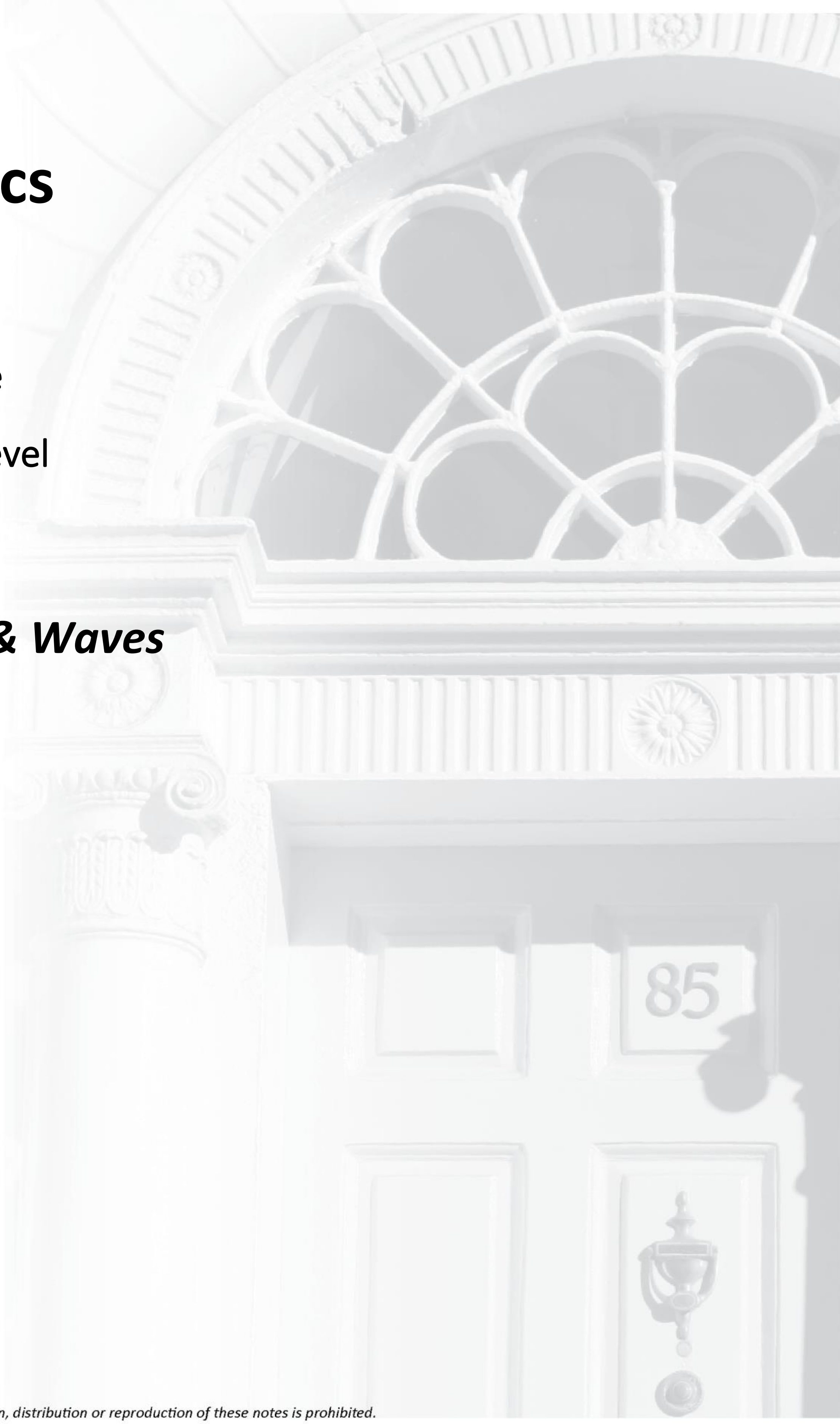
THE INSTITUTE OF EDUCATION



Physics

Pat Doyle

Higher Level

2020-21

Sound & Waves

Unauthorised publication, distribution or reproduction of these notes is prohibited.

Sound and Waves

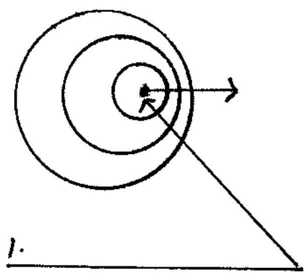
The Doppler Effect

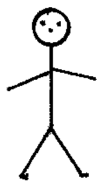
You are standing on the side of a road listening to the sound from a siren on the roof of a stationary car that is 500 m down the road. The car starts to move towards you and you notice that the frequency of the sound is different (higher). The car passes by you and moves away from you. The frequency of the sound is different again (lower). This is due to the Doppler effect.

