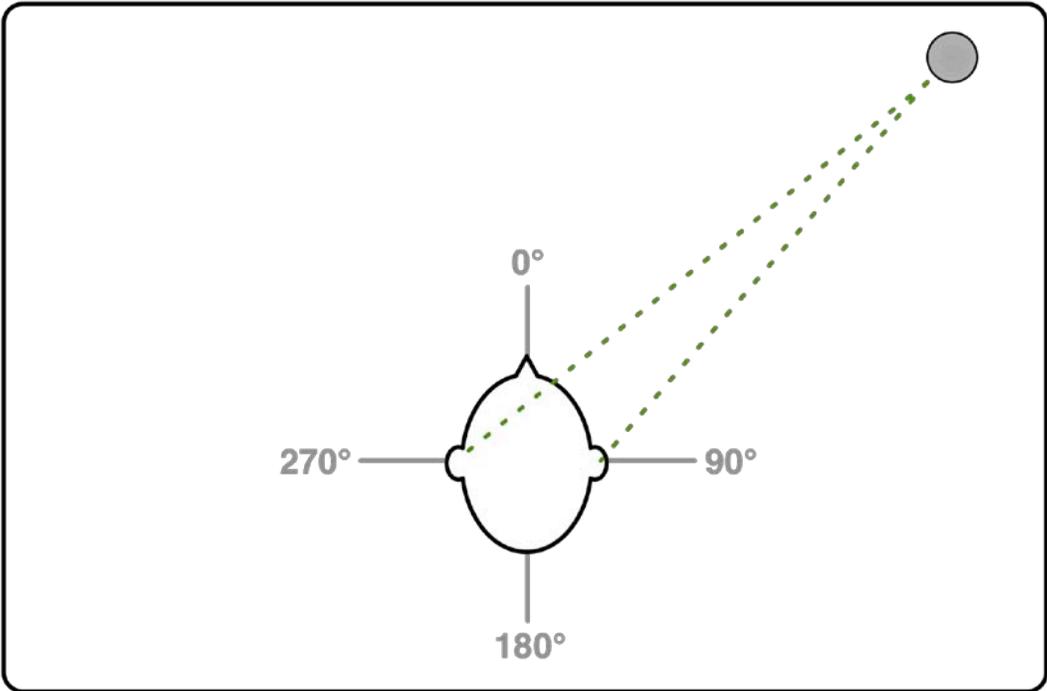
$$C = \cos^{-1}\left(\frac{a^2 + b^2 - c^2}{2ab}\right)$$
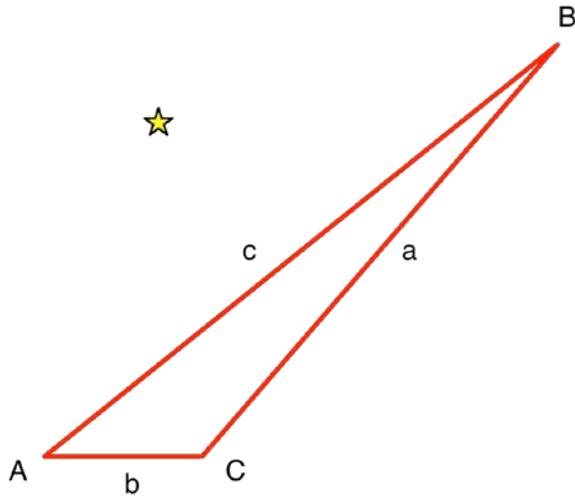
$$c = \sqrt{a^2 + b^2 - 2ab \cos C}$$

