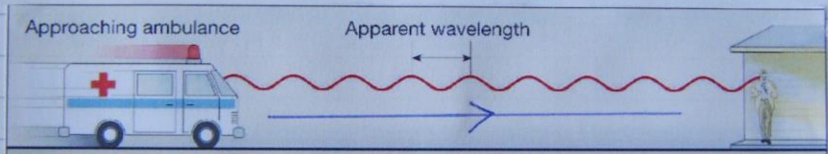
Doppler Effect and Red Shift - B McMULLEN

The Doppler Effect is observed for both sound and light.
This involves a change in the observed frequency and wavelength of a wave when there is relative motion between a source and an observer.

This effect can be illustrated in simple terms when we think about an ambulance coming towards or moving away from a stationary observer.

1.



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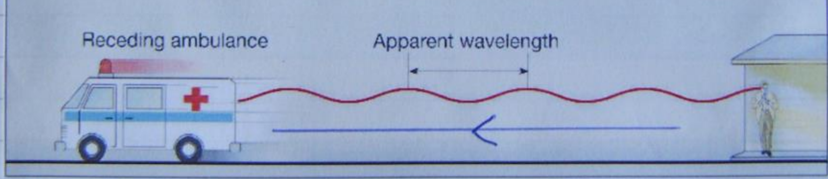
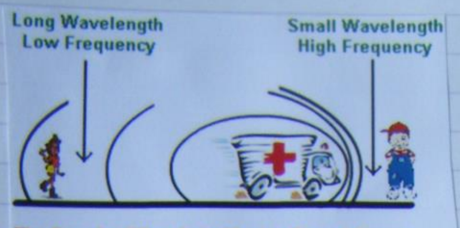


In Case 1. the ambulance is moving towards the stationary observer.
The number of sound waves per second reaching the observer increases as the apparent wavelength of the waves decreases. ($f\uparrow$ as $\lambda\downarrow$)

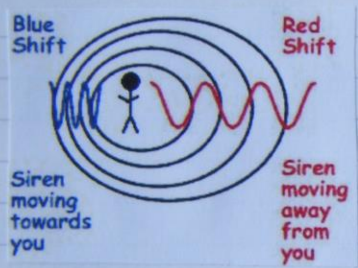
In Case 2. the ambulance is moving away from the stationary observer. This is the opposite to Case 1. and so $f\downarrow$ as $\lambda\uparrow$.



The Doppler Effect for a Moving Sound Source

The ambulance is moving away from the stationary girl and towards the stationary boy.

- Stationary girl $\Rightarrow f\downarrow \therefore \lambda\uparrow$ (away from)
- stationary boy $\Rightarrow f\uparrow \therefore \lambda\downarrow$ (towards)



Why Blue Shift and Red Shift?

Blue Shift $\Rightarrow$ Blue Light, $\lambda \approx 400nm$

Red shift $\Rightarrow$ Red Light, $\lambda \approx 700nm$

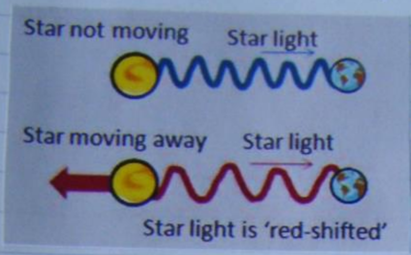
<u>Conclusion</u>

Red light and Blue light are at opposite ends of the visible spectrum

$\therefore$ Red light $\Rightarrow \lambda\uparrow$ and $f\downarrow$
ie source moving away from a stationary observer. $\Rightarrow$ Red Shift.

$\therefore$ Blue light $\Rightarrow \lambda\downarrow$ and $f\uparrow$
ie Source moving towards a stationary observer $\Rightarrow$ Blue Shift.

Red and Blue shift applied to stars.



- towards $\Rightarrow f \uparrow$ and $\lambda \downarrow$
- away $\Rightarrow f \downarrow$ and $\lambda \uparrow$.
- stationary star $\Rightarrow f$ and λ Constant

WORKING THE RED SHIFT

What a nightmare!!

We will revisit Red Shift, Blue Shift and no Shift later!!

Doppler Effect equation $\Rightarrow$ stationary observer.

$$\boxed{f_o = f_s \left(\frac{V}{V \pm V_s} \right)}$$

$f_o \Rightarrow$ frequency of sound reaching the stationary observer. (Hz)

$f_s \Rightarrow$ frequency of the source. (Hz)

$V \Rightarrow$ Speed of Sound in air $\Rightarrow 340\,ms^{-1}$

$V_s \Rightarrow$ Speed of the source (ms^{-1})

Red Shift $\Rightarrow + \Rightarrow$ Source moving away from the observer.

