ELECTROMAGNETIC WAVES

Electromagnetic waves are transverse waves* made up of continually changing electric and magnetic fields. Like mechanical waves, electromagnetic waves can travel through most solids, liquids and gases. They can also travel through a **vacuum** – an empty space where there are no particles of air or any other matter. All electromagnetic waves are invisible, except for those that make up light.

ELECTROMAGNETIC SPECTRUM

The complete range of electromagnetic waves, arranged in order of their wavelength* and frequency*, is known as the **electromagnetic spectrum**. At one end are waves with a short wavelength and high frequency, and at the other are waves with a long wavelength and low frequency. They all travel at the same speed – approximately 300,000 kilometers per second. This is known as the **speed of light**.

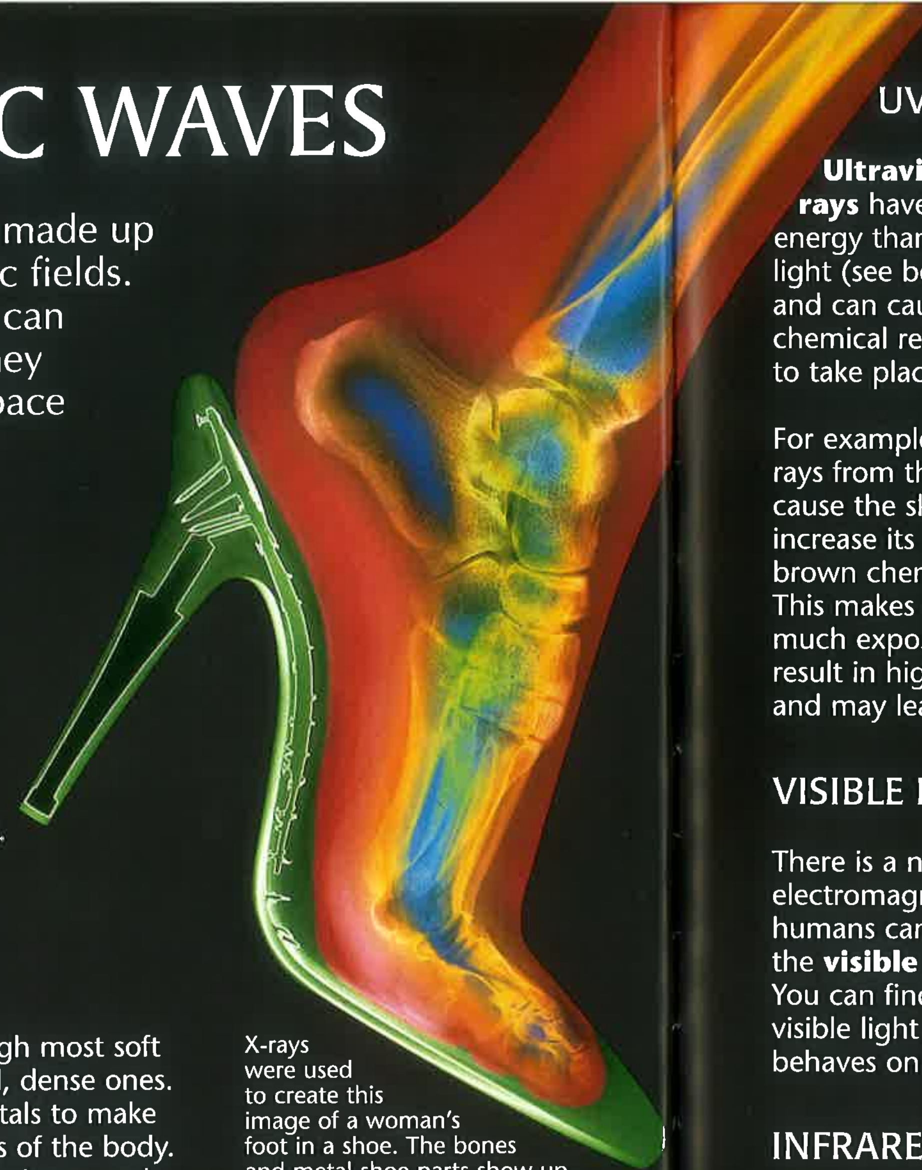
GAMMA RAYS

Gamma rays are short, high-frequency waves. They can kill living cells and are used to sterilize medical equipment by destroying any germs on them.

Gamma rays are used to keep these forceps free of germs.

X-RAYS

X-rays can travel through most soft substances but not hard, dense ones. X-rays are used in hospitals to make shadow pictures of parts of the body. They travel through soft tissue, such as skin and muscle, but not through hard bone. X-rays are also used for security at airports to check what may be hidden in people's luggage.



X-rays were used to create this image of a woman's foot in a shoe. The bones and metal shoe parts show up most clearly because the X-rays could not pass through them.

* Frequency, Transverse waves, Wavelength, 9.

UV RAYS

Ultraviolet (UV) rays have more energy than visible light (see below) and can cause chemical reactions to take place.

Sunscreen protects skin by blocking out harmful UV rays.

For example, UV rays from the Sun cause the skin to increase its production of a brown chemical called **melanin**. This makes the skin tanned. Too much exposure to UV rays can result in high levels of melanin, and may lead to skin cancer.

VISIBLE LIGHT

There is a narrow section of the electromagnetic spectrum that humans can see. This is called the **visible light spectrum**. You can find out more about visible light and the way it behaves on pages 20-23.

INFRARED RAYS

Infrared rays are given out by anything hot. For example, heat from the Sun travels to the Earth as infrared rays.

RADIO WAVES

Radio waves are those with the longest wavelength and lowest frequency. You can read more about them on page 32.