Problems

For each of the problems below, calculate the angle of arrival for each of the sound waves. Create a triangle with the two sound wave paths for two of the sides and complete the triangle by drawing a line connecting the ears. Then measure the sides of the triangle and use the provided formulas above to determine the other necessary values. Show your work!
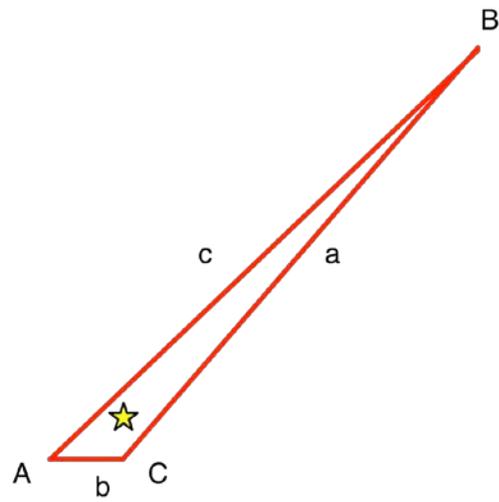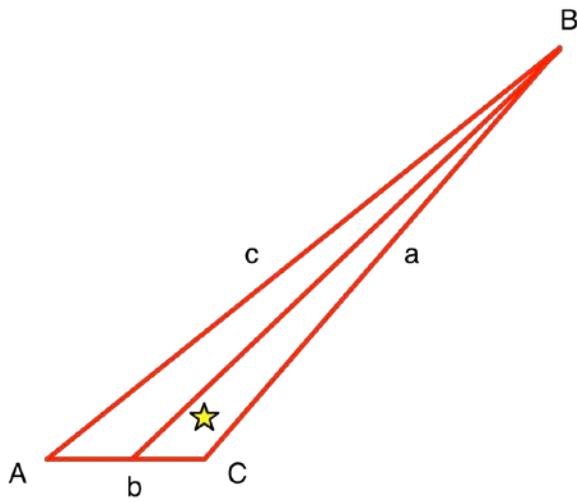
Problem 1:

Problem 2:
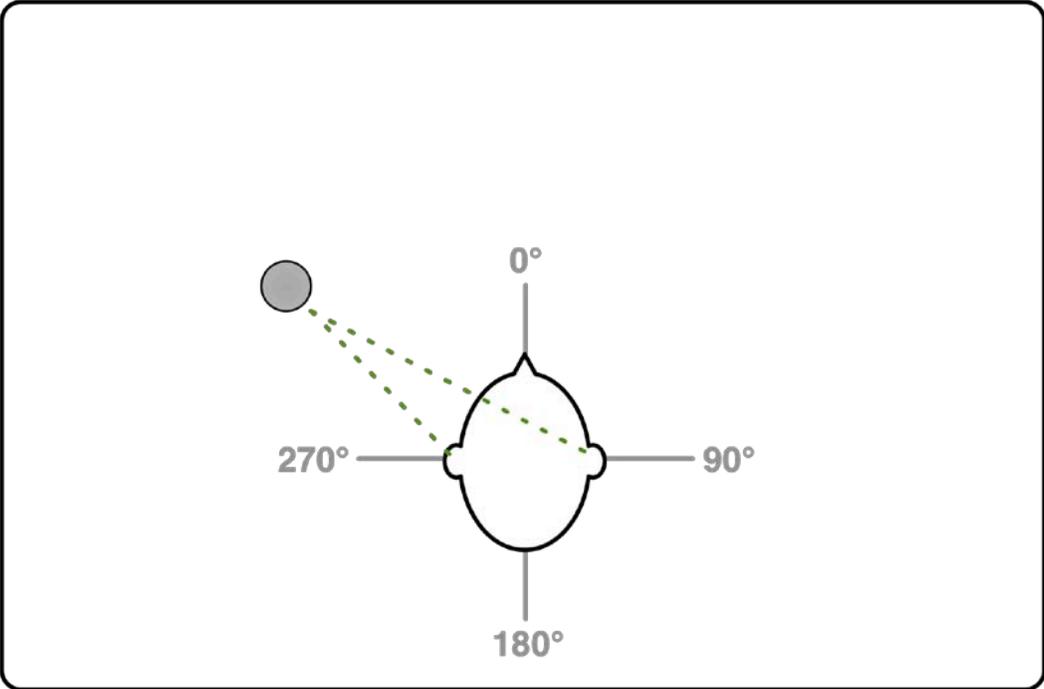
Problem 3:
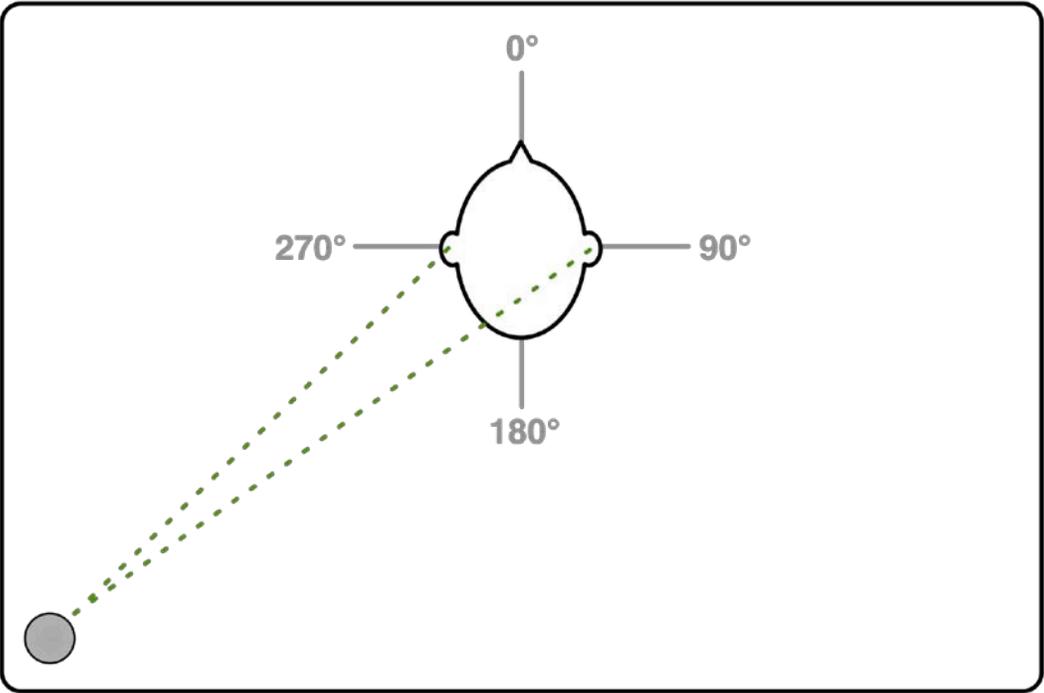
Problem 4:
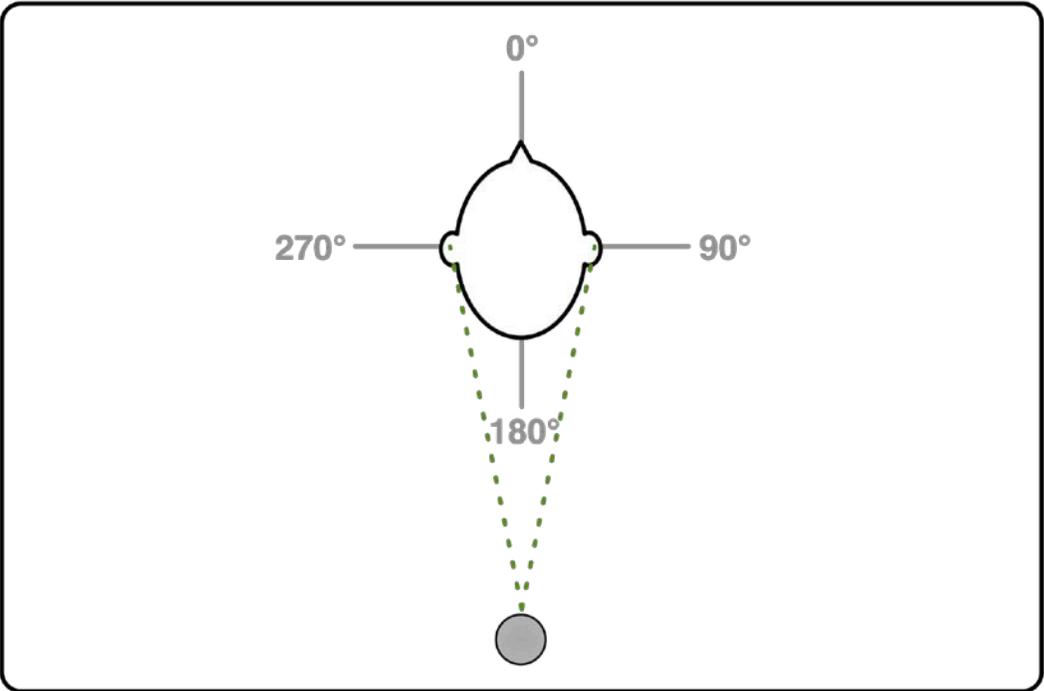
Determining the Direction of Arrival of Sound Waves Worksheet Answers

