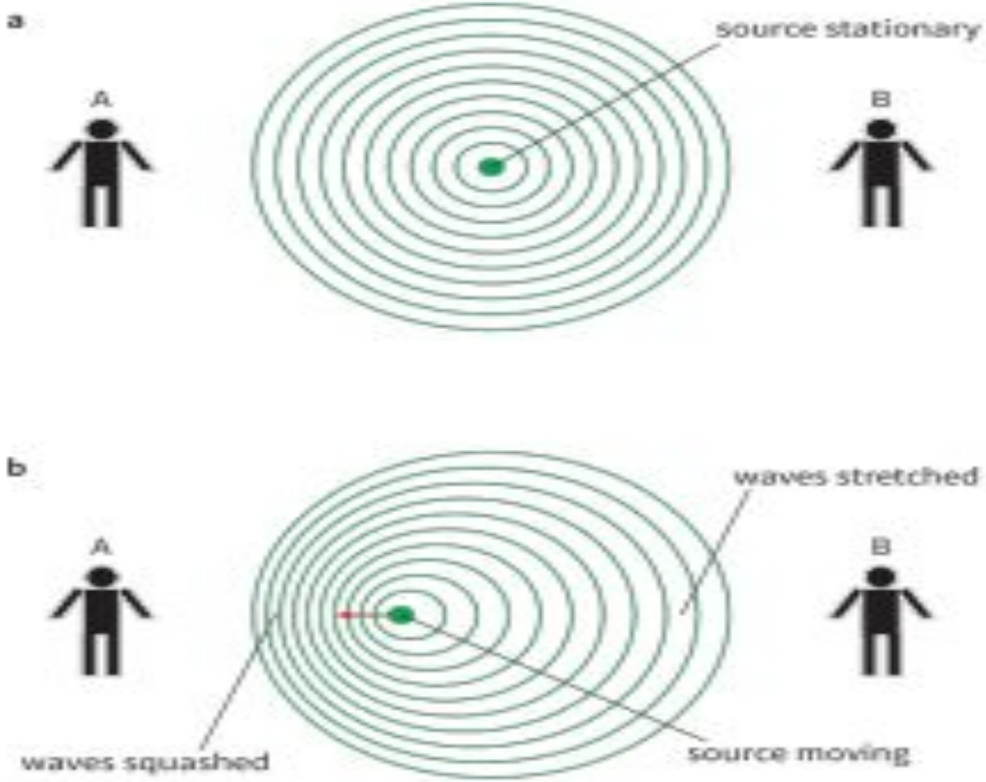
Doppler Effect for Sound Wave

Figure 12.11 shows why this change in frequency is observed. It shows a source of sound emitting waves with a constant frequency f_S, together with two observers A and B.

- If the source is stationary (Figure 12.11a), waves arrive at A and B at the same rate, and so both observers hear sounds of the same frequency f_S.
- If the source is moving towards A and away from B (Figure 12.11b), the situation is different. From the diagram, you can see that the waves are squashed together in the direction of A and spread apart in the direction of B.

Observer A will observe, or detect, waves whose wavelength is shortened. More wavelengths per second arrive at A, and so A observes a sound of higher frequency than f_S. Similarly, the waves arriving at B have been stretched out and B will observe a frequency lower than f_S.



The frequency and wavelength observed by an observer will change according to the speed v_s at which the source is moving relative to the stationary observer. Figure 12.12 shows how we can calculate the observed wavelength λ_0 and the observed frequency f_0.

The wave sections shown in Figure 12.12 represent the f_s wavelengths emitted by the source in 1 s. Provided the source is stationary (Figure 12.12a), the length of this section is equal to the wave speed v. The wavelength observed by the observer is simply:

$$\lambda_0 = \frac{v}{f_s}$$

The situation is different when the source is moving away (receding) from the observer (Figure 12.12b).

In 1 s, the source moves a distance v_s. Now the section of f_s wavelengths will have a length equal to $v + v_s$.

