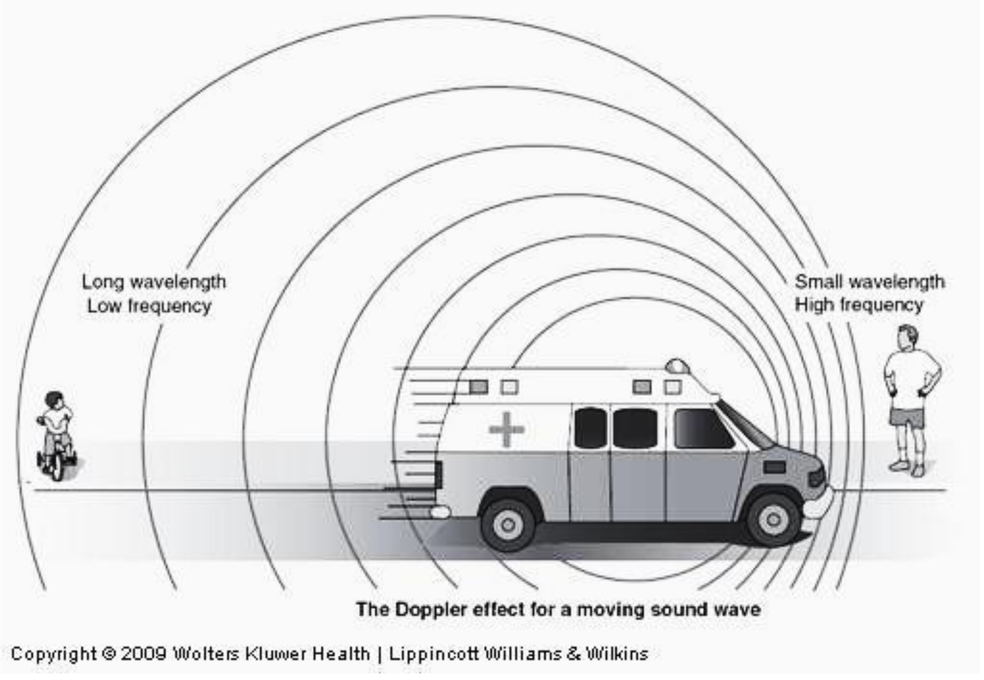
Physics 115 Lecture 14

The Doppler Effect I

February 23, 2018

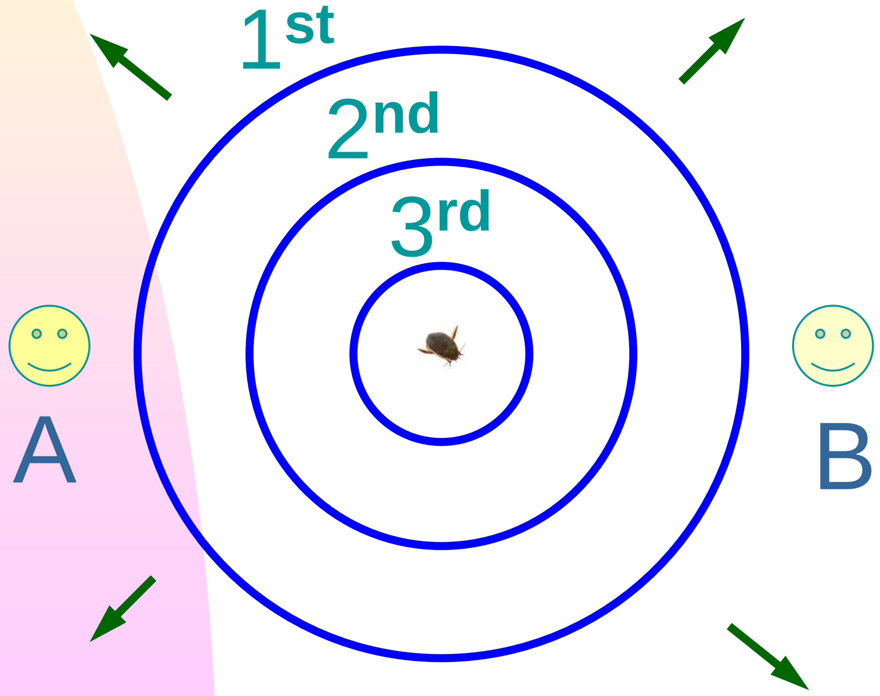
The Doppler effect

- The frequency detected by a listener depends on the speeds of the source and the listener relative to the medium through which the waves travel (usually air for sound waves).
- Video demonstration (sounds)
- Video demonstration (ripple tank)
- Animated applet
- Another applet