Microwaves are radio waves with a relatively short wavelength. They are easy to control and direct, and have many different uses.

In an ordinary oven, heat is passed from molecules at the edge of the food to ones in the middle. Microwave ovens work by making all the molecules in a food substance vibrate at the same time. This heats and cooks the food more quickly.

Microwave oven (cut away)

RADAR

Radar (which stands for **ra**dio **d**etection **a**nd **r**anging) uses microwaves to find the position of distant objects, such as ships and aircraft. A transmitter sends out a beam of microwaves that is reflected off a solid object and picked up again by a receiver. This information is transformed into a screen image that shows the distance and direction of the object.

Radio telescope dishes like this one can pick up microwaves that travel from distant stars and planets. They can detect things that are too dark or too far away to be seen with normal telescopes.

Internet links

Go to **www.usborne-quicklinks.com** for links to the following Web sites:

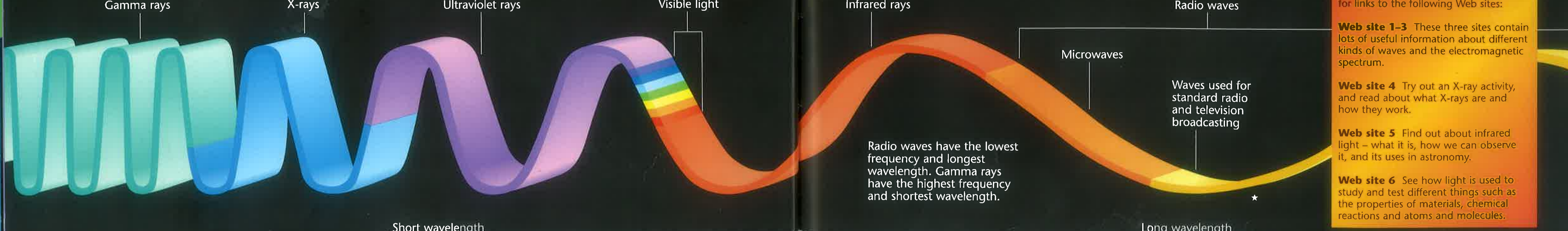
Web site 1–3 These three sites contain lots of useful information about different kinds of waves and the electromagnetic spectrum.

Web site 4 Try out an X-ray activity, and read about what X-rays are and how they work.

Web site 5 Find out about infrared light – what it is, how we can observe it, and its uses in astronomy.

Web site 6 See how light is used to study and test different things such as the properties of materials, chemical reactions and atoms and molecules.

The electromagnetic spectrum



LIGHT AND SHADOW

Light is a form of energy. It is made up of electromagnetic waves which are part of the electromagnetic spectrum*. This part is known as **visible light** because it can be seen.

The beacon in this lighthouse rotates, flashing with intense bright light that can reach ships many miles out at sea.

LIGHT

Light waves are a type of transverse wave*. Like other waves, they transport energy from a source to its surroundings.

Any object that gives off light, for example the Sun or a light bulb, is said to be **luminous**. Most objects are non-luminous and can be seen only because they are reflecting the light from something luminous. For example, the Moon can only be seen when light from the Sun bounces off it.

Light from the Sun reflects off the surface of the Moon, enabling it to be seen.

Some luminous objects give off more light than others. The level of brightness is called **intensity**. The further you are from a source of light, the less intense the light is. This is because light waves spread out as they travel away from the source.

The bright flashlight gives more intense light than the small candle.

The light fades as the vibrations of the light waves become gradually smaller.

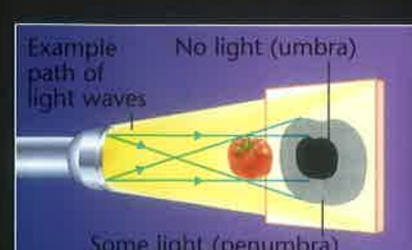
SHADOWS

Different types of substances allow different amounts of light to pass through them. Substances through which light can pass fully, such as clear glass, are said to be **transparent**. Substances which only let some light through are **translucent**. Frosted glass is translucent.

When light shines on an **opaque** object, the waves cannot pass through, so a dark area, called a **shadow**, forms on the other side.

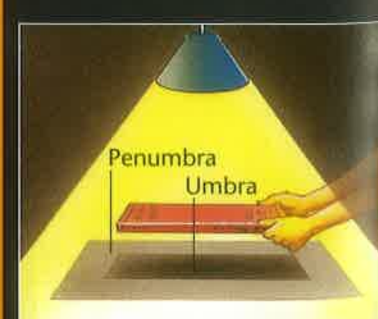
Light cannot pass through this ball, so a shadow is formed.

Opaque objects cast two types of shadow. If no light reaches an area, a dark shadow, called an **umbra**, is formed. If some light reaches an area, gray shadow is formed. This is called a **penumbra**, and it forms around the edge of the umbra. The smaller the light source, the more umbra and less penumbra it creates.



See for yourself

To see the two different kinds of shadow, hold a book over a piece of white paper under the light of a lamp. Notice the types of shadow it casts. If you move the book closer to the paper, you will see more umbra and less penumbra.



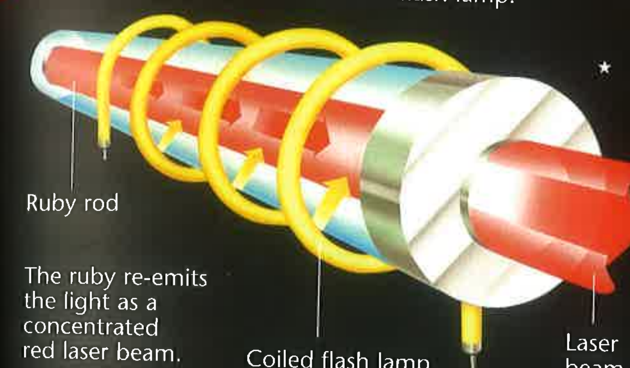
* Electromagnetic spectrum, 18-19; Transverse waves, 9.