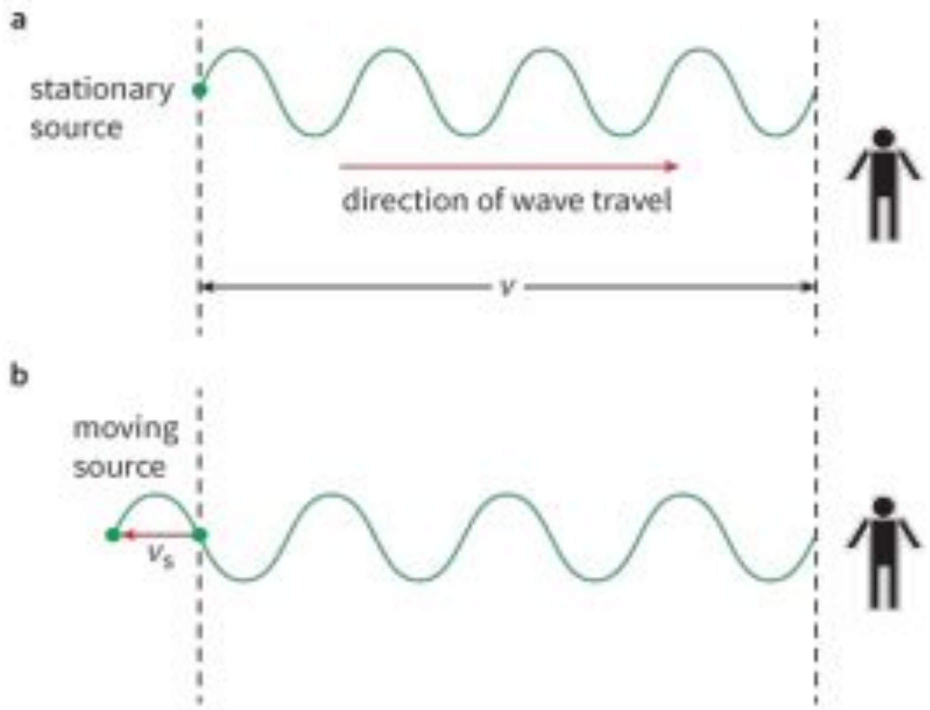


Figure 12.12: Sound waves, emitted at constant frequency by **a** a stationary source, and **b** a source moving with speed v_s *away* from the observer (that is, the person hearing the sound).

The observed wavelength is now given by:

$$\lambda_0 = \frac{(v+v_s)}{f_s}$$

The observed frequency is given by:

$$f_0 = \frac{v}{\lambda_0} = \frac{f_s \times v}{(v+v_s)}$$

where f_0 is the observed frequency, f_s is the frequency of the source, v is the speed of the wave and v_s is the speed of the source relative to the observer.

This shows us how to calculate the observed frequency when the source is moving away from the observer. If the source is moving towards the observer, the section of f_s wavelengths will be compressed into a shorter length equal to $v - v_s$, and the observed frequency will be given by:

$$f_0 = \frac{v}{\lambda_0} = \frac{f_s \times v}{(v-v_s)}$$

We can combine these two equations to give a single equation for the Doppler shift in frequency due to a moving source:

$$\text{observed frequency, } f_0 = \frac{f_s \times v}{(v \pm v_s)}$$

where the plus sign applies to a receding source and the minus sign to an approaching source. Note these important points:

- The frequency f_s of the source is not affected by the movement of the source.
- The speed v of the waves as they travel through the air (or other medium) is also unaffected by the movement of the source.

3 A train with a whistle that emits a note of frequency 800 Hz is approaching a stationary observer at a speed of 60 m s^{-1}.
Calculate the frequency of the note heard by the observer.
speed of sound in air = 330 m s^{-1}

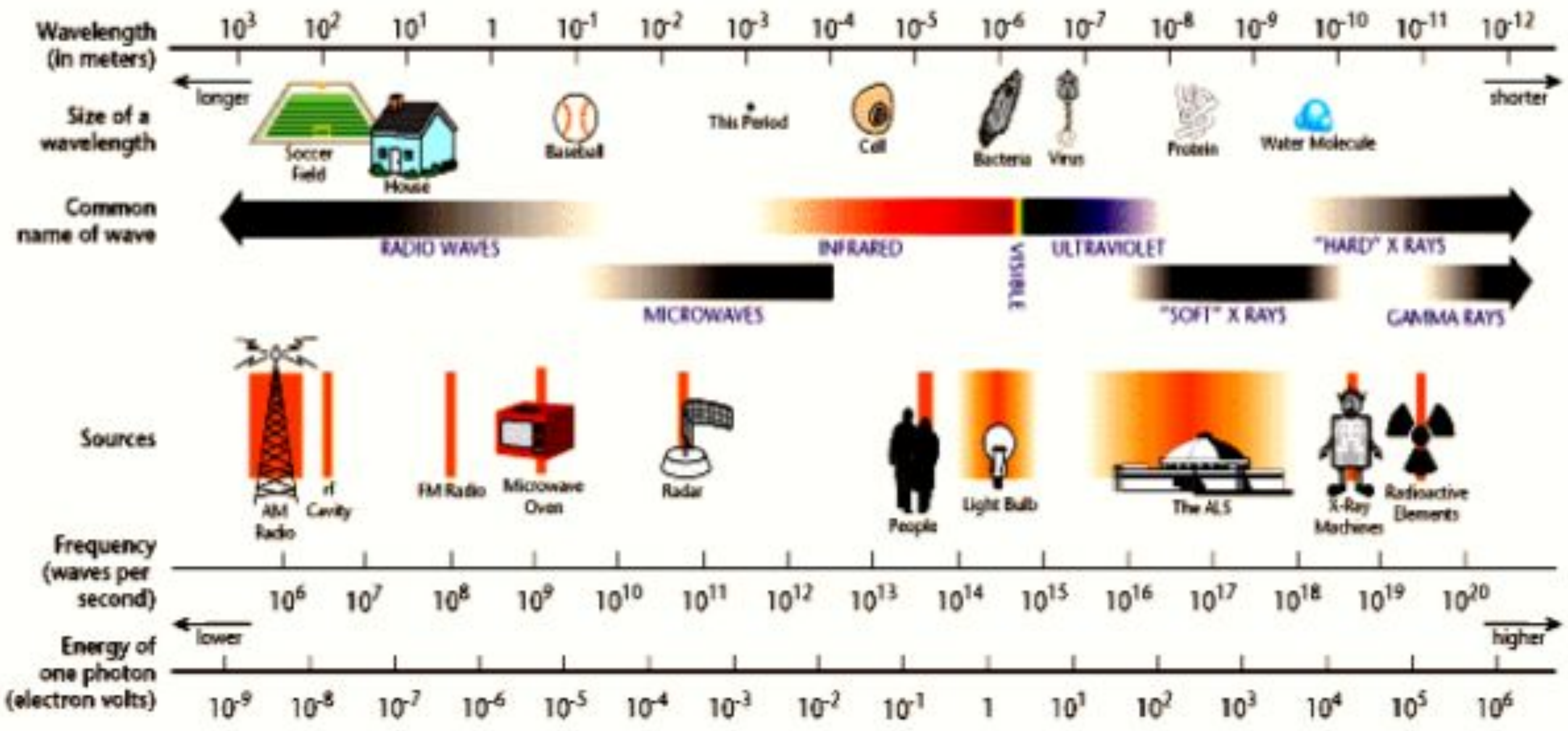
10 A plane's engine emits a note of constant frequency 120 Hz. It is flying away from a stationary observer at a speed of 80 m s^{-1}. Calculate:

a the observed wavelength of the sound received by the observer

b its observed frequency.

(Speed of sound in air = 330 m s^{-1}.)

THE ELECTROMAGNETIC SPECTRUM



Type of EM wave	Typical Wavelengths λ and its corresponding frequency, f.	Orders of magnitude for wavelength, λ / m
Gamma (γ) rays	λ = 1 pm = 10^{-12} m f = 3×10^{20} Hz	$\mathbf{10^{-12}}$
x-rays	λ = 100 pm = 10^{-10} m f = 3×10^{18} Hz	$\mathbf{10^{-10}}$
UV ultraviolet	λ = 10 nm = 10^{-8} m f = 3×10^{16} Hz	$\mathbf{10^{-8}}$
Visible light	λ_{red} = **700 nm** λ_{green} = 600 nm = 0.6 μm λ_{violet} = **400 nm** f_{green} = 5×10^{14} Hz	$\mathbf{10^{-6}}$
IR (infra-red)	λ = 100 μm = 10^{-4} m f = 3×10^{12} Hz	$\mathbf{10^{-4}}$
Radio wave (*includes microwaves, UHF, VHF etc*)	λ = 3 m f = 10^{8} Hz	$\mathbf{10^{0} \sim 10^{-2}}$

Properties of Electromagnetic Waves

1) EM waves have the same **speed, *c*, in vacuum** ($c \approx 3 \times 10^{8}$ m s^{-1}).
2) EM waves consist of oscillating **electric and magnetic fields** that are perpendicular to each other.
3) EM waves are all **transverse waves**.

POLARISATION

Electromagnetic Wave : Electric Field & Magnetic Field

- A light wave is an electromagnetic wave that travels through the vacuum of outer space.
- Electromagnetic wave is a transverse wave that has both an electric and a magnetic component.

