1. Details of Module and its structure

Subject Name	Physics
Course Name	Physics 01 (Physics Part 2,Class XI)
Module Name/Title	Unit 10, Module 15, Doppler's Effect Chapter 15, Waves
Module Id	keph_201507_eContent
Pre-requisites	Wave, wave motion, two types of waves, transverse and longitudinal waves, wave equation, frequency, speed of sound, properties of waves reflection of sound, refraction of sound, diffraction of sound, interference of sound, relative motion, source frequency
Objectives	After going through this module, the learners will be able to • Understand relative motion may be there between a sound source and observer • Conceptualise of apparent change of frequency • Know Doppler's effect in sound • Deduce the relationships for apparent frequency, when source and observer are in relative motion. • Explain Doppler's effect in light and deduce the formula for Doppler's shift • Know about applications based on Doppler's effect
Keywords	frequency, apparent frequency, wavelength, Doppler shift, relative motion, applications of Doppler effect, Doppler effect in sound, Doppler effect in light

2. Development team

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Oscillations and waves
Chapter 14: oscillations

Periodic motion, time period, frequency, displacement as a function of time, periodic functions Simple harmonic motion (S.H.M) and its equation; phase; oscillations of a loaded spring-restoring force and force constant; energy in S.H.M. Kinetic and potential energies; simple pendulum derivation of expression for its time period.
Free forced and damped oscillations (qualitative ideas only) resonance

Chapter 15: Waves
Wave motion transverse and longitudinal waves, speed of wave motion , displacement, relation for a progressive wave, principle of superposition of waves , reflection of waves, standing waves in strings and organ pipes, fundamental mode and harmonics, beats, Doppler effect

2. MODULE-WISE DISTRIBUTION OF UNIT SYLLABUS 15 MODULES

Module 1	• **Periodic motion** • **Special vocabulary** • **Time period, frequency,** • **Periodically repeating its path** • **Periodically moving back and forth about a point** • **Mechanical and non-mechanical periodic physical quantities**
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	In phase **not in phase**
Module 3	• **Kinematics of an oscillator** • **Equation of motion** • **Using a periodic function (sine and cosine functions)** • **Relating periodic motion of a body revolving in a circular path of fixed radius and an Oscillator in SHM**
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	• Using a simple pendulum plot its L-T^2graph and use it to calculate the acceleration due to gravity at a particular place
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Module 12	• Special cases of superposition of waves • Standing waves • Nodes and antinodes • Standing waves in strings • Fundamental and overtones • Relation between fundamental mode and overtone frequencies, harmonics • To study the relation between frequency and length of a given wire under constant tension using sonometer • To study the relation between the length of a given wire and tension for constant frequency using a sonometer

Module13	• **Standing waves in pipes closed at one end,** • **Standing waves in pipes open at both ends** • **Fundamental and overtones** • **Relation between fundamental mode and overtone frequencies** • **Harmonics**
Module 14	• **Beats** • **Beat frequency** • **Frequency of beat** • **Application of beats**
Module 15	• **Doppler effect** • **Application of Doppler effect**

MODULE 15

3. WORDS YOU MUST KNOW

Let us remember the words we have been using in our study of this physics course

- Displacement the distance an object has moved from its starting position moves in a particular direction.SI unit: m, this can be zero, positive or negative
- Non mechanical displacement periodically changing electric, magnetic, pressure of gases, currents, voltages are non-mechanical oscillations. They are represented by sin and cosine functions like mechanical displacements.
- For a vibration or oscillation, the displacement could ne mechanical, electrical magnetic. Mechanical displacement can be angular or linear.
- **Energy:** In equilibrium position $y = 0$, we have
  Potential energy of the body, $U = 0(zero)$
  And kinetic energy of the body, $K = \frac{1}{2}m\,\omega^2\,a^2 = E_{max}$
  In maximum displace position $(y = a)$, we have
  Potential energy of the body, $U = \frac{1}{2}m\,\omega^2\,a^2 = E_{max}$
  And kinetic energy of the body, $K = O(zero)$
- **Wave:** A wave is a disturbance in the medium which causes the particles of the medium to undergo vibratory motion about their mean position.
- Wave motion method of energy transfer from a vibrating source to any observer.

- **A progressive wave:** The propagation of a wave in a medium means the particles of the medium perform simple harmonic motion without moving from their positions, then the wave is called a simple harmonic **progressive wave**

  In progressive wave, the disturbance produced in the medium travels onward, it being handed over from one particle to the next. Each particle executes the same type of vibration as the preceding one, though not at the same time. In this wave, energy propagates from one point in space to the other.

- Mechanical wave energy transfers by vibration of material particles in response to a vibrating source examples water waves, sound waves, waves in strings
- Longitudinal mechanical waves a wave in which the particles of the medium vibrate along the direction of propagation of the wave
- Transverse mechanical wave a wave in which the particles of the medium vibrate perpendicular to the direction of propagation of the wave
- The speed of wave in medium depends upon elasticity and density
  - **Motion and Rest:** Rest and motion are the relative terms since it closely depends on the observer's frame of reference. Therefore, if two observers are not at rest with respect to each other, then they will get different outcomes when they will observe motion or the rest position of a body. So as per the theory of relativity, it is said that an object is "at rest relative to" another with an inertial frame of reference. So as per general theory of relativity it is evident that only the relative difference in velocity between the observer and the source needs to be considered.