LASERS

Visible light is made up of several colors of different wavelengths* and frequencies*. Machines called **lasers** create beams of intense, pure color of one wavelength and frequency.

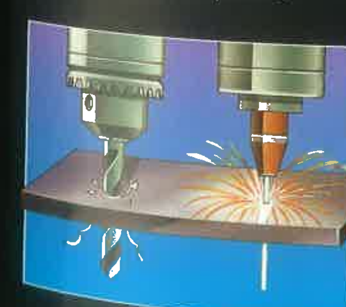
In a simple laser, a ruby rod absorbs light energy from a bright lamp. Atoms in the ruby gain the energy and give off bursts of light of a certain wavelength and frequency. Each burst of light causes other atoms in the ruby to give off light waves of the exact same type. Together they form a **laser beam**.

In this laser, a rod of ruby absorbs light from a coiled flash lamp.



The waves in a laser beam are **coherent**. This means that they travel in step with each other as everything about them is exactly the same. They stay together in a narrow, concentrated beam, making them easy to direct.

Some powerful lasers produce extremely hot beams of infrared light*. These are used in industry for melting through metals, diamonds and other tough materials. Less powerful lasers are used in certain types of eye surgery, such as replacing a detached retina. The laser makes a small heat scar which welds the detached part back into place.



The drill (far left) makes a rough hole in the metal and produces waste shavings.

The powerful laser beam, by contrast, melts a clean hole.

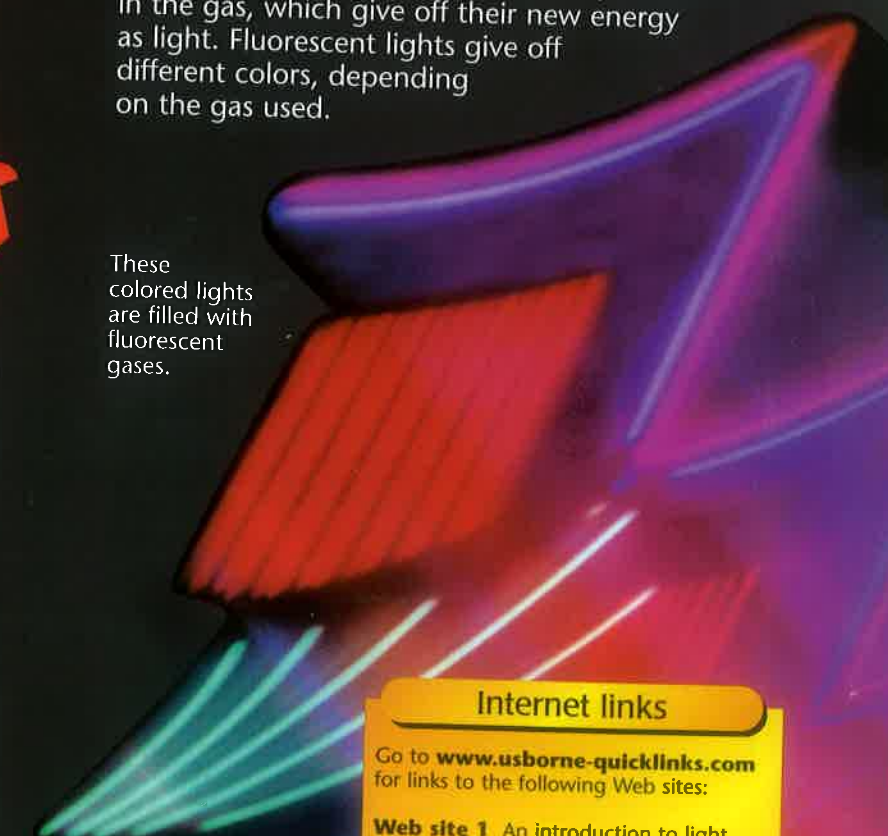
* Frequency, 9; Infrared rays, UV rays, 19; Wavelength, 9.

FLUORESCENCE

Some substances can absorb energy, such as electricity or ultraviolet (UV) rays*, and give it out as light. They are described as **fluorescent** substances. They are widely used in advertising and paints as they make colors seem to glow.

This T-shirt has been washed with a washing powder containing fluorescent substances that absorb UV rays from the Sun and make white clothes look whiter.

Fluorescent lights consist of a tube filled with a gas such as neon. When electricity is passed through the tube, it gives energy to particles in the gas, which give off their new energy as light. Fluorescent lights give off different colors, depending on the gas used.



These colored lights are filled with fluorescent gases.

Internet links

Go to **www.usborne-quicklinks.com** for links to the following Web sites:

Web site 1 An introduction to light.

Web site 2 Take a trip to the Sun and learn about its energy.

Web site 3 Find out about lasers.

Web site 4 A comprehensive look at light and its properties.

Web site 5 Find out more about the physics of light.

Web site 6 See how amazing 3D images, called holograms, are made using lasers.

COLOR

Visible light appears colorless. It is also known as **white light**. In fact, it is made up of seven different colors: red, orange, yellow, green, blue, indigo and violet. Each color has a different wavelength* and frequency*. Together they make up the **visible light spectrum**. Colors of the spectrum are called **chromatic colors**.