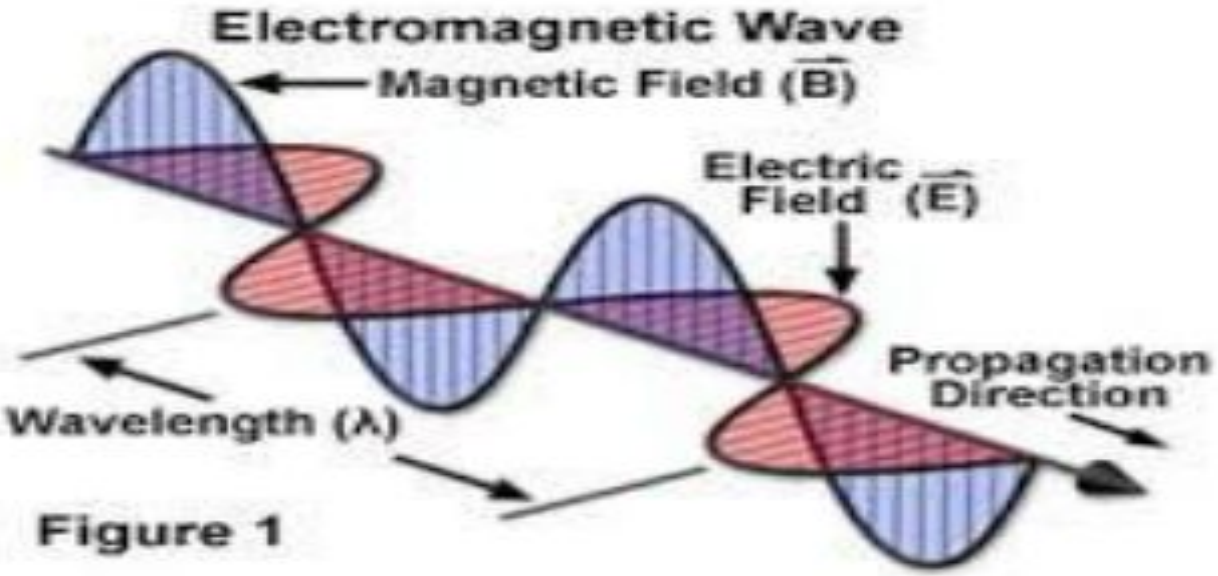
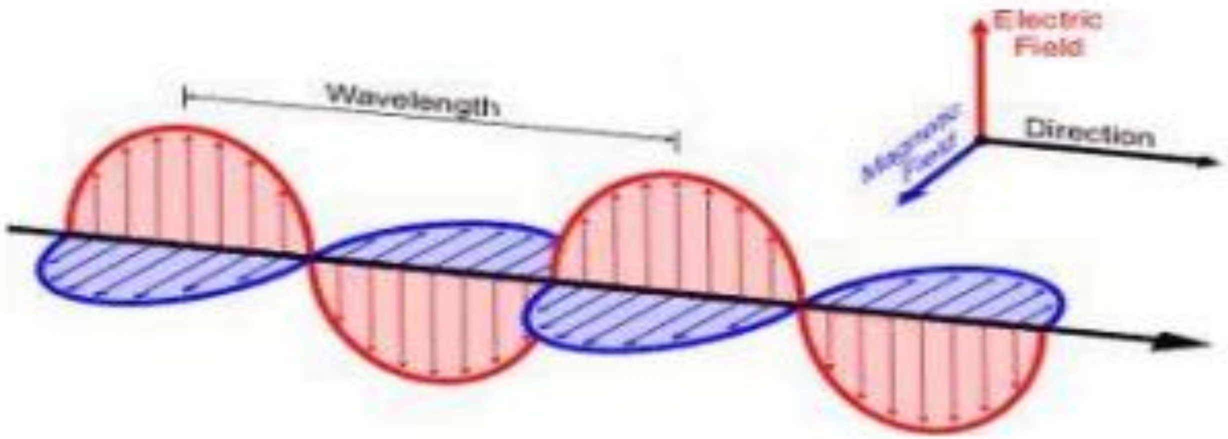


Figure 1

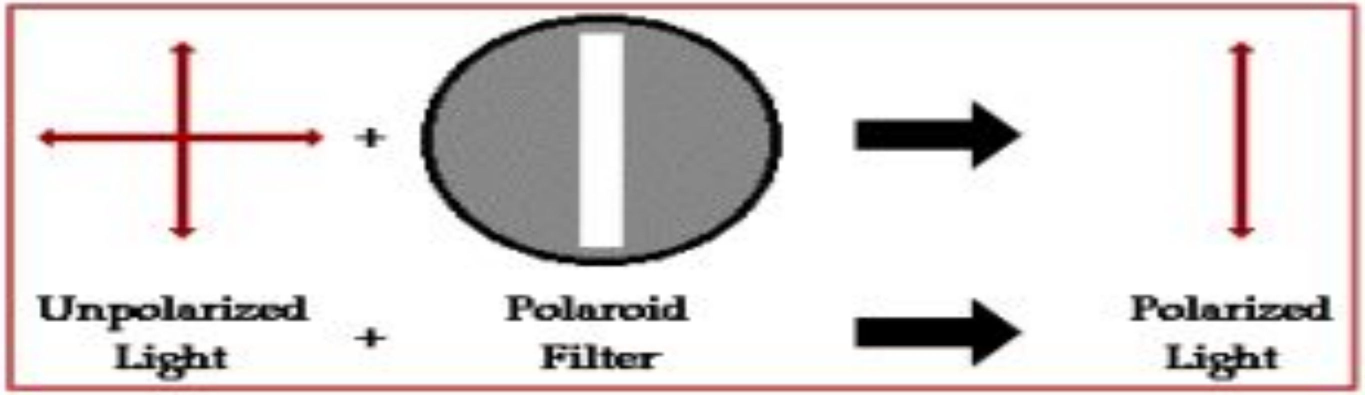
Electromagnetic Wave : Electric Field & Magnetic Field

