**28 Understand and use the terms amplitude, frequency, period, speed and wavelength**

**Amplitude:** The amplitude of a wave is the maximum displacement from its equilibrium position. **Frequency:** The frequency is the number of oscillations per second. Period: The period is the time taken from one complete oscillation to take place. Wavelength: The wavelength is the length between two points in consecutive cycle that are in phase.

**29 Identify the different regions of the electromagnetic spectrum and describe some of their applications** Light is a small part of the electromagnetic spectrum, consisting only of the part to which our eyes are sensitive. All electromagnetic spectrum share some common properties:

* They are all transverse waves

* They all consist of an oscillating electric field and magnetic field

**Applications of electromagnetic waves** These are just some of the applications of different parts of the electromagnetic spectrum.

**Radio waves**: Broadcast communications for TV and radio are the most obvious use for radio waves. These are particularly easy to generate as any alternating current can produce them. Since these will not interfere with those of another frequency, many radio stations can broadcast in the same area. An upper layer in atmosphere, the ionosphere is electrically charged and will reflect and refract radio waves. This is useful for long-distance broadcasting as the waves won't get lost out of Earth. However, radio communication with satellites is not possible.

**Microwaves**: Microwaves has higher frequency and thus is not reflected by the ionosphere. Thus they are used for communications with satellites. They are used for handheld communication devices such as mobile phones.

**Infrared**: Infrared waves can travel through glass in a very similar way to visible light can use total internal reflection to be carried along optical fibres. They are used for wired communication along with visible light, to increase the number of available frequencies, simultaneously, maximizes the amount of data that can be transmitted. They are used by some alarm system, toasters/grills to cook food taking advantage of heat radiation by radio waves.

### Experiment: Wave machine or computer simulation of wave properties

### 30 Use the wave equation

The speed of the wave is given by the equation $v = f\lambda$,(f= frequency, $\lambda$=wavelength)

### 31 Recall that a sound wave is a longitudinal wave which can be described in terms of the displacement of molecules

Sound waves are longitudinal waves. They travel as the particles of air displaces from their equilibrium position and produce compression and rarefraction.

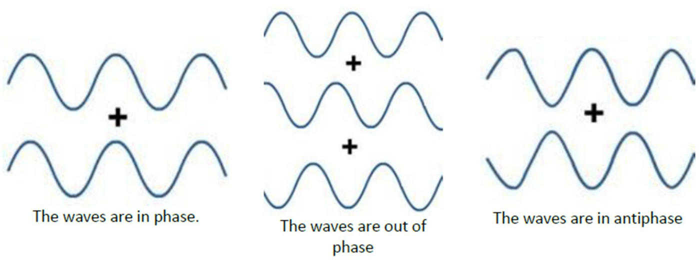
**Experiment: Demonstration using a loudspeaker Experiment: Demonstration using waves on a long spring**

**32 Use graphs to represent transverse and longitudinal waves, including standing (stationary) waves**

**33 Explain and use the concepts of wavefront, coherence, path difference, superposition and phase**

**Wavefront**: The line that joins the particles of the same phase (all the crests or all the troughs) is called wave fronts.

**Phase**:




If one wave appears with crest and trough in the same position as other, they are said to be **in phase**.

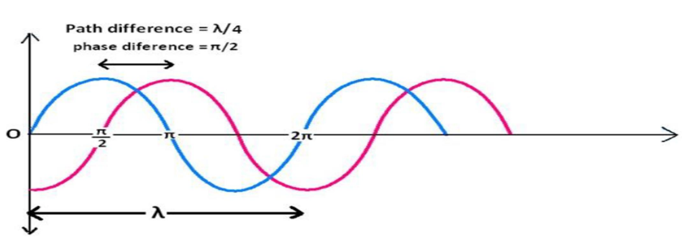
There is no phase difference in these waves. If the crests and troughs of the waves do not coincide with each other, they are said to be **out of phase**.

If the crest of one wave is the in the same degree as the other's trough, then they are completely out of phase. They are said to be **in antiphase**. Their path difference is λ/2.

