Physics

Big idea (age 11-14)
PSL: Sound, light and waves

What's the big idea?

The idea of waves is useful because it is the key to explaining how energy can be transferred from one object to another object by radiation, even when the objects are not touching. Waves carry information that can be detected by humans or manufactured detectors. Understanding waves helps us to communicate, explore the universe, and transfer energy to where we want it.

Topics

The big idea is developed through a series of key concepts at age 11-14, which have been organised into teaching topics as follows:

Topic PSL1
Sound and light

Key concepts:

- 1.1 Production and transmission of sound
- 1.2 Characteristics of light

Topic PSL2
How we see

Key concepts:

- 2.1 The 'passive eye' model of vision
- 2.2 Seeing in colour

Topic PSL3
Making images

Key concepts:

- 3.1 The ray model of light to explain images
- 3.2 Refraction and lenses

Topic PSL4
Waves

Key concepts:

- 4.1 Waves on water and ropes
- 4.2 A wave model of sound

The numbering gives some guidance about teaching order based on research into effective sequencing of key concepts. However, the teaching order can be tailored for different classes as appropriate.

Guidance notes

Ideas about the nature of light are often taken for granted at this stage of school science. This is not helpful as it is common for students to have persisting misunderstandings that need to be addressed in order for them to develop a clear understanding of how we see things, and also of the refraction, diffraction and dispersion of light they will encounter in their future studies. For this reason the ideas covered in key concept: *1.2 Characteristics of light* need careful consideration.

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Learning progression

The science story associated with the big idea develops from age 5 to age 16, and could be summarised as follows:

Science story at age 5-11

Sources of light

Luminous objects, such as lamps, flames, and the Sun, are sources of light. Light travels out in all directions from a source. It illuminates objects that it hits, enabling us to see them. Darkness is the absence of light.

Sound

Sounds are caused by something vibrating. Sources of sound include musical instruments, loudspeakers, and the human voice. Sound travels in straight lines from its source, getting fainter as it goes.

Sounds can vary in loudness and in pitch. Loudness is linked to the strength of the vibrations causing the sound. Pitch is linked to features of the source (such as the length, thickness and tightness of strings).

Shadows

Light travels in straight lines from its source. Light can pass through transparent objects and materials, but is stopped by opaque ones. When an object stops some of the light from a source, a shadow is formed. The shadow is the region which light from the source cannot reach.

A light ray is an imaginary line that shows the direction in which light is travelling. By drawing rays from a source, we can explain and predict the position, shape and size of the shadow caused by an opaque object placed in front of it.

Science story at age 11-14

A general model of radiation

Some objects can affect others at a distance by emitting radiation which travels from one object (the source) to another (the receiver), through the material or the space (the medium) between them. Light and sound are examples of radiation.

Radiation travels out from a source in straight lines in all directions. When it strikes another object, it may go straight through (transmission), bounce off (scattering or reflection), or be stopped (absorption) – or a combination of these. When radiation is blocked by an opaque object, this causes a shadow region. The effects of radiation get steadily less the further it goes, because it is spread over an ever-increasing area, and because it may be gradually absorbed by the medium it is travelling through. When radiation is absorbed by an object, it has an effect on the object; this might be a chemical effect, an electrical effect or a heating effect.

Some characteristics of light and sound

Sound travels at a high speed. The speed of light, however, is very much higher, though it does travel at a finite speed.

Sound requires a medium (gas, liquid or solid) to travel through. It travels faster in liquids and solids than in gases. Light (unlike sound) can travel through a vacuum.

The pitch of a sound depends on the frequency of vibration of the source (the number of vibrations per second). The loudness depends on the amplitude of the vibrations of the source (the maximum distance the source moves from its rest position when vibrating).

When sound hits a surface, some of it is usually reflected. This is the cause of echoes. Similarly, when light hits a surface, some of it is usually reflected diffusely (scattered) in all directions. For surfaces which are very smooth (such as a mirror, shiny metal, or a water surface), an incident light beam of light is reflected as a beam, at the same angle as it hits the surface. This is known as specular reflection.

The 'passive eye' model of vision

We see an object when light from it enters our eye. We see a non-luminous object when light from a source strikes the object, and some of the scattered light from it enters our eye. A beam of light travelling between two objects is not directly visible. We only see the path of the beam when some of the light is scattered into our eye by particles (e.g. of dust, or water droplets) in its path.

White light is a mixture of lights of different colours

When a beam of white light is passed through a prism, the emerging light beam has the colours of the spectrum (ROYGBV). A second prism can recombine this coloured light beam into a beam of white light. This suggests that the colours are in the light rather than being caused by the material of the prism. We can think of white light as a mixture of lights of all the colours of the spectrum.

A coloured filter works by allowing light of one or more spectrum colours through (transmission) and absorbing light of the other colours.

An object appears white if it scatters all the colours of light that fall on it, and black if it scatters none (and absorbs all). It appears coloured if it scatters light of some colours and absorbs light of other colours. Its observed colour is that of the light it scatters.

The 'three primary colours' model of human colour vision

The human eye has three types of colour sensor, which detect red, green and blue light respectively. These are called the primary colours. If beams of red, green and blue light are shone on a white screen, the area on which all three beams fall appears white. Areas on which two primary colours fall show the three secondary colours: yellow (R+G), cyan (turquoise) (G+B), and magenta (R+B). Any colour can be produced by combining the three primary colours.

