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PHYSICAL SCIENCE
The DOPPLER EFFECT

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The Doppler Effect is the apparent change in frequency of a wave, as the object making the wave(source) approaches or moves away, relative to an observer. (or if the observer moves relative to the source)

Sound and Doppler Effect.

Basics

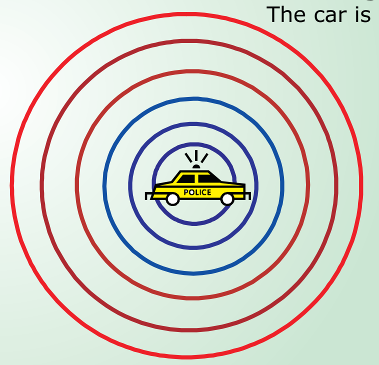
1. Sound travels at 330m·s^{-1} in air. (approximate)
2. This speed does NOT depend on how fast the object making the sound travels. **eg.**
   - If a police car is at rest and sounds its siren, the speed of the sound will be 330m·s^{-1}
   - If the police car was moving at 40m·s^{-1}, the speed of the sound would still be 330m·s^{-1}
     - (not 40 + 330 = 370m·s^{-1})
   - sound can never be at rest, only the object making the sound can be at rest
   - an object can travel faster than the sound it makes

In **Diagram 1** the police car (source) is stationary with the siren on. The frequency of the sound from the siren is 400Hz and the speed of the sound is 330m·s^{-1}.

The diagram shows sound waves leaving the car.
The RED wave would have been emitted first, and then the others followed in sequence.

At what frequency would the man hear the sound?

Diagram 1
The car is at rest



Source = police car
source at rest $v_{(s)} = 0$
sound frequency at source f_s = 400Hz
sound speed v = 330m·s^{-1}

listener
listener at rest $v_{(L)} = 0$
sound frequency at listener f_L = 400Hz
sound speed v = 330m·s^{-1}

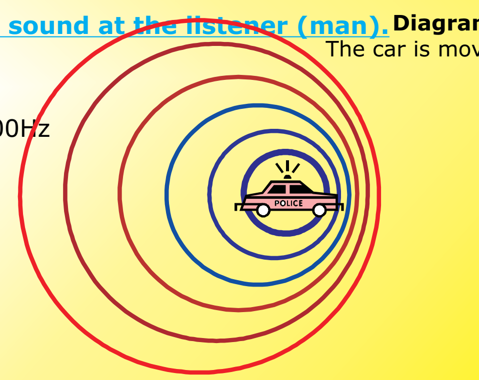
Since the SOURCE and the LISTENER are at rest, the listener hears the correct frequency of 400Hz.

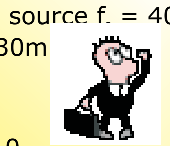
In **Diagram 2** the police car (source) is moving towards the listener at 40m·s^{-1} with the siren on. The frequency of the sound from the siren is 400Hz and the speed of the sound is 330m·s^{-1}.

The diagram shows sound waves leaving the car.
The RED wave would have been emitted first, and then the others followed in sequence.

Calculate the frequency of the sound at the listener (man).

Diagram 2
The car is moving





source = police car
source $v_{(s)}$ = 40m·s^{-1}
sound frequency at source f_s = 400Hz
sound speed v = 330m·s^{-1}

listener
listener at rest $v_{(L)} = 0$
sound frequency at listener f_L = ?
sound speed v = 330m·s^{-1}

Since the SOURCE is moving towards the LISTENER, the listener hears a different frequency.

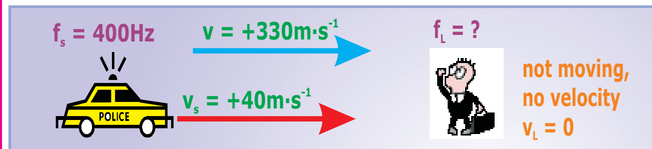
This frequency is calculated as shown below.