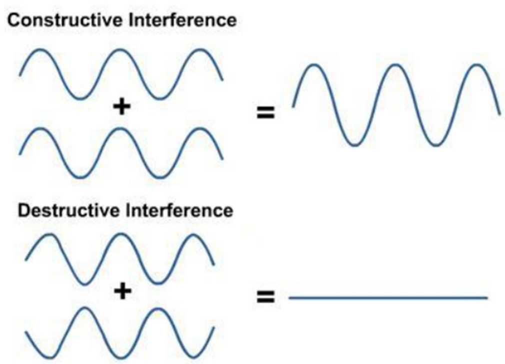
**Coherence**: The sources of waves are called coherent if they have the same wavelength, frequency and the two waves are exactly in phase or keep exactly the same phase difference all the time.

**Path difference**: The difference in distance of waves from each source to a particular point is called the path difference. It is measured as fractions of wavelength.

**Phase difference**: Phase difference is the same as path difference i.e. the difference in distance of two waves. But it is measured as degrees or radians.



**Superposition**: The principle of the superposition states that: Where two or more waves meet, the total displacement at any point is the sum of the displacements that each individual wave would cause at that point. If the two waves meet in phase, the superposition is constructive. Meaning that the amplitude will double the original wave. If two waves meet in antiphase, then the superposition is destructive. Meaning that the amplitude will be zero.




**Experiment: Demonstration with ripple tank**

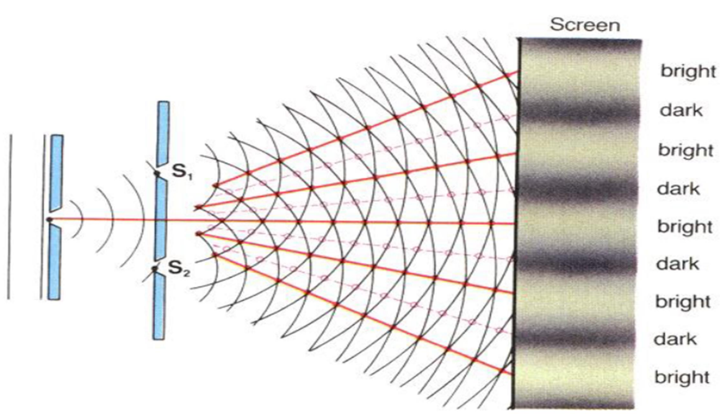
**34 Recognise and use the relationship between phase difference and path difference Interference**

Interference is the effect of the superposition of waves.

When two coherent waves interact with each other, the point in space where two crests or two troughs meet will be constructive interference. The point in space where a crest meets a trough will result in cancellation of each other called destructive interference.

In Young's slits experiment, light first passes through a single slit and diffracts. The light then passes through two slits. These slits act as a source of light waves.

The two wave diffract and overlap. When they overlap, there can be constructive or destructive interference. In the diagram below, all the constructive interference wavefronts are in red and all the destructive interference are in light pink. These form antinodal and nodal lines.



For constructive interference the path difference between the two waves must be a whole number of wavelengths or an even number of half wavelengths

$\frac{2\lambda}{2}, \frac{4\lambda}{2}, \frac{6\lambda}{2}$ etc.

For destructive interference to occur the path difference between the two waves must be an add half a wavelength

$\frac{\lambda}{2}, \frac{3\lambda}{2}, \frac{5\lambda}{2}$ etc.

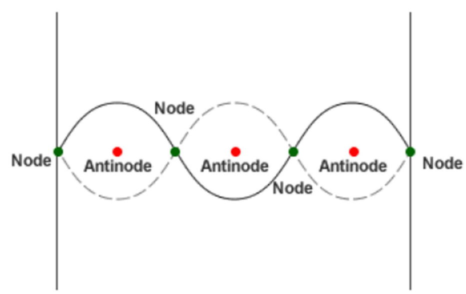
**35 Explain what is meant by a standing (stationary) wave, investigate how such a wave is formed, and identify nodes and antinodes**

Waves can be classified into two types: progressive and stationary.

Progressive waves are waves in which the positions of its peaks and troughs are moving. These waves are important because of their properties as energy carriers.

A standing wave remains in a constant position i.e. the peaks and troughs are not moving. Their importance lies in oscillation that occur in many systems, including stretched strings and in column of air and in structures such as bridges and vehicle components.

