Key Stage 5 – Wave machine

Student worksheet

Superposition

When waves meet, the resultant effects are the same as the **sum** of all of the effects that the waves would have had individually.

If waves with different frequencies are combined then sometimes the peaks (and troughs) of both waves will coincide and the resultant combined wave at that point will have a bigger amplitude.

Describe the effect of an increased amplitude on a

- Sound Wave
- Water Wave
- Light Wave

If the waves are such that the trough of one wave coincides with the peak of the other, the waves will tend to cancel each other out resulting in a reduced overall amplitude.

The combination of different waves is called **superposition**.

Interference

Interference is a form of superposition where the waves are the same frequency and have the same or very similar amplitudes.

Consider two waves with the same frequency and amplitude. If the waves are exactly in step with each other, they are said to **constructively** interfere producing a wave of the same frequency but twice the amplitude i.e., producing a louder sound, a brighter light, etc. If they are exactly out of step with each other they **destructively** interfere and the waves cancel each other out i.e., producing silence, darkness, etc.

See figure 1.

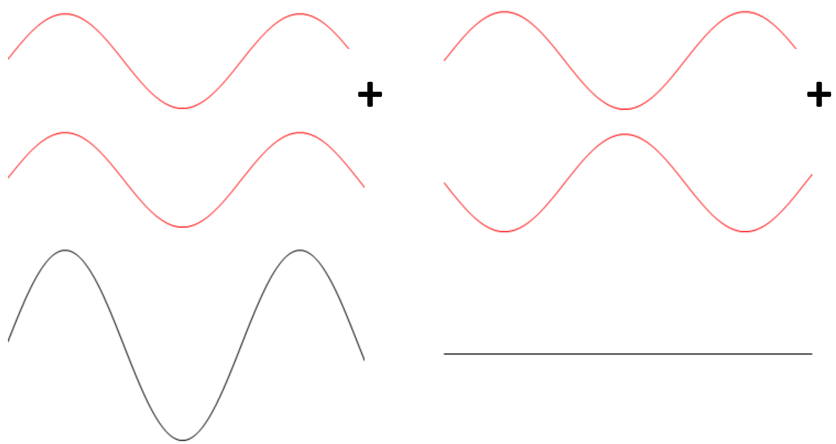

Figure 1 Constructive and Destructive interference

Coherence

Waves capable of interference are said to be **coherent.** This means they must have the same frequency and the phase difference between the two must remain constant. In practice, this is achieved by using light from the same point source or laser which is then split in some way and recombined.

Uses of Interference – Coatings on lenses

In order to reduce the amount of light which is reflected from them, camera lenses are sometimes coated with a thin layer of Magnesium Fluoride (MgF_2). See picture below.

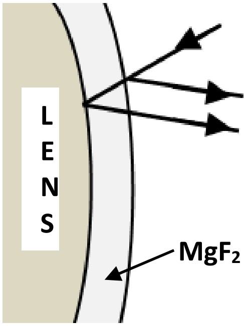

Figure 2 Lens and coating

When light of all colours hits the camera lens, some of the light is reflected from the surface of the coating and some from the surface of the lens. The thickness of the coat is arranged so that the path of the light reflecting from the lens is equivalent to $\lambda/2$ further than the light reflecting off the coating - where λ is the wavelength for light in the middle of the visible spectrum.

The light reflecting from the lens has travelled the equivalent of $\lambda/2$ further than the light reflected off the coating. This means that light of wavelength λ experiences destructive interference, i.e., very little green is reflected and therefore most of it is transmitted through the lens. The wavelengths closest to λ are reflected the least and those at the ends of the spectrum, the reds and blues, are reflected the most. As a result a lens with a coating like this will appear purple. This is often referred to as **blooming**.

Uses of Interference - Interferometers

Interferometers are instruments used by scientists for a variety of purposes including measuring very small distances.

A simplified diagram of an interferometer is shown in figure 2.

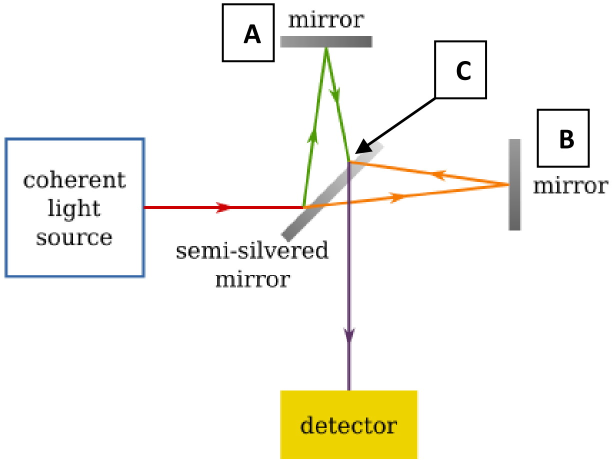

Figure 3 Michelson Interferometer

Light from a coherent light source strikes a half-silvered (semi-silvered) mirror which causes it to split into two light beams.

One of the beams hits mirror A and is reflected back to the half-silvered mirror, one hits mirror B and is also reflected then both light beams recombine at point C on the half-silvered mirror. These two paths are at right angles to each other and are known as the **arms** of the interferometer.

When the beams recombine they interfere with each other creating an interference pattern. The dark parts of the pattern correspond to where the beams have destructively interfered with each other and the bright ones where they have constructively interfered.

If the path of one of the beams is then altered in some way e.g., being increased in length by moving the mirror B further away from the half silvered mirror, then the interference pattern would change. So if a point on the detector was previously dark (where the waves hitting it were exactly out of phase), moving the mirror such that the distance to that point changed by half a wavelength would put the waves back in phase with each other and that point would become bright.

So by looking at the change in the interference patterns scientists can measure very small changes in the path taken by the light in one of the arms of the interferometer.

Explain why introducing a sample with a different refractive index (e.g., a thin section of glass) would change the interference pattern.

Gravity Waves

Einstein predicted that when masses accelerate they cause gravity waves which distort space-time itself. However, until recently gravity waves had not been detected as usually the distortions are extremely small.

However scientists believed a gravity wave caused by a violent and energetic process, such as two black holes colliding would create distortions just big enough to be measured.

The Advanced Laser Interferometer Gravitational-Wave observatory (Advanced LIGO) was a project to create an interferometer sensitive and accurate enough to detect the distortions. As part of the project two interferometers were built in the USA. A similar project, VIRGO, was built in Italy.

When gravity waves from space pass through the Earth they cause the whole of the Earth to be very slightly stretched in one direction and squashed in the other.

The interferometer is set up so that the lengths of its two arms are **perfectly** out of phase and no light is detected at the detector. If a gravity wave passes through the interferometer one of the arms will be stretched slightly and the other squashed making the distance travelled by the light very slightly different in the two arms. Thus the relative phase would shift and light would be detected in the detector (where it was no longer perfectly out of phase).

In practice, this is an incredibly difficult engineering challenge which requires the arms of the interferometer to be several kilometres long but still aligned perfectly. In addition, vibrations caused by traffic, etc., have to be filtered out so that the signal from the gravitational waves can be separated from other sources of noise.

The results of the two LIGO detectors in the USA and the VIRGO detector in Italy are also compared to check they are consistent with each other.

In 2016 gravity waves were detected for the first time proving Einstein's predictions from a hundred years previously were correct. In 2017 the Nobel Prize was awarded for this achievement.