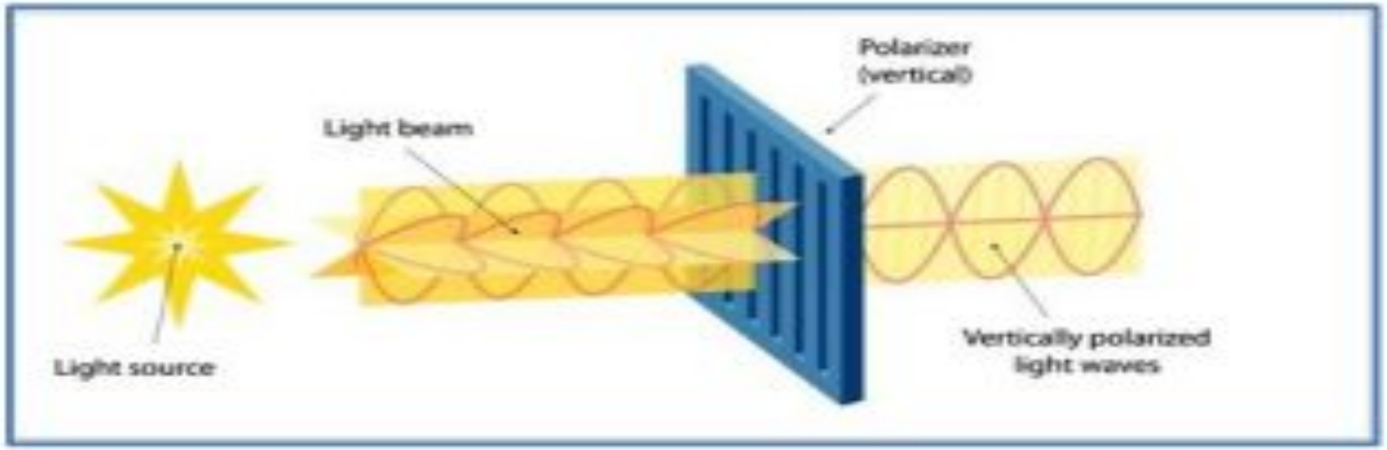
- A light wave that is vibrating in more than one plane is referred to as **unpolarized light**.
- Light emitted by the sun, by a lamp in the classroom or by a candle flame are examples of unpolarized light.
- Such light waves are created by electric charges and vibrate in a variety of directions.



Polarization is a phenomenon associated with transverse waves

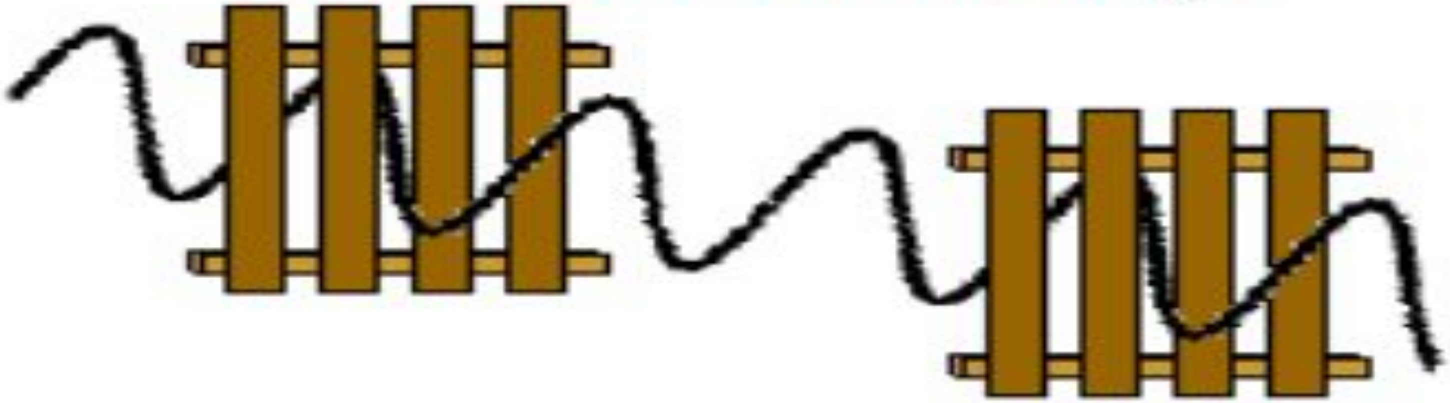
- Process by which a wave's oscillations are made to occur in ***one plane*** only.
- Associated with ***transverse waves*** only.