Materials

- protractor (to check answers)
- ruler
- pencil
- calculator

Legend

Legend		
⬭ Your head		
⚫ Sound source	Scale 1 cm = 75 m	
- - - - Sound wave path		

Formulas

$$A = \cos^{-1}\left(\frac{-a^2 + b^2 + c^2}{2bc}\right) \qquad a = \sqrt{b^2 + c^2 - 2bc\cos A}$$

$$B = \cos^{-1}\left(\frac{a^2 - b^2 + c^2}{2ac}\right) \qquad b = \sqrt{a^2 + c^2 - 2ac\cos B}$$

$$C = \cos^{-1}\left(\frac{a^2 + b^2 - c^2}{2ab}\right) \qquad c = \sqrt{a^2 + b^2 - 2ab\cos C}$$

Problems

For each of the problems below, calculate the angle of arrival for each of the sound waves. Create a triangle with the two sound wave paths for two of the sides and complete the triangle by drawing a line connecting the ears. Then measure the sides of the triangle and use the provided formulas above to determine the other necessary values. Show your work!

Problem 1:

a = 6.75 cm = 506.25 m   A = 45.479°

b = 2 cm = 150 m   B = 12.196°

c = 8 cm = 600 m   C = 122.325°

a = 6.75 cm = 506.25 m   A = 51.577°

b = 1 cm = 75 m   B = 6.098°

c = 7.33 cm = 549.75 m   C = 128.423°

Angle of arrival = 38.423°

Problem 2:
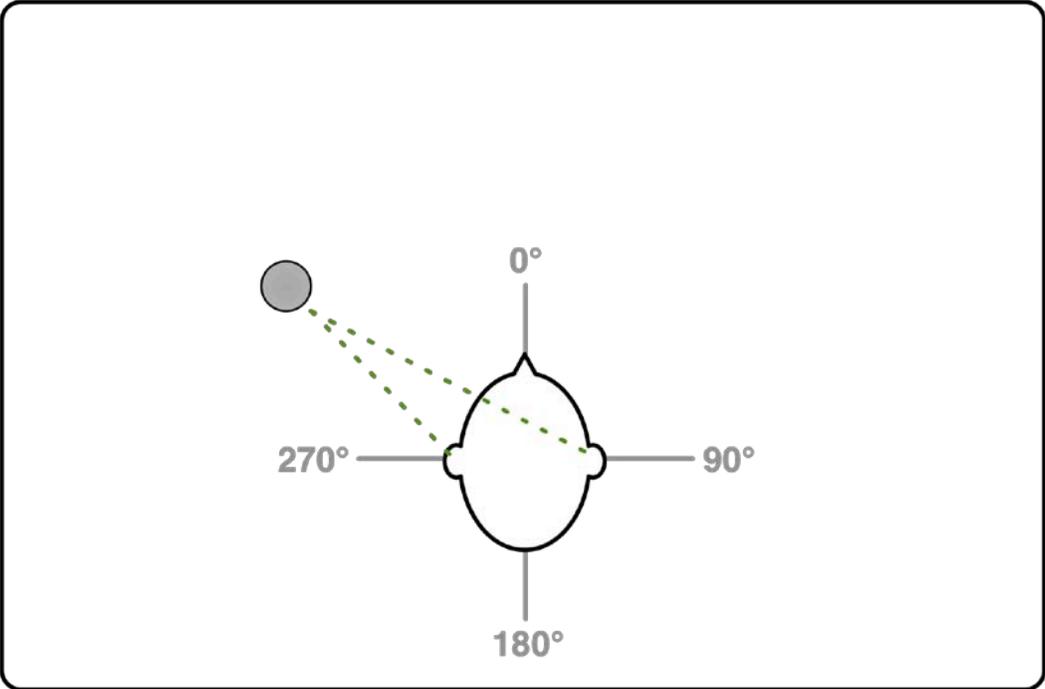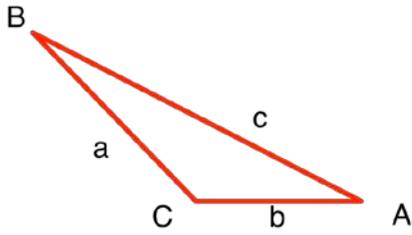
a = 2.75 cm = 206.25 m   A = 31.467°