The Doppler Effect

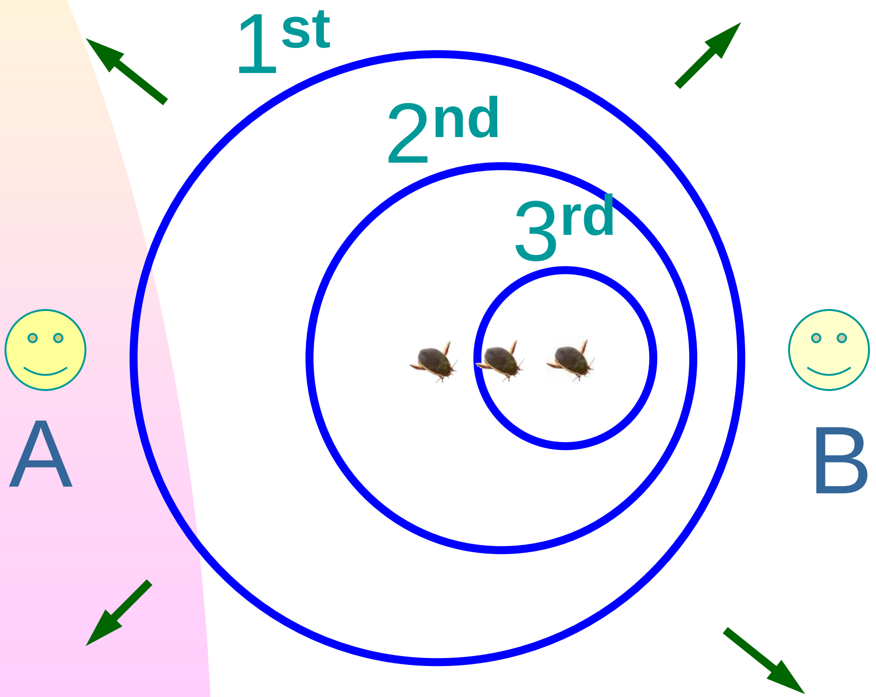
- Consider water waves made by a bug jumping up and down in calm water:



Observers A and B measure the <u>same</u> frequency for the passing waves.

The Doppler Effect

- Now consider what would happen if the bug were moving to the right while jumping up and down in calm water:



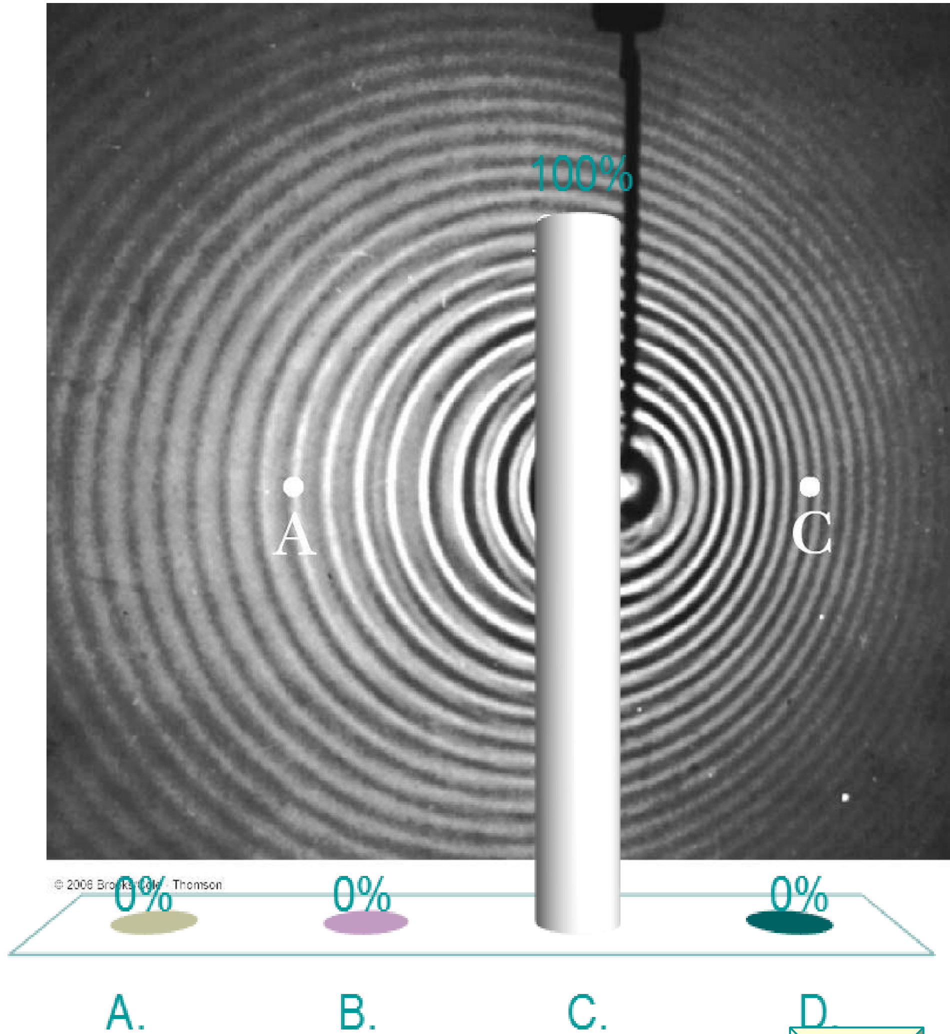
Observer B measures a higher frequency than does Observer A.