This model can be used to explain and predict the effect of filters, and the appearance of coloured objects when illuminated by lights of different colours. It can also explain the effects of mixing pigments (paints) of different colours.

The ray model of light to explain images

A light ray is an imaginary line that shows the direction in which light is travelling.

By drawing light rays, we can explain how an image is produced by a pinhole camera. Light from any given point on the object can only pass through the pinhole in one direction, and must all come to the same point on the screen. This results in a sharp, inverted (top to bottom and side to side) image of the object appearing on the pinhole camera screen.

When an object is placed in front of a plane mirror, we see a reflection of the object which appears to be behind the mirror. By drawing any two light rays that go from the same point on the object to the mirror, and are then reflected towards the eye, the position of the reflection of this point on the object can be located. By doing this with several points on the object, we can locate the position of the whole reflection. It is the same distance behind the mirror as the object is in front.

Refraction

When a light beam passes from one transparent medium into another, at an angle to the boundary between the media, its direction changes. This is called refraction.

When we look at an object through a transparent medium, its image is not in the same place as the object, because of refraction of light at the boundary between the medium and air. For example, the image of an object under water is closer to the surface than the object really is. This can be explained by drawing two light rays from a point on the object that are refracted towards the eye, and identifying the point from which these appear to have come.

A convex lens refracts parallel light beams so that they meet at a point, called the focus. The thicker the lens, the closer the focus is to the centre of the lens.

A convex lens can form an image of an object. Many rays go from each point on the object to the lens, and all are brought together at a single point on the image.

The human eye contains a convex lens. The cornea and the fluid behind it is also convex and acts as a lens. Together they form an image of objects in front of the eye on the retina, at the back of the eyeball.

Mechanical waves and a wave model of sound

Ripples on water surfaces and waves on ropes are described as transverse waves. As transverse waves travel across the surface of water or along a rope, water particles or bits of rope vibrate at right angles to the direction the wave travels in. As a wave travels this can be seen by observing a cork bobbing up and down on the surface of water, or a mark on a piece of rope moving from side to side.

Moving water particles (or short sections of rope) cause adjacent particles to move in a similar way, which is the mechanism by which a wave transfers energy as it moves forward.

Sound waves in air are described as longitudinal waves. As a sound wave passes through air, the particles vibrate backwards and forwards along the direction in which the wave travels. Placing a candle flame in front of a loudspeaker allows these vibrations to be seen.

The number of pulses produced each second (and hence the number passing any given point as the wave passes) is the frequency of sound. The higher the frequency of a wave, the more quickly energy is transferred by the wave. Energy also transfers more quickly if each ripple or vibration is larger (has a bigger amplitude).

Neither frequency nor amplitude change the speed of a wave. Speed of a wave depends only on the medium through which the wave is travelling.

Science story at age 14-16

Waves in air, fluids and solids

All waves can be described in terms of their amplitude, wavelength, frequency and period. The amplitude of a wave is equal to the maximum size of the disturbance it makes. Wavelength (λ), measured in metre (m), is the distance from one wave crest (or wave trough) and the next. Frequency (f), measured in Hertz (Hz), is the number of waves each second. The velocity of a wave can be measured indirectly:

- Velocity of a wave = wavelength x frequency
- Velocity of a wave = distance travelled / time

A wave model of light

Light and sound both behave in ways that are similar to mechanical waves (such as water waves, or waves on a spring): they are reflected by surfaces, refracted at boundaries between media, and diffracted at edges. And light and sound from two identical sources interfere: they add to produce a larger disturbance at some places (or times) and cancel each other out at other places (or times).

In contrast to mechanical waves and sound, light can travel through a vacuum.

The frequency of a light wave determines the colour of the light.

Frequency range of the spectrum

An electromagnetic wave is made of vibrating electric and magnetic fields, which can travel through a vacuum. Light is one example of an electromagnetic wave that we can detect with our eyes. In space all electromagnetic waves have the same velocity, and they all transfer energy from source to absorber

The main groupings of the electromagnetic spectrum are: radio, microwave, infra-red, visible (red to violet), ultra-violet, X-rays and gamma-rays. Radio waves have the longest wavelength and lowest frequency, and gamma-rays the shortest wavelength and highest frequency.

Each grouping has a set of distinct properties that allow it to be detected and used in a particular way. The higher the frequency of an electromagnetic wave, the more energy it has and the more dangerous it can be to humans.

Light can refract (change direction) as it enters or leaves a transparent material if it travels at a different velocity than in the air.

Interactions of electromagnetic radiation with matter and their applications

Different substances may absorb, transmit, refract, or reflect electromagnetic waves in ways that vary with wavelength. Radio waves can be produced by oscillations in electrical circuits and can themselves induce oscillations in electrical circuits. Because they can be transmitted and received, they can be used for communication.

Micro-waves can also be used for communication and also for heating foods that contain water. Infra-red is used for heating and infra-red detectors help observe objects that are warmer or cooler than their surroundings. Ultra-violet can be used to make fluorescent materials glow so that security features on banknotes and credit cards can be seen. X-rays and gamma-rays can be used to observe the inner-workings of a human body. Ultra-violet waves, X-rays and gamma-rays can each have hazardous effects, notably on human bodily tissues.