In these waves the point with maximum displacement (maxima) is known as antinodes and the point with no or minimum displacement (minima) is known as nodes.




Standing waves can occur when the medium is moving in the opposite direction to the wave or it can arise in a stationary medium as a result of interference between two waves travelling in opposite directions(the most obvious source – guitars etc.).

**Examples of a stationary wave: Guitar string**

An example of a stationary wave is the wave set up when the string of a guitar is plucked. When the string is plucked, it vibrates. Parts of the string vibrate to and fro, while other parts do not move. At its simplest, the string vibrates in a single loop, with a stationary point at either end and a point of maximum oscillation in the middle. The shape of the vibrating guitar is due to the formation of a stationary wave on it. At the instant the string is plucked a progressive transverse wave travels along it from left to right. This wave is reflected

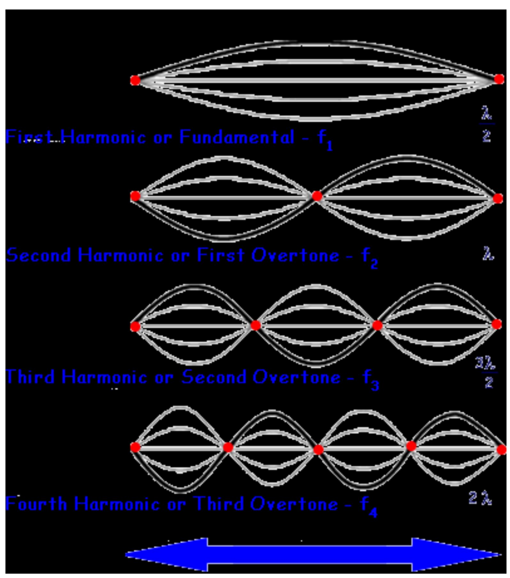
back from the end of the string, and the result is a stationary wave. The principle of superposition can be used to explain how two progressive waves travelling in opposite direction can produce stationary wave.

**Harmonics**

The standing wave pattern is only created within the medium at specific frequencies of vibration. These frequencies are known as harmonic frequencies, or merely harmonics. At any frequency other than a harmonic frequency, the interference of reflected and incident waves leads to a resulting disturbance of the medium that is irregular and non-repeating. For a string stretched between two rigid boundaries, it has a node on both the end. Given this restriction, it can be shown that the only waves that are possible on the string are those where:

$$\lambda = \frac{2l}{n}$$

This means that the node will occur on the string at a distance of 0, λ/2, λ, 3λ/2 from the end of it, and that neighbouring nodes are separated by a distance

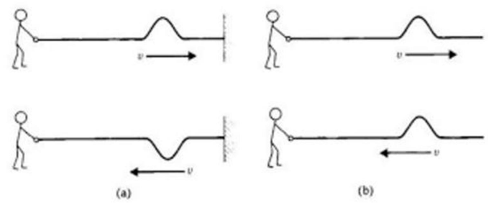



The fundamental frequency or first harmonic happens when the string vibrates with a wavelength twice the length of the string. The second and the rest can be found out by the equation discussed above.

**Reflection at the end of the string**

The formation of a stationary wave on a string relies on the reflection of a progressive wave at the ends of the string.

What happens to a wave moving through a medium at the end of that medium? It depends on whether the end is fixed or free. If the end is fixed, a hard reflection occurs and the wave change phase of 180o. If the end is free, reflection also occurs but there will be no phase change.




(a) Fixed boundary (b) Free boundary

**Finding the frequency for harmonics**

Equations:

1. $v = \sqrt{\frac{T}{\mu}}$, where T is the tension in the string and $\mu$ is the mass per unit length of the string.

2. $v = f\lambda$

3. $\lambda = \frac{2l}{n}$

Substituting all these equation, we get,

$$f = \frac{n}{2l} \times \sqrt{\frac{T}{\mu}}$$

**Worked example**
A piece of copper wire is fixed firmly at one end, and the other end is passed over a pulley and attached to a mass of 2 kg. The length of the wire between the fixed support and the pulley is 1.5m. Separate measurements show that the mass per unit length of the wire is 20 g $m^{-1}$. What is the fundamental frequency of the wire if it is set in free oscillation?

