# Lesson 51: Doppler Effect

You've probably noticed that when an ambulance passes you with its siren going, or a plane flies overhead, you can hear the sound change.

- I'm not talking about louder or quieter, but rather the **pitch** of the sound.
    - As it comes closer to you the pitch (frequency) of the siren will seem to *increase*.
    - When it is moving away, it seems like the frequency *decreases*.
- When the **true** frequency of a **source of sound** is changed so that an **observer** hears a different **apparent** frequency as they move relative to each other, it is known as the **Doppler Effect**.

This change was described by the Austrian Christian Doppler in 1842. An experimental proof was performed by the Dutch scientist Buys Ballot in 1845 using trains and trumpets.

- In his version of the experiment, he had **trumpet players** (**source of sound**) stand on a flatbed train car and move past a stationary **observer**.
- The **observer** recorded the notes that he thought the **trumpet players** were playing.

Video Killed the Radio Star!
Watch a BBC video of a reenactment of this experiment by clicking here

## "Bob the Swimming Bug" (*aka Why Frequency Changes*)

To see why this change in frequency happens, I want you to imagine a very special bug named "Bob."

- I have trained Bob to do a very special trick. He can tread water!
- When I first trained him to do this, he could only do it while staying in exactly one spot. If we were to look down on Bob as he treads water, we would see waves that look like Figure 1…

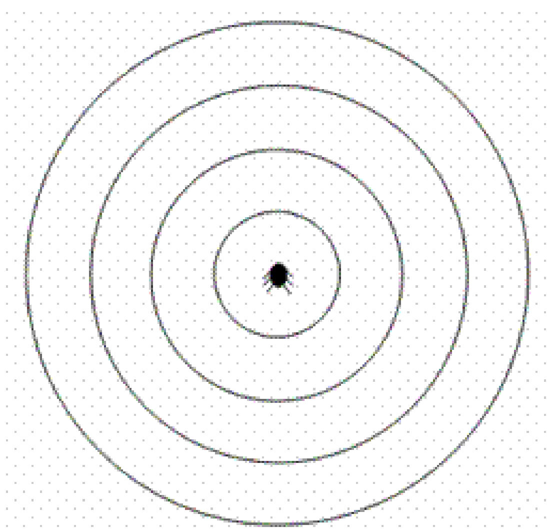

*Illustration 1: Bob treading water, creating concentric waves as seen from above.*

Notice how Bob is in the middle and all the waves are spreading out evenly from him in the water.

- If I asked you to stand on the right side of Bob, and then later on the left of Bob, and measure the frequency of the waves (how many pass you per second) you would give the same number.

- Let’s say that Bob is bobbing up and down at exactly 4 Hz, and he always treads water at this frequency. No matter where you are standing, you will measure the same frequency for Bob's waves. No Doppler Effect yet.

After years of training I am able to get Bob to tread water while slowly moving to the right.
- Each time he starts to make a new wave, he’ll be in a spot slightly to the right of where he used to be.
- That means the centre of each new circle will be slightly to the right of where he made his previous wave circle.
- The **red** circle is the first wave he made, then **blue**, **pink**, and finally **black**.
- Each wave ripple continues to spread out as Bob moves to the right.

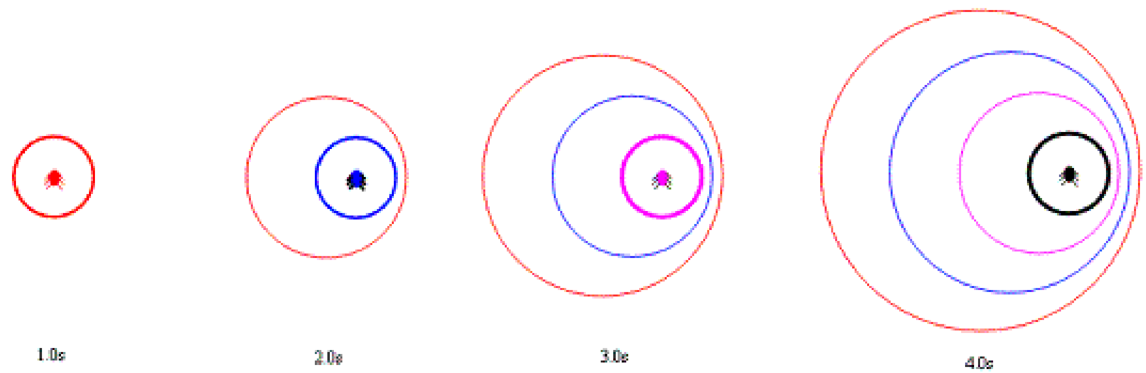


*Illustration 2: As time passes Bob moves to the right, catching up to old waves while creating new waves.*