The DOPPLER Equation for Sound

$$f_L = \left\{\frac{v - v_L}{v - v_S}\right\} f_S$$

f_L = frequency at Listener
v = speed of sound (this does not change even if the car is moving or is at rest)
v_L = speed of listener (if the listener is also moving
v_s = speed of the source (how fast is the car, train, etc. moving)
f_s = real frequency of the sound (at the source)

Solution
Draw carefully, and include arrows for the **directions of velocity** of the:
SOUND V (this arrow MUST point towards the listener; label this arrow positive in every example)
SOURCE V_s (label this arrow positive or negative compared to the direction of the sound)
LISTENER V_L (label this arrow positive or negative compared to the direction of the



$$f_L = \left\{\frac{v - v_L}{v - v_S}\right\} f_S$$

$$f_L = \left\{\frac{330 - 0}{330 - 40}\right\} 400$$

$$f_L = 455\text{Hz}$$

N.B. The SHIFT is 55Hz

Notice
1. The car **approaches** the man, and a **HIGHER frequency** Is heard.
2. f_L and f_s are always positive
3. v is always positive
4. v_L may be positive or negative
5. v_s may be positive or negative

Practice Questions

1. What is meant by the Doppler Effect?
The **Doppler Effect** is the apparent change in frequency of a wave, as the object making the wave(source) approaches or moves away, relative to an observer.

2.1. Does the Doppler Effect occur only for sound waves?
The Doppler Effect occurs for all types of waves; sound waves, light waves

2.2. Does the Doppler Effect occur for transverse waves?
Yes. such as light waves

3. Write down the Doppler Equation for sound waves, and state What each symbol means.

$$f_L = \left\{\frac{v - v_L}{v - v_S}\right\} f_S$$

f_L = frequency at Listener
v = speed of sound (this does not change even if the car is moving or is at rest)
v_L = speed of listener (if the listener is also moving
v_s = speed of the source (how fast is the car, train, etc. moving)
f_s = real frequency of the sound (at the source)

4. A police-car is moving towards you with its siren on. Would you expect to hear a higher or lower frequency of sound? Explain
Higher frequency, As the car approaches, each progressive new wave has a shorter and shorter distance to travel to reach the listener. This creates a higher frequency.

5. A police car is stationary some distance away from a stationary listener. The police sounds the siren at a frequency of 400Hz. The speed of the sound is 330m·s^{-1}.

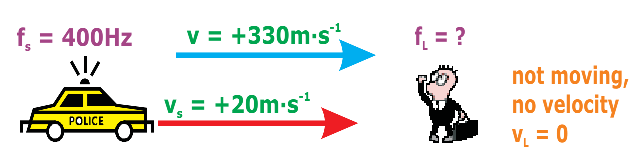
5.1. What is meant by the term frequency of 400Hz?
400 waves are emitted every second

5.2. At what frequency will the listener hear the siren?
The listener will hear the sound at 400Hz

5.3. Now the police car moves towards the listener at a speed of 20m·s^{-1} .

5.3.1. What would be the speed of the sound when the police car moves at 20m·s^{-1} towards the listener?
330m·s^{-1} (sound speed is not affected by the speed of the car)

5.3.2. Calculate the frequency at which the listener will hear the siren.



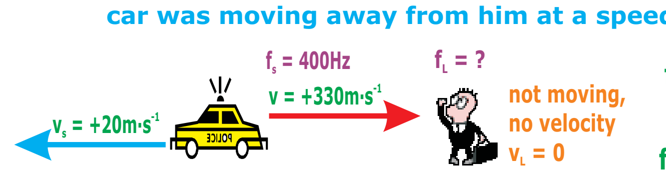
$$f_L = \left\{\frac{v - v_L}{v - v_S}\right\} f_S$$

$$f_L = \left\{\frac{330 - 0}{330 - 20}\right\} 400$$

$$f_L = 425{,}81\text{Hz}$$

5.3.3. Why is the frequency different from the actual frequency of the emitted siren?
. The source (car) is "rushing" towards the man, and each new wave has a shorter distance to travel to reach the man. Hence the man hears a greater frequency.

5.3.4. At what frequency will the listener hear the siren if the police car was moving away from him at a speed of 20m·s^{-1} ?



$$f_L = \left\{\frac{v - v_L}{v - v_S}\right\} f_S$$

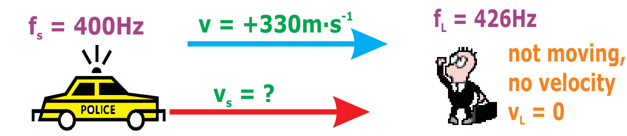
$$f_L = \left\{\frac{330 - 0}{330 - (-20)}\right\} 400$$

$$f_L = 377{,}14\text{Hz}$$

REMEMBER
- The SOUND VELOCITY arrow always points Directly FROM the SOURCE to The LISTENER.
- Always label the SOUND VELOCITY arrow as POSITIVE.
- The SOURCE VELOCITY or LISTENER arrow is labeled positive or negative depending on which way they are moving.