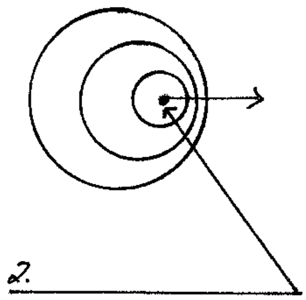
Definition of Doppler effect: The Doppler effect is the apparent change in the frequency of a wave due to the relative motion between source and observer.

Explanation of Doppler effect:

Source moving towards observer — *Stationary observer* — *Source moving away from observer*







Source moving towards observer:

(i) wavefronts closer together

(ii) observed **wavelength smaller**

(iii) observed **frequency higher**

Source moving away from observer:

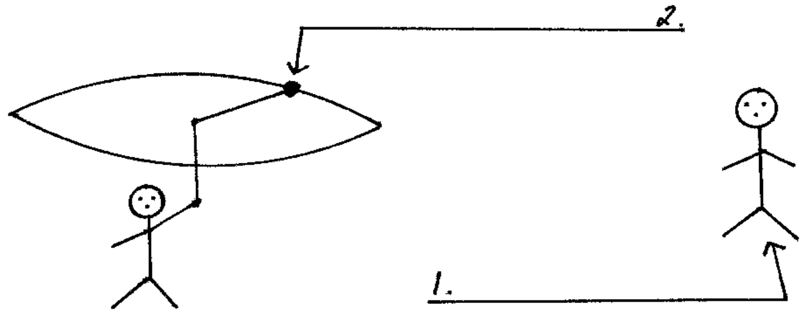
(i) wavefronts further apart

(ii) observer **wavelength longer**

(iii) observed **frequency lower**

The observed wavelength and frequency change as the source moves past observer !!!!!!!!!!

Demonstration (laboratory) experiment for the Doppler Effect:



- A battery powered electronic buzzer is attached to a string 50 cm long. The emitted frequency is set at 300 Hz.
- The buzzer is spun in circular motion on the end of the string quite fast.
- An observer standing 2 m away will notice the frequency from the buzzer change as it rotates.
- The observed frequency changes as the buzzer moves towards and then moves away from the person.

Maths of Doppler effect:

$$f^{!} = \frac{f\ c}{c \pm u}$$ ……………………P. 59

($f^{!}$ = observed frequency; f = frequency of source; c = speed of wave; u = speed of source)

Use the $-$ when source moves towards the observer

Use the $+$ when the source moves away from the observer

Note: It is very easy to confuse $f^{!}$ and f. I propose we use the following

$$f_o = \frac{f_s\ c}{c \pm u}$$

(f_o = observed frequency; f_s = frequency of source)

Sample question 1: A police car is travelling at $25\,m\,s^{-1}$ and has a siren emitting a sound at a frequency of 480 Hz. What is the frequency detected by a stationary observer

(i) as the car approaches

(ii) as the car moves from the person.

(speed of sound in air = $340\,m\,s^{-1}$)

Solution: (i)

$$f_o = \frac{f_s\ c}{c - u}$$

$$f_o = \frac{480 \times 340}{340 - 25}$$

$$f_o = 518\ Hz$$

(ii)

$$f_o = \frac{f_s\ c}{c + u}$$

$$f_o = \frac{480 \times 340}{340 + 25}$$

$$f_o = 447\ Hz$$

Sample question 2: A train's whistle emits a continuous note of frequency 640 Hz as it approaches a person standing near the track. To the person the frequency appears to be 720 Hz. Calculate the speed of the train.

(speed of sound in air = $340\,m\,s^{-1}$)

Solution: the train approaches the person so use

$$f_o = \frac{f_s \; c}{c - u}$$

$$c - u = \frac{f_s \; c}{f_o}$$

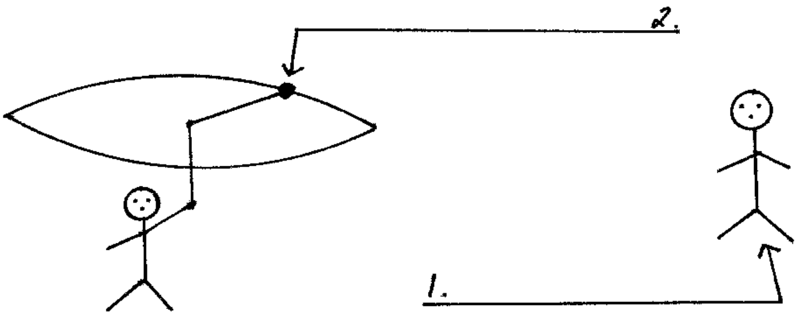
$$340 - u = \frac{640 \times 340}{720}$$

$$340 - u = 302.2$$

$$340 - 302.2 = u$$

$$37.8\,m\,s^{-1} = u$$

Sample question 3: A whistle emitting a note of 1 kHz is whirled in a horizontal circle on the end of a string 1.2 m long at a constant angular speed of $50\ rad\ s^{-1}$. What are the highest and lowest frequencies heard by a person standing some distance away. (speed of sound in air = $340\,m\,s^{-1}$)