- At one second, Bob is at the centre of the **red** wave he has created.
- At two seconds, he is at the centre of the next wave he is creating, a **blue** one. His **red** wave continues to grow outwards with its centre where he was at one second.
- At three seconds, the **pink** circle is created with Bob at the centre. The **blue** and **red** circles are still expanding with their centres at the same spots as when they were originally created.
- This pattern would continue for as long as Bob is bobbing up and down and moving to the right.

Now let’s look at what you would measure about Bob’s frequency if you were standing on the left side compared to the right side. Remember that Bob is **truly** treading water at 4 Hz.
- On the *left* side the waves have been spread further apart.
  - Spread out more means that the **wavelength** is bigger. Since wavelength and frequency are inversely related, you would say the waves have a lower **frequency** (maybe something like 2Hz). The waves are not passing you as frequently.
- On the *right* hand side the waves are squished closer together.
  - If I was standing on the right side, I would say that the waves have a smaller **wavelength**, so they must also have a higher **frequency** (like maybe 6Hz). They are passing you more frequently.
- In both cases you measured an **apparent** frequency of Bob’s treading that is different from his **true** frequency, but you have no way of knowing this unless you have measured his **true** frequency when he was motionless relative to you.

The exact same thing happens with sounds!
Imagine that instead of Bob, you now have an ambulance coming towards you with its siren going.

- As the ambulance is moving away you, you will hear a lower frequency because the waves are more spread apart, just like standing on the left of Bob.
- If the ambulance is coming towards you, you will hear a higher frequency sound because the waves are squished together, just like standing on the right hand side of Bob.
- You will get the same effect if the ambulance stands still and *you* start moving towards it (squishing the waves together), or away from it (spreading them apart).
- The **Doppler effect** (the **apparent** change from the **true** frequency) will happen if there is any difference between the velocity of the source and the observer.

DID YOU KNOW?
This compression of waves in front of the source of the sound is also why it is difficult to go faster than the speed of sound. As the vehicle gets near the speed of sound, it must push through that wall of compressed air... not an easy thing to do. Click here to watch a quick video of a jet breaking the sound barrier... can you figure out why it looks like clouds form around it?

There is a formula that lets you calculate the **apparent frequency** of a sound (what you hear) if you know the **true frequency** of the sound (from the original **source**) and the velocity of the source.

$$f = \left(\frac{v}{v \pm v_s}\right) f_s$$

$f$ = **apparent frequency** (Hz)
$f_s$ = **true source frequency** (Hz)
$v$ = speed of sound (m/s)
$v_s$ = velocity of source (m/s)

On the bottom of the formula...

- if the source is moving **towards** the observer, use the **minus** sign (you're getting closer).
- if the source is moving **away from** the observer, use the **plus** sign (you're getting further apart).

**Example 1**: A siren is making a sound at a frequency of 8500 Hz while driving down the street. It is a cold day and the speed of sound is 300m/s.

a) If the ambulance approaches you at 25 m/s, **determine** the frequency you will hear.
b) If the ambulance is moving away from you at 25m/s, **determine** the frequency you will hear.

To figure these out, use the formula you were given above. Be careful with figuring out when to use the plus or minus sign on the bottom of the formula. I'm not going to be paying attention to sig digs in my calculations here because I want you to see how the frequency changes. ***You still need to use sig digs when you do your calculations!***

a) The source is approaching the observer at 25m/s, so we will use the minus sign.

$$f=\left(\frac{v}{v\pm v_s}\right)f_s$$

$$f=\left(\frac{300}{300-25}\right)8500$$

$$f=9273Hz=9.27e3Hz$$

This is a higher frequency than the original, so you will hear it as a higher pitch.

b) The source is moving away from the observer at 25 m/s, so we use a plus sign.

$$f=\left(\frac{v}{v\pm v_s}\right)f_s$$

$$f=\left(\frac{300}{300+25}\right)8500$$

$$f=7846Hz=7.85e3Hz$$

This is a lower frequency than the original, so you will hear it as a lower pitch.

**Homework**

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