Ans: Since, they wanted fundamental frequency, n = 1
T = Weight of mass = 2 x 9.81 = 19.6
μ = 20/1000 = 0.02
l = 1.5

$$f = \frac{1}{2 \times 1.5} \times \sqrt{\frac{19.6}{0.02}} = \mathbf{10.4\ Hz}$$

**Experiment: Melde's experiment, sonometer**

**36 Recognise and use the expression for refractive index 1μ2 = sin i/sin r = v1/v2, determine refractive index for a material in the laboratory, and predict whether total internal reflection will occur at an interface using critical angle**

**Relation of refractive index, sine angle of incidence and sine of angle of refraction.**

This relationship is known as Snell's law.

$$^1\mu_2 = \frac{\sin i}{\sin r}$$

$^1\mu_2$ indicates the refractive index of wave moving from medium 1 to medium 2.

**Relation of refractive index and speed**

$$^1\mu_2 = \frac{\text{speed in medium 1}}{\text{speed in medium 2}} = \frac{v_1}{v_2}$$

$$^1\mu_2 = \frac{v_2}{v_1} = \frac{1}{1\mu 2}$$

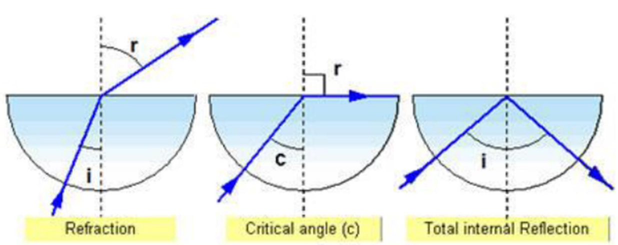
**Worked Example**

A ray of light enters a diamond. If it travels at c = $3 \times 10^8$ m/s in air, how fast does the light travel in diamond. (RI of diamond = 2.42)

- $^1\mu_2 = \frac{3\times10^8}{v_2}$
- $v_2 = 1.24 \times 10^8$ m/s

**Total internal reflection and critical angle**

When light falls on the surface of a lighter medium from denser medium at an angle of incidence greater than critical angle, then the light does not refracts. It rather reflects in the self-medium. This type of reflection is called total internal reflection.

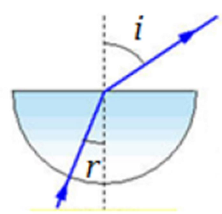



Condition of total internal reflection:

1. Light should fall in the surface of lighter medium from denser medium.
2. Angle of incidence must be greater than the critical angle.

## 37 Investigate and explain how to measure refractive index

**Experiment: Measure the refractive index of solids and liquids**



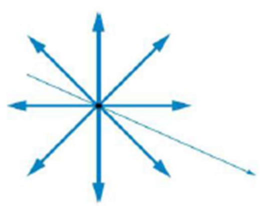

- Find i and corresponding r
- Plot sin r and sin i
- Gradient = $\frac{1}{1\mu2}$

## 38 Discuss situations that require the accurate determination of refractive index

Sometimes the refractive index of a material needs to be known very accurately. For example, the glass used to make spectacle lenses must have a precisely known refractive index if the lens grinder is to match the lens shape to the exact power needed for a person's eye prescription.

## 39 Investigate and explain what is meant by plane polarised light

• When the oscillations in a light take place in all planes at right angles to the direction of travel, it is said to be unpolarised light.

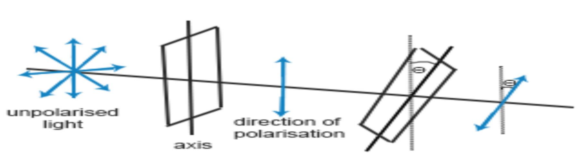


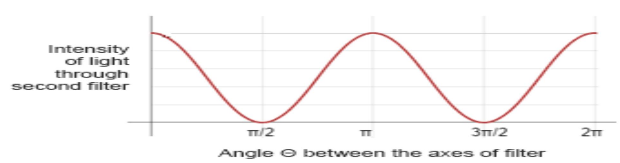
* When the oscillations in a light take place in one plane at right angles to the direction of travel, it is said to be polarised light.

The phenomenon of polarization is only showed by transverse waves.