  - **Wavelength:** It is the distance between consecutive corresponding points of the same phase like trough, crest and it gives physical feature of both travelling and standing waves. A sinusoidal wave moving at a fixed wave speed, wavelength is inversely proportional to frequency of the wave or it is distance travelled by wave particles in one cycle.

  - **Frequency:** The number of occurrences of a repeating event per unit time. It is also referred to as temporal frequency, which emphasizes the contrast to spatial frequency and angular frequency. The period is the duration of time of one cycle in a repeating event, so the period is the reciprocal of the frequency.

  - **Amplitude:** The maximum displacement of an oscillation from the equilibrium position (zero level), the difference between the zero level and peak is known as amplitude.

  - **Velocity of wave:** The Wave velocity refers to speed, that is velocity implies both speed and direction. The velocity of a wave is equal to the product of its wavelength and frequency and is independent of its intensity.

- **Principle of Superposition:** The net displacement of the medium / particles (through which waves travel) due to the superposition is equal to the sum of individual displacements (produced by each wave).

- **Conditions for special cases of superposition:**

Interference: the process in which two or more light, sound, or electromagnetic waves of the same frequency combine to reinforce or cancel each other, the amplitude of the resulting wave being equal to the sum of the amplitudes of the combining waves.

Stationary waves: is a *wave* which oscillates in time but whose peak amplitude profile does not move in space. The locations at which the amplitude is minimum are called nodes, and the locations where the amplitude is maximum are called antinodes.

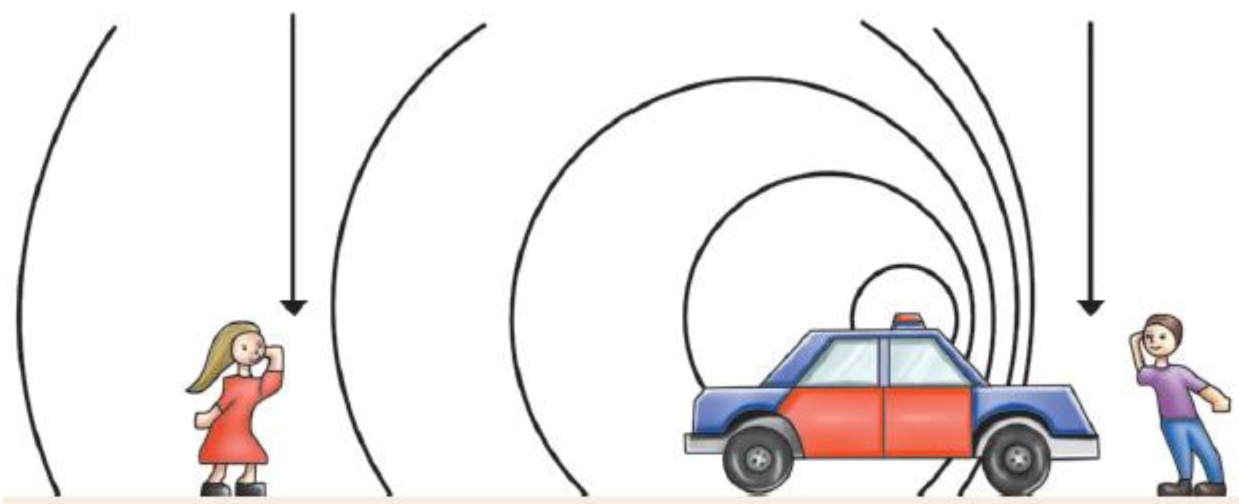
4. INTRODUCTION

Imagine yourself standing on the pavement at a traffic signal

A police car with a siren passes on the intersecting road.

The pitch or frequency of the siren on approach is different from when the police car moves away

It can be easily observed that the pitch of an approaching police car is higher than the actual pitch. Similarly, it drops suddenly after it passes us. This is due to a **phenomenon called Doppler Effect**.



Doppler's effect

Do you think the siren frequency actually changed?

Do you think the siren frequency only appeared to change?

What was the cause for the apparent change in frequency?

What if the police car was also stationary?

The frequency change is due to motion of the police car?

The Frequency change is due to relative motion between you and the police car?

Would there be a change if instead of the police car you were moving?

If there is no medium present, the Doppler shifts are nearly the same irrespective of whether the source moves or the observer moves. Such a case would not be applicable to sound waves, as they need a medium to travel.

5. DOPPLER EFFECT

Watch an applet on Doppler's effect

http://lectureonline.cl.msu.edu/~mmp/applist/doppler/d.htm

When a speeding car passes you, do you observe Doppler effect, if you are also moving but not as fast? Does the direction you are moving makes a difference to the sound you hear?

If you are moving in the same direction and with the same speed as an object generating a siren sound, will you experience the Doppler effect?

When a sound-source fixed at a place produces sound, an observer standing at a distance hears sound of the same frequency as produced by the source.

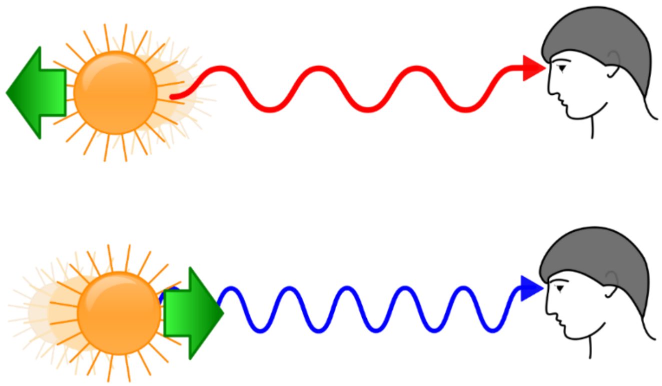
If, however, the sound-source, or the observer, or both, are in the state of motion; then the frequency of the sound appears changed to the observer.