6. A car is moving at an unknown speed towards a stationary listener in a 60km.h^{-1} zone. The car emits a siren at a frequency of 400Hz, and the speed of the sound is 330m·s^{-1} . The listener records that he hears the frequency of the sound at 426Hz.

6.1. Calculate the speed of the car in m·s^{-1} .



$$f_L = \left\{\frac{v - v_L}{v - v_S}\right\} f_S$$

$$f_L = \left\{\frac{330 - 0}{330 - V_s}\right\} 400$$

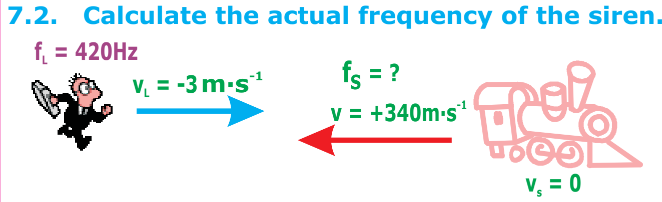
$$f_L = 20{,}14\text{m·s}^{-1}$$

6.2. Is the car breaking the speed limit?
20,14m·s^{-1} x 3,6 = 72,5km.h^{-1}
Yes, he is breaking the speed limit which is 60km.h^{-1}

7. A train is at rest, but sounds a siren at an unknown frequency. The speed of the sound is 340m·s^{-1} . A passenger runs directly towards the train at a speed of 3m·s^{-1} and hears the siren at a frequency of 420Hz.

7.1. Is the actual frequency of the siren lesser or greater than 420Hz. Explain.
The actual is greater than 420Hz. The LISTENER hears a frequency of 420Hz as result of running towards the train where the sound originates from. He is thus hearing the higher frequency. The actual siren is lower in frequency.

7.2. Calculate the actual frequency of the siren.



$$f_L = \left\{\frac{v - v_L}{v - v_S}\right\} f_S$$

$$420 = \left\{\frac{330 - (-3)}{330 - V_s}\right\} f_S$$

$$f_S = 416{,}33\text{Hz}$$

7.3. Calculate the actual wavelength of the siren sound.
v = f
340 = 416,33
= 0,82m

7.4. If the train now moves off at 3m·s^{-1} with the passenger running directly behind the train, at what frequency will he hear the siren?
416,33Hz
Since relative to the train he is at rest, no Doppler effect occurs.
He thus hears the real frequency.

Radar

1. The Doppler effect is also used in some forms of radar to measure the velocity of detected objects.
2. A radar beam is fired at a moving car by police to detect speeding motorists.
3. As a car moves away, each successive wave has to travel further to reach the car, before being reflected and re-detected near the source. As each wave has to move further, the gap between each wave increases, increasing the wavelength, and decreasing the frequency.
4. In some situations, the radar beam is fired at the moving car as it approaches, in which case each successive wave travels a lesser distance, decreasing the wavelength and increasing the frequency.
5. In either situation, calculations from the Doppler effect accurately determine the car's velocity.

Sonic Boom

1. When the **source** is moving **at the speed of sound** in a medium, the source is said to be moving at Mach 1.
2. The speed of sound in air at sea level is about 340 m·s^{-1}.
3. If the source (eg. a plane) travels at the same speed as its sound, then the wavefronts in front of the source would all bunch up at the same point.
4. As a result, an observer in front of the source will detect nothing until the source arrives. (Most of the time, the source travels slower, and the sound is heard first)
5. The pressure front will be quite intense (a shock wave), due to all the wavefronts adding together, and will not be perceived as a pitch but as a "thump" of sound as the pressure wall passes by.
6. When the **source** is traveling **faster** than the **speed of sound** (broken the sound speed barrier), it is moving faster than the sound waves it creates.
7. The source is actually in front of the sound it is creating.
8. The **source** will reach and pass by a stationary observer before the observer actually hears the oncoming sound.
9. It is this intense pressure front that causes the **shock wave** known as a **sonic boom** as a supersonic aircraft passes overhead.
10. The **shock wave** advances at the **speed of sound** ***v***, and since it is built up from all of the combined wave fronts, the sound heard by an observer will be quite intense.