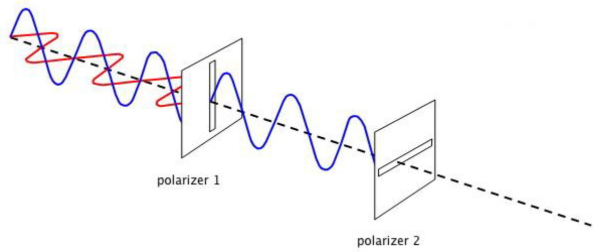
**Polarising filter**

If unpolarised light encounters a polarizing filter, some of it is absorbed and the emerging light is polarized. If polarized light encounters a polarizing filter, polarized light emerges, and its brightness and plane of polarization depend on the orientation of the filter.



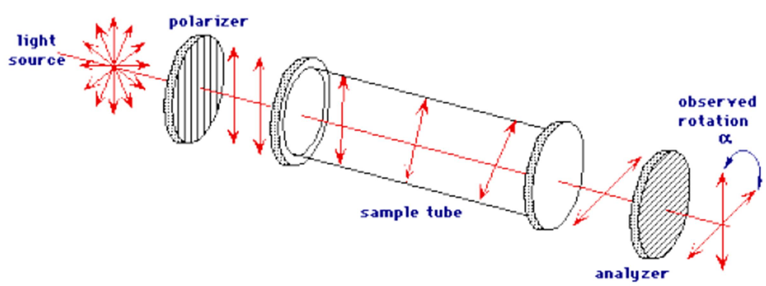
If two polarizing filters are arranged so that they are orientated at right angles to each other, then they will completely absorb unpolarised light. The filters are said to be crossed.




**Optical activity**

Optically active substances such as sugar solutions rotate the plane of polarization by an amount of proportion to their concentration and the depth of liquid through which the light travels. This can be used to measure the concentration of sugar solutions. The process is called polarimetry and is used in confectionery industry to manufacture sweets.

**Experiment: Models of structures to investigate stress concentrations**




Two polarizing filters and a 360$_o$ protractor can be used to measure the effect of the concentration of a sugar solution on the plane polarization of light, but simple polarimeters are widely available. Distilled water is put into the cell to check that the scale reading is zero when the filters are crossed and the light-emitting diode (LED) blacked out.

A number of sugar solutions of different concentration (20 – 100g in 100 ml of distilled water) are prepared. The cell is filled to a fixed level with the solution. The upper filter is rotated until the light source disappears. The angle of rotation is measured. The angle is found for all known concentrations and some unknown solutions, including those containing clear honey and syrup. A graph of the angle of rotation against the concentration is plotted and used to find the values for the unknown concentrations.

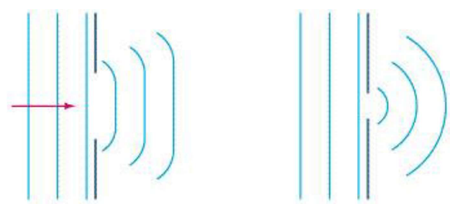
**40 Investigate and explain how to measure the rotation of the plane of polarization**

You need a polarising filter with a known plane of polarisation (usually marked on the filter). It should be mounted in a holder with an angle scale.

To measure the plane of polarisation (of a beam of light say) you place the filter in the beam and rotate the filter; when the amount of light transmitted is a maximum (e.g measured with a light meter) the plane of polarisation of the filter is the same as the plane of polarisation of the light. You just read-off the angle.

### 41 Investigate and recall that waves can be diffracted and that substantial diffraction occurs when the size of the gap or obstacle is similar to the wavelength of the wave

When a wave passes through a gap or around a barrier it may be deviated from its path. This deviation is called diffraction.
The amount of diffraction that occurs depends on the relationship between the size of the gap or the object and the wavelength of the wave. When the two are similar in size, diffraction occurs.



**Experiment: Demonstration using a ripple tank**

### 42 Explain how diffraction experiments provide evidence for the wave nature of electrons

A beam of electrons were directed at a crystal in an experiment. This produced a pattern like this:

The electron beam must have diffracted through the layers of atoms in the crystal. This proves that electrons can behave like waves. The wavelength of the electron must be similar to the length of the gap in layers of atoms.