If, as a result of motion, the distance between the source and the observer is decreasing; then the frequency of the source appears to be increased to the observer. On the other hand, if the distance between them is increasing, the frequency appears to be decreased to the observer.

The apparent change in the frequency of the source due to a relative motion between the source and the observer is known as 'Doppler effect'.

This kind of change in frequency or wavelength of a wave for an observer who is moving relative to the wave source is apparent change.

It is named after the **Austrian physicist Christian Doppler, who described this phenomenon in 1842.**



Source: Wikimedia

6. DOPPLER EFFECT IN SOUND

The Doppler Effect is that **when the source of the waves is moving towards the observer**, each successive wave crest is emitted from a position closer to the observer than the previous wave. Therefore**, each wave crest takes slightly less time to reach the observer than the previous wave crest.**

Hence, the **time between the arrivals of successive wave crests at the observer is reduced, causing an increase in the frequency.**

While they are travelling, the distance between successive wave crests is reduced, so the waves "bunch together".

Conversely,

If the **source of waves is moving away from the observer**, **each wave crest is emitted from a position farther from the observer than the previous wave crest, so the arrival time between successive wave crests is increased, reducing the frequency.**

The **distance between successive wave crests is then increased**

For waves which do not require a material medium, such as light or gravity in general relativity, only the relative difference in velocity between the observer and the source needs to be considered.

More details watch the video:

https://en.wikipedia.org/wiki/Frequency

We shall analyse changes in frequency under different situations:

(1) Observer is stationary but the source is moving,

(2) Observer is moving but the source is stationary, and

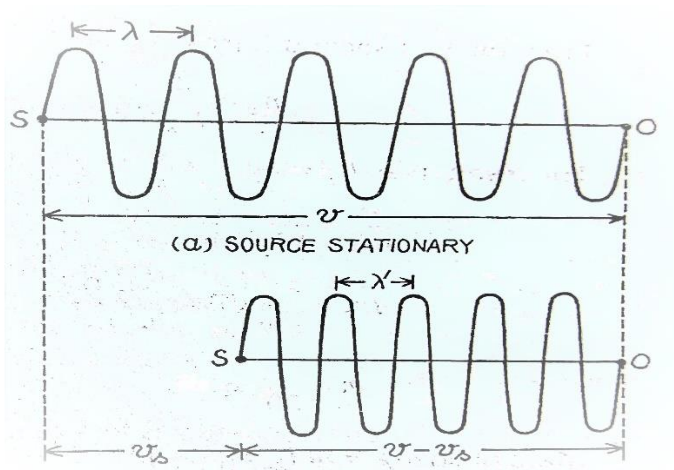
(3) Both the observer and the source are moving

Case I—SOURCE MOVING; OBSERVER STATIONARY

Let us choose the convention to take the direction from the observer to the source as the positive direction of velocity.

Suppose the **observer O is stationary** and the sound -**source S is coming towards the observer with a velocity v_s.**

If the source was also stationary, then the observer would have received n waves coming from the source in 1second shown below (Fig. a).



Then the n waves emitting in 1 second will spread in a distance $v - v_s$ only, because in 1 second the source itself moves a distance v_s towards the observer $(Fig. b)$.

Thus, the wavelength will be shortened.

Let it be λ'. Then

$$\boldsymbol{\lambda' = \frac{v - v_s}{n}} \ .$$

Therefore, the observer will receive waves of wavelength λ'.

Hence, the **frequency of sound will appear to be changed for him.**

Let this frequency be n' , then

$$n' = \frac{v}{\lambda'} = \frac{v}{(v - v_s)/n}$$

Or $$\mathbf{n' = n\left(\frac{\upsilon}{\upsilon - \upsilon_s}\right)}$$

Since $\frac{v}{v - v_s} > 1$, $\quad \therefore \mathbf{n' > n}$.

That is, the apparent frequency is greater than the true frequency

Hence in this case, the **sound of the source appears to the observer shriller (of higher pitch).**

With the same logic, if the **source is going away from the observer**, then the wavelength will be increased and become $\frac{\upsilon + \upsilon_s}{n}$.

In this case, the **apparent frequency of sound** will be given by

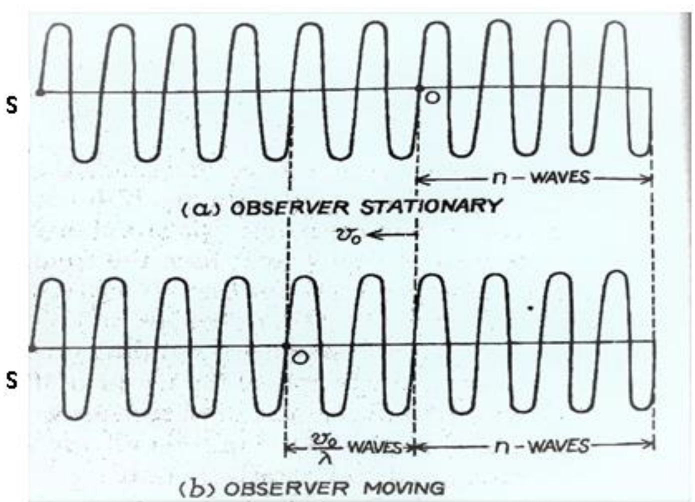
$$n' = n\left(\frac{\upsilon}{\upsilon + \upsilon_s}\right).$$

Since $\frac{\boldsymbol{v}}{\boldsymbol{v} + \boldsymbol{v_s}} < 1$, $\quad \therefore \mathbf{n' < n}$.

