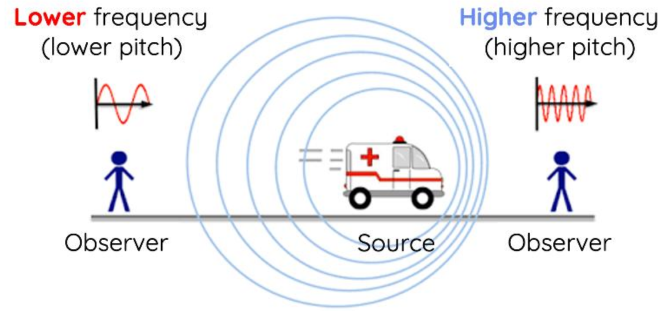
The Doppler Effect

For a stationary observer and a moving source of sound, the frequency (f_{obs}) of sound perceived by the observer is

The Doppler Formula:

$$f_{obs} = f_s \left(\frac{v_w}{v_w \pm v_s} \right)$$



f_s is the frequency of sound from a source,
v_s is the speed of the source,
v_w is the speed of sound.

1. A car is honking its horn at a frequency of $f_s = 500$ Hz. It moves toward a stationary observer at $v_s = 20$ m/s. Assume the speed of sound is $v_w = 340$ m/s.
   (a) What frequency does the observer hear?
   (b) If instead the car were moving away at 20 m/s, what would be the observed frequency?

2. A fireworks truck siren emits a tone of $f_s = 800$ Hz. When the truck is moving away from a stationary observer at $v_s = 25$ m/s, what is the observed frequency? Take $v_w = 340$ m/s.

3. A factory whistle has a known frequency of $f_s = 450$ Hz. An observer on a sidewalk hears a frequency of $f_{obs} = 480$ Hz as the source approaches. If $v_w = 340$ m/s, find the speed of the whistle by rearranging the Doppler formula to solve for v_s.

4. A train horn is known to be $f_s = 300$ Hz. A stationary observer records $f_{obs} = 280$ Hz as the train moves away. If $v_w = 340$ m/s, how fast is the train traveling?

5. An ambulance siren's frequency is $f_s = 700$ Hz.
   (a) If the ambulance travels toward a stationary observer at $v_s = 30$ m/s, find f_{obs}.
   (b) Once it passes and travels away at the same speed, what does the observer measure then? (Assume $v_w = 340$ m/s.)

6. A race car's engine produces a tone of $f_s = 1000$ Hz. The car moves at $v_s = 60$ m/s (about 216 km/h).
   (a) Calculate the observed frequency as the car approaches.
   (b) Calculate the observed frequency as the car recedes. (Assume $v_w = 340$ m/s.)

7. A distant alarm is known to sound at $f_s = 600$ Hz. A stationary observer measures an observed frequency of $f_{obs} = 630$ Hz. If the speed of sound is $v_w = 343$ m/s, how fast is the source moving toward the observer?

8. The speed of sound v_w can be approximated as: $v_w \approx 331 + 0.6T$ (in m/s), where T is the temperature in °C. A music speaker on a cart emits a frequency f_s = 440 Hz. On a cool morning (T = 10°C), the observed frequency for an approaching cart is f_{obs} = 452 Hz. Determine v_s, the speed of the cart.
   (a) First calculate v_w for T = 10°C.
   (b) Use the Doppler formula to find v_s.

9. Suppose a truck's back-up beeper has a frequency f_s = 300 Hz. You measure two different observed frequencies in two different scenarios (both with you staying still):

   f_{obs1} = 310 Hz at a certain truck speed v_{s1}.

   f_{obs2} = 320 Hz at a faster truck speed v_{s2}.

   Both times, the truck is moving toward you. Assuming v_w = 340 m/s, find:
   (a) The two speeds v_{s1} and v_{s2}.
   (b) By what ratio did the truck's speed increase?

10. A sports car wants its engine note (source frequency f_s = 600 Hz) to be heard at f_{obs} = 650 Hz by track-side microphones.
    (a) How fast must the car travel (assume v_w = 340 m/s) so that the microphones pick up 650 Hz when it approaches?
    (b) Is this speed practical if the car can only reach a maximum of 90 m/s (about 324 km/h)? Explain.

11. Imagine an aircraft moving toward you at a speed just below the speed of sound.
    (a) How does the pitch (frequency) of the sound change as the aircraft gets faster but stays below the speed of sound?
    (b) What happens to the sound waves in front of the aircraft as its speed gets closer to the speed of sound?

12. As the aircraft's speed reaches the speed of sound, the sound waves in front of it begin to pile up.
    (a) Why do the sound waves pile up in front of the aircraft?
    (b) What physical challenges might this cause for the aircraft?

13. When an aircraft travels faster than the speed of sound, it creates a shock wave instead of the usual Doppler effect.
    a) Why does the Doppler formula, $f_{obs} = f_s\left(\frac{v_w}{v_w \pm v_s}\right)$, no longer work when the aircraft moves faster than sound?
    b) What happens to the sound waves once the aircraft goes supersonic?

14. A supersonic aircraft creates a cone-shaped shock wave that reaches the ground as a sonic boom. Why does an observer only hear the sonic boom once as the aircraft has already passed overhead?

15. The Mach number tells us how fast an object is moving compared to the speed of sound.
    (a) If an aircraft is traveling at Mach 1.2, why do you hear a sonic boom?
    (b) How does the angle of the shock wave change if the aircraft goes even faster, like Mach 2.0?