### 43 Discuss how scientific ideas may change over time, for example, our ideas on the particle/wave nature of electrons

Just like most theories, electrons were initially thought to be particles. However, in 1924 de Broglie suggested it might have wave properties which was later confirmed by Clinton Davisson and George Thomson by the electron diffraction experiment.

### 44 Recall that, in general, waves are transmitted and reflected at an interface between media

**Partial reflection**

In most cases of reflection, not all the incident light is reflected. In general, at any boundary between media, some wave energy passes across the boundary – it is **transmitted** – whilst some of the energy is reflected. You may have noticed this when trying to look under a water surface which is reflecting a lot of light.

**Experiment: Demonstration using a laser 45 explain how different media affect the transmission/ reflection of waves travelling from one medium to another**

Density of materials affects the transmission and reflection of waves travelling from one medium to another. The greater the difference in density between the two materials, the stronger the reflection occurs. Some other boundary behavior are below: ⍰ the wavelength is always greatest in the least dense medium, ⍰ the frequency of a wave is not altered by crossing a boundary, ⍰ the reflected pulse becomes inverted when a wave in a less dense medium is heading towards a boundary with a more dense medium, ⍰ the amplitude of the incident pulse is always greater than the amplitude of the reflected pulse.

**46 Explore and explain how a pulse-echo technique can provide details of the position and/or speed of an object and describe applications that use this technique**

**Finding position**

Radar sends a pulse of radio waves which hits nearby object and reflects back to the detector. The time taken is measured, and we know the speed of radio waves i.e. 3 x 10⁸ m/s.

**Worked Example**

A radar sends a pulse of radio waves, which returns 0.20 ms later. Calculate the distance to the reflecting object. The speed of radio waves is $3 \times 10^8$ m/s.

---

$distance = speed \times time$ = $3 \times 10^8 \times 0.20$ ms = 60 000 m

So the distance to the reflecting object is 30 km. (Distance should be halved as the waves have travelled there and back)

**Finding speed**

To work out the speed of a moving vehicle a radar gun will send out an initial pulse and measure the distance of the vehicle. It will send out a second pulse several seconds later and measure the distance again. Then calculate the distance difference and divide it by total time. You will get the speed of the object.

**Worked example**

A radar gun sends out an impulse and finds that a car is 50m away. A second impulse is sent out 2s later and the car is now 100m away. Find the speed in which the car is moving.

---

In 2s, the car has travelled = 100 – 50 = 50m

So, $speed = \frac{distance}{time} = \frac{50}{2} = 25\ m/s$

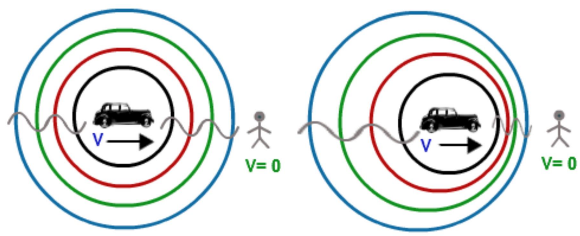
**Application**

This technique is used by bats, dolphins to move. Engineers have developed similar pulse-echo ranging and imaging systems in a very wide range of technological applications, from sonar on ships and submarines to air traffic control radar, medical imaging and the measurement of distance to asteroids and to the Moon.

**47 Explain qualitatively how the movement of a source of sound or light relative to an observer/detector gives rise to a shift in frequency (Doppler effect) and explore applications that use this effect**

**Doppler effect**

Imagine that you are standing on a pavement and a police car is approaching you. As the police car gets closer the pitch of its siren gets higher. As it moves away the pitch gets lower.

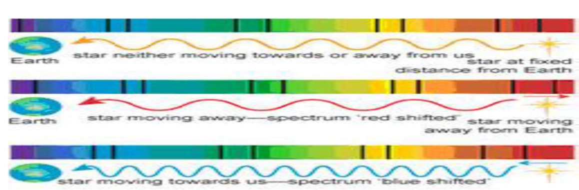



Source at rest Source in motion

As the siren approaches you the sound waves get bunched up and gets closer together. In other words they are of higher frequency. As the siren moves away from you the sound waves spread further apart and are of lower frequency. This effect is called **Doppler effect**. It is defined as the change in frequency of a wave for an observer moving relative to its source. The shift in frequency is proportional to the relative speed of the motion.