The Doppler Effect

The motion of the wave source, and/or the motion of the observer, can cause the frequency measured by the observer to differ from the frequency emitted by the wave source. This is the Doppler effect.

Consider "listeners" at points A, B, and C in the figure. Which of the following is true?

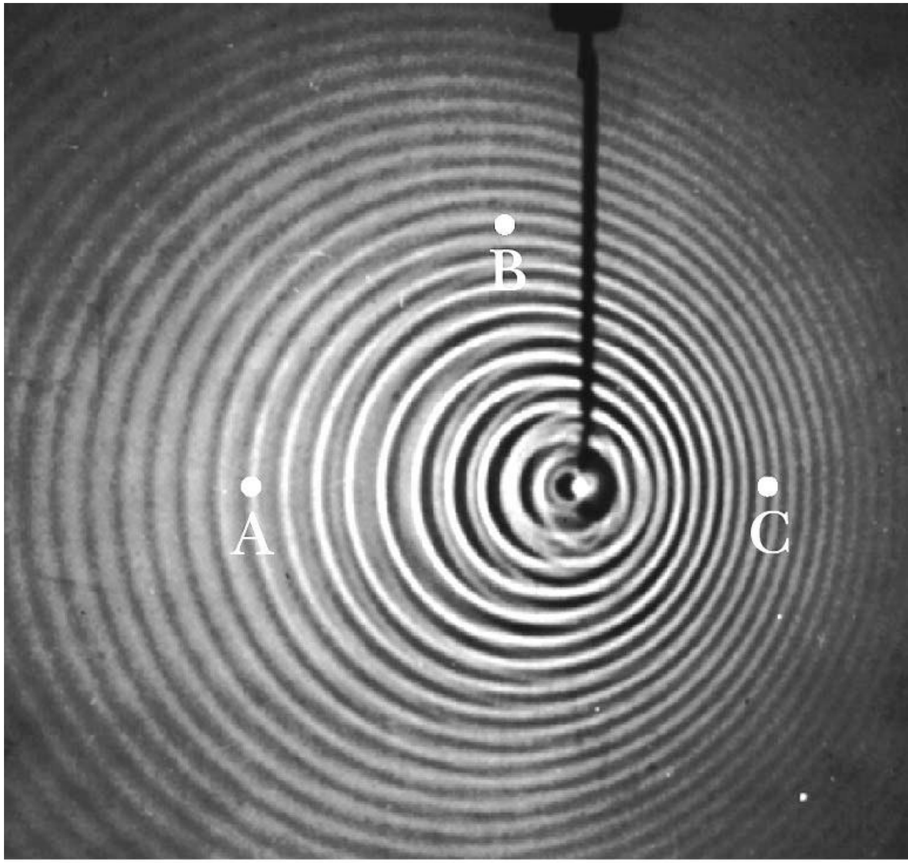
A. The wave speed is highest at point C.
B. The detected wavelength is largest at point C.
C. The detected frequency is highest at point C
D. The detected wavelength is largest at point B.



20 of 46

Consider "listeners" at points A, B, and C in the figure. Which of the following is true?

A. The wave speed is highest at point C.
B. The detected wavelength is largest at point C.
C. **The detected frequency is highest at point C**
D. The detected wavelength is largest at point B.