Blue Shift $\Rightarrow - \Rightarrow$ Source moving towards the observer

Why for the +ve and −ve ?

f_s and the speed of sound in air are constant. (ie V)

$\therefore f_o \propto \dfrac{1}{V \pm V_s}$

KEY: $\uparrow \Rightarrow$ high
$\downarrow \Rightarrow$ low

- If +ve $\Rightarrow f_o \propto \dfrac{1}{V+V_s}$

$\therefore$ Denominator $(V+V_s)$ is $\uparrow$ $\therefore f_o$ is $\downarrow$

$\therefore$ Red Shift $\Rightarrow$ source moving away from the observer.

- If −ve $\Rightarrow f_o \propto \dfrac{1}{V-V_s}$

$\therefore$ Denominator $(V-V_s)$ is $\downarrow$ $\therefore f_o$ is $\uparrow$

$\therefore$ Blue Shift $\Rightarrow$ Source moving towards the observer.

Ex 1

Q

An emergency vehicle, travelling at $22\,m\,s^{-1}$, emits sound of frequency 1020 Hz. The vehicle approaches a stationary pedestrian, as shown in Figure 15.

Figure 15

The frequency detected by a stationary observer when a sound source moves relative to the observer is given by

$$f_o = f_s \frac{v}{v \pm v_s}$$

where the symbols have their usual meanings.

Calculate the frequency heard by the stationary pedestrian as the emergency vehicle approaches.

A

As the emergency vehicle approaches the frequency of the sound reaching the observer increases. ($\therefore V - V_s$)

$$\therefore \quad f_o = f_s \left(\frac{V}{V - V_s} \right)$$

$$\Rightarrow f_o = 1020 \left(\frac{340}{340 - 22} \right)$$

$$\Rightarrow f_o = 1020 \left(\frac{340}{318} \right)$$

$$\Rightarrow f_o = 1020 \times 1{\cdot}069$$

$$\Rightarrow f_o = 1090\,Hz$$

Ex2

Q

A train emits a sound of frequency 800 Hz as it passes through a station. The sound is heard by a person on the station platform as shown in Figure 18.

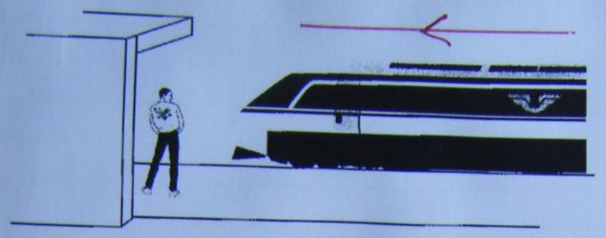


Figure 18

(i) Describe how the frequency of the sound, heard by the person, changes as the train passes through the station.

(ii) Explain, in terms of wavefronts, why this frequency change occurs. You may wish to include a diagram as part of your answer.

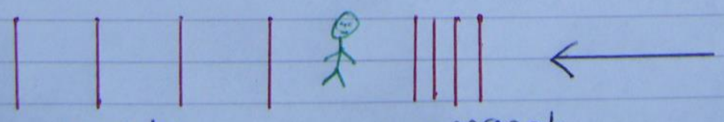
(iii) At one instant the person hears a sound of frequency 760 Hz. Calculate the speed of the train relative to the person on the platform at this time.

A

i) The frequency of the sound increases as it approaches and then decreases as it passes by the stationary observer.

ii) The waves are closer together when they approach ($\lambda\downarrow \therefore f\uparrow$) and are then further apart when they pass by the stationary observer. ($\lambda\uparrow \therefore f\downarrow$)

OR



pass by. approach

iii) $f_0 = f_s\left(\frac{V}{V+V_s}\right)$

$760\text{Hz} < 800\text{Hz} \therefore$ passed by

$$760 = 800\left(\frac{340}{340+V_s}\right) \Rightarrow 340+V_s = \frac{340\times800}{760} = 358$$

$$\Rightarrow \underline{V_s = 18\,ms^{-1}}$$

(7)

Ex3

Q

The train is stopped and a passenger hears a siren on another train approaching along a parallel track. The approaching train is travelling at a constant speed of $28{\cdot}0\,\mathrm{m\,s^{-1}}$ and the siren produces a sound of frequency 294 Hz.