Solution: step 1: change angular speed to linear speed

$$v = r \times \omega$$

$$v = 1.2 \times 50$$

$$v = 60\,m\,s^{-1}$$

Step 2: whistle moving towards the observer

$$f_o = \frac{f_s \; c}{c - u}$$

$$f_o = \frac{1000 \times 340}{340 - 60}$$

$$f_o = 1214\,Hz$$

Step 3: whistle moving away from observer

$$f_o = \frac{f_s \; c}{c + u}$$

$$f_o = \frac{1000 \times 340}{340 + 60}$$

$$f_o = 850\,Hz$$

Sample question 4: The yellow line emitted by a Helium discharge tube in the laboratory has a wavelength of 587 nm. The same yellow line in the helium spectrum of a star has a measured wavelength of 590 nm.

(i) what can you deduce about the motion of the star

(ii) calculate the speed of the star.

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

Solution: (i) the observed wavelength is longer therefore the star moves away from the earth.

(ii) change the wavelengths to frequencies

$$\text{True frequency (source)} = f_s = \frac{c}{\lambda} = \frac{3 \times 10^8}{587 \times 10^{-9}} = 5.11 \times 10^{14}\ Hz$$

$$\text{Observed frequency} = f_o = \frac{c}{\lambda} = \frac{3 \times 10^8}{590 \times 10^{-9}} = 5.0847 \times 10^{14}\ Hz$$

Now rearrange $f_o = \frac{f_s\ c}{c + u}$ to get $c + u = \frac{f_s\ c}{f_o}$

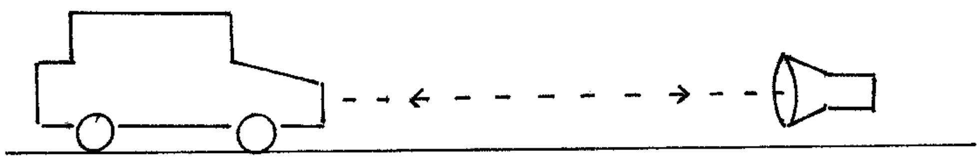
$$c + u = \frac{5.11 \times 10^{14} \times 3 \times 10^8}{5.0847 \times 10^{14}}$$

$$3 \times 10^8 + u = 3.015 \times 10^8$$

$$1.5 \times 10^6\ m\,s^{-1} = u$$

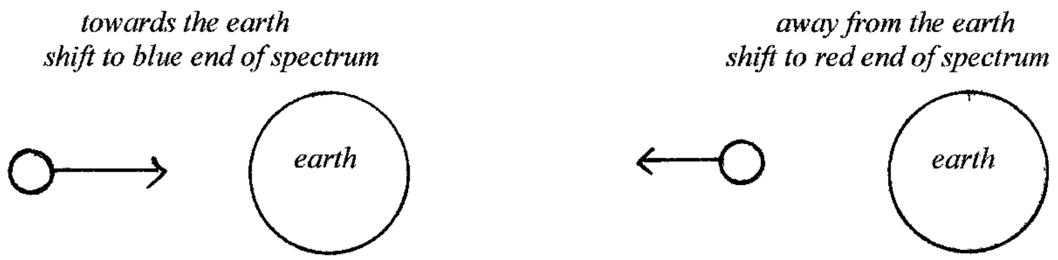
Applications of the Doppler effect:

Checking the speed of a car:



- An electromagnetic wave of **known frequency** f_s is directed at a moving car.
- The speed of this wave is also known as all electromagnetic waves the same speed. The value of the speed of the wave c is $3 \times 10^8\ m\,s^{-1}$
- The wave reflected off the car will have a different frequency to the incident wave. This reflected frequency f_o is measured electronically.
- The values of f_s, f_o and c are now all known. We calculate the speed of the car u using $f_o = \frac{f_s\ c}{c \pm u}$

Studying the stars:



- If a star is moving towards the earth the frequency of the light from the star appears higher. The wavelength appears smaller. There is a shift towards the violet end of the spectrum
- If a star is moving away from the earth the frequency of the light from the star appears lower. The wavelength appears longer. There is a shift towards the red end of the spectrum. " **red shift**".
- The actual speed of a star can be calculated using our Doppler formula.