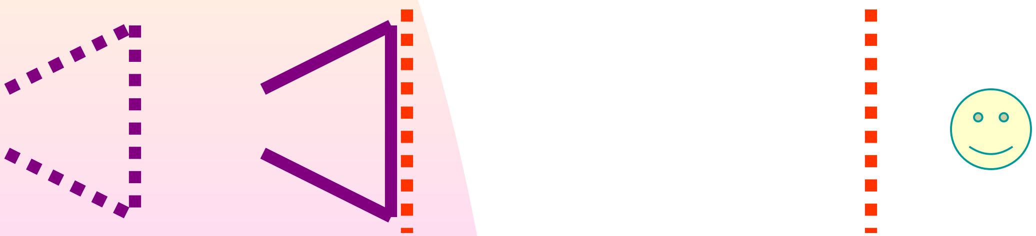


Source approaches stationary observer

At $t = 0$, the horn launches a crest

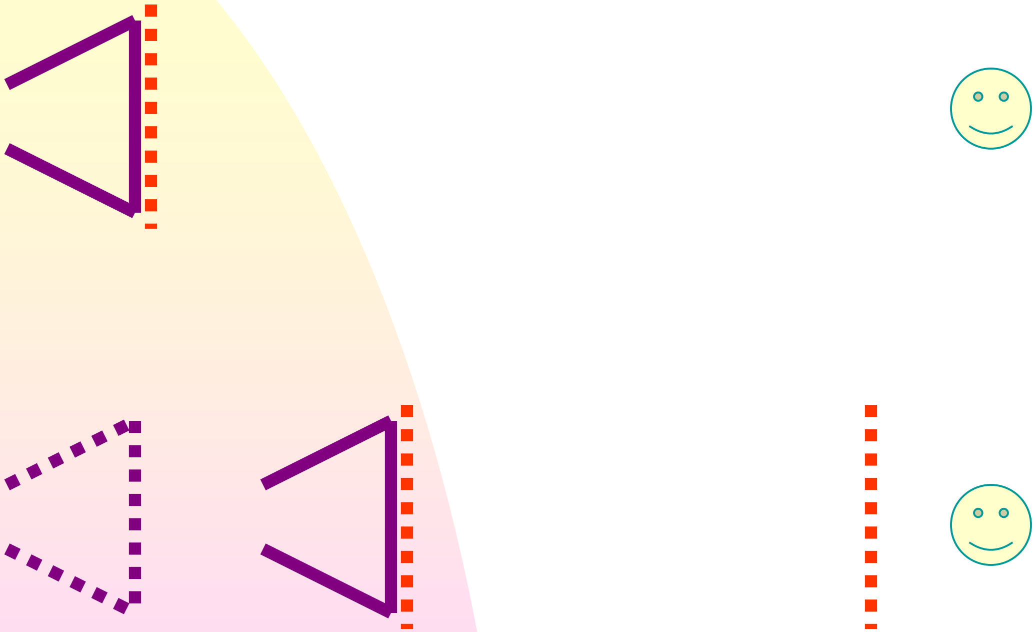
Source approaches stationary observer

At t = 0, the horn launches a crest



At t = T, the horn launches the next crest

Source approaches stationary observer



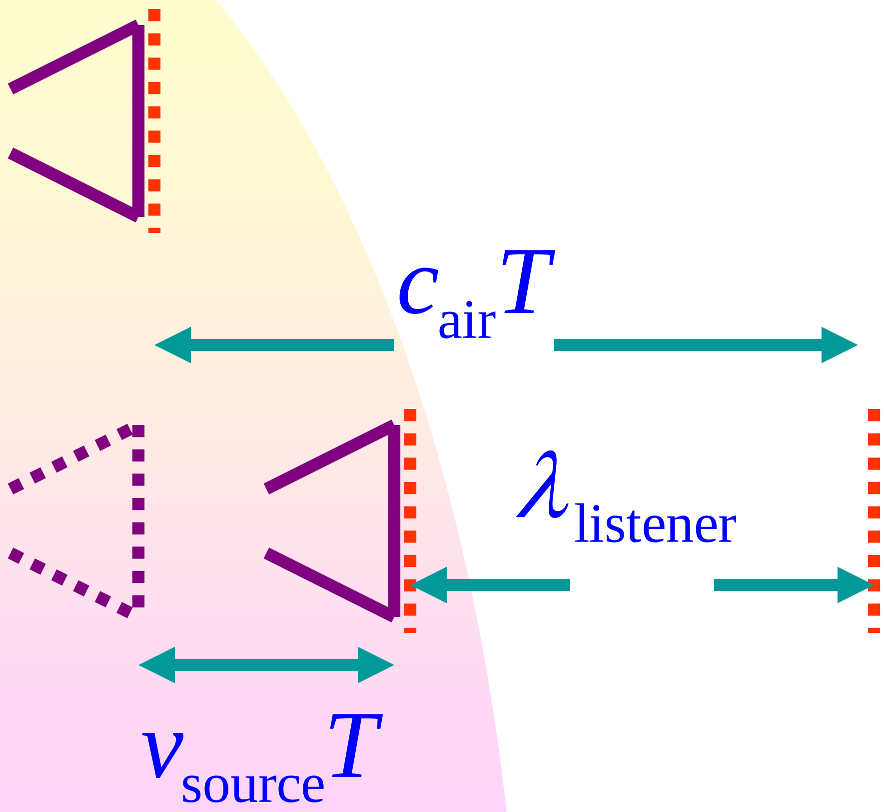
At t = 0, the horn launches a crest

At t = T, the horn launches the next crest

Note: Frequency of wave source = 1 / T

⇨ $f = 1 / T$ ⇨ $T = 1 / f$

Source approaches stationary observer



$$\lambda_{listener} = c_{air}T - v_{source}T$$

$$\lambda_{listener} = T\left(c_{air} - v_{source}\right)$$

$$\frac{c_{air}}{f_{listener}} = T\left(c_{air} - v_{source}\right)$$

$$\frac{c_{air}}{f_{listener}} = \frac{1}{f_{source}}\left(c_{air} - v_{source}\right)$$

