

KWV EDUCATION



KWV PHYSICS GRADE 12

DOPPLER EFFECT NOTES

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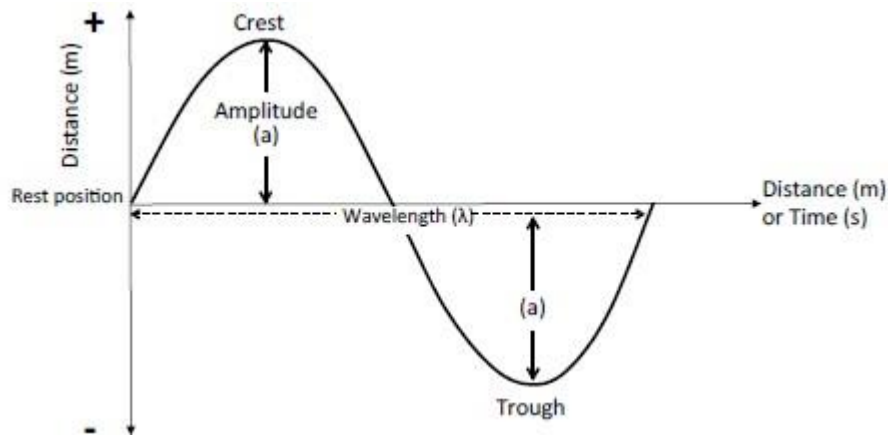
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WHERE TO START IN MATHS AND SCIENCE

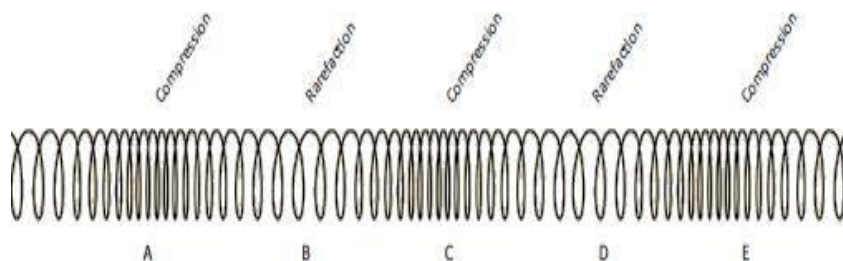
❖ DOPPLER EFFECT

➤ TRANSVERSE WAVES



- ✓ The disturbance of the medium is perpendicular to the direction in which the wave is propagated (transmitted).
- ✓ **EXAMPLES:** water waves, electromagnetic waves (**light, radio waves, X-rays etc.**)

➤ LONGITUDINAL WAVES



- ✓ The disturbance of the medium is parallel to the direction of propagation of the pulse.
- ✓ **EXAMPLES:** sound waves, slinky spring

➤ WAVE EQUATIONS AND PROPERTIES

$$\text{frequency} = \frac{\text{number of waves}}{\text{total time}}$$

$$T = \frac{1}{f} \quad \text{OR} \quad f = \frac{1}{T}$$

- ✓ The amplitude (height) of a wave motion is the maximum displacement of the particles from their equilibrium (rest) position.
- ✓ The amplitude determines the volume of a sound wave.
- ✓ The wavelength (λ) of a wave is the distance between two consecutive points in the wave which are in phase and is measured in metres (m).
- ✓ It is therefore also the distance between two successive crests or the distance between two successive troughs.
- ✓ The frequency (f) of a wave motion is the number of complete waves passing a specific point per second and is measured in hertz (Hz).
- ✓ The frequency of a sound wave determines its pitch.
- ✓ The frequency of a light wave determines its colour.
- ✓ The frequency of a wave determines the energy of the wave. ✓ The higher the frequency, the higher the energy i.e. $E \propto f$

➤ LIGHT

- ✓ The visible spectrum of light is just a small section of a much greater series of wavelengths called the electromagnetic spectrum.
- ✓ The speed of light (and all other electromagnetic radiation) is constant ($3 \times 10^8 \text{m} \cdot \text{s}^{-1}$).
- ✓ The colour of light depends on its frequency.
- ✓ In the colour spectrum, red has the longest wavelength and lowest frequency and violet has the shortest wavelength and the highest frequency.

➤ FREQUENCY

- ✓ Frequency (f) is the number of waves that pass a point per second.
- ✓ It is measured in hertz.
- ✓ Most sirens produce sound with a frequency of 2 000 Hz, this means 2 000 waves pass a listener per second.
- ✓ When referring to sound waves, frequency can be referred to as pitch.
- ✓ Sound wave with a higher pitch means the sound wave has a higher frequency.