That is, **the apparent frequency is less than the true frequency**. Hence in this case, **the frequency of sound of the source will appear to the observer grave (of low pitch).**

Case II—OBSERVER MOVING; SOURCE STATIONARY

To derive an expression for Doppler shift when the observer is moving with velocity v_o towards the source and the source is at rest, we have to proceed in a different manner.



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Since the observer himself covers a distance υ_o towards the source in 1 second, hence in addition to n waves it also receives υ_o/λ waves contained in the distance υ_o (Fig. b). Therefore, the total waves received by the observer in 1 second, that is, the apparent frequency of the source is

$$n' = n + \frac{\upsilon_o}{\lambda} = n + \frac{\upsilon_o}{\upsilon/n} \qquad \left[\because \lambda = \frac{\upsilon}{n}\right]o$$

Or $$= n\left(1 + \frac{\upsilon_o}{v}\right) = \mathbf{n}\left(\frac{\upsilon + \upsilon_o}{\upsilon}\right),$$

Since $$\frac{\upsilon + \upsilon_o}{\upsilon} > 1, \qquad \therefore\ n' > n.$$

That is, the apparent frequency is **greater** than the true frequency. Hence in this case, the frequency of sound of the source will appear to the observer shriller (of high pitch).

If the observer is going away from the source, then he will receive only $\left(n - \frac{\upsilon_o}{\lambda}\right)$ waves in 1 second.

In this case, the apparent frequency of sound will be given by

$$n' = n - \frac{\upsilon_o}{\lambda} = n - \frac{\upsilon_o}{\upsilon/n}$$

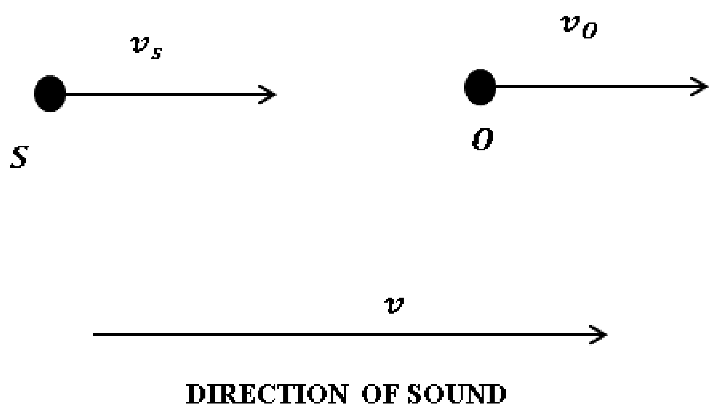
Or $$n' = n\left(\frac{\upsilon - \upsilon_o}{\upsilon}\right),$$

Since $$\frac{\upsilon - \upsilon_o}{\upsilon} < 1, \qquad \therefore\ n' < n.$$

That is, the apparent frequency is less than the true frequency. Hence in this case, the sound of the source will appear to the observer grave (of low pitch).

Case (III) - BOTH THE SOURCE AND THE OBSERVER ARE MOVING:

Suppose, the source S and the observer O are moving with velocities υ, respectively in the direction of sound (Shown in fig.).



Suppose, if only the source were moving, then the apparent frequency heard by the observer would have been n_1. Then, according to eq. (i), we have

$$n_1 = n\left(\frac{\upsilon}{\upsilon - \upsilon_s}\right).$$

But since the observer is also going away from the source, the apparent frequency n_1 will change to n'. According to eq. (iv), we have

$$n' = n_1 \left(\frac{\upsilon - \upsilon_o}{\upsilon}\right).$$

Substituting the value of n_1 from above, we get

$$\mathbf{n' = n\left(\frac{\upsilon \pm \upsilon_o}{\upsilon \pm \upsilon_s}\right)}$$

If the direction of motion of the source of the observer is opposite to the direction of sound, then the sign of the velocity v_s or v_0 in the above equation will be changed.

If the source and observer are moving towards each other, we can put the signs, on υ_o and υ_s, in such a way that the frequency increases due to both the terms.

If the source and observer are moving away from each other, we can put the signs on υ_o and υ_s in such a way that the frequency decreases.

GENERAL STATE OF APPARENT FREQUENCY:

Suppose, the observer and the sound both are not moving along the direction of sound. Let the angle between the direction of the observer and that of sound, and the angle between the direction of velocity of sound-source and that of sound. Then, the apparent frequency heard by the observer is given by

$$n' = n_1 \left(\frac{\upsilon \pm \upsilon_o \cos\alpha}{\upsilon \pm \upsilon_s \cos\beta}\right).$$

EFFECT OF WIND: If wind is also blowing with a velocity in the direction of sound, then its velocity is added to the velocity of sound. Hence in this condition the apparent frequency is given by

$$n' = n \left(\frac{\upsilon + w - \upsilon_o}{\upsilon + w - \upsilon_s}\right)$$

If source and observer both are stationary, that is, $\upsilon_s = 0, \upsilon_o = 0$, then

$n' = n.$

Similarly, if source and observer both are moving in the same direction with the same velocity, that is, $\upsilon_s = \upsilon_o$, even then $n' = n$, hence it is clear that if there is **no relative motion between the source and the observer then the wind does not affect the frequency of the source.**

EXAMPLE

The frequency of a stationary police car's siren is 1500 Hz when at rest.