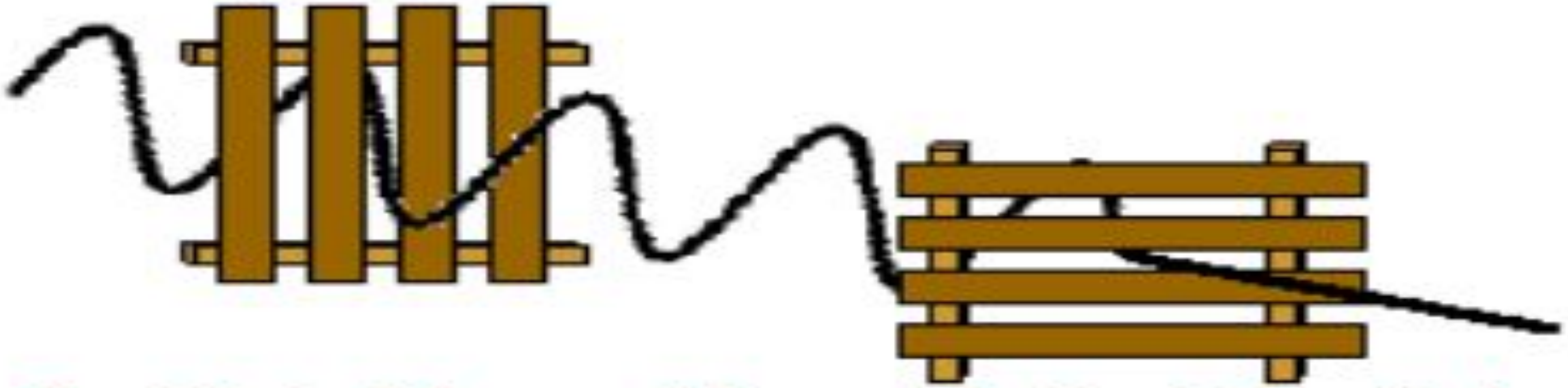


Note : Here, Polarization of light is analogous to that shown in the diagrams.

The Picket Fence Analogy



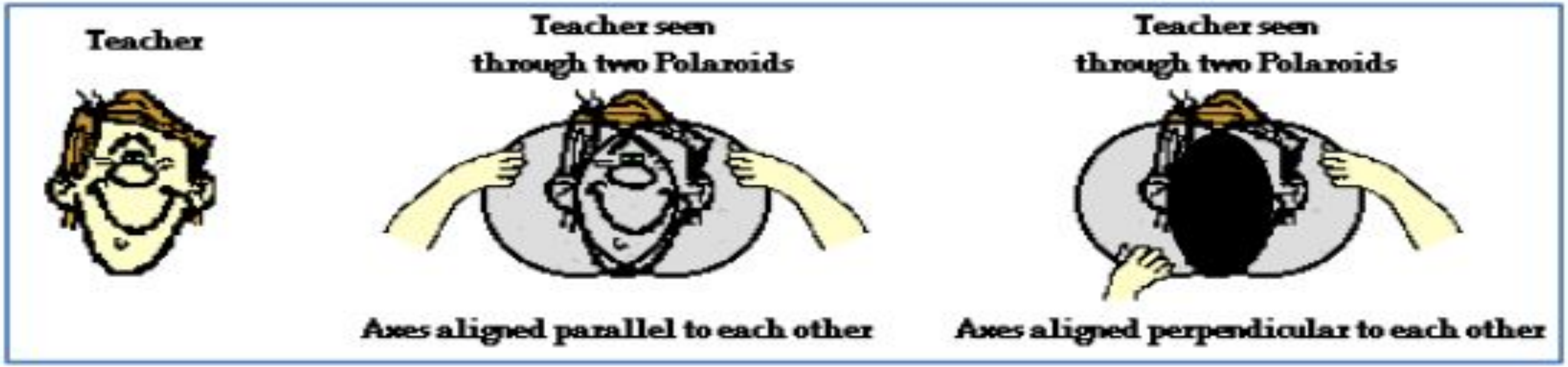
When the pickets of both fences are aligned in the vertical direction, a vertical vibration can make it through both fences.