b = 2 cm = 150 m   B = 22.312°

c = 4.25 cm = 318.75 m   C = 126.222°
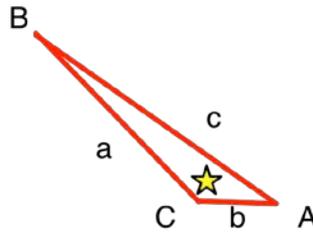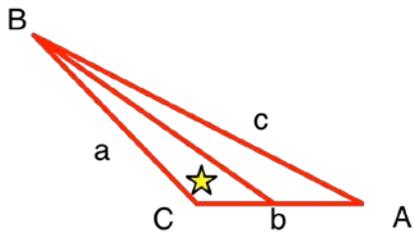
a = 2.75 cm = 206.25 m   A = 42.623°

b = 1 cm = 75 m   B = 11.156°

c = 3.437 cm = 257.78 m   C = 126.222°

Angle of arrival = 312.623°

Problem 3:
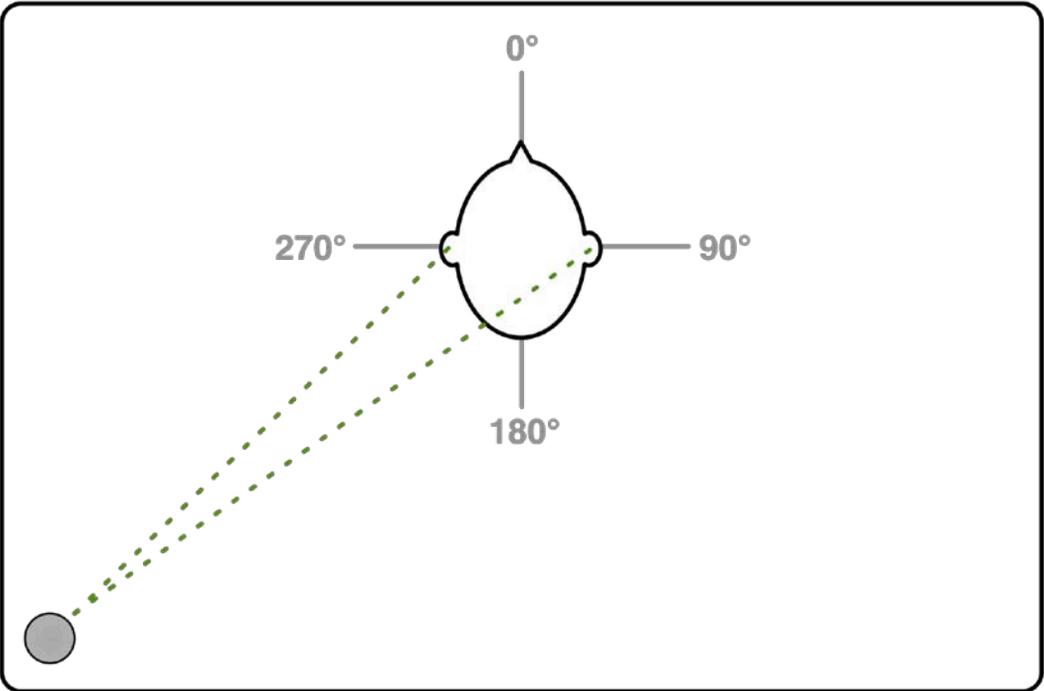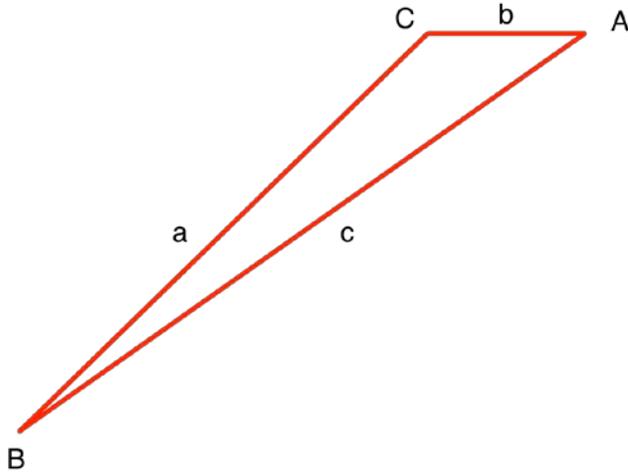
a = 7 cm = 525 m   A = 36.729°