➤ WAVELENGTH

- ✓ Wavelength (λ) is the distance between two consecutive points which are in phase.
- ✓ It is measured in metres (m).

➤ SPEED

- ✓ The speed of a wave measured in $3 \times 10^8 \text{ m.s}^{-1}$.
- ✓ At constant speed, the frequency (f) of a wave is inversely proportional to the wavelength (λ) of the wave.
- ✓ If the wavelength of a sound wave is increased, then the frequency of the new sound wave will decrease.
- ✓ If the wavelength of a sound wave is decreased, then the frequency of the new sound wave will increase.
- ✓ The speed depends on the medium through which the sound propagates (the density and the elasticity of the medium)

➤ EQUATIONS

KEY! : Always start with the full original formula

$$f_L = \frac{v \pm v_L}{v \pm v_s} f_s$$

f_L = frequency of listener (Hz)

v = speed of sound ($\text{m}\cdot\text{s}^{-1}$)

OR

v = speed of light ($3 \times 10^8 \text{ m}\cdot\text{s}^{-1}$)

v_L = velocity of listener ($\text{m}\cdot\text{s}^{-1}$)

v_s = velocity of source ($\text{m}\cdot\text{s}^{-1}$)

f_s = frequency of source (Hz)

➤ MATERIAL WAVES (SOUND)

 $v = f \lambda$

v = speed of wave ($\text{m} \cdot \text{s}^{-1}$)

f = frequency of sound (Hz)

λ = wavelength (m)

➤ ELECTROMAGNETIC RADIATION

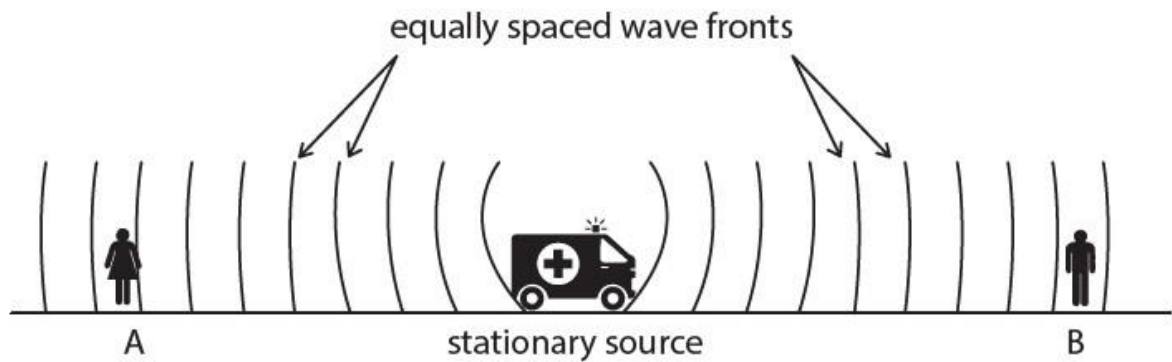
 $c = f \lambda$

c = speed of light ($3 \times 10^8 \text{ m} \cdot \text{s}^{-1}$)

f = frequency of sound (Hz)

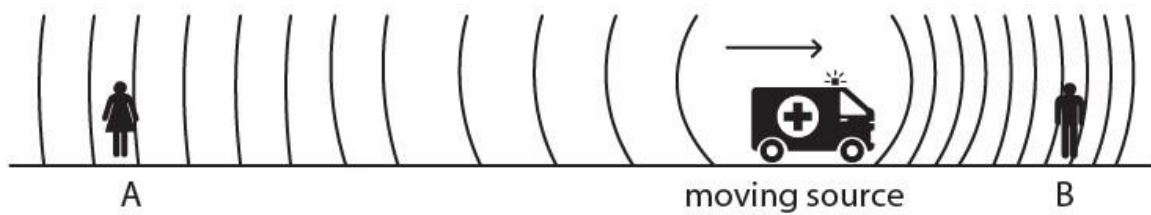
λ = wavelength (m)

1. BOTH THE SOURCE AND LISTENER ARE STATIONARY



- ✓ Consider a stationary ambulance and the siren of the ambulance is on.
- ✓ The siren is the source (s) of the sound.
- ✓ The sound waves produced by the stationary siren are shown moving away from the source:
- ✓ The frequency of the sound heard by the stationary listeners (f_L) is the same as the frequency of the stationary source (f_S).
- ✓ In other words when the source and the listener are stationary, then the frequency observed by the listener is the same as the frequency of the source.