After some algebra…

$$\boxed{f_{listener} = f_{source}\left(\frac{c_{air}}{c_{air} - v_{source}}\right)}$$

Source recedes from stationary observer

At t = 0, the horn launches a crest

Source recedes from stationary observer

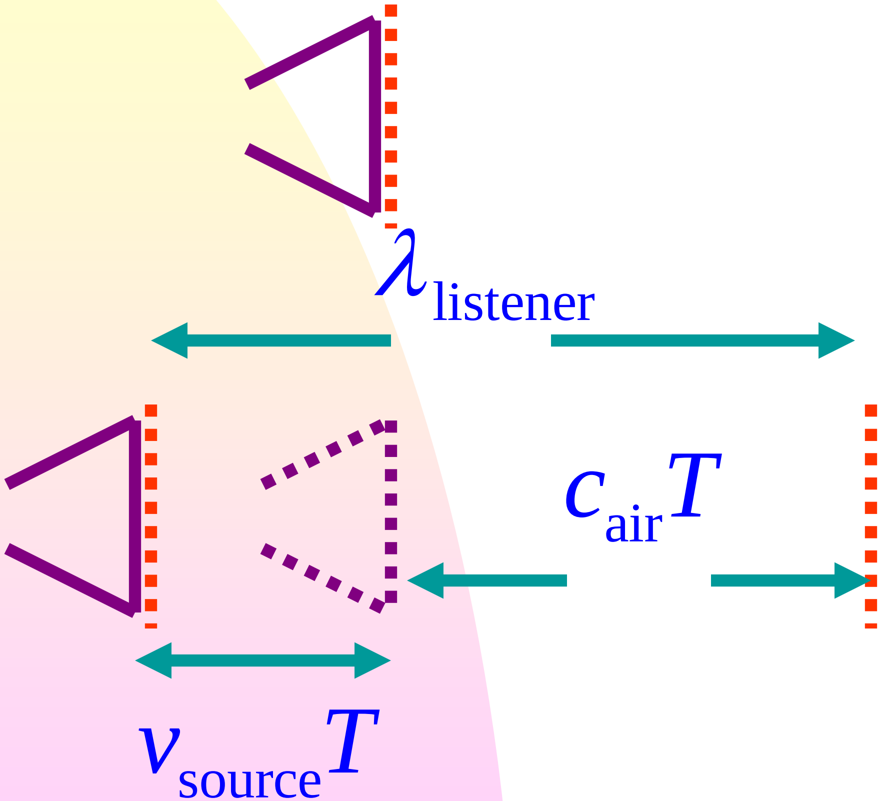
At $t = 0$, the horn launches a crest

At $t = T$, the horn launches the next crest

Note: Frequency of wave source = $1 / T$

$\Rightarrow$ $f = 1 / T$ $\Rightarrow$ $T = 1 / f$

Source recedes from stationary observer



$$\lambda_{\text{listener}} = c_{\text{air}}T + v_{\text{source}}T$$

$$\lambda_{\text{listener}} = T\left(c_{\text{air}} + v_{\text{source}}\right)$$

$$\frac{c_{\text{air}}}{f_{\text{listener}}} = T\left(c_{\text{air}} + v_{\text{source}}\right)$$