What frequency do you detect if you move, with a speed of 30.0 m/s

(a) toward the police car, and

(b) away from the police car?

SOLUTION

$$\mathbf{n' = n \left(\frac{\upsilon \pm \upsilon_o}{\upsilon \pm \upsilon_s}\right)}$$

a) **Moving towards the police car**

V = 330m/s, v_0 = 30m/s, v_s = 0

$$n' = 1500 \left(\frac{330 + 30}{330 \pm 0}\right)$$

$$n' = 1500 \left(\frac{360}{330}\right)$$

$$n' = 1636.36 \text{ Hz}$$

So we will hear 1636.36 Hz instead of 1500 Hz

b) **Moving away from the police car**

v = 330m/s, v_0 = 30m/s, v_s = 0

$$n' = 1500 \left(\frac{330 - 30}{330 \pm 0}\right)$$

$$n' = 1500 \left(\frac{300}{330}\right)$$

$$n' = 1250 \text{ Hz}$$

we will hear 1250 Hz instead of 1500 Hz

EXAMPLE

A toy car moves at a speed of 240 m/s directly toward a stationary pole (through stationary air) while emitting sound waves at frequency *f* = 1250 Hz.

(a) What frequency *f ′*is sensed by a detector that is attached to the pole?

(b) Some of the sound reaching the pole reflects back to the car, which has an onboard detector. What frequency *f ″* does it detect?

SOLUTION

$$\mathbf{n' = n \left(\frac{\upsilon \pm \upsilon_o}{\upsilon \pm \upsilon_s}\right)}$$

a) Here v = 330 m/s, v_0 = 0 m/s, v_s = 240 m/s, frequency = 1250 Hz

$$n' = 1250 \left(\frac{330+0}{330-240}\right)$$

$$n' = 1250 \left(\frac{330}{90}\right)$$

$$n' = 4583 \text{ Hz}$$

b) Here v = 330m/s, v_0 = 240 m/s, v_s = 0

$$n' = 4583.3\left(\frac{330 + 24\,0}{330}\right)$$

$$n' = 4583.3\left(\frac{570}{330}\right)$$

$$n' = 7916.3\text{Hz}$$

TRY THESE

- **A large auditorium has part of the orchestra in the front and part in the back. A person, walking rapidly towards the stage, while both segments are playing at once reports that the two segments sound out of tune. Why?**
- **Suppose that Site blows a whistle and Nita hears it. Will she hear an increased frequency when she is running toward Nita or Nita is running toward her?**
- **The frequency of its horn drops from 900 Hz to 875 Hz, as heard by a stationary observer. The air temperature is 0°C. Calculate the speed of the car. In which direction it is moving?**
- **Two people hear the 1700 Hz siren of an ambulance. One person is in front and the other person is behind the ambulance. If the ambulance is travelling at 120 km/h, what is the difference in frequencies heard by the two people? Assume the speed of sound to be 333 m/s.**
- **A siren emits a sound at 1700 Hz. Assume a speed of sound of 332 m/s. What frequency would a stationary observer hear if the car, with the siren, is travelling at**
  - **(*a*) 25 m/s toward the observer?**
  - **(*b*) 25 m/s away from the observer?**
  - **(*c*) 140 km/h toward the observer?**
- **A SONAR system fixed in a submarine operates at a frequency 30000 Hz. An enemy submarine moves towards the SONAR with a speed of 250 km/ hr. What is the frequency of sound reflected by the submarine? Take the speed of sound in water to be 1450 m/ s.**
- **A train, standing at the outer signal of a railway station blows a whistle of frequency 300 Hz in still air.**

  (*i*) What is the frequency of the whistle for a platform observer when the train

  - **(*a*) approaches the platform with a speed of 10 m/s,**
  - **(*b*) recedes from the platform with a speed of 10 m /s?**

  (*ii*) What is the speed of sound in each case? The speed of sound in still air can be taken as 340 m/ s.

- **A train, standing in a station-yard, blows a whistle of frequency 350 Hz in still air. The wind starts blowing in the direction from the yard to the station with a speed of 10 m/ s.**
- **What are the frequency, wavelength, and speed of sound for an observer standing on the stations platform?**
- **Is the situation exactly identical to the case when the air is still and the observer runs towards the yard at a speed of 10 m/ s. The speed of sound in still air can be taken as 340 m /s.**