Rainbows, like this one, form when light hits tiny drops of water in the air and splits up into separate colors.

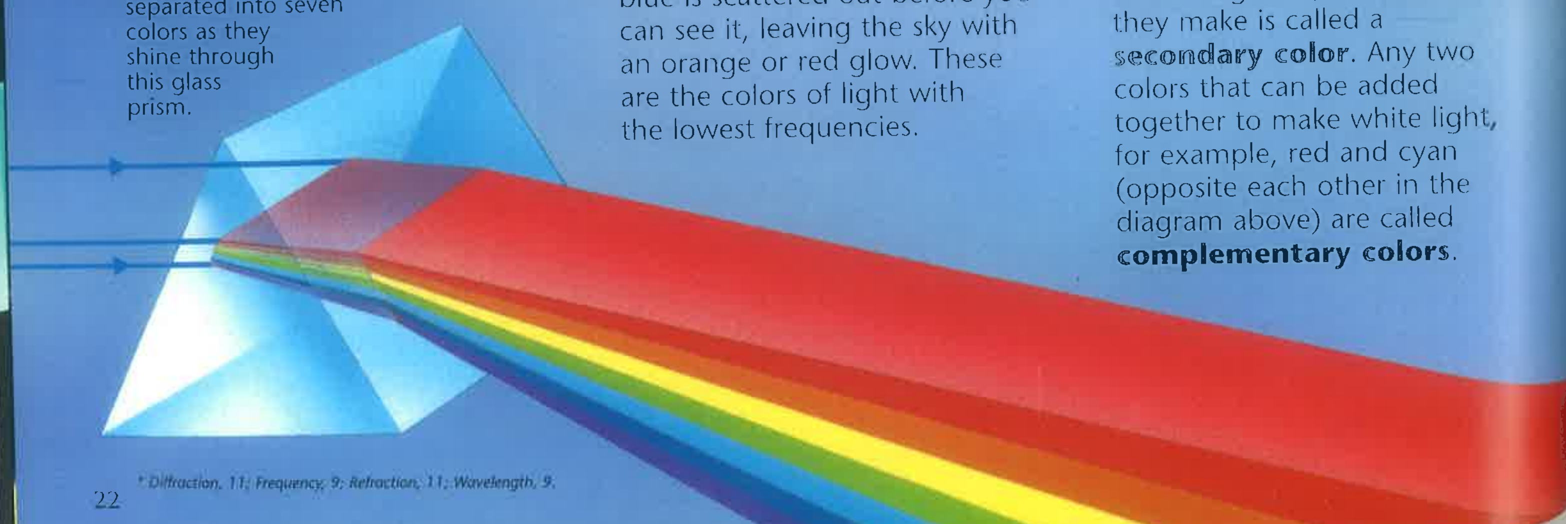
DISPERSION

In 1666, scientist Isaac Newton discovered that white light could be divided into separate colors. This process is called **dispersion**. He dispersed light using a **prism** – a transparent solid with two flat surfaces at an angle to each other.

The picture below shows a prism. As light hits the first surface, the colors in it are bent (refracted*) by various amounts. This splits up the light into its separate colors. This dispersed light is refracted further when it hits the second surface. Colors with the shortest wavelengths, namely blue and violet, are refracted the most.

A rainbow is a result of dispersion that happens naturally. Water particles in the air act like prisms, separating sunlight into colors.

Rays of white light are separated into seven colors as they shine through this glass prism.



COLOR OF THE SKY

The color of the sky is a result of sunlight being scattered by small particles in the atmosphere. They reflect and diffract* sunlight, scattering high-frequency light waves, such as blue, most of all. When you look up at the sky, it appears blue because some of this scattered blue light reaches your eyes.

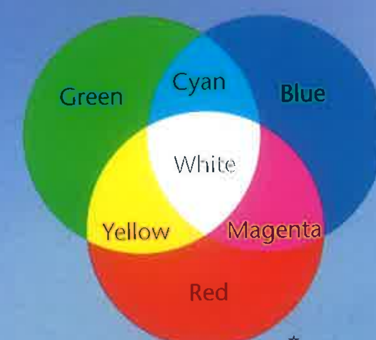
The different colors of this evening sky are caused by light scattering.

At sunrise and sunset, the light has to travel through more of the atmosphere before reaching your eyes. This means that the blue is scattered out before you can see it, leaving the sky with an orange or red glow. These are the colors of light with the lowest frequencies.

MIXING LIGHT

Almost any color of light can be made by **additive mixing**, that is, by using different combinations of red, green and blue light. For this reason red, green and blue are known as the **primary colors** of light.

Red, blue and green are the primary colors of light.



Cyan, magenta and yellow are the secondary colors of light.

When two primary colors are added together, the color they make is called a **secondary color**. Any two colors that can be added together to make white light, for example, red and cyan (opposite each other in the diagram above) are called **complementary colors**.

* Diffraction, 11; Frequency, 9; Refraction, 11; Wavelength, 9.

SEEING IN COLOR

You can see colors when light reflecting off objects is detected by color-sensitive cells in your eyes.

All colored objects and paints contain **pigments**. These are substances that absorb certain colors and reflect others. You can see the color of an object because it reflects only light of that color. For example, a red flower reflects red light and absorbs all the other colors of the spectrum.

This bottle looks blue because it reflects only blue light and absorbs all the other colors.

White objects appear white because they reflect all the colors of light equally. Black objects absorb all the colors, so hardly any light is reflected, making the object look black. Black and white are known as **achromatic colors**.

The white feathers on this penguin reflect all the light that hits them.

The black feathers absorb all the light that hits them.