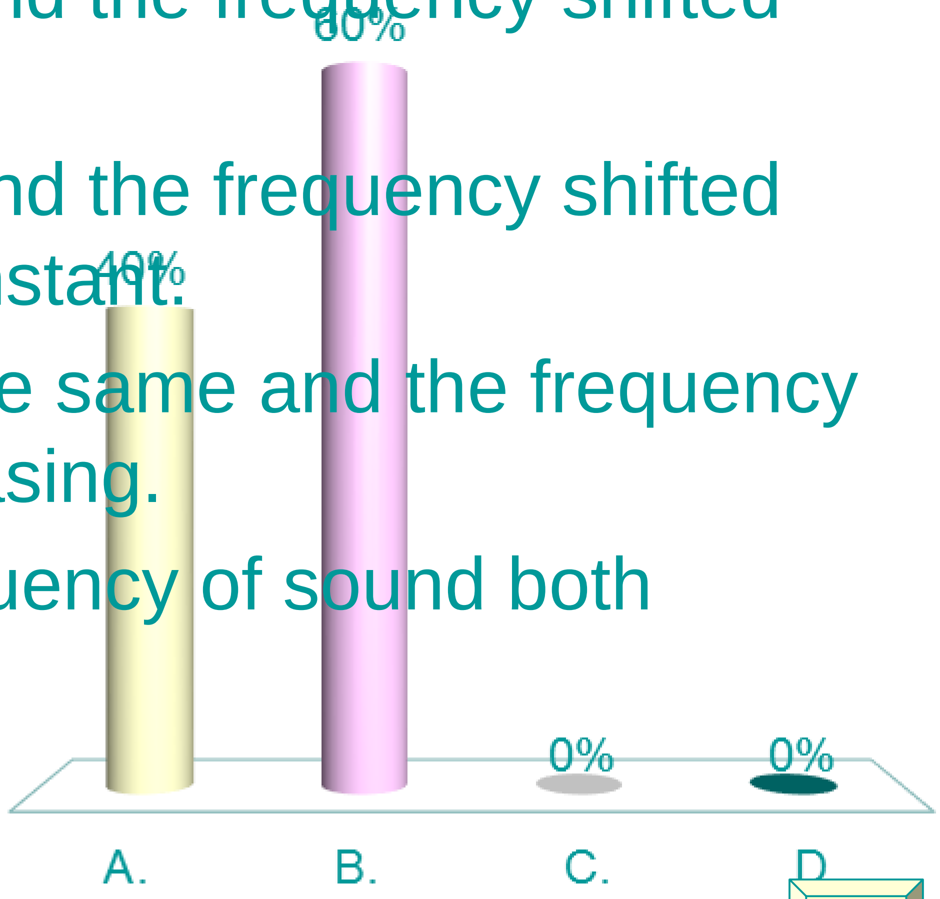
$$\frac{c_{\text{air}}}{f_{\text{listener}}} = \frac{1}{f_{\text{source}}}\left(c_{\text{air}} + v_{\text{source}}\right)$$

After some algebra…

$$\boxed{f_{\text{listener}} = f_{\text{source}}\left(\frac{c_{\text{air}}}{c_{\text{air}} + v_{\text{source}}}\right)}$$

You stand on a platform at a train station and listen to a train as it approaches at constant speed, but before it arrives. You will hear

A. the intensity increasing and the frequency shifted higher and increasing.
B. the intensity increasing and the frequency shifted higher and remaining constant.
C. the intensity remaining the same and the frequency shifted higher and decreasing.
D. the intensity and the frequency of sound both remaining the same.



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You stand on a platform at a train station and listen to a train as it approaches at constant speed, but before it arrives. You will hear

A. the intensity increasing and the frequency shifted higher and increasing.

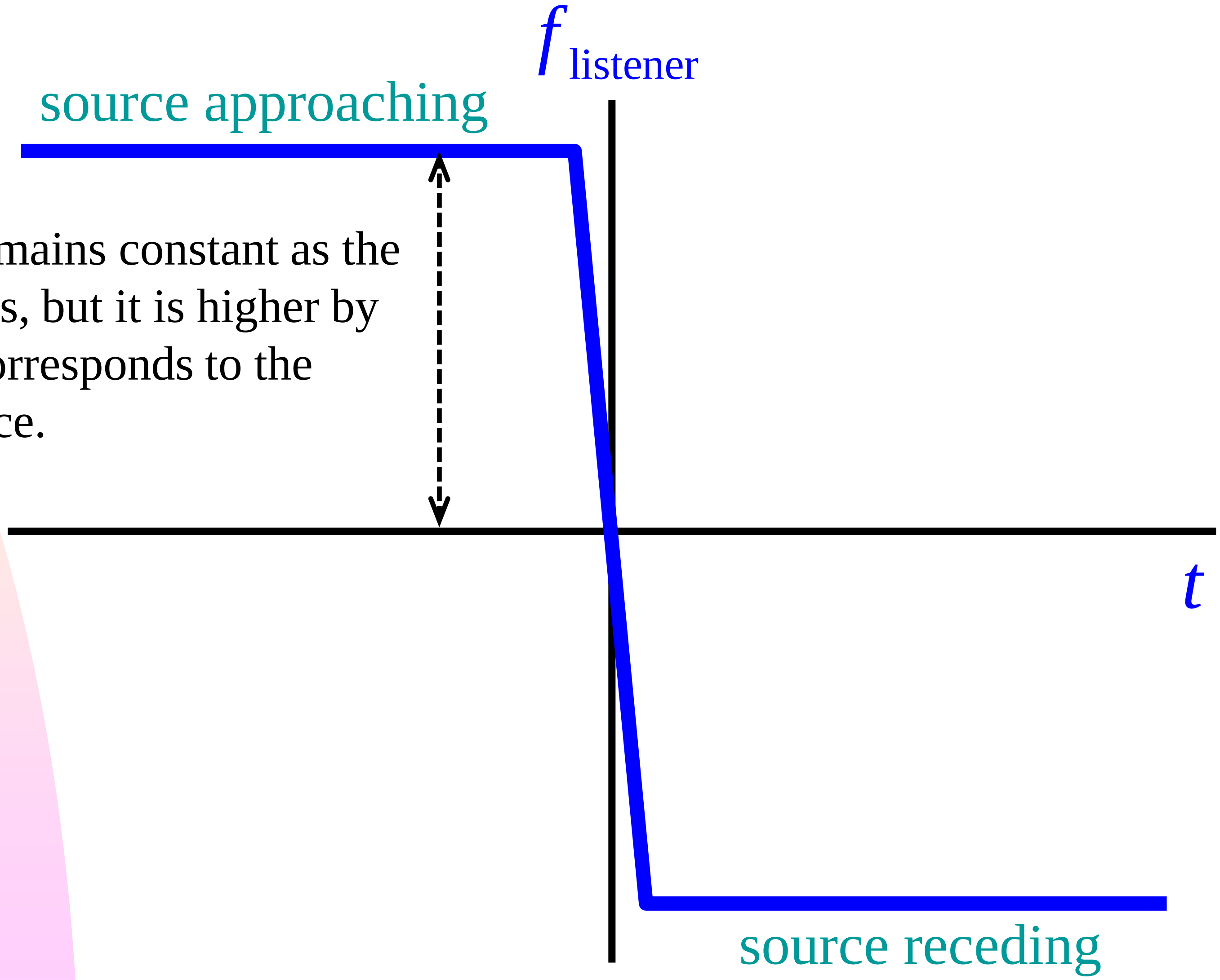
B. the intensity increasing and the frequency shifted higher and remaining constant.