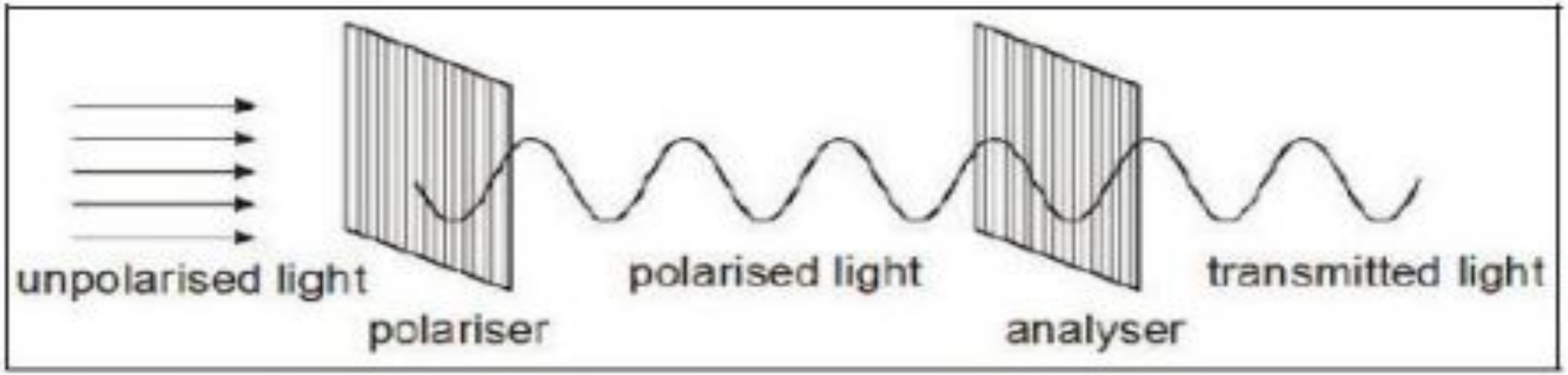


When the pickets of the second fence are horizontal, vertical vibrations which make it through the first fence will be blocked.

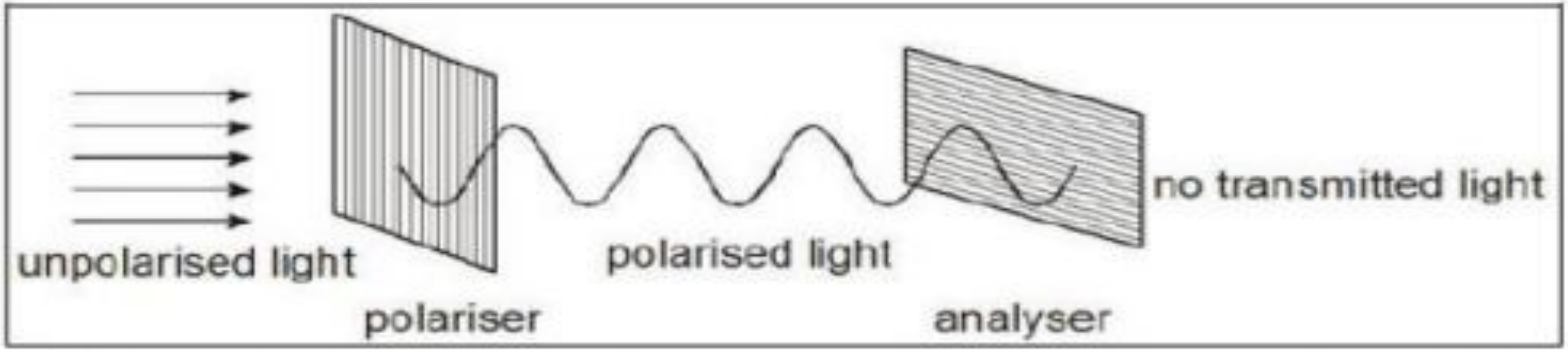
Polarization by Use of a Polaroid Filter

- The most common method of polarization involves the use of a **Polaroid filter**.
- Polaroid filters are made of a special material that is capable of blocking one of the two planes of vibration of an electromagnetic wave.
- In this sense, a Polaroid serves as a device that filters out one-half of the vibrations upon transmission of the light through the filter. When unpolarized light is transmitted through a Polaroid filter, it emerges with one-half the intensity and with vibrations in a single plane; it emerges as polarized light.





Light travelling *parallel* to polariser → the transmitted light has (almost) the same intensity as the polarised light (i.e. the amplitude of the light wave is identical).



When the 2nd polariser, or the Analyser is *perpendicular* to polariser, no transmitted light is observed. Hence, intensity is zero. (i.e. the amplitude of the light wave is zero).

A longitudinal waves cannot be Polarised. Why?

A longitudinal waves cannot be polarised because the particles in the wave oscillate parallel to the wave direction and cannot be restricted to vibrate in any plane.

Applications of Polarizations

1) Polaroid sunglasses

- The glare from reflecting surfaces can be diminished with the use of Polaroid sunglasses.
- The polarization axes of the lens are vertical, as most glare reflects from horizontal surfaces.

1. Suppose that light passes through two Polaroid filters whose polarization axes are parallel to each other. What would be the result?

The first filter will polarize the light, blocking one-half of its vibrations. The second filter will have no affect on the light. Being aligned parallel to the first filter, the second filter will let the same light waves through.