- **A bird is flying directly toward a stationary bird-watcher and emits a frequency of 1250 Hz. The bird-watcher, however, hears a frequency of 1290 Hz. What is the speed of the bird?**
- **A bat chirp has a frequency of 25 kHz. How fast would the bat have to fly, and in what direction, for you to just barely be able to hear the chirp at 20 kHz?**
- **Standing on a pavement, you hear a frequency of 560 Hz from a siren of an approaching car. After it passes, the observed frequency of the siren is 480 Hz. Determine the car's speed from these observations.**
- **A stationary motion detector sends sound waves of 0.150 MHz toward a truck approaching at a speed of 45.0 m/s. What is the frequency of the waves reflected back to the detector?**
- **A train is travelling at 30.0 m/s in still air. The frequency of the note emitted by the train whistle is 262 Hz. What frequency is heard by a passenger on a train moving in the opposite direction to the first at 18.0 m/s and a) approaching the first? b) receding from the first.**
- **A police car with a siren emitted at 1600 Hz overtakes and passes a cyclist pedalling a bike at 2 m/s. After being passed, the cyclist hears a frequency of 1590 Hz. How fast is the police car moving?**
- **Two buses travel at the same speed. They are far apart on adjacent lanes and approach each other essentially head-on. One driver hears the horn of the other bus at a frequency that is 1.14 times the frequency he hears when the buses are stationary. At what speed is each bus moving?**

APPLICATIONS OF DOPPLER EFFECT

Several practical applications of Doppler effect have emerged during part few decades. In all these applications, the same basic principle is used: A stationary transmitter shoots waves at a moving object. The waves hit the object and bounce back. The transmitter (now a receiver) detects the frequency of the reflected waves. Based on the magnitude of Doppler shift, the speed of the object can be determined. Let us have a look at few specific examples.

POLICE RADAR

The handheld radar guns, used by police to check for speeding vehicles rely on the Doppler effect.

A police officer takes a position on the side of the road. The officer aims his radar gun at an approaching vehicle. The gun sends out a burst of radio waves at a particular frequency.

The radio waves strike the vehicle and bounce back toward the radar gun. The radar gun measures the frequency of the returning waves. Because the car is moving toward the gun, the frequency of the returning waves will be higher than the frequency of the waves initially transmitted by the gun. The faster the car's speed, the higher the frequency of the returning wave. The difference between the emitted frequency and the reflected frequency is used to determine the speed of the vehicle. A computer inside the gun performs the calculation instantly and displays a speed to the officer.

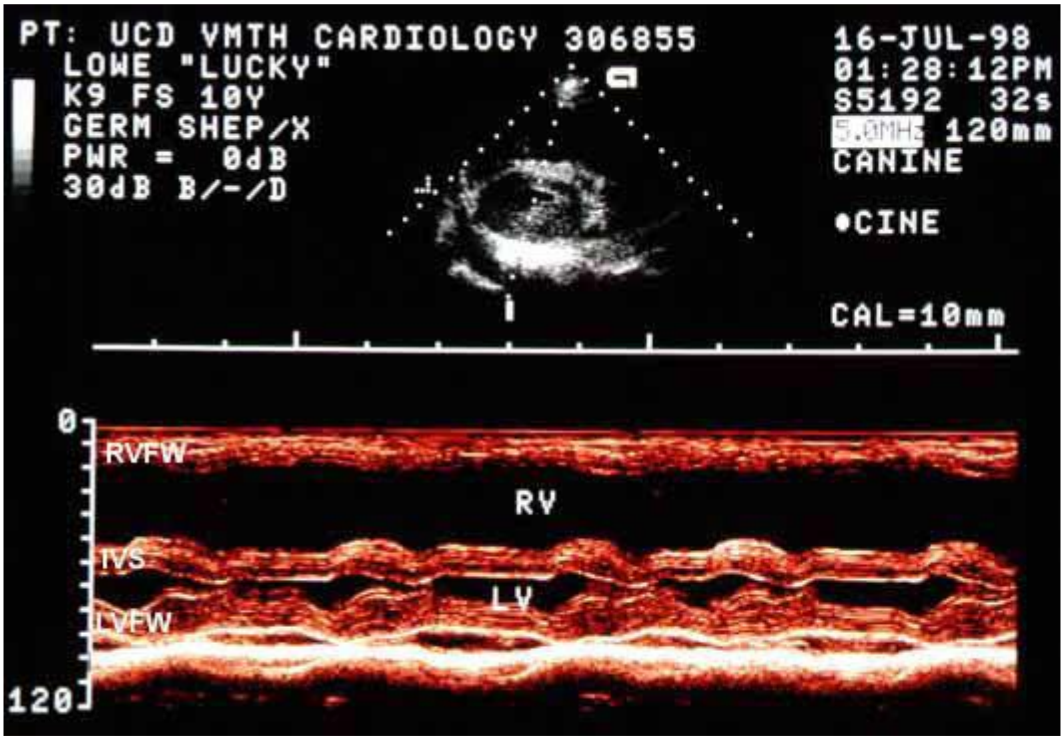
DOPPLER RADAR

Meteorologists use a similar principle to read weather events. In this case, the stationary transmitter is located in a weather station and the moving object being studied is a storm system. This is what happens: Radio waves are emitted

from a weather station at a specific frequency. The waves are large enough to interact with clouds and other atmospheric objects. The waves strike objects and bounce back toward the station. If the clouds or precipitation, are moving away from the station, the frequency of the waves reflected back decreases. If the clouds, or precipitation are moving toward the station, the frequency of the waves reflected back increases. Computers in the radar electronically convert Doppler shift data about the reflected radio waves into pictures showing wind speeds and direction.