C. the intensity remaining the same and the frequency shifted higher and decreasing.

D. the intensity and the frequency of sound both remaining the same.

The frequency depends only on speed, not distance

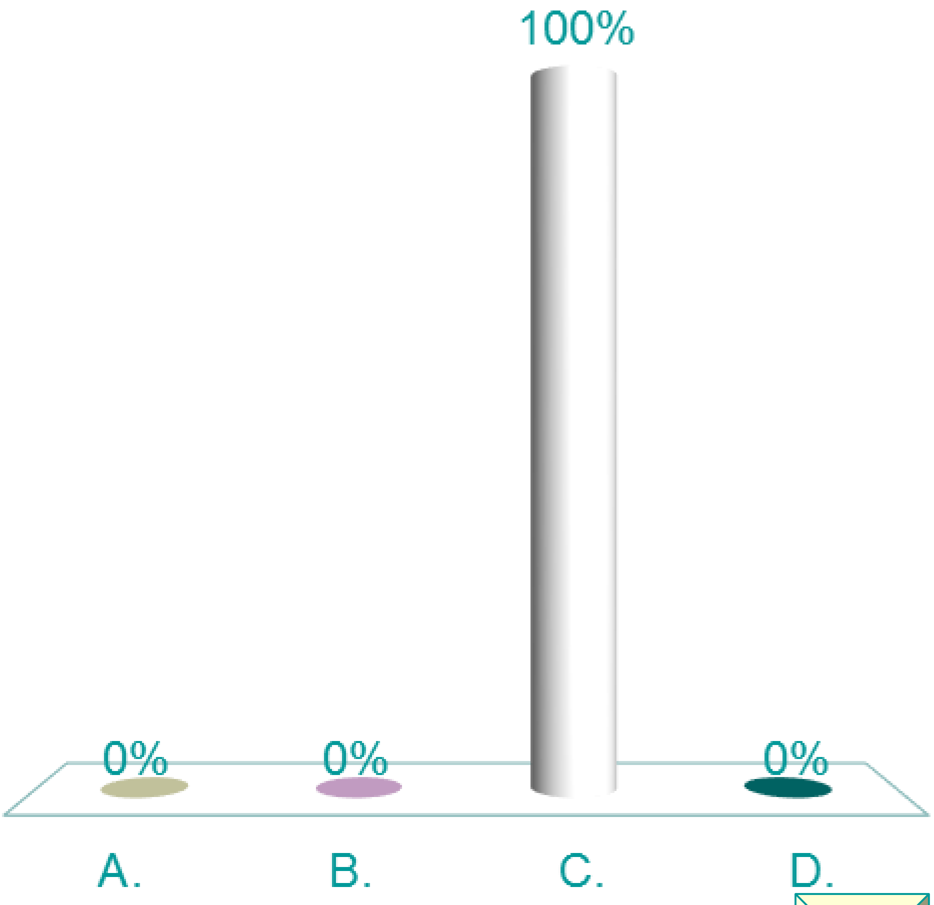
Let the source pass at time t = 0



The frequency remains constant as the source approaches, but it is higher by an amount that corresponds to the speed of the source.

What is the frequency you hear when a 500 Hz siren recedes from you at 25 m/s? Assume c_{air} = 343 m/s.

A. 432 Hz
B. 500 Hz
C. 466 Hz
D. 534 Hz



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What is the frequency you hear when a 500 Hz siren recedes from you at 25 m/s? Assume c_{air} = 343 m/s.

