Doppler Effect

Unit: Mechanical Waves

NGSS Standards/MA Curriculum Frameworks (2016): N/A

AP® Physics 2 Learning Objectives/Essential Knowledge (2024): 14.5.A, 14.5.A.1, 14.5.A.2, 14.5.A.2.i, 14.5.A.2.ii, 14.5.A.2.iii

Mastery Objective(s): (Students will be able to…)

- Explain the Doppler Effect and give examples.
- Calculate the apparent shift in wavelength/frequency due to a difference in velocity between the source and receiver.

Success Criteria:

- Descriptions & explanations account for observed behavior.
- Variables are correctly identified and substituted correctly into the correct equations.
- Algebra is correct and rounding to appropriate number of significant figures is reasonable.

Language Objectives:

- Explain how loudness is measured.

Tier 2 Vocabulary: shift

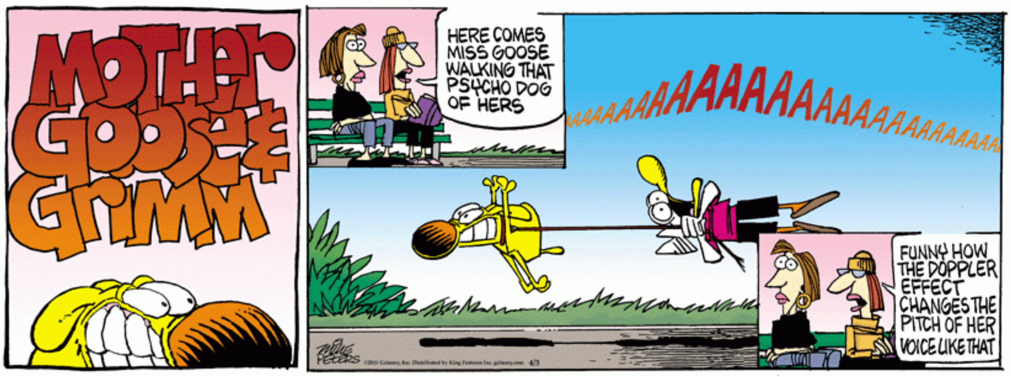
Labs, Activities & Demonstrations:

- Buzzer on a string.

Notes:

Doppler effect or Doppler shift: the apparent change in frequency/wavelength of a wave due to a difference in velocity between the source of the wave and the observer. The effect is named for the Austrian physicist Christian Doppler.

You have probably noticed the Doppler effect when an emergency vehicle with a siren drives by.

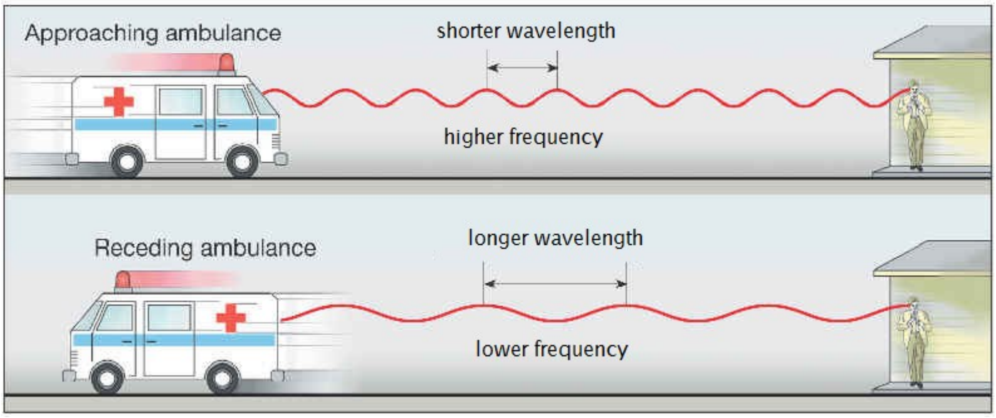


Why the Doppler Shift Happens

The Doppler shift occurs because a wave is created by a series of pulses at regular intervals, and the wave moves at a particular speed.

If the source is approaching, each pulse arrives sooner than it would have if the source had been stationary. Because frequency is the number of pulses that arrive in one second, the moving source results in an increase in the frequency observed by the receiver.

Similarly, if the source is moving away from the observer, each pulse arrives later, and the observed frequency is lower.



Calculating the Doppler Shift

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The change in frequency is given by the equation:

$$f = f_o\left(\frac{v_w \pm v_r}{v_w \pm v_s}\right)$$

where:

f = observed frequency
f_o = frequency of the original wave
v_w = velocity of the wave
v_r = velocity of the receiver (you)
v_s = velocity of the source

The rule for adding or subtracting velocities is:

- The receiver's (your) velocity is in the numerator. If you are moving toward the sound, this makes the pulses arrive sooner, which makes the frequency higher. So if you are moving ***toward*** the sound, ***add*** your velocity. If you are moving ***away*** from the sound, ***subtract*** your velocity.
- The source's velocity is in the denominator. If the source is moving toward you, this makes the frequency higher, which means the denominator needs to be smaller. This means that if the source is moving ***toward*** you, ***subtract*** its velocity. If the source is moving ***away*** from you, ***add*** its velocity.

Don't try to memorize a rule for this—you will just confuse yourself. It's safer to reason through the equation. If something that's moving would make the frequency higher, that means you need to make the numerator larger or the denominator smaller. If it would make the frequency lower, that means you need to make the numerator smaller or the denominator larger.

AP® only

Note that the AP® Physics exam requires only a qualitative treatment of the Doppler effect; you will not be required to calculate Doppler shifts.

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Sample Problem:

Q: The horn on a fire truck sounds at a pitch of 350 Hz. What is the perceived frequency when the fire truck is moving toward you at $20\,\frac{\text{m}}{\text{s}}$? What is the perceived frequency when the fire truck is moving away from you at $20\,\frac{\text{m}}{\text{s}}$? Assume the speed of sound in air is $343\,\frac{\text{m}}{\text{s}}$.

A: The observer is not moving, so $v_r = 0$.

The fire truck is the source, so its velocity appears in the denominator.

When the fire truck is moving toward you, that makes the frequency higher. This means we need to make the denominator smaller, which means we need to ***subtract*** v_s:

$$f = f_o\left(\frac{v_w}{v_w - v_s}\right) = 350\left(\frac{343}{343-20}\right) = 350(1.062) = 372\,\text{Hz}$$

When the fire truck is moving away, the frequency will be lower, which means we need to make the denominator larger. This means we need to ***add*** v_s:

$$f = f_o\left(\frac{v_w}{v_w + v_s}\right) = 350\left(\frac{343}{343+20}\right) = 350(0.9449) = 331\,\text{Hz}$$

Note that the pitch shift in each direction corresponds with about one half-step on the musical scale.