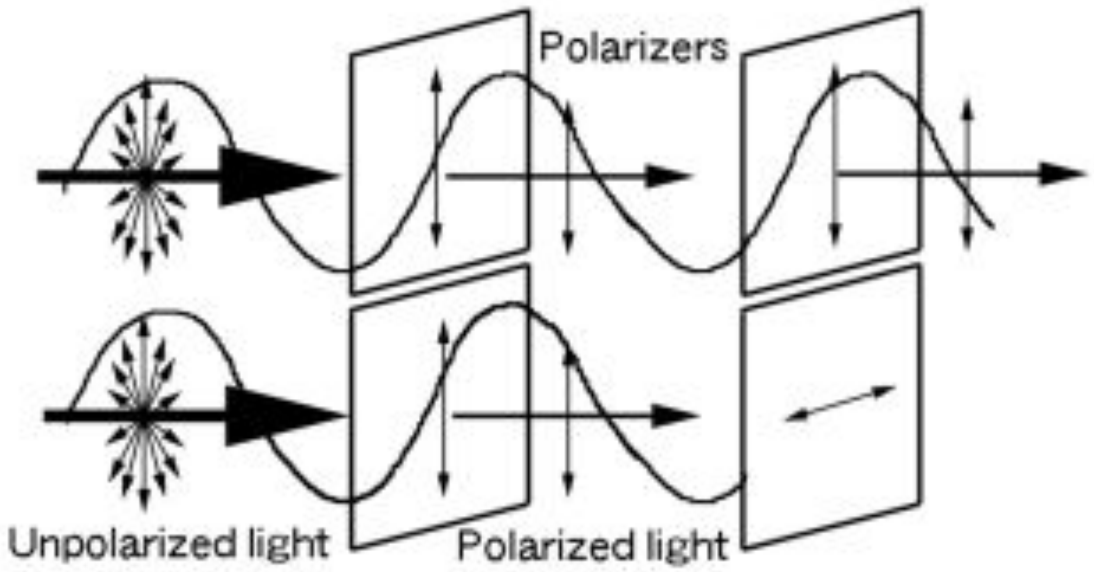


Figure 12.20: Polarising filters are used in photography – there is no glare and you can see the sharks and the boy snorkeling.

Malus's law

Figure 12.21 shows plane polarised light incident at a Polaroid. The transmission axis of this Polaroid is at an angle θ to the plane of the incident light. Now you already know that when $\theta = 0$, then the light will go through the Polaroid, and when $\theta = 90°$, there is no transmitted light. The intensity of the transmitted light depends on the angle θ.

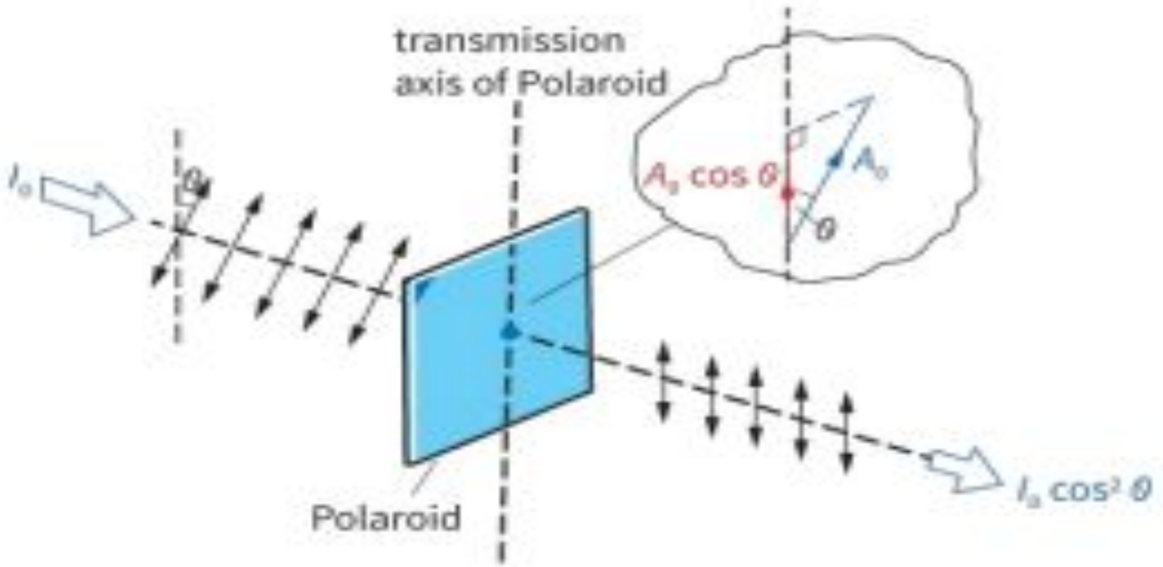


Figure 12.21: The amplitude, and hence the intensity of light, transmitted through the Polaroid depends on the angle θ.

Consider the incident plane polarised light of amplitude A_0. The component of the amplitude transmitted through the Polaroid along its transmission axis is $A_0 \cos \theta$. You know that the intensity of light is directly proportional to the amplitude squared. So, the intensity of light transmitted will be given by the expression:

$$I = I_0 \cos^2 \theta$$

where I_0 is the intensity of the incident and I is the transmitted intensity at an angle θ between the transmission axis of the Polaroid and the plane of the incident polarised wave.

The relationship is known as Malus's law.