A. 432 Hz

B. 500 Hz

C. 466 Hz

D. 534 Hz

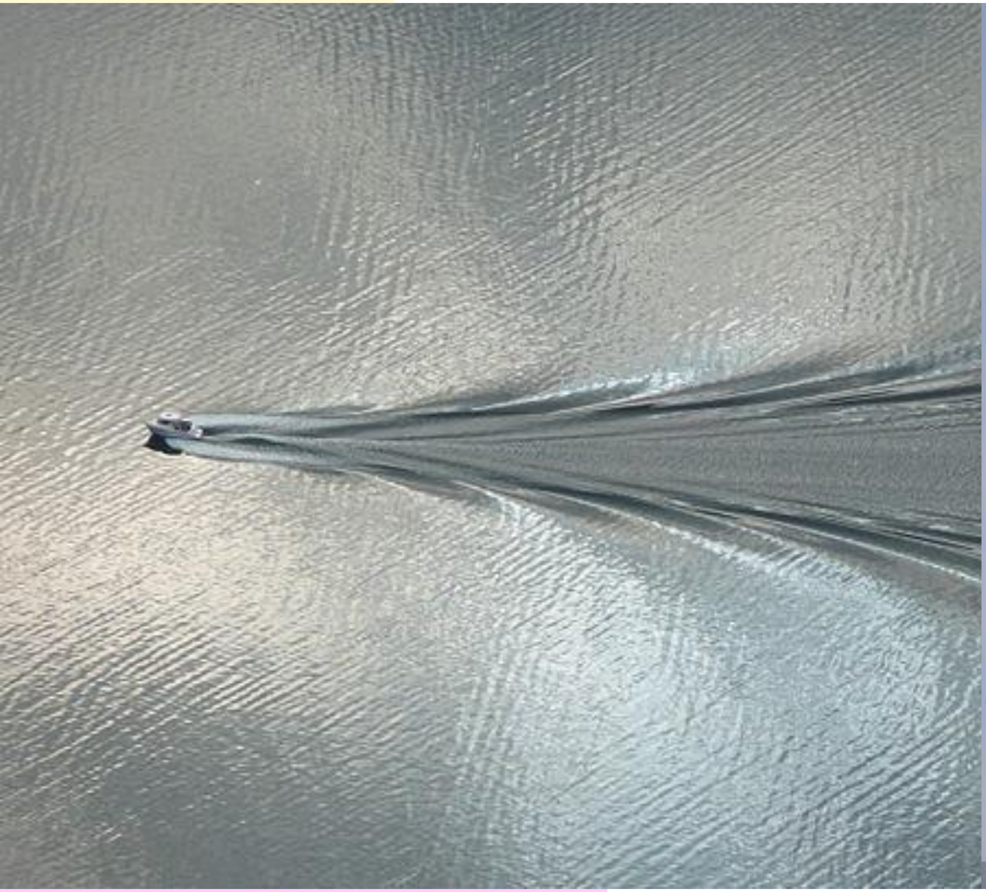
$$f_{\text{listener}} = f_{\text{source}}\left(\frac{c_{\text{air}}}{c_{\text{air}} + v_{\text{source}}}\right)$$

$$= (500 \text{ Hz})\left(\frac{343 \text{ m/s}}{343 \text{ m/s} + 25 \text{ m/s}}\right)$$

$$f_{\text{listener}} = \boxed{466 \text{ Hz}}$$

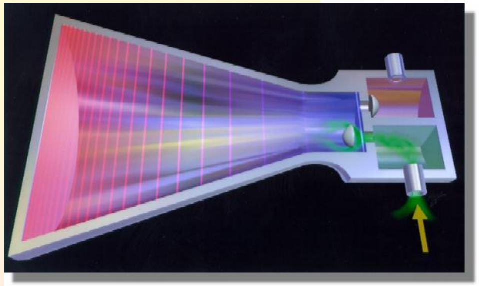
Shock waves

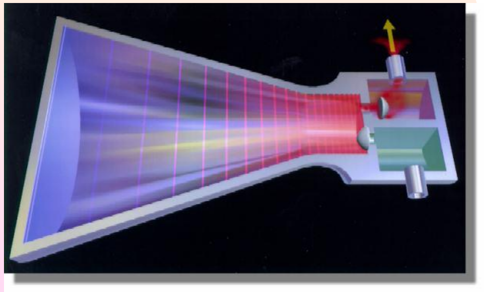
If the speed of the source exceeds the wave speed, a shock wave is formed.



YouTube video

Common shock waves





- Crack of a whip
- Airplane propeller
- Helicopter blades
- Sonic boom

- Fun fact: if shock waves are suppressed, acoustic refrigeration is possible!

Doppler effect applications

- Doppler radar
- Police radar
- Galactic rotation measurement