Doppler Effect

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Learning Outcome

I highly recommend you to finish this checklist to determine whether you've achieved the learning objectives.

- ☐ describe the *Doppler Effect* for sound waves and electromagnetic waves, intensity and frequency.
- ☐ use the equation $f_0 = \frac{f_s \cdot v}{v \pm v_s}$, know the conditions of when to use $+/-$

Leadin

In the famous TV sitcom "The Big Bang Theory", Dr. Sheldon Cooper wears a costume representing doppler effect in The Middle-Earth Paradigm, Season 1. Actually, the costume is hard to comprehand, but the doppler effect is common in our daily life, especially when an ambulance comes and leaves you. It is named after the Austrian physicist — Christian Andreas Doppler who desribed such phenomenon in 1842.

Figure 1: Christian Andreas Doppler 1803-1853

Wavefront Model

In the wave intro if all the crest in the space are connected, viewed from the top, the wave can be expressed by the *wave front*

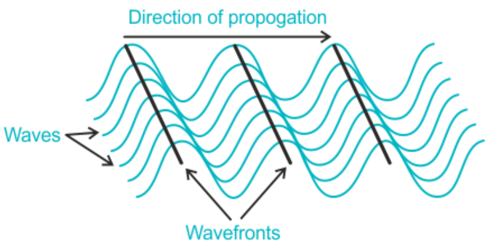

Figure 2: The black line is the wave front of the planar wave

A wavefront is a set or locus of all points at a particular instant of time, which have **the same phase**, but ususally, points at crest are choosen.

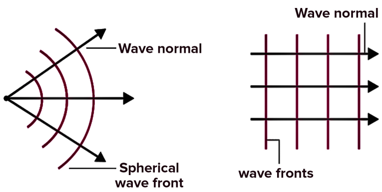

Figure 3: Two types of wavefront.

And does the planar wavefront reminds you something? The wifi signal! yes, it is still a type of wave.

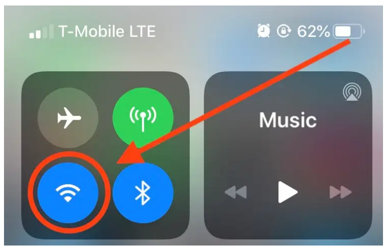

Figure 4: nearly all wifi icon looks like this

Example

- Is the wavefront model derived from a d-t graph or d-x graph?
- What is the relationship between the wavefront and the direction of propagation of the wave?
- What does the distance bewteen two consective wavefronts mean?
- What is the phase difference bewteen two consective wavefronts?

Doppler Effect

watch the NorTek detecting and using Doppler Effect. Generally speaking, when there is relation motion between the source and the observer, the obeserved frequency will changed accordingly. It does not equal to the real frequency of the source.

Task

Watch the video, and state a qualitative conclusion about what have changed when the car with horn approach and leaves you.

As the source come closer, the sound intensity (increase/decreases), and the *pitch*(frquency) of the sound seems (higher/lower).
When the source leaves the observer, the sound intensity (increase/decreases), and the pitch(frquency) of the sound seems (higher/lower).

That is the Doppler Effect, which summarises as below:

Summary

The freqency of a wave will change in relation to an observer who is moving relative to the wave source.

Doppler Effect Formula

Now, let's deduce the formula from the illustration, suppose that the observer is stationary relative to the ground.

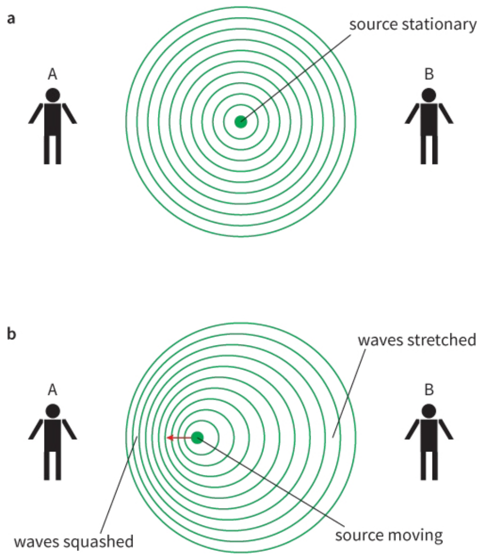

Figure 5: For observe A, the source is approach; For observe B, the source is leaving

Approaching

Example

Deriving the frequency of the sound from observer A, given that the speed of source is v_s, the speed of sound wave is v, and the orignal frequency is f_s when the source is stationary.