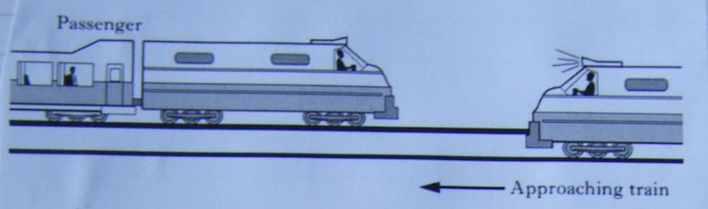


Figure 6D

Calculate the frequency of the sound heard by the passenger:

(A) as the train approaches;

(B) once the train has passed the passenger.

A

A) Train approaches ($f_o \uparrow \therefore V - V_s$)

$$f_o = f_s\left(\frac{V}{V-V_s}\right)$$

$$\Rightarrow f_o = 294\left(\frac{340}{340-28}\right) = 294 \times \frac{340}{312}$$

$$\Rightarrow \underline{\underline{f_o = 320\,Hz}}$$

B) Train passes by ($f_o \downarrow \therefore V + V_s$)

$$f_o = f_s\left(\frac{V}{V+V_s}\right) = 294\left(\frac{340}{340+28}\right) = 294 \times \frac{340}{368}$$

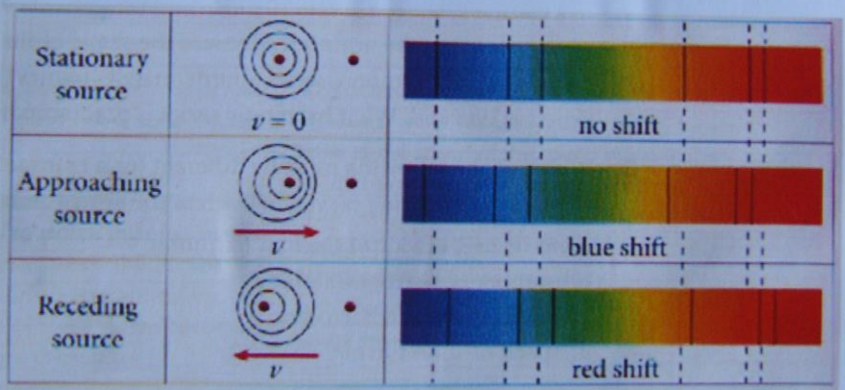
$$\Rightarrow \underline{\underline{f_o = 272\,Hz}}$$

Fraunhofer Lines

Joseph Von Fraunhofer
(1787–1826 GERMANY)

He is known for discovering dark absorption lines (now known as Fraunhofer lines) in the continuous spectrum of the Sun.

Doppler Effect



Measuring the relative velocities of stars by the Doppler shift.

You can clearly seen how the lines (absorption) have all shifted to the red end of the continuous spectrum with a red shift and to the blue end of the continuous spectrum with a blue shift. The stationary source is used for these comparisons.

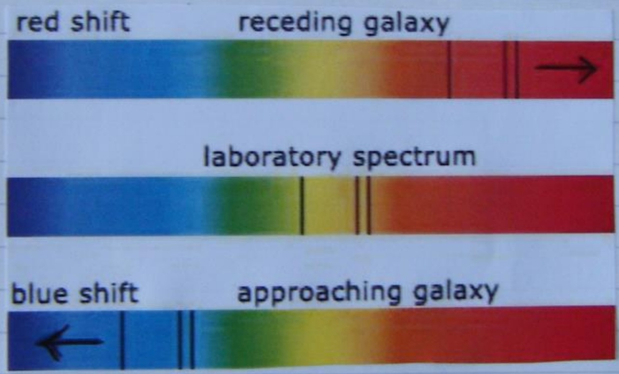
Movement of stars and galaxies.

- Stars or galaxies moving towards us is known as a blue shift.

Why?

Blue light has a low wavelength and hence a high frequency.

The Doppler Effect has shown us that the frequency will increase when a source is moving closer to a stationary observer.



- Stars or galaxies moving away from us is known as a red shift.

Why?

Red light has a high wavelength and a low frequency.
The Doppler Effect has shown us that the frequency will decrease when a source is moving further away from a stationary observer.

Ex4

Q// An observer on Earth notes that the frequency of light from a distant galaxy is Doppler shifted towards the red end of the spectrum.

State whether the galaxy is moving towards or away from Earth. **You must justify your answer**.

A// Red Shift. Red light has a high wavelength which means that it has a low frequency.
In the Doppler Effect the low frequency means that the galaxy is moving further away from the stationary observer on Earth.

Ex5

Q// The spectrum of light from most stars contains lines corresponding to helium gas.

Figure 15(*a*) shows the helium spectrum from the Sun.