2. THE SOURCE IS MOVING TOWARDS A STATIONARY LISTENER



- ✓ The source of the sound waves is moving towards the listener at point B.
 - ✓ The wave fronts in front of the source are closer together.
 - ✓ The wavelength of the sound waves in front of the source has decreased.
 - ✓ If the wavelength of the sound waves has decreased then the frequency of the sound waves must increase.
 - ✓ The sound observed by the listener at B will have a higher pitch.
 - ✓ There are more waves passing listener B per second.
 - ✓ This apparent change in frequency of a sound wave is known as the Doppler Effect.
- ✚ The apparent change in frequency of a source when there is relative motion between the source and the observer.
- ✓ When the source is moving towards a stationary listener, then the frequency observed by the listener is higher than the frequency of the source.

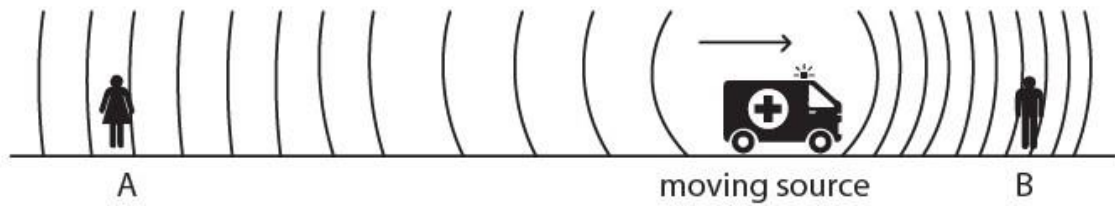
Source to listener (-)

Increase in observed frequency.

$$f_L = \frac{v \pm v_L}{v \pm v_s} f_s$$

$$f_L = \frac{v}{v - v_s} f_s$$

3. THE SOURCE IS MOVING AWAY FROM A STATIONARY LISTENER



- ✓ The source of the sound waves is moving away from the listener at point A.
- ✓ The wave fronts behind of the source are further apart.
- ✓ The wavelength of the sound waves behind the source has increased.
- ✓ If the wavelength of the sound waves has increased then the frequency of the sound waves must decrease.
- ✓ The sound observed by the listener at A will have a lower pitch.
- ✓ There are fewer waves passing listener A per second.
- ✓ When the source is moving away from stationary listener, then the frequency observed by the listener is less than the frequency of the source.

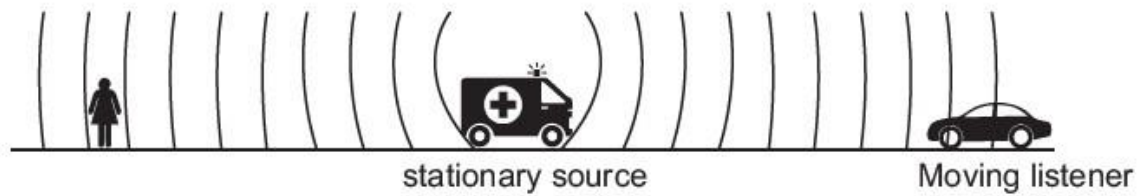
Source away from listener (+)

Decrease in observed frequency.

$$f_L = \frac{v \pm v_L}{v \pm v_s} f_s$$

$$f_L = \frac{v}{v + v_s} f_s$$

4. THE LISTENER IS MOVING TOWARDS A STATIONARY SOURCE



- ✓ The listener is moving towards a stationary source.
- ✓ The listener is moving towards the source, therefore the listener is moving through more wave fronts per second.
- ✓ The frequency observed by the listener must be higher than source
- ✓ The moving listener will observe a higher pitched sound than that of the source.
- ✓ The wavelength of the observed sound waves has decreased.
- ✓ When the listener is moving towards a stationary source, then the frequency observed by the listener is higher than the frequency of the source.

Listener to source (+)

Increase in observed frequency.

$$f_L = \frac{v \pm v_L}{v \pm v_s} f_s$$

$$f_L = \frac{v + v_L}{v} f_s$$

5. LISTENER IS MOVING AWAY FROM A STATIONARY SOURCE



- ✓ The listener is moving away from the source, therefore the listener is moving through fewer wave fronts per second.
- ✓ The frequency observed by the listener must be lower than the source
- ✓ The moving listener will observe a lower pitched sound than that of the source.
- ✓ The wavelength of the observed sound waves has increased.
- ✓ When the listener is moving away from a stationary source, then the frequency observed by the listener is less than the frequency of the source.

