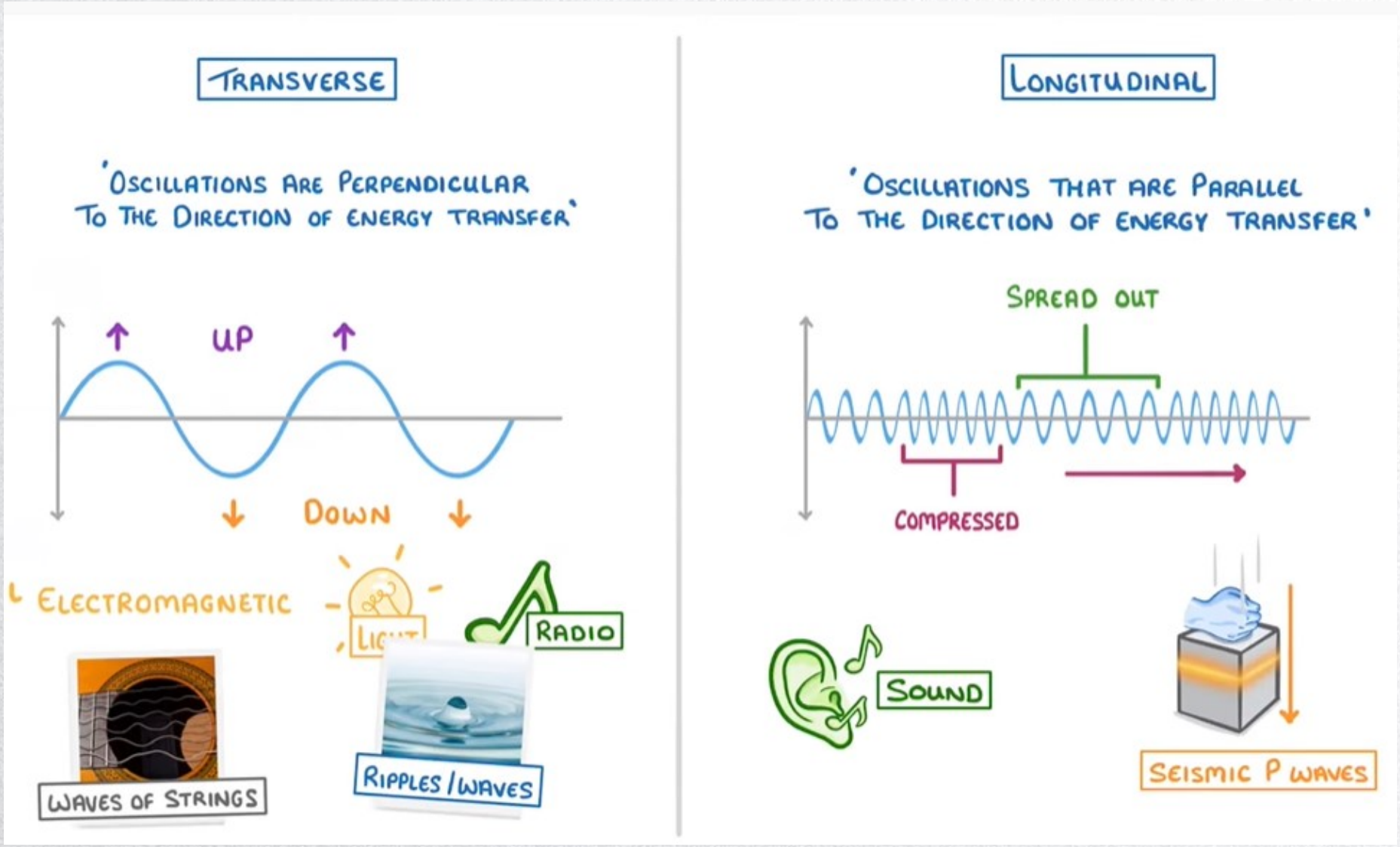
英华国际学校
YINGHUA INTERNATIONAL SCHOOL

Cambridge IGCSE Physics
Waves

By: Chaoyang Chu

Types of waves



Types of waves

Longitudinal waves

- Particles vibrate **parallel** to direction of wave
- The vibrations are along the same direction as the wave transfers energy
- **Compression**s (particles closest together) and **rarefaction**s (particles furthest apart)
- ex.: sound waves, ultrasound waves, seismic P-waves (primary), a slinky spring when you push the end

Transverse waves

- Particles vibrate **perpendicular** to wave direction
- The vibrations are at 90◦ to the direction energy is transferred by the wave.
- **Peak**s (particles highest from rest position) and **trough**s (particles lowest from rest position)
- ex.: EM waves, light, ripples on water, seismic S-waves (secondary), a slinky spring wiggles up and down