The original wavelength is $\lambda_s = {}^{v}/_{f_s}$, while for a time of $t = {}^{1}/_{f_s}$, the distance that the source has moved is $d = v_s \cdot t =$.
Thus, the new wavelength for observe A is $\lambda_o = \lambda_s - d$, which is

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

The most important thing is that, despite the source is moving, the speed of the sound wave does not change for observer. Thus, the new obserered frequency can be calculated through $f_o = {}^{v}/_{\lambda_o}$.

$$\begin{aligned} f_o &= \frac{v}{\lambda_o} \\ &= \frac{v}{\lambda_s - d} \\ &= \frac{v}{(v-v_s)/f_s} \\ &= f_s \cdot \underline{\qquad\qquad} \end{aligned}$$

Leaving

Example

Deriving the frequency of the sound from observer B, given that the speed of source is v_s, the speed of sound wave is v, and the orignal frequency is f_s when the source is stationary.

Summary

Combining the two situations, the Formula for the Doppler Effect can be summarised into:

Summary

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

State, when to use $+$ sign, and when to use $-$ sign.

Understand Relative Speed

If the source of a louderspeaker is moving in a circle with a constant speed of $v_s = 20\,\mathrm{m\,s^{-1}}$. The frquency of the louderspeaker is $f_s = 1500\,\mathrm{Hz}$. State at which point will the observer hear the highest and lowest frquency, and determine what are the frquencies respectively. Given that the sound velocity is $330\,\mathrm{m\,s^{-1}}$.

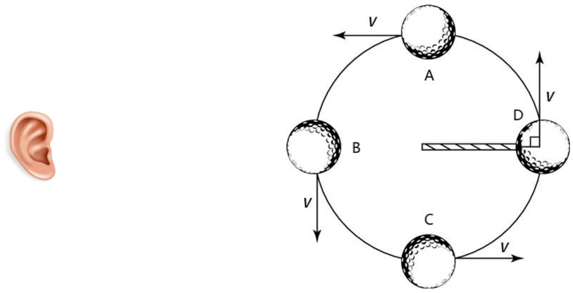

Figure 6: the observe is stationary

Red Shift of spectrum

Doppler Effect is common to any **waves**, Thus, it is also common to electromagnetic waves or light. Astronomers has proved that the light emitted from other stars has the famous phenomenon of "red shift", as shown in the Fig.7: But actually, the light would still be a "white light". Red shift does not mean that the light you receive become red. After the dispersion and absorption lines will appear, and compare the absorption lines with the white light from Sun, all wavelength tend to move to red region, which means the increase of wavelength, or equivalently, decrease of frequency, as shown in Fig.8.

A *Spectrum*[1] is a band of colors, as seen in a rainbow, produced by separation of the components of light by their different degrees of refraction according to wavelength.

[1] def:

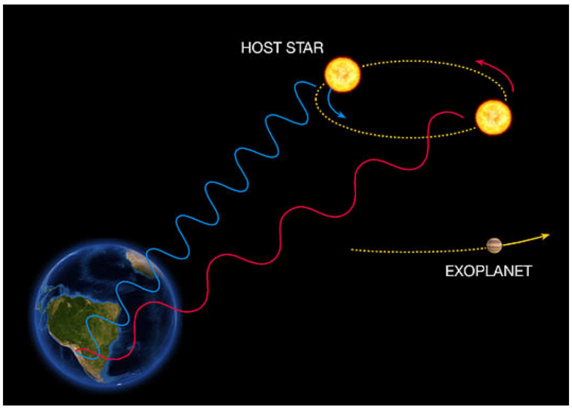

Figure 7: Doppler Effect with light

This means the star is (leaving/moving towards) us.

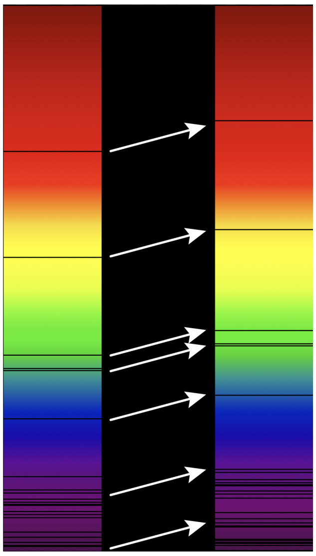

Figure 8: the move of abosorption lines in the spectrum shows red shift