Figure 15(*b*) shows the helium spectrum from a distant star.

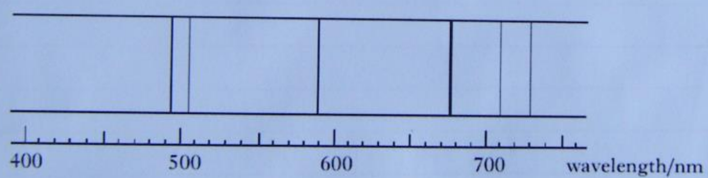


Figure 15(*a*)

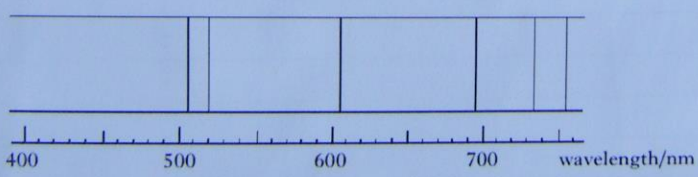


Figure 15(*b*)

By comparing these spectra, what conclusion can be made about the distant star? Justify your answer.

A// The distant star is moving further away from the stationary observer on Earth.
Red Shifted $\Rightarrow \lambda \uparrow$ or $f \downarrow$.

Red Shift formulae

(1) $$\boxed{Z = \frac{\lambda_{OBSERVED} - \lambda_{REST}}{\lambda_{REST}}}$$

Z → Red Shift (No units!!)
$\lambda_{OBSERVED}$ (nm) → λ of the light observed from a star or galaxy
λ_{REST} (nm) → λ of the light from the continuous spectrum from the Sun.

- If a star or galaxy are moving away from us then:

$$\lambda_{OBSERVED} > \lambda_{REST} \quad (\text{ie } \lambda\uparrow \text{ as } f\downarrow)$$

∴ Z is +ve ie Red Shift is positive.

- If a star or galaxy are moving towards us then:

$$\lambda_{OBSERVED} < \lambda_{REST} \quad (\text{ie } \lambda\downarrow\ f\uparrow)$$

∴ Z is −ve ie Blue Shift is negative.

CONCLUSION
The Red shift equation can also be used for blue shift except the answer will be negative.

(This is similar to the idea that deceleration can be shown by the acceleration equation with a negative answer)

$$z = \frac{v}{c}$$

z = redshift
v = recessional velocity
c = speed of light

The Red Shift ratio can also be used to work out the recessional velocity of stars or galaxies.

For a Blue Shift Z is negative and v will be negative as the star or galaxy will be moving towards us.

Ex6

Q The blue-green absorption line for Hydrogen has a wavelength of 525nm, when a stationary observer on Earth views a distant galaxy.

a) Use the data sheet to find the wavelength of the blue-green absorption line on the continuous spectrum.

b) Calculate the Red Shift Ratio for this distant galaxy.

c) Explain whether this distant galaxy is moving towards or away from the Earth.

d) Calculate the velocity of the distant galaxy relative to the Earth.

A a) $\lambda = 486nm$ (FROM DATA SHEET)

b) $$Z = \frac{\lambda_{OBSERVED} - \lambda_{REST}}{\lambda_{REST}}$$

$$\Rightarrow Z = \frac{525 - 486}{486} = \frac{39}{486} = \underline{\underline{0 \cdot 08}}$$

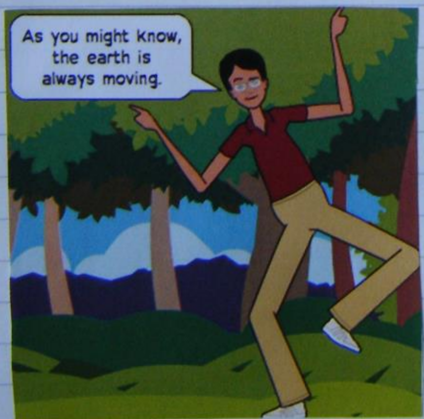
c) The distant galaxy is moving away from us as the observed wavelength > Rest wavelength (ie Z is positive ⇒ Red shift)

d) $$Z = \frac{V}{C}$$

$$\Rightarrow 0 \cdot 08 = \frac{V}{3 \times 10^8}$$

$$\Rightarrow V = 0 \cdot 08 \times 3 \times 10^8$$

$$\Rightarrow \underline{\underline{V = 2 \cdot 4 \times 10^7 ms^{-1}}}$$



The velocity of stars and galaxies are also talked about in terms of being relative to Earth.

This is due to the Earth always moving!!