DOPPLER ECHOCARDIOGRAM

A traditional echocardiogram uses sound waves to produce images of the heart. In this procedure, a radiologist uses a transducer to transmit, and receive, ultrasound waves, which are reflected when they reach the edge of two structures with different densities. The image produced by an echocardiogram shows the edges of heart structures but it cannot measure the speed of flowing through the heart. Doppler techniques must be incorporated to provide this additional information. In a Doppler echocardiogram, sound waves of a certain frequency are transmitted into the heart. The sound waves bounce off blood cells moving through the heart and blood vessels. The movement of these cells, either toward, or away, from the transmitted waves, results in a frequency shift that can be measured. This helps



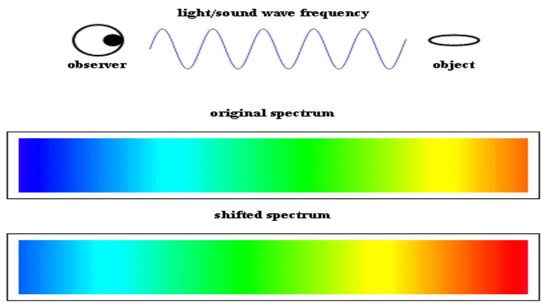
Doppler echocardiogram

cardiologists determine the speed and direction of blood flow in the heart. In addition, the Doppler effect is used at airports to guide aircraft, and in the military to detect enemy aircraft. Astrophysicists use it to measure the velocities of stars.

The Doppler effect is used in many technologies that benefit people. But it can have a negative impact, as well. For example, sonic boom, which are caused by supersonic airplanes, can cause objectionable sounds and vibrations on the ground. This is why supersonic airplanes are not allowed to fly over residential areas. Sonic booms are directly related to the Doppler effect. They occur when airplanes, flying at the speed of sound or higher, actually fly faster than the sound waves they are producing. All the waves bunch up behind the craft, in an extremely small space. When the bunched-up waves reach an observer, they are "heard" all at once -- as a resounding boom. The Air Force and NASA are experimenting with several inventions that help mitigate sonic booms. One such invention is a spike extending from the nose of the airplane. This spike essentially lengthens the plane and distributes the waves over a greater distance. This reduces the boom experienced by an observer on the ground

7. DOPPLER EFFECT IN LIGHT: DOPPLER'S SHIFT

Doppler Effect is observed in light also. Whenever there is a relative motion between a source of light and observer, the apparent frequency of light received by the observer is different from the true frequency of light emitted by the source. If the distance between the source and the observer is decreasing, the apparent Frequency of light is increased (of wavelength is decreased). If, on the other hand, the distance between the source and the observer is increasing, the apparent frequency is decreased (or wavelength is increased). ***The phenomenon of apparent change in frequency (of wavelength) of light due to a relative motion between the source of light and the observer is called Doppler effect in light'.***



Source: Wikipedia

There is, however, a difference between, Doppler Effect in sound and that in light. In sound, the Doppler Effect depends not only upon the relative motion of the sound-source and the observer, but also depends upon whether the source or the observer in moving. For example, if the source is stationary and the observer is moving toward the source is moving with the same velocity toward the observer. The reason is that sound waves require a medium for their propagation and the velocity of sound is always "with respect to the medium". Thus, for sound waves, "source in motion" and "observer in motion" refer separately to motion with respect to the medium and represent physically different situations. Hence, they lead to different equations for the Doppler Effect. We say that the **Doppler Effect in sound is asymmetrical.**

Light waves, however, can travel in vacuum, without any medium. Therefore, 'a source of light moving with velocity υ towards and observer' and 'an observer moving with velocity υ towards the source of light' is physically identical situations. Therefore, Doppler Effect in light depends only upon the relative motion of the source and the observer, no matter which one is moving. Hence only one equation is enough to describe Doppler Effect in light. We say that the **Doppler Effect in light is symmetrical.**

Suppose the frequency of light emitted by a source is ν. It can be shown by the theory of relativity that if the distance between the light-source and the observer is decreasing (either due to the motion of the source or due to the motion of the observer), then the apparent frequency of the source is given by

$$\nu' = \nu\sqrt{\frac{1 + (\upsilon/c)}{1 - (\upsilon/c)}}$$

Where υ is the velocity of the light-source or the observer, and c is the velocity of light. Thus, the apparent frequency of light is increased, of wavelength is decreased, so that the spectral lines are shifted towards the blue end of the spectrum (blue shift).

To determine the apparent change in wavelength, known as Doppler's shift, let λ be the real wavelength of light emitted by the source and λ′ be the apparent wavelength. Then

$$\nu = \frac{c}{\lambda} \quad and \quad \nu' = \frac{c}{\lambda'}$$

Substituting there values of ν and ν′ in above equation, we get

$$\frac{c}{\lambda'} = \frac{c}{\lambda}\sqrt{\frac{1 + (\upsilon/c)}{1 - (\upsilon/c)}}$$

$$\frac{\lambda'}{\lambda} = \sqrt{\frac{1-(\upsilon/c)}{1+(\upsilon/c)}} = \left(1 - \frac{\upsilon}{c}\right)^{\frac{1}{2}}\left(1 + \frac{\upsilon}{c}\right)^{-\frac{1}{2}} = \left(1 - \frac{1}{2}\frac{\upsilon}{c} + \ldots\right)\left(1 - \frac{1}{2}\frac{\upsilon}{c} + \ldots\right)$$

In practice, $\upsilon \ll c$, and so the terms containing higher powers of υ/c can be ignored.

$$\therefore \frac{\lambda'}{\lambda} = \left(1 - \frac{1}{2}\frac{\upsilon}{c}\right)\left(1 - \frac{1}{2}\frac{\upsilon}{c}\right) = 1 - \frac{\upsilon}{c}$$