Note: Other uses of the Doppler effect would include

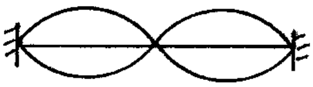
- Blood flow measurement (echocardiogram)
- Checking the heart beat of a foetus.

Resonance and Stretched Strings

Fundamental mode of vibration:

- If a string is fixed at both ends and plucked in the centre the most simple or fundamental type of vibration is shown in the above diagram.
- For the fundamental mode the string vibrates at its lowest frequency

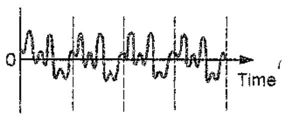
Harmonics: *2nd harmonic* *3rd harmonic*

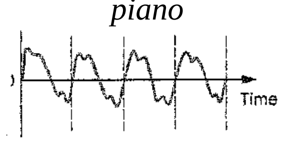


- **Harmonics are multiples of the fundamental mode of vibration**
- The diagram above shows the string vibrating in the second and the third harmonic
- The **overtones** are all the harmonics except the first harmonic.

Pitch:
- **Pitch is related to the frequency of a sound**. The higher the frequency the higher the pitch
- "pitch is to sound as colour is to light"

Quality: *violin* *piano*





- The same note played on two different instruments does not sound the same e.g. the piano and the violin.
- **The quality of a sound depends on the number and intensity of the harmonics (overtones) present**

Loudness:
- **The loudness of a sound depends on the amplitude of the vibration of the sound wave**.
- Loudness is subjective.

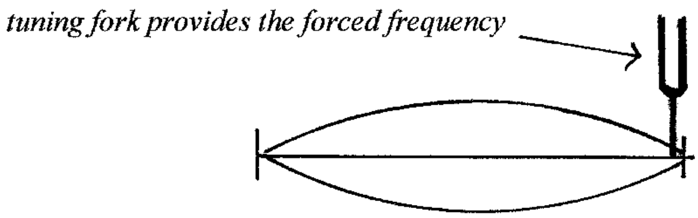
Characteristics of a sound:
- The characteristics of a sound are pitch, quality and loudness. These are the three ways in which sounds differ.

Natural frequency:

- When a system that is capable of vibrating is made to vibrate it will do so at its natural frequency.
- When a stretched elastic band is plucked in the middle it will vibrate at its natural frequency

Forced frequency:

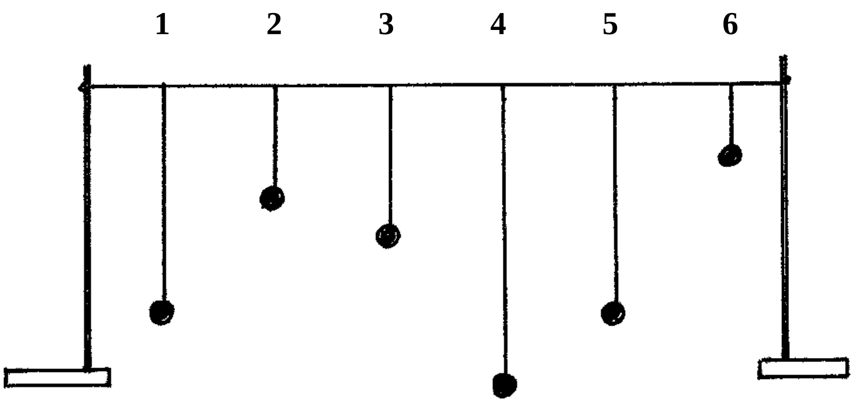
- When an external vibration force acts on a system that is capable of vibrating the external force provides the forced frequency.
- Touch a vibrating tuning fork to a stretched string. The string vibrates at the same frequency as the tuning fork. The frequency of the tuning fork is the forced frequency.



Resonance:

- Resonance happens when a vibrating system responds with maximum amplitude to a forced frequency.
- Resonance happens when the forced frequency is equal to the natural frequency of the vibrating system.
- An example would be a singer who shatters a wine glass.
  - → The wine glass is the system capable of vibrating. It has a natural frequency.
  - → The sound from the singer provides the forced frequency.
  - → When forced frequency equals the natural frequency resonance happens. The glass shatters.

Demonstration (laboratory) of resonance: **(Barton's pendulums)**



- A number of pendulums are arranged as shown above.
- Pendulum 1 is made swing in and out of the plane of the page.
- All the pendulums start to swing a little but pendulum 5 swings most.
- Pendulums 1 and 5 have the same length and therefore the same natural frequency.
- Energy is transferred back and forth between the pendulums of the same natural frequency.