MIXING PIGMENTS

Pigments mix by a process called **subtractive mixing**. For example, the pigment in yellow paint absorbs blue light and the pigment in cyan paint absorbs red light. So when you mix yellow and cyan paints, the mixture can only reflect green light, making it look green. The primary colors of pigments are cyan, yellow and magenta. Red, blue and green are the secondary colors.

Yellow and cyan pigments mix to make green because they absorb blue and red light.

See for yourself

You can see the colors of the spectrum form white light by making a color spinner. Draw around the bottom of a jar on some stiff cardboard. Cut out the circle, divide it into seven sections and paint them with the colors of the rainbow. Push a pencil through the middle and spin it on a table. As it spins, the colored light reflecting off it merges to make white.

COLOR PRINTING

Color printing in books and magazines uses dots of magenta, yellow and cyan ink, along with black ink to make the pictures look sharper. This process is called **four-color printing**.

This magnified picture shows how all the colors are made up of tiny dots of magenta, yellow, cyan and black.

If you look through a magnifying glass at any picture in this book, you will see the dots which make up the image.

Colors used in four-color printing

Internet links

Go to **www.usborne-quicklinks.com** for links to the following Web sites:

Web sites 1–2 Two sites that contain a wealth of information about rainbows, from what they are to detailed explanations about the physics behind them.

Web sites 3–4 Find out about light and color on these two fascinating Web sites.

Web site 5 Lots of great experiments that play tricks with light and color.

Web site 6 Watch a movie about the many different uses of lasers and take a quiz to test your knowledge.

LIGHT BEHAVIOR

Like all electromagnetic waves, light travels incredibly quickly – about 300,000 kilometers per second when measured in a vacuum. The direction in which light waves travel is shown in diagrams by arrows. These are called **light rays**. Light waves usually travel in a straight path but may change direction when they meet an obstacle, or move from one substance into another.

The colors on the surface of soap bubbles are caused by light interference.

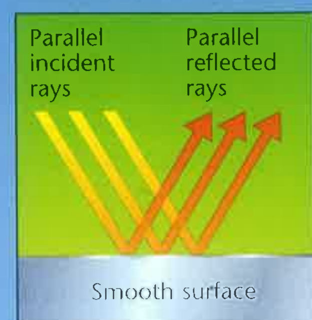
REFLECTION OF LIGHT

Light rays traveling toward an object are known as **incident rays**. If they hit the object and bounce off it, they are then called **reflected rays**. Each ray is reflected at the same angle as it hits the object.

When parallel light rays hit a smooth, shiny surface, they are reflected so that the reflected rays are also parallel. This is called **regular reflection**.

When parallel light rays hit a rough surface, the reflected rays are scattered in different directions. This is **diffuse reflection**. It is the most common type of reflection as most surfaces are rough (though they may not seem so unless seen with a microscope).

Regular reflection of light rays



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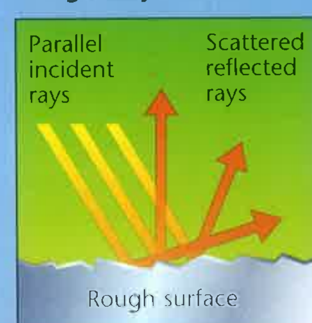
Diffuse reflection of light rays



*

When you look at an object, the light that reflects off it goes directly into your eyes, so you see the object where it really is. If you look at an object in a mirror, the rays bounce off the object and then bounce off the mirror before entering your eyes. What you are looking at is the **image** of the object. In this case the image appears to be behind the mirror.

REFRACTION OF LIGHT

If light rays pass from one substance to another of a different density, their speed will change. If they are also bent, they are known as **refracted rays**. The amount of speed change and refraction depends on the change in density. Light rays speed up on moving into a less dense substance, and slow down on moving into a denser one.

For instance, light rays bouncing off objects in water can make the objects look distorted. This is because the rays are refracted as they pass out of the water into the less dense air. You can find out more about refraction on page 11.

See for yourself

To see light refraction, look at a straw in a glass of water from all sides. It seems to bend in different ways. The unbroken lines in the diagram show the real path of the light rays looking from above. But the brain assumes they travel straight, so it sees the end of the straw at X.

*

The rays of sunlight breaking through these clouds show that light travels in straight lines.

LIGHT DIFFRACTION

When light rays pass through tiny gaps, or meet the edge of an opaque object, they are diffracted, or spread out. For more about diffraction, see page 11.

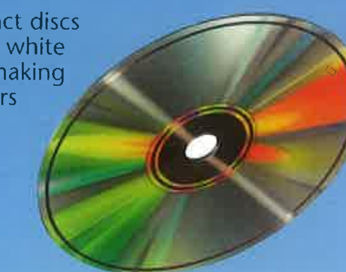
LIGHT INTERFERENCE

When light rays are reflected or diffracted, their paths may cross, causing interference. See page 11 for more about interference.

As light rays interfere with each other, some wavelengths of light are strengthened and some are weakened, so certain colors become visible. The colors on a compact disc and on the surface of soap bubbles, for example, are caused by interference.

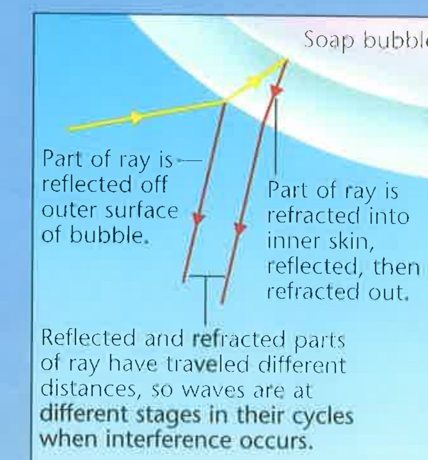
The metallic sheen on the wings of this butterfly is caused by light interference.