**Red shift**

Another example of this effect can be seen we observe the distant galaxies. If a light emitting object is moving towards a stationary observer, the light waves will bunch up and have a shorter wavelength. In other words it will be shifted to the blue end of the spectrum (**blue-shift**). If a light emitting object is moving away from a stationary observer, the light waves will spread out and have a longer wavelength. In other words it will be shifted to the red end of the spectrum (**red-shift**). So what we observe that the spectra of the distant galaxies are shifted to the red end of the spectrum. This gives the evidence that the universe is expanding.



**Doppler radar**

Weather monitoring and air traffic control both use radar to find the position and movement of storms and planes, respectively. In both cases, the system uses the basic pulse-echo idea. However, by also measuring any change in the wavelength – the Doppler shift – of the echo compared with the original pulse, the system can calculate the speed of the object reflecting the waves.

**Worked example**

A radar trap emits a pulse of radio waves of frequency 24 GHz. A car moving at 30 mph causes a change of frequency of 1070Hz. The reflected pulse from a car in a 30 mph zone has a wavelength of 1.249 999 x $10^{-2}$m. Was the car moving towards or away from the radar trap, and was it speeding?

---

Calculate the received frequency using

$$f = \frac{v}{\lambda} = \frac{3 \times 10^{8}\ ms^{-1}}{1.249\,999 \times 10^{-2}\ m} = 2.400\,0002 \times 10^{10}\ Hz = 24.000\,002\ GHz$$

As the frequency has increased from 24 GHz, the car was moving towards the source.

The change in frequency is 2000 Hz. This is larger than the change at 30 mph, so this car was speeding at approximately double the speed limit as the change is frequency is proportional to the relative speed of the motion.

**Experiment: Demonstration using a ripple tank or computer simulation**

**48 Explain how the amount of detail in a scan may be limited by the wavelength of the radiation or by the duration of pulses**

**Ultrasound**

Sounds waves with frequencies from 20 – 20 000 Hz can be heard by human beings. This is our audible frequency range. Sounds with a frequency above 20 kHz are known as ultrasound. These waves are used in variety of applications, in particular medical scans. This is most familiar to people as scans on unborn babies as it is less harmful than x-rays.

**How ultrasound image is created?**

Ultrasound imaging relies on the fact that at any boundary between media, there will be a partial reflection of sound waves. The difference in density at any boundary where a reflection occurs dictates how strong the reflection is. This type of tissue boundary involved in any reflection can be determined as this affects the proportion of energy reflected. The ultrasound transmitting device also acts as the detector for reflections, so it can accurately time how long the echo has taken to return, along with how much energy was reflected. With knowledge of the wave speed, a computer can calculate the depth within the body that each reflection occurs and build up an image showing features in different depths.

**How wavelength affects detail?**

The shorter the wavelength of the wave, the less diffraction they undergo. Therefore the shorter the wavelength of sound, the less the waves spread out when they travel. This means that shorter wavelengths can map tissues of different interfaces more precisely producing a clearer image. Ultrasound also uses short pulses (usually lasting a few microseconds). This prevents reflections from nearby interfaces from reaching the transducer before the pulse has finished. The gap between each pulse must be quite long (usually at least 1 millisecond). This is to make sure that all the reflected waves from one pulse return back to the transducer before the next pulse is emitted.

**49 Discuss the social and ethical issues that need to be considered, e.g. when developing and trialing new medical techniques on patients or when funding a space mission** Remember the acronym

**SEES**.

**Safety**

Will it cause more harm than good? e.g. an X-ray could solve a medical problem, but are known to damage cells. Long exposures can cause cancer.

**Ethical**

Is it morally right? e.g. ultrasound scans can reveal the gender of a foetus. However this may lead to unnecessary termination.

**Expense**

Do benefits outweigh the cost? e.g. MRI scanner can produce a much clearer image than ultrasound and are safer than X-rays but are more expensive.

**Social**

Will it benefit society or adversely affect people? e.g. Doctors can scan foetuses for birth problems such as abnormal growth which they could put right. Alternatively this could lead to termination.