It is important to remember that when a **source gets faster**, the speed of the **sound** it makes **does not also get faster**. The **sound speed remains the same**, hence the **source can actually overtake the sound**!

RED SHIFT

1. The **DOPPLER EFFECT** also occurs for **light**.
2. If the **light source approaches you**, a **higher frequency** would be observed. If a **RED LIGHT SOURCE** approaches you very fast, the perceived frequency would be greater, and the light would appear to have a greater frequency, and **appear closer to BLUE. (Blue Shift)**
3. The same happens should a **BLUE LIGHT** move **away from you very fast**. The perceived frequency would **decrease**, creating a **RED LIGHT observation**. (RED SHIFT)
4. On a **celestial** scale, luminous objects in the sky have been observed to be experiencing the **RED SHIFT** showing that objects are **moving away** from the Earth. This supports the **Expanding Universe Theory**.

8. A police-car moves towards a listener at a speed of 25m·s^{-1} and emits a siren with a wavelength of 1,2m. The speed of the sound is 340m·s^{-1} . The listener moves directly towards the police-car at a speed of 4m·s^{-1} .

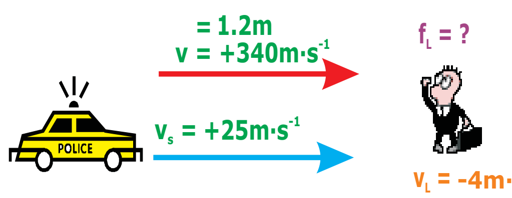
8.1. What is meant by the term wavelength?
distance between two consecutive points in phase

8.2. Are sound waves longitudinal or transverse?
longitudinal

8.3. Calculate the frequency of the siren at the source.
v= f
340 = f(1,2)
f = 283,33Hz

8.4. Calculate the period of the siren sound.
T = 1/f
T = $^{1}/_{283,33}$
T = 0,0035s

8.5. At what frequency will the listener hear the siren?



$$f_L = \left\{\frac{v - v_L}{v - v_S}\right\} f_S$$

$$f_L = \left\{\frac{330 - (-4)}{330 - 25}\right\} 283.33$$

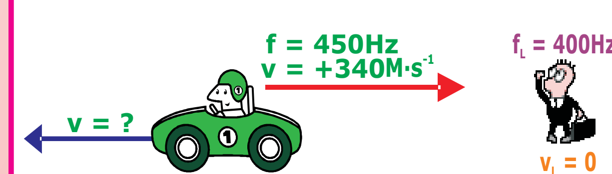
$$f_L = 309{,}41\text{Hz}$$

8.6. What should be the velocity of the listener in order for him to hear the frequency of the siren at the real frequency? Explain.
He must move at 25m·s^{-1} in the same direction as the car. Then relative to the car, he would not be moving, and the Doppler Effect would not occur.

9. **A stationary man watches a race-car moving away at an unknown speed. A siren from the car emits a sound at a frequency of 450Hz and the man hears the sound at a frequency that is 50Hz different. The speed of the sound is 340m·s^{-1} .**

9.1. At what frequency does the man hear the siren?
400Hz. He would hear a frequency shifted by 50Hz lesser since the car is moving AWAY from him.

9.2. Calculate the speed of the car.



$$f_L = \left\{\frac{v - v_L}{v - v_S}\right\} f_S$$

$$f_L = \left\{\frac{340 - 0}{330 - V_s}\right\} 450$$

$$V_s = 42.5\text{m·s}^{-1}$$

The speed of the car is 42,5m·s^{-1}

10. A plane is travelling at Mach 1.
Why is MACH 1 not a velocity itself?
The speed of sound is different under different conditions. On a certain day, the speed of sound may be 330m·s^{-1} and when a plane also reaches a speed of 330m·s^{-1} , it is travelling at the same speed as the sound. Thus $^{330}/_{330}$ = Mach 1
On a different day, the speed of sound may be 340m·s^{-1} . If the plane is still travelling at 330m·s^{-1} then it is now slower than the speed of this sound.
Then $^{330}/_{340}$ = Mach 0,97
Only if the plane now travels at 340m·s^{-1} as well, will it be travelling at Mach 1 on this new day: $^{340}/_{340}$ = Mach 1
Thus Mach is just a factor that compares the speed of the vehicle to the speed of the sound at that place.
Mach 1 at one place is not necessarily the same speed a Mach 1 at another place.