The shiny side of a compact disc has tiny bumps on it. When light enters the gaps between them, the waves are diffracted and interfere, so certain colors are seen at different angles.



Compact discs diffract white light, making its colors visible.

The rainbow colors on a soap bubble appear when light reflected off the outer surface of the bubble interferes with light reflected off the inner surface.

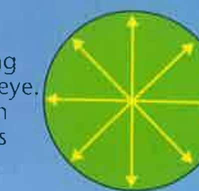


*

The colors are constantly changing, giving a shimmering effect called **iridescence**. This is also seen on the wings of some insects and birds.

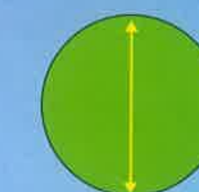
POLARIZATION

Light waves are made up of vibrations in electric and magnetic fields. The vibrations change direction many millions of times per second, but are always at right angles to the direction the wave is traveling.



Imagine a normal light wave traveling directly into your eye. Its vibrations are in many directions, as shown here.

When light is **polarized**, the vibrations only occur in one direction, such as up and down.



A polarized light wave is filtered so that its vibrations are in just one direction, as shown here.

Polarizing sunglasses work by filtering out all light wave vibrations that are not in a certain direction. This shields the eyes from excessive glare.

Polarizing sunglasses only allow light vibrations through in one direction.

Internet links

Go to **www.usborne-quicklinks.com** for links to the following Web sites:

Web sites 1–2 Explore the intriguing world of optical illusions on these two Web sites.

Web site 3 Lots of information about light and optics.

Web site 4 A description of light experiments in an underwater lab.

Web site 5 Find out what makes a diamond sparkle.

LENSES AND MIRRORS

A **lens** is a piece of transparent substance with curved surfaces, that makes light passing through it bend in a particular way. A **mirror** is a shiny surface that reflects nearly all of the light that hits it. Lenses and mirrors have many uses, for example in cameras and telescopes.

This photograph of New York City was taken through a fish-eye lens. This curved lens creates a distorted, circular image, covering an angle of 180°.

LENSES

Lenses are shaped so that light passing through them is bent (refracted*) in a particular way. There are two main shapes of lens: convex and concave. In a **convex lens**, one or both surfaces curve outwards. In a **concave lens**, one or both surfaces curve inwards.

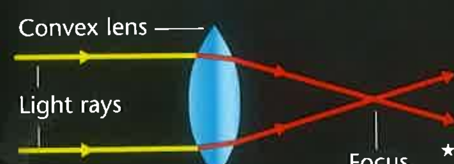
Types of convex lenses

Types of concave lenses

Lenses are described as converging or diverging lenses, depending how the light rays are refracted. For example, a glass convex lens in air acts as a converging lens and a glass concave lens in air acts as a diverging lens.

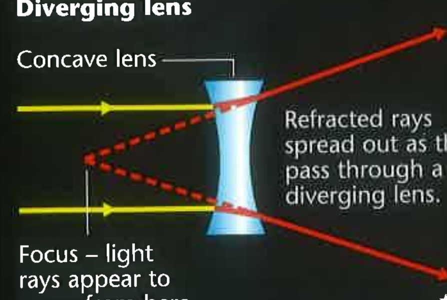
Any point where light rays come together or appear to come from is called a **focus**. A **converging lens** causes parallel rays of light passing through it to come together at a focus.

Converging lens



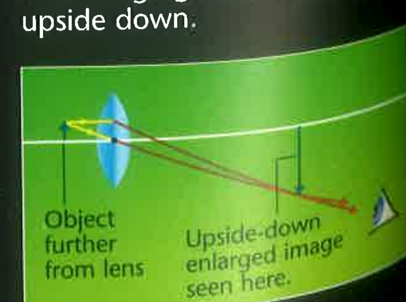
A **diverging lens** makes parallel rays of light spread out.

Diverging lens



The size and position of an image seen through a converging lens depends how far the object is from the lens. If the object is very close to a converging lens, the image is upright and enlarged.

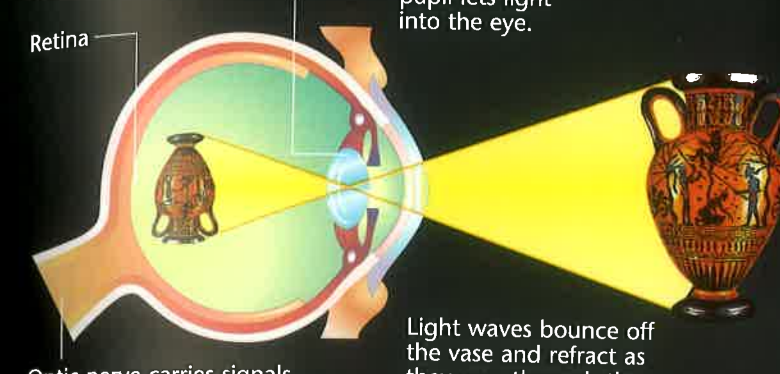
If the object is further away from a converging lens, the image is upside down.



* Refraction, 11.

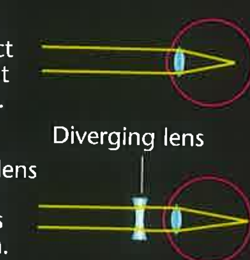
EYES AND EYESIGHT

Your eye turns light reflected from an object into an image that can be recognized by your brain. The front part of the eye is a convex converging lens. It focuses the light rays so that they form an image on a layer called the **retina**, at the back of the eye. The image formed is upside down, but your brain then corrects this so you see things right-side up.