Listener away from source (-)

Decrease in observed frequency.

$$f_L = \frac{v \pm v_L}{v \pm v_s} f_s$$

$$f_L = \frac{v - v_L}{v} f_s$$

KEY!

❖ Source moving towards a stationary listener

- Wavelength decreases/ waves are compressed.
- Frequency increases.
- Velocity constant.
- Pitch of sound increases.

❖ Source moving away a stationary listener

- Wavelength increases/ waves are further apart
- Frequency decreases
- Velocity constant
- The pitch of sound decreases

➤ APPLICATIONS OF THE DOPPLER EFFECT

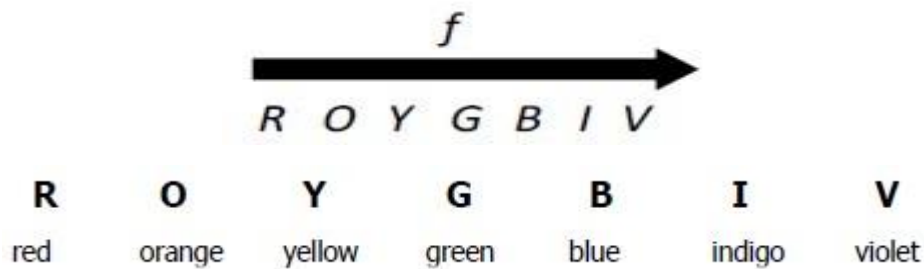
- ✓ The Doppler flow meter is used to measure the rate of blood flow in a patient's blood vessels.
- ✓ Ultrasound is a longitudinal wave with a very high frequency of above 20 kHz that we cannot hear.
- ✓ It gives out a sound wave at ultrasound frequency.
- ✓ The blood velocity through the heart causes a 'Doppler shift' in the frequency of the returning waves.
- ✓ The meter measures this and compares the frequencies.
- ✓ The receiver detects the reflected sound and an electronic counter measures the reflected frequency.
- ✓ From the change in frequency, the speed of the blood flow can be determined and narrowing of blood vessels identified.

KEY!

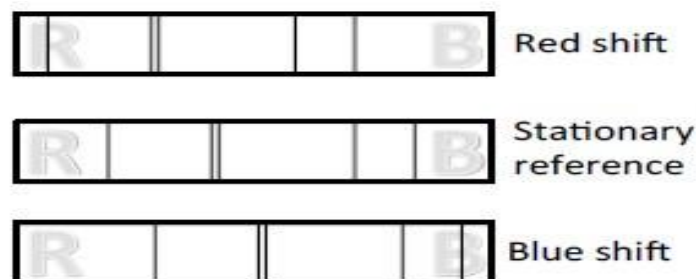
- ✓ Used by traffic department as speed traps.
- ✓ Blood flow rate can be measured. (medical use)
- ✓ Speed of the planets and stars can be determined.
- ✓ Used to measure heartbeat of the unborn foetus in the womb. (medical use)
- ✓ Used in weather stations to detect precipitation.

➤ DOPPLER EFFECT WITH LIGHT

❖ RED SHIFT AND BLUE SHIFT



- ✓ A **red shift** is the shift in the spectra of distant galaxies (STARS) toward longer wavelength OR toward the red end of the spectra.
- ✓ The Doppler Effect is characteristic of all waves – including light.
- ✓ All stars emit white light and stars moving away from the earth will display light with longer wavelengths – the red colours of the spectrum, due to the Doppler Effect.
- ✓ NB: Astronomers have found that all stars exhibit a red shift – are moving away from the earth and from each other, this suggest the **universe is expanding**
- ✓ A **blue shift** is any decrease in wavelength, with a corresponding increase in frequency, of an electromagnetic wave; the opposite effect is referred to as **red shift**.
- ✓ In visible light, this shifts the color from the red end of the spectrum to the blue end



KEY!

- ✓ Stars, like the sun, emit light.
- ✓ When a star moves away from the Earth, its spectrum shifts to longer wavelength.
- ✓ In other words, the red side of the spectrum. The star appears red.
- ✓ When a star moves towards the Earth, its spectrum shifts to shorter wavelengths (higher frequencies) – in other words, the blue side of the spectrum. The star appears blue.