Or $$1 - \frac{\lambda'}{\lambda} = \frac{\upsilon}{c}$$

Or $$\frac{\lambda - \lambda'}{\lambda} = \frac{\upsilon}{c}$$

But λ – λ′ = Δ λ (Doppler's shift).

$$\therefore \quad \Delta\lambda = \frac{\upsilon}{c}\lambda$$

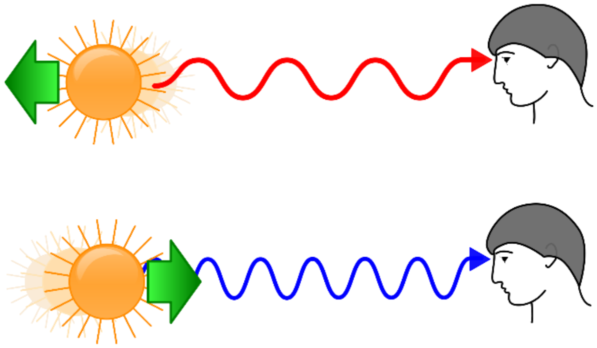
If either the source or the observer is moving away from the other (that is, the distance between them is increasing), then the apparent frequency of the source is given by

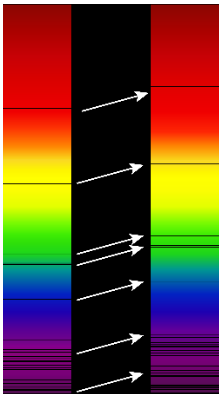
$$\boldsymbol{\nu' = \nu\sqrt{\frac{1 - (\upsilon/c)}{1 + (\upsilon/c)}}}$$

Thus, in this case, the apparent frequency of light is decreased, or wavelength is increased, so that the spectral lines are shifted towards the red end if the spectrum (red shift).

Again, in term of wavelength, the Doppler's shift is

$$\Delta\lambda = \frac{\upsilon}{c}\lambda$$





Source: Wikipedia

HOW THIS IS USED?

i. The Doppler Effect in light has many applications in astronomy. For example, it is used to determine the velocities at which stars and galaxies are moving toward or away from earth. The spectrum of light of coming from stars and galaxies has spectral lines of hydrogen, helium, sodium, etc. A photograph of the spectrum from a star (for example) is taken. These spectral lines are compared with the same lines obtained in the spectra of elements in the laboratory. ***If the spectral lines of the star are found shifted towards the blue end of the spectrum (blue shift) then the star is approaching the earth; but if they are found shifted towards the red end of the spectrum (red shift) then the star is receding away from the earth.*** If $\Delta\lambda$ be the Doppler shift, then $\Delta\lambda = \left(\frac{\upsilon}{c}\right)\lambda$. Hence, measuring $\Delta\lambda$, the velocity υ of the star can be calculated. It is important to note that Doppler shift measures only the radial component (along the line of sight) of the relative velocity υ.

ii. Doppler Effect has been used to measure the speed of rotation of the sun about its own axis which is about 2 km/s.

iii. Doppler Effect is used in estimating the velocity of an aeroplane in air. Radio waves from a radar station are sent in air towards the aeroplane and the waves reflected from the plane are received at that station. If the aeroplane is coming towards the radar-station, then the frequency of the radio waves reflected from the aeroplane is increased; and if it is going away from the station then the frequency of the reflected waves is decreased. From the difference in frequencies of the waves sent from the station towards the aeroplane and received at the station from the aeroplane, the velocity of the aeroplane can be calculated. Similarly, the velocity of a submarine moving under water can be determined. Such calculations are very useful during war time.

iv. Doppler Effect can also be used in knowing the speeds of vehicles on the road by the traffic police. Electromagnetic waves of known frequency are reflected by a vehicle in motion. From the difference in frequencies of the incident and reflected waves, the velocity of the vehicle can be found.

v. Doppler Effect is used to measure the temperature of plasma.

EXPANSION OF UNIVERSE:

All galaxies for which measurements have been made show red shift, indicating that they are receding away from earth. This suggests that the universe is expanding.

8. SUMMARY:

The Doppler Effect is

i. The Apparent change in frequency of a wave cause by its relative motion between source and observer
ii. Applied to mechanical and light wave as well
iii. Increases the frequency of a wave when the source move towards the observer
iv. Decreases the frequency of the wave when source move away from the observer.
v. A wave is not motion of matter as a whole in a medium. A wind is different from the sound wave in air. The former involves motion of air from one place to the other. The latter involves compressions and rarefactions of layers of air.
vi. In a wave, energy and not the matter is transferred from one point to the other.
vii. Energy transfer takes place because of the coupling through elastic forces between neighboring oscillating parts of the medium.
viii. Transverse waves can propagate only in medium with shear modulus of elasticity, longitudinal waves need bulk modulus of elasticity and are therefore, possible in all media, solids, liquids and gases.
ix. In a harmonic progressive wave of a given frequency all particles have the same amplitude but different phases at a given instant of time. In a stationary wave, all particles between two nodes have the same phase at a given instant but have different amplitudes.
x. Relative to an observer at rest in a medium the speed of a mechanical wave in that medium (v) depends only on elastic and other properties (such as mass density) of the medium. It does not depend on the velocity of the source.
xi. For an observer moving with velocity v_o relative to the medium, the speed of a wave is obviously different from v and is given by $v \pm v_o$.