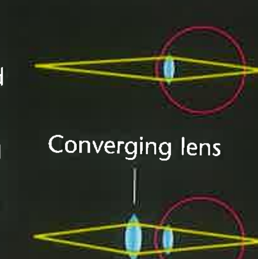
Distant objects are blurred for people with short sight. This is because the lenses in their eyes bend the light rays too much and the image forms in front of the retina.

Short sight



Far-sighted people can't see nearby objects well. This is because the lens does not bend the light rays enough so the rays focus behind the retina.

Far sight



See for yourself

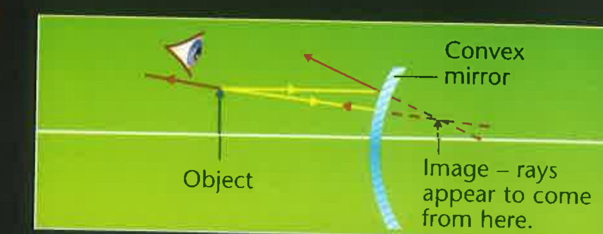
Look at your reflection in the bowl of a shiny metal spoon. If you hold the spoon very close to your face, the reflection will be enlarged. If you hold it a little further away, the reflection will be upside down. Look at the two diagrams at the bottom of the column on the right to see why this happens.

MIRRORS

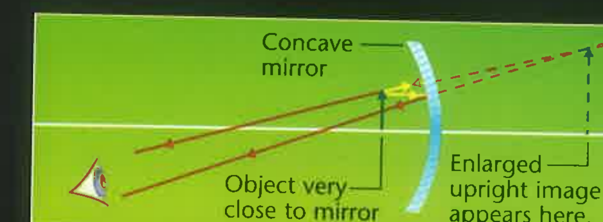
When light from an object hits a flat mirror straight on, it is reflected straight back. The image produced is the same size and same way up as the object but the left and right sides are switched around. The image is the same distance behind the mirror as the object is in front of the mirror.

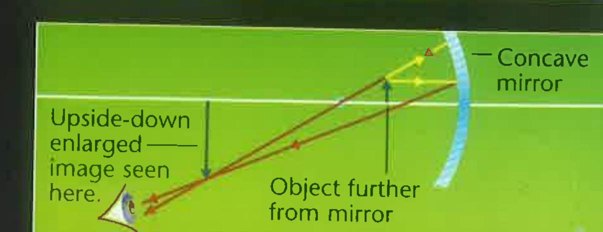
Curved mirrors bounce light off at an angle, producing different kinds of images. A **convex mirror** curves outward. The image formed is upright and reduced in size.

Car wing mirrors are convex.



Concave mirrors curve inward. If an object is very close to the mirror, an enlarged image is produced. If the object is further away, the image is upside down. The bowl of a shiny metal spoon acts like a concave mirror.





Internet links

Go to **www.usborne-quicklinks.com** for links to the following Web sites:

Web site 1 Find out how glasses bend light to help people see.

Web site 2 Experiments with reflection and refraction.

Web site 3 Interactive activities connected with optics.

TV AND RADIO

The first radio transmissions were made about 100 years ago. Television was invented in 1926. The first signals could only be sent over very short distances, but today satellites can instantly broadcast clear signals around the world.

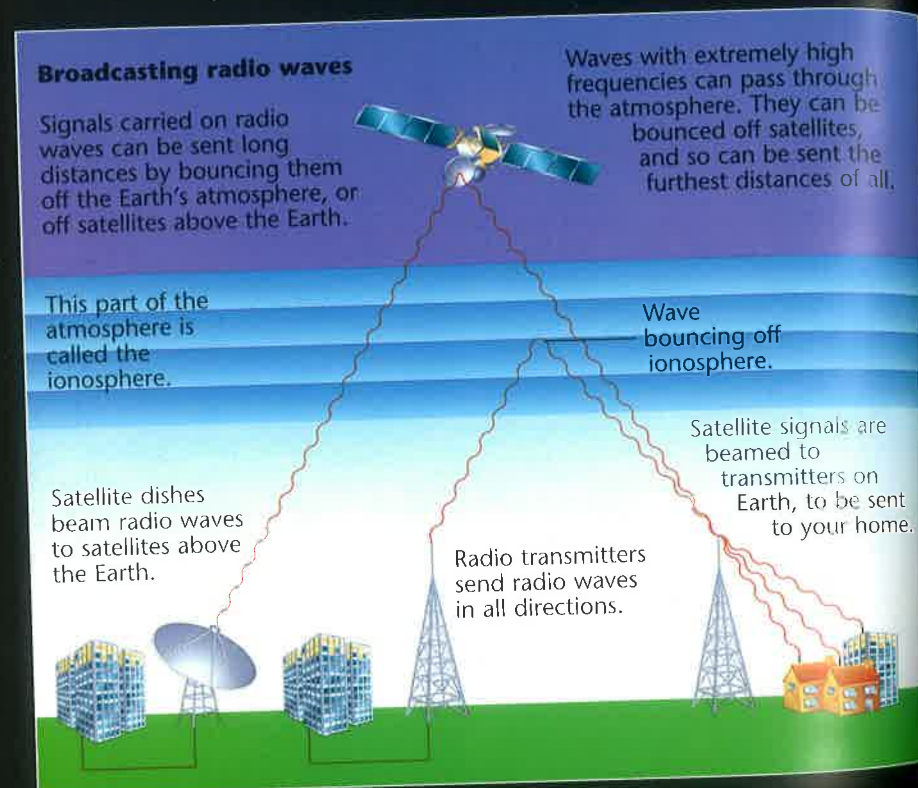
This early radio was invented by Marconi. It was called a marconiphone.