b = 2 cm = 150 m   B = 9.838°

c = 8.5 cm = 637.5 m   C = 133.433°
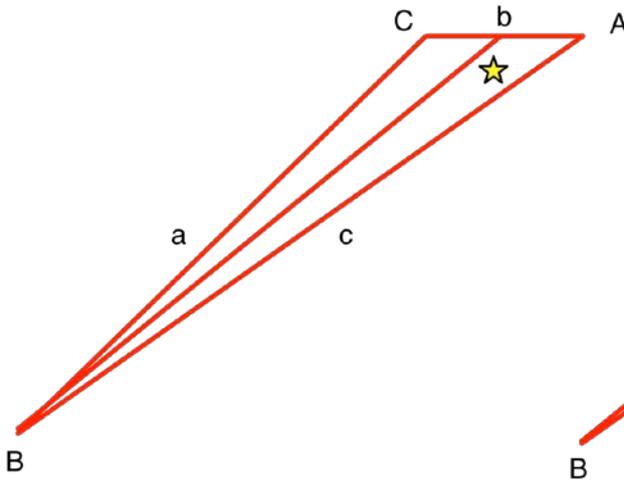
a = 7.72 cm = 579 m   A = 36.729°

b = 1 cm = 75 m   B = 4.919°

c = 8.5 cm = 637.5 m   C = 138.352°
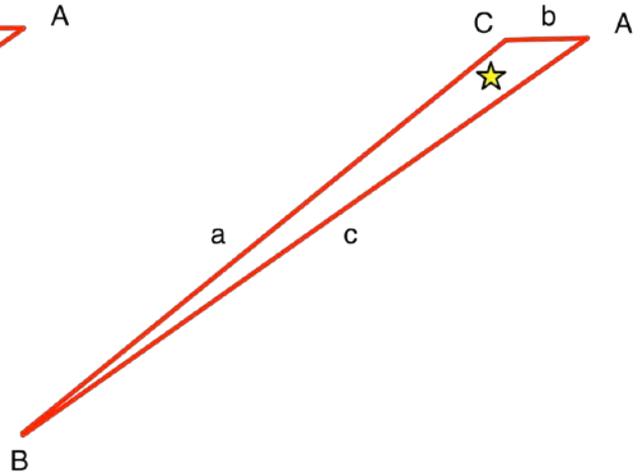
Angle of arrival = 228.352°

Problem 4:

B   c   A

a   b

C
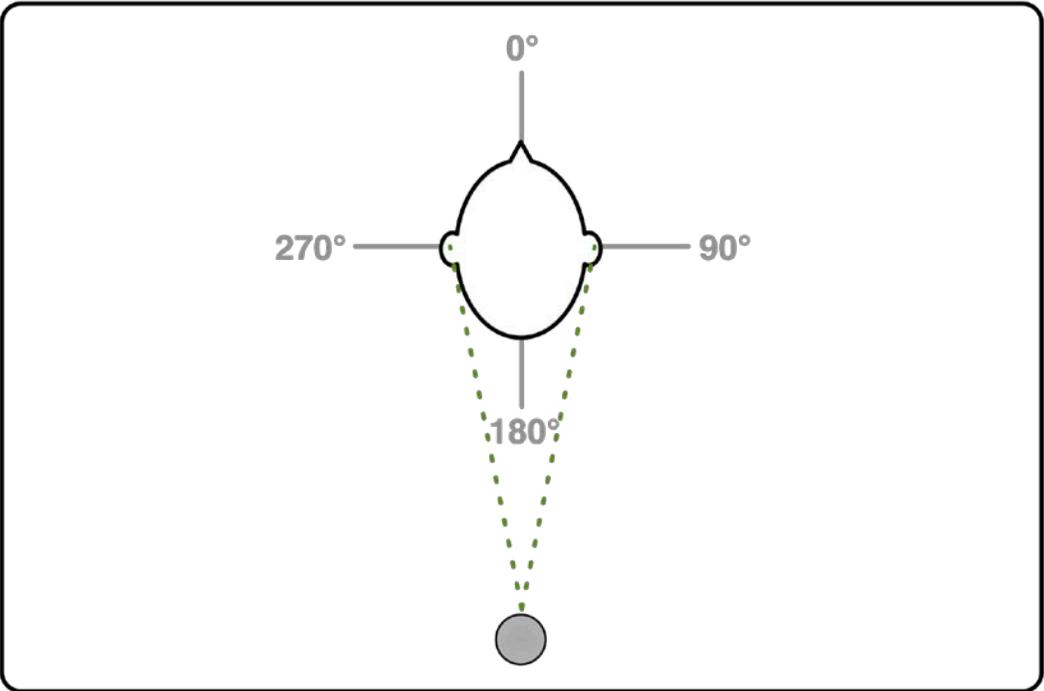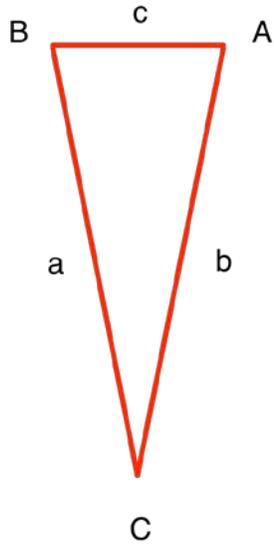
a = 5 cm = 375 m	A = 78.463°
b = 5 cm = 375 m	B = 78.463°
c = 2 cm = 150 m	C = 23.074°
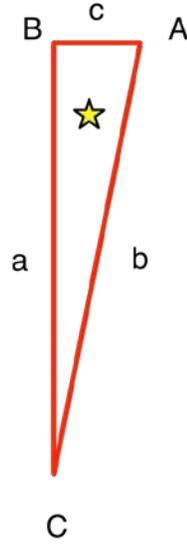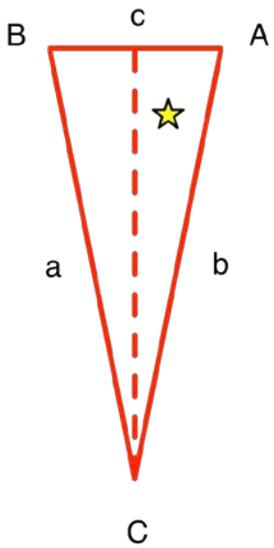
a = 4.899 cm = 367.425 m	A = 78.463°
b = 5 cm = 375 m	B = 90.0°
c = 1 cm = 75 m	C = 11.537°

Angle of arrival = 180°