Sound waves

Production of Sound Waves

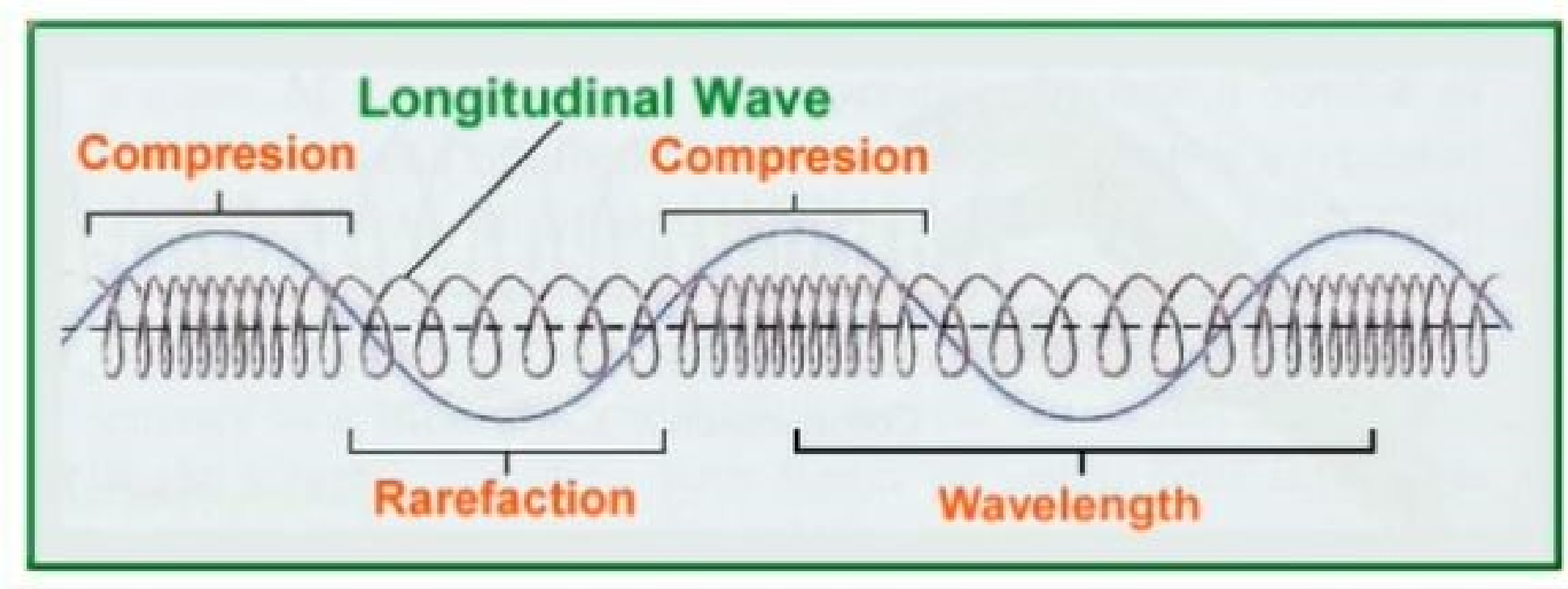
What is sound and how is sound produced?

Sound is produced when an object **vibrate**s, creating a **longitudinal** wave. This wave causes particles in the surrounding **medium** (air, water, or solid) to have **vibrational motion**. As the particles vibrate, they move nearby particles, transmitting the sound further through the medium.

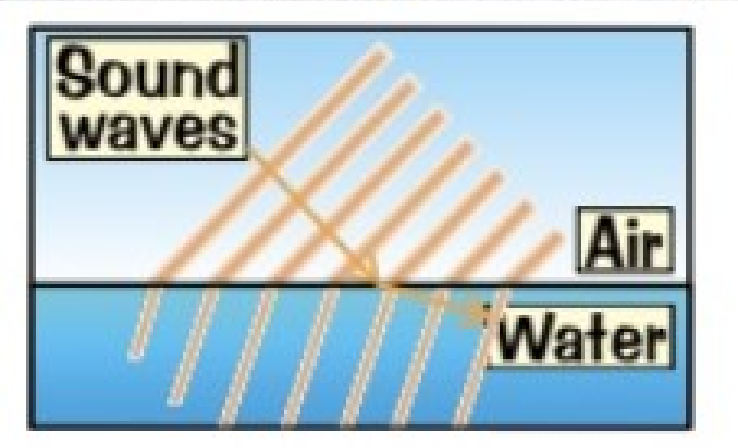
Production of Sound Waves

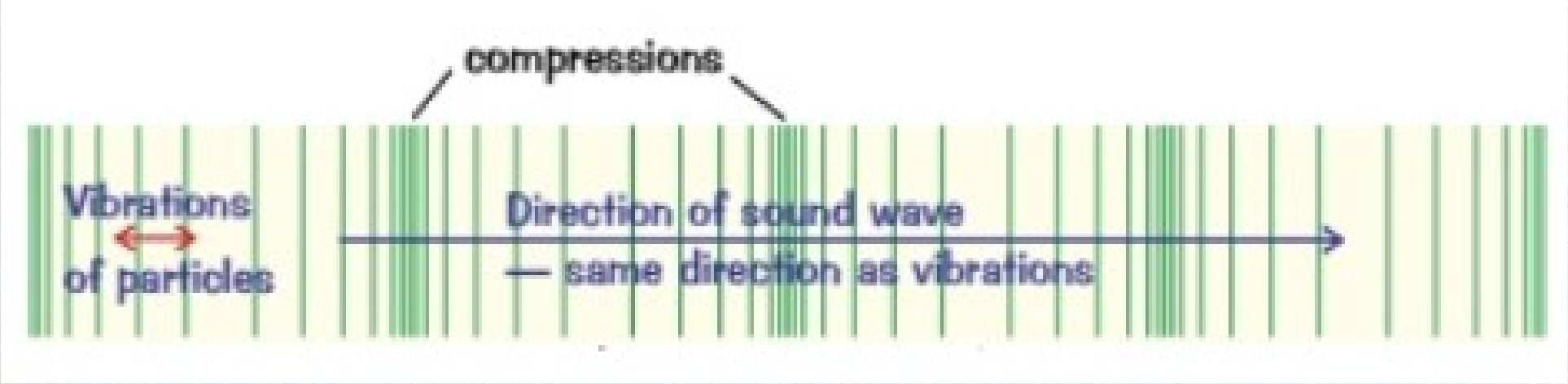
- Sound is a result of vibrating objects that cause a vibration of air molecules
- We hear sound when sound waves reach out ear which causes vibrations in our ear drums
- The human ear is capable of hearing sounds with frequencies between **20 Hz to 20 000 Hz**.
- All waves (including sound) have a frequency and amplitude
  - ✓ Frequency (Hz) is the number of waves that passes a fixed point per second
    - ❖ The higher the **frequency** the higher the **pitch**
  - ✓ The amplitude of wave is the maximum displacement of the vibration particles
    - ❖ The larger the **amplitude** the higher the **loudness**

Production of Sound Waves



Sound waves


Sound waves
Air
Water


compressions
Vibrations
of particles
Direction of sound wave
— same direction as vibrations

Sound waves

- Sound waves are **longitudinal** waves (with compressions and rarefactions) caused by **vibrating objects**. The vibrations are passed through the surrounding medium as a series of compressions.
- Since sound waves are caused by vibrating particles, in general **the denser the medium, the faster sound travels through it**. This also means it **can't travel through a vacuum**.
- Sound waves will be **reflect**ed by hard flat surfaces. Things like carpets and curtains act as **absorb**ing surfaces, which will absorb sounds rather than reflect them.
- Sound waves will also **refract** as they enter different media. As they enter denser material, they speed up (However, since sound waves are always spreading out so much, the change in direction is hard to spot under normal circumstances).

Ultrasound

- Ultrasound is defined as sound with a frequency **higher than 20 kHz**
- The uses of ultrasound in non-destructive testing of materials, medical scanning of soft tissue, and sonar including calculation of depth or distance from time and wave speed

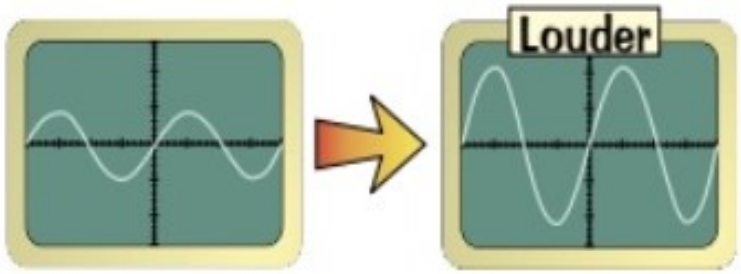
Sound waves

An Oscilloscope Can Display Sound Waves

1) A sound wave receiver, such as a microphone, can pick up sound waves travelling through the air.
2) To display these sound waves, and measure their properties, you can plug the microphone into an oscilloscope. The microphone converts the sound waves to electrical signals.
3) An oscilloscope is a device which can display the microphone signal as a trace on a screen.
4) The appearance of the wave on the screen tells you whether the sound is loud or quiet, and high- or low-pitched. You can even take detailed measurements to calculate the frequency of the sound (see next page) by adjusting the settings of the display.

Loudness Increases with Amplitude

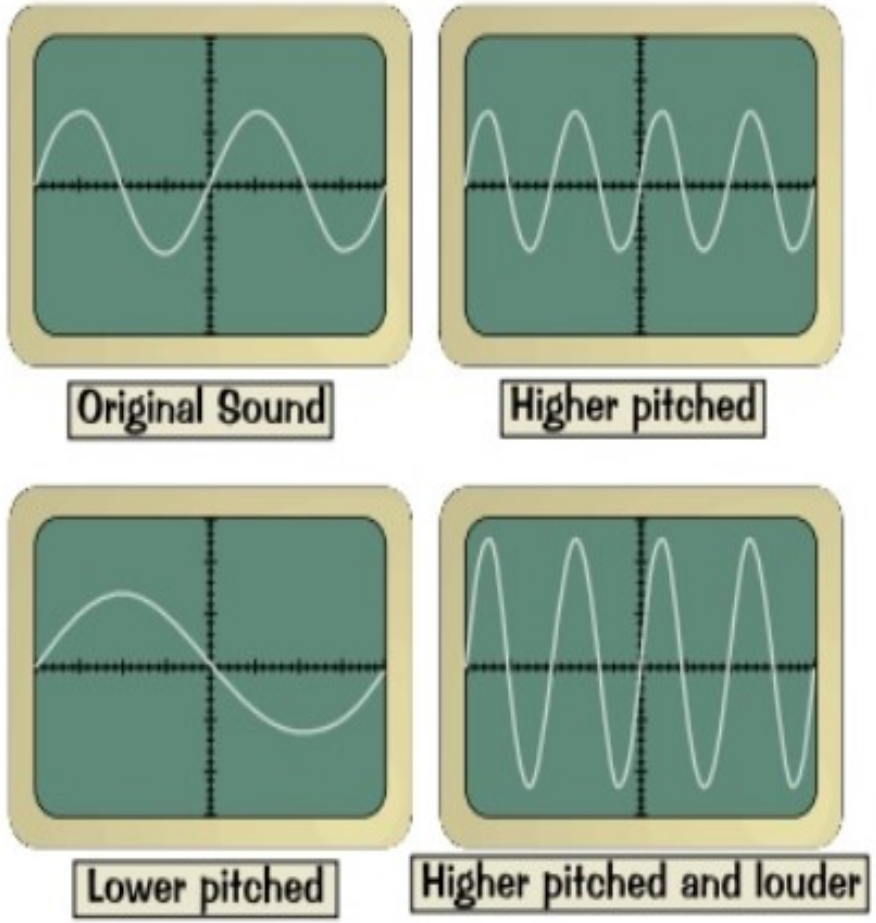
The greater the amplitude of a wave, the more energy it carries. In sound this means it'll be louder. Louder sound waves will also have a trace with a larger amplitude on an oscilloscope.



Sound waves

The Higher the Frequency, the Higher the Pitch

1) Frequency is the number of complete vibrations each second, and it's measured in hertz (Hz) — 1 Hz is equal to 1 vibration per second. Other common units are kHz (1000 Hz) and MHz (1 000 000 Hz).
2) You can compare the frequency of waves on an oscilloscope — the more complete cycles displayed on the screen, the higher the frequency (if the waves are being compared on the same scale — see the next page).
3) If the source of sound vibrates with a high frequency the sound is high-pitched, e.g. a squeaking mouse. If the source of sound vibrates with a low frequency the sound is low-pitched, e.g. a mooing cow.
4) The traces on the right are very important, so make sure you know them.



Speed of Sound

- Sound cannot travel through **vacuum**
- Sound must be transmitted through vibrations of particles within a medium
- The closer the particles are within the medium, the faster sound will travel
  - ✓ Air particles are very spread out, so sound does not travel very fast
  - ✓ Metals on the other hand are usually solids, and particles are much closer together allowing quicker transmission of sound waves
  - ✓ Sound speed in air = 330 m/s (approximately 330–350 m / s)

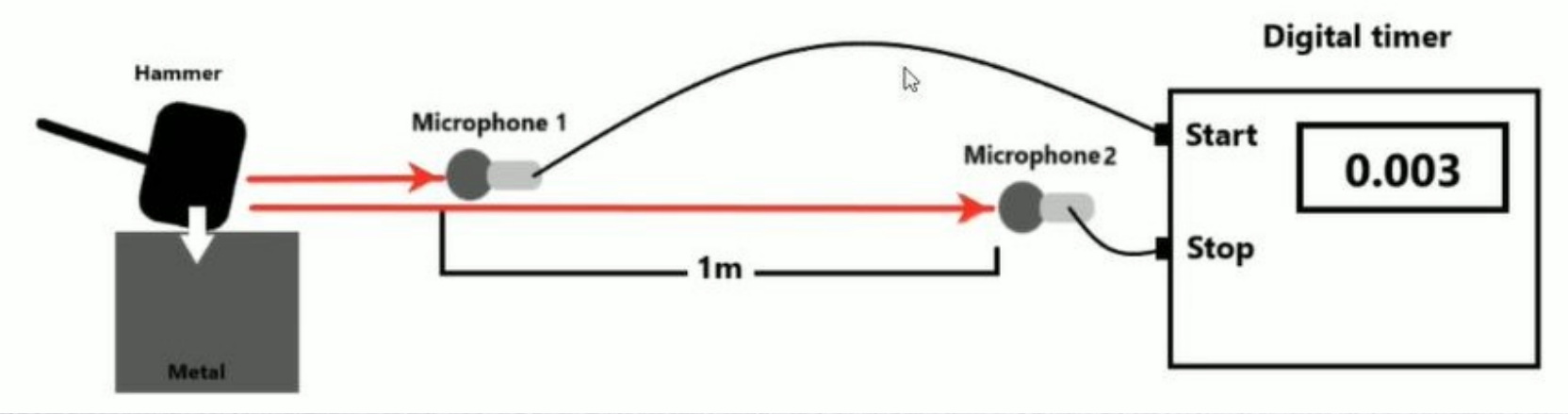
    Sound in water = 1500 m/s

    Sound in metals = 5000 m/s

Determining of Speed of Sound in Air

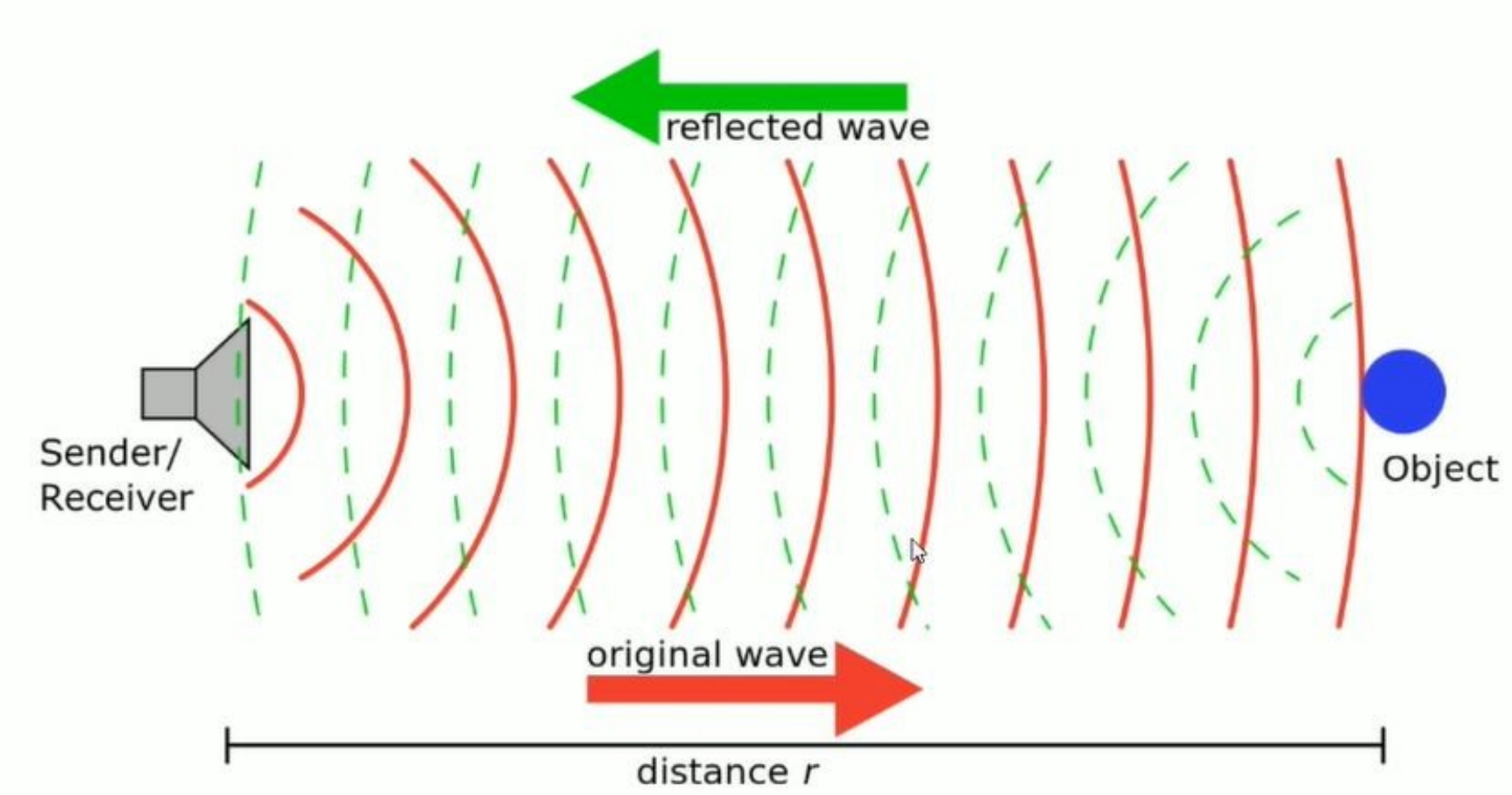
We can experimentally determine the speed of sound in air:

- 2 microphones are separated by exactly 1 m
- They are connected to a digital timer that starts when it gets signal from mic 1 and stops when it gets a signal from mic 2
- A hammer is used to hit a metal block to make sound
- The timer will record to travel between mic 1 and mic 2 the time taken from sound (i.e. 0.003 s)
- Speed = distance / time taken = 1/0.003 = 330 m/s



Echoes

When sound waves get reflected off a surface, it generates an echo



Sound waves

A group of students wants to determine the speed of sound in air.

Describe a method they can use. State the measurements they need to make.

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..... [4]

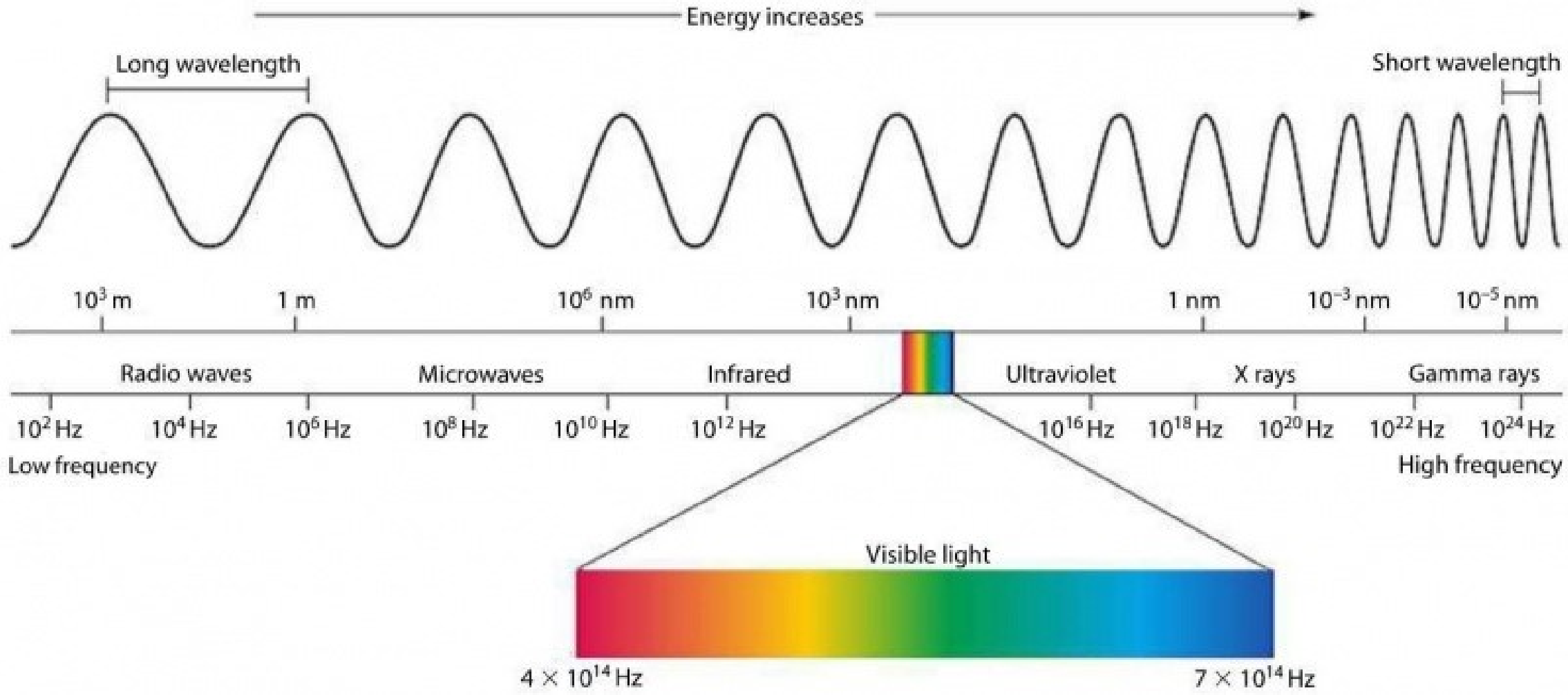
[Total: 4]

Sound waves

Answer	Marks
for full marks the method described must work any **four** from: means of producing sharp sound use of suitable reflecting surface measure distance travelled by sound method for measurement of time for sound to travel measured distance use of speed = distance / time	**4**

Electromagnetic Spectrum

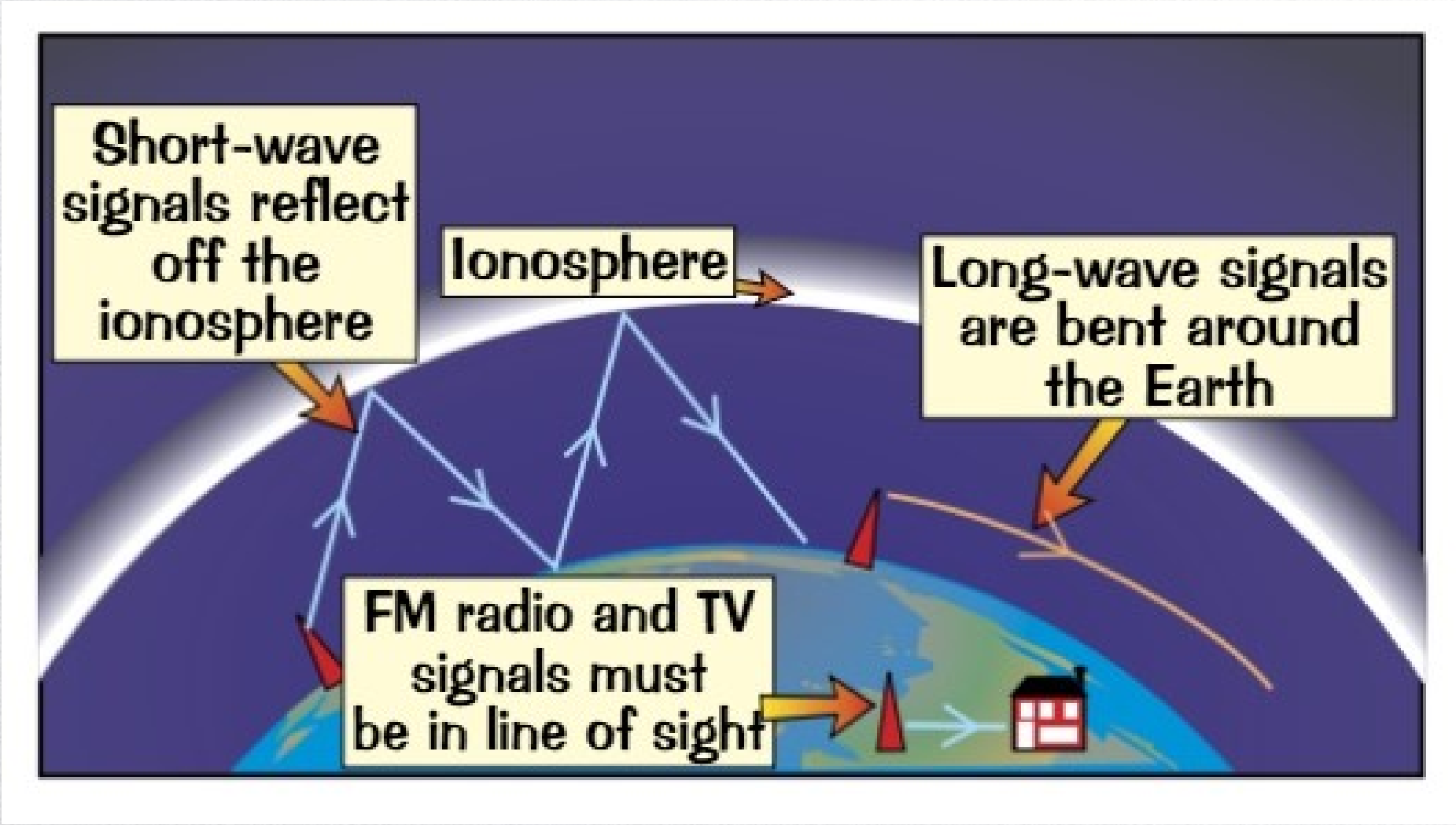
Electromagnetic (EM) waves



Electromagnetic (EM) waves

- All electromagnetic waves are **transverse**.
- The speed of electromagnetic waves in a vacuum is **3.0 × 10^8 m/s** and is approximately the same in air.
- The higher the frequency, the higher the energy of radiation.

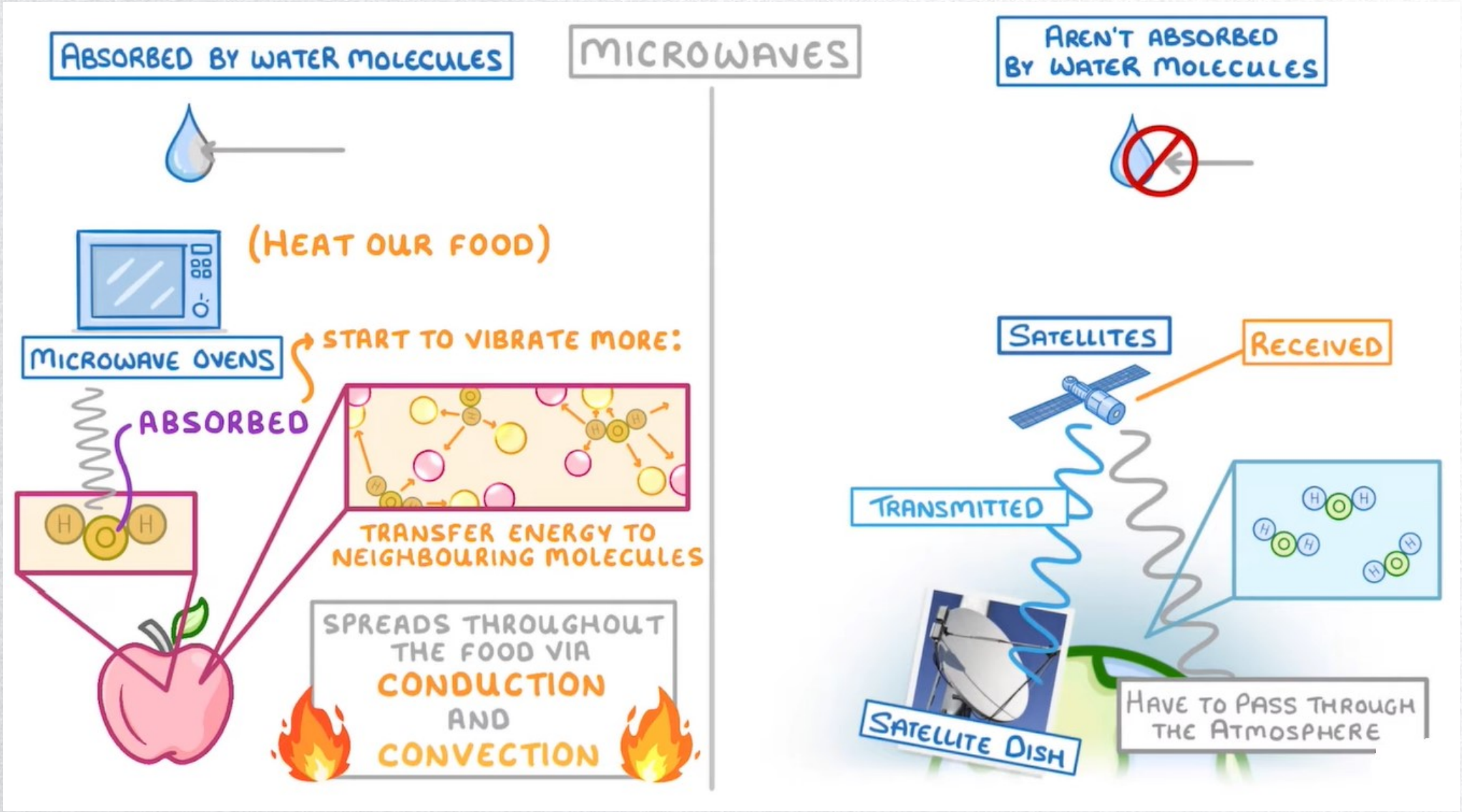
Radio waves


Short-wave signals reflect off the ionosphere
Ionosphere
Long-wave signals are bent around the Earth
FM radio and TV signals must be in line of sight

Radio waves

- Radio waves are mainly used **for communications**:
  - ✓ Long-wave radio: can be transmitted a long way because long wavelengths are bent around the curved surface of the Earth.
  - ✓ Short-wave radio: can also be received at long distances from the transmitter. That's because they are reflected from the ionosphere (a layer of the Earth's atmosphere).
  - ✓ The radio waves used for TV and FM radio broadcasting have very short wavelengths. To get reception, you must be in direct sight of the transmitter – the signal doesn't bend around hills.

Microwaves


ABSORBED BY WATER MOLECULES
MICROWAVES
AREN'T ABSORBED BY WATER MOLECULES
(HEAT OUR FOOD)
MICROWAVE OVENS
START TO VIBRATE MORE:
ABSORBED
TRANSFER ENERGY TO NEIGHBOURING MOLECULES
SPREADS THROUGHOUT THE FOOD VIA CONDUCTION AND CONVECTION
SATELLITES
RECEIVED
TRANSMITTED
SATELLITE DISH
HAVE TO PASS THROUGH THE ATMOSPHERE

Microwaves

- Microwaves are used for **satellite communication** and **heating food**
  - ✓ Satellite communication (including satellite TV signals and satellite phones) uses microwaves.
  - ✓ For satellite TV, the signal from a transmitter is transmitted into space, where it's picked up by the satellite receiver dish orbiting thousands of kilometers above the Earth. The satellite transmits the signal back to Earth where it's received by a satellite dish on the ground.

Microwaves

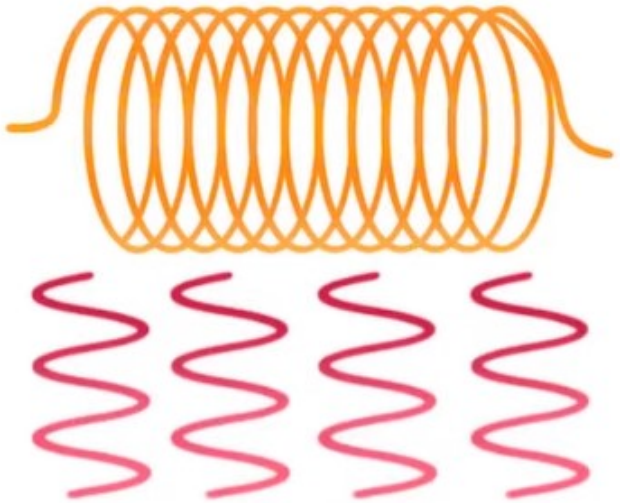
- Microwaves are used for **satellite communication** and **heating food**
  - ✓ Mobile phone calls also travel as microwaves from your phone to the nearest transmitter.
  - ✓ Microwaves are also used for cooking. These microwaves are absorbed by water molecules in the food. They penetrate a few centimeters into the food before being absorbed. The energy is then conducted or convected to other parts of the food.

Infrared (IR)

INFRARED RADIATION (IR)

(OVENS + GRILLS)

- COOKING:

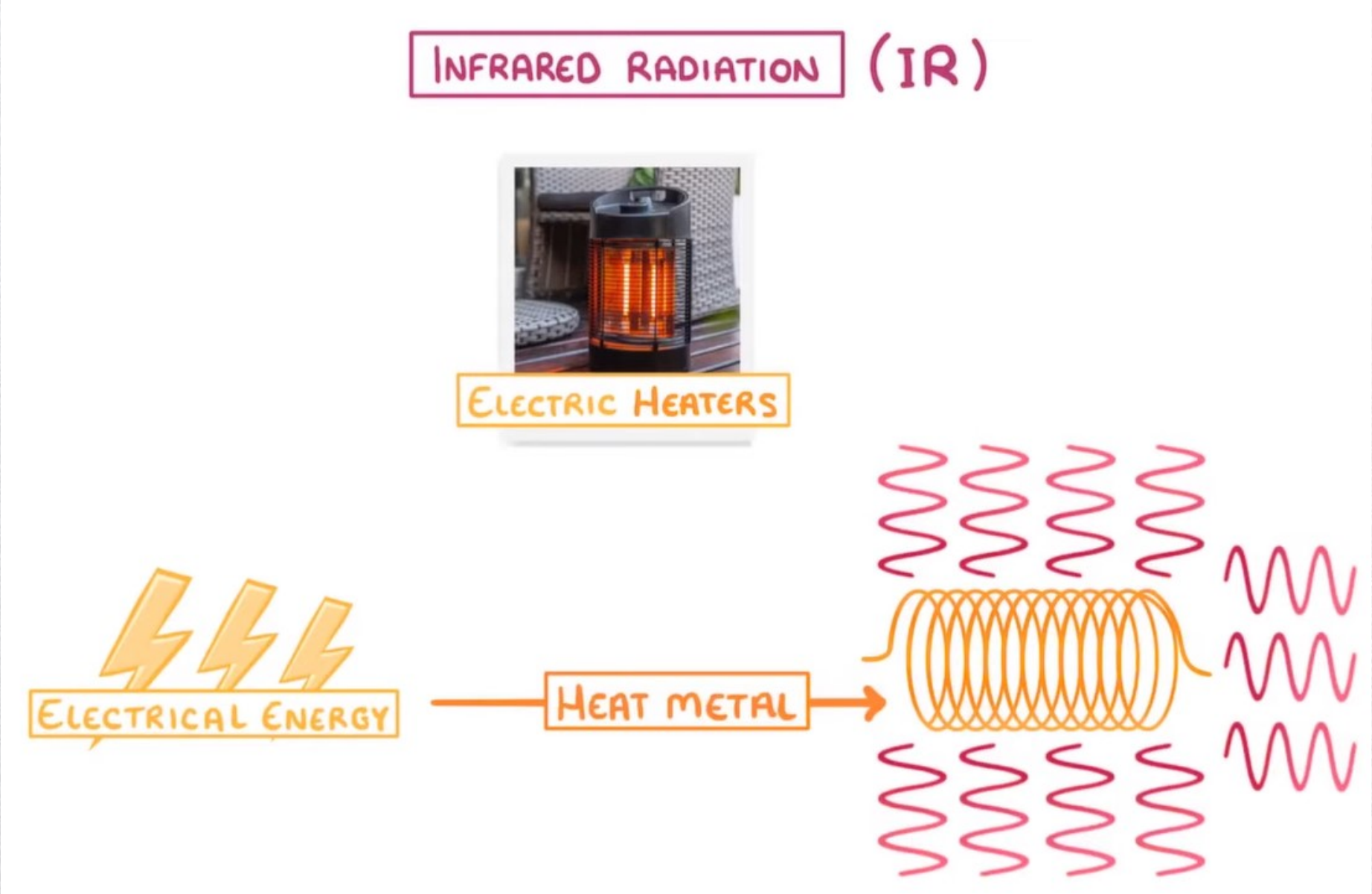


WHY BREAD TOASTS

- EMIT LOTS OF INFRARED RADIATION
  (DOESN'T PENETRATE THE SURFACE)

HEAT OUR FOOD BY TRANSFERRING THE HEAT ENERGY

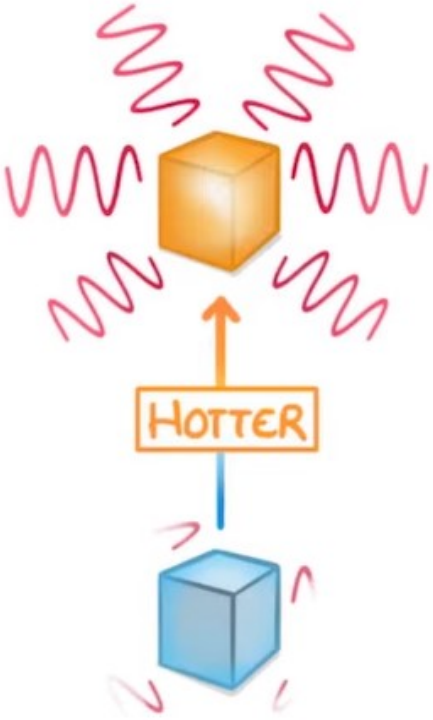
Infrared (IR)


INFRARED RADIATION (IR)
ELECTRIC HEATERS
ELECTRICAL ENERGY
HEAT METAL

Infrared (IR)

INFRARED RADIATION (IR)

- EMITTED FROM ALL OBJECTS THAT HAVE THERMAL ENERGY (DEPENDING ON THE OBJECT'S TEMP.)



INFRARED CAMERA

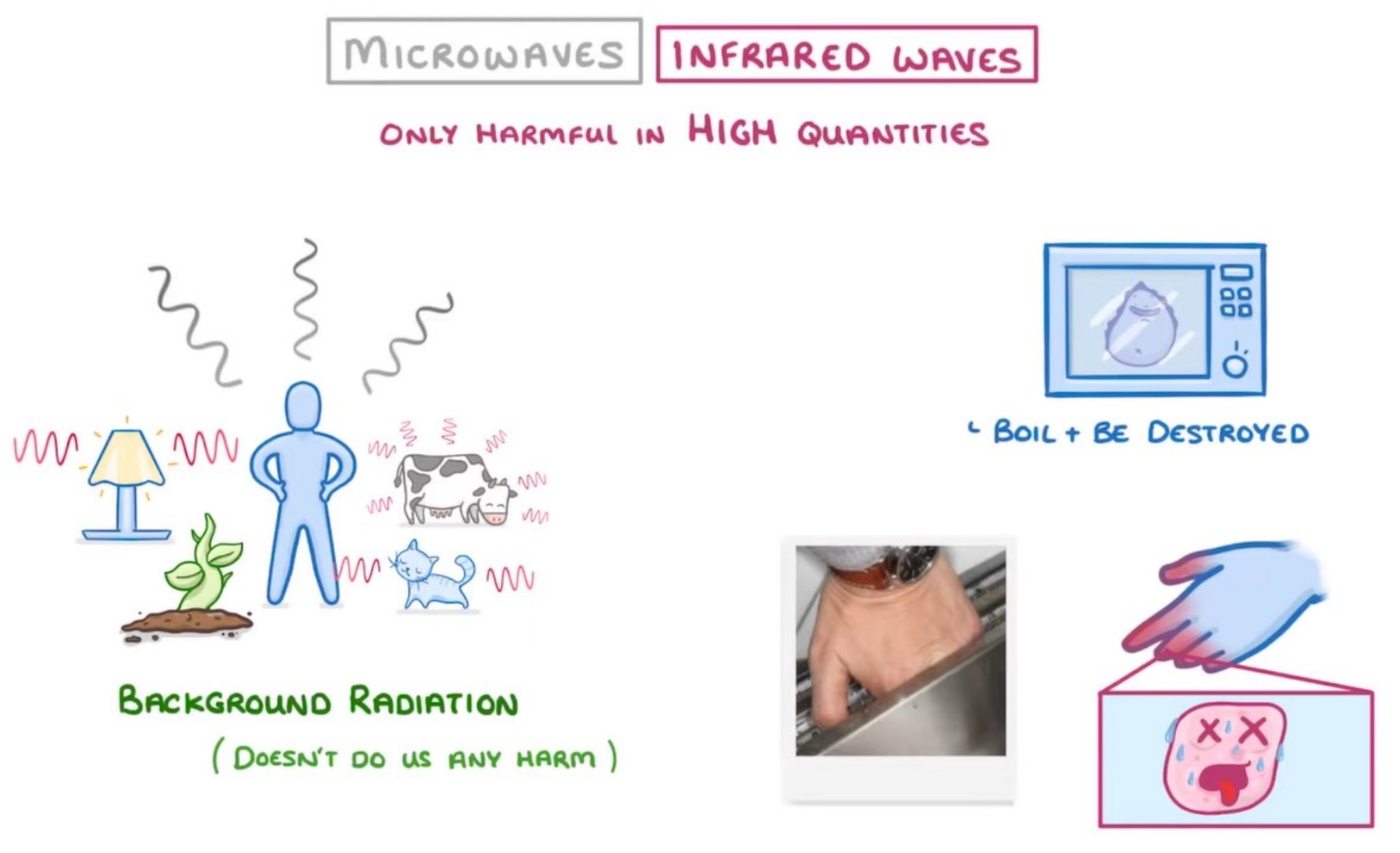
- SEE IN THE DARK

SPOT LIVING ORGANISMS