BROADCASTING

Most radio and television shows are broadcast as **radio waves**. These are a band of waves in the electromagnetic spectrum* with a range of different frequencies* and wavelengths*.

Radio waves are the longest waves in the electromagnetic spectrum.

Before broadcasting, sounds and images first have to be converted into electrical signals. Sounds are made into electrical signals by microphones. Cameras create electrical signals from images.

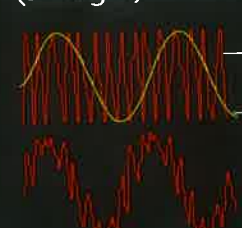


MODULATION

To enable them to be broadcast, electrical signals have to be altered, using a method called **modulation**. This is done by mixing the electrical sound and picture signals with radio waves, called **carrier waves**.

As a result of modulation, the shape of the carrier wave varies depending on the electrical sound and picture signals. The picture on the right shows an example of this.

With **frequency modulation (FM)** the electrical signals are altered to match the frequency of the carrier wave. With **amplitude modulation (AM)** the electrical signals are altered to match the amplitude* (strength) of the carrier wave.



HOW A RADIO WORKS

A radio works by receiving modulated radio waves through its antenna, and then converting them back into very weak electrical signals.

Radio receives many different signals. Tuner is adjusted to select wavelength of broadcast required.

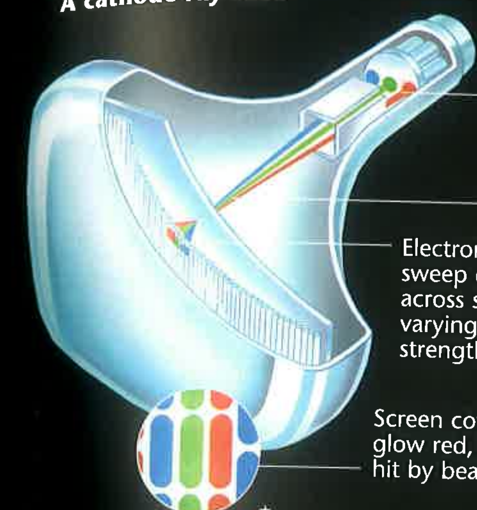
The signal is strengthened (amplified) and a loudspeaker turns it into a sound that can be heard.

* Amplitude, 9; Electromagnetic spectrum, 18-19; Frequency, Wavelength, 9.

HOW TV WORKS

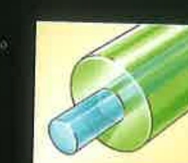
Television signals are carried by radio waves. As well as the sound signals, the waves carry picture signals. A television converts these signals into sound and pictures. The sound is converted in the same way as in a radio. The picture signals are converted into pictures by a **cathode ray tube**. The pictures are built up from about 350,000 tiny shapes called **pixels** (short for picture elements).

A cathode ray tube



CABLE BROADCASTING

TV and radio signals can be carried along cables, too. The cables can convey more signals than when they are transmitted through the air, so more channels are available. A vast network of underground cables exists. These can also be used to carry phone signals.



Fiber-optic cables are used for carrying television and radio signals.

DIGITAL BROADCASTING

By 2010 most radio and television broadcasting will be done **digitally**. Digital signals are electrical signals which carry information as a code made up of millions and millions of just two components: either "on" (1) or "off" (0).

The digital code is mixed onto – and then carried by – radio waves. Digital information can be compressed (see *Transmission Speed*, page 51, for an example) so far more can be sent. As a result, broadcasters can offer more channels than previously.

INTERACTIVE TV

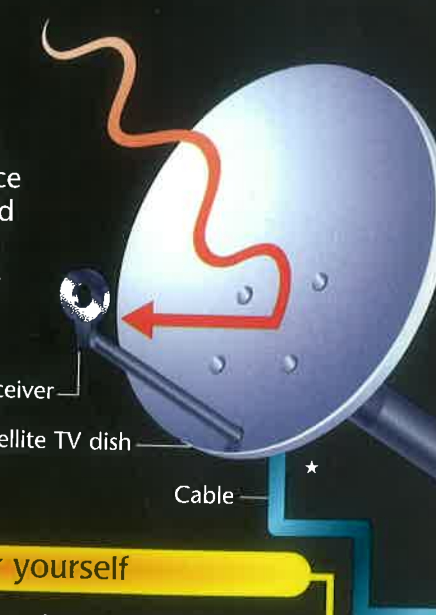
Digital broadcasting makes it possible to communicate in two directions. As a result, you can send information back through your TV, to order programs to watch whenever you want, or to buy things, or even to take part in games and competitions. This is called **interactive TV**.

This TV shows an interactive game to play during a soccer game.

Competitors predict the scorers of goals and the game's outcome. Their predictions are registered with the TV company and if they are right they win instant prizes.

SATELLITE TV

Satellite TV companies bounce signals off space satellites, to be received directly by a small dish that is fixed to the side of your home.



The dish focuses the TV signal onto a receiver. The signals travel along a cable to a television set.

See for yourself

Put a magnifying glass up close to your TV set while it is on. Look carefully and you'll be able to see the pixels that make up the picture.

Internet links

Go to **www.usborne-quicklinks.com** for links to the following Web sites:

Web site 1 Find out about the history of radio technology, from the nineteenth century to the present day.

Web site 2 Read about Marconi's invention and the first radio transmissions.

Web site 3 Find out about the history of TV.

Web site 4 Watch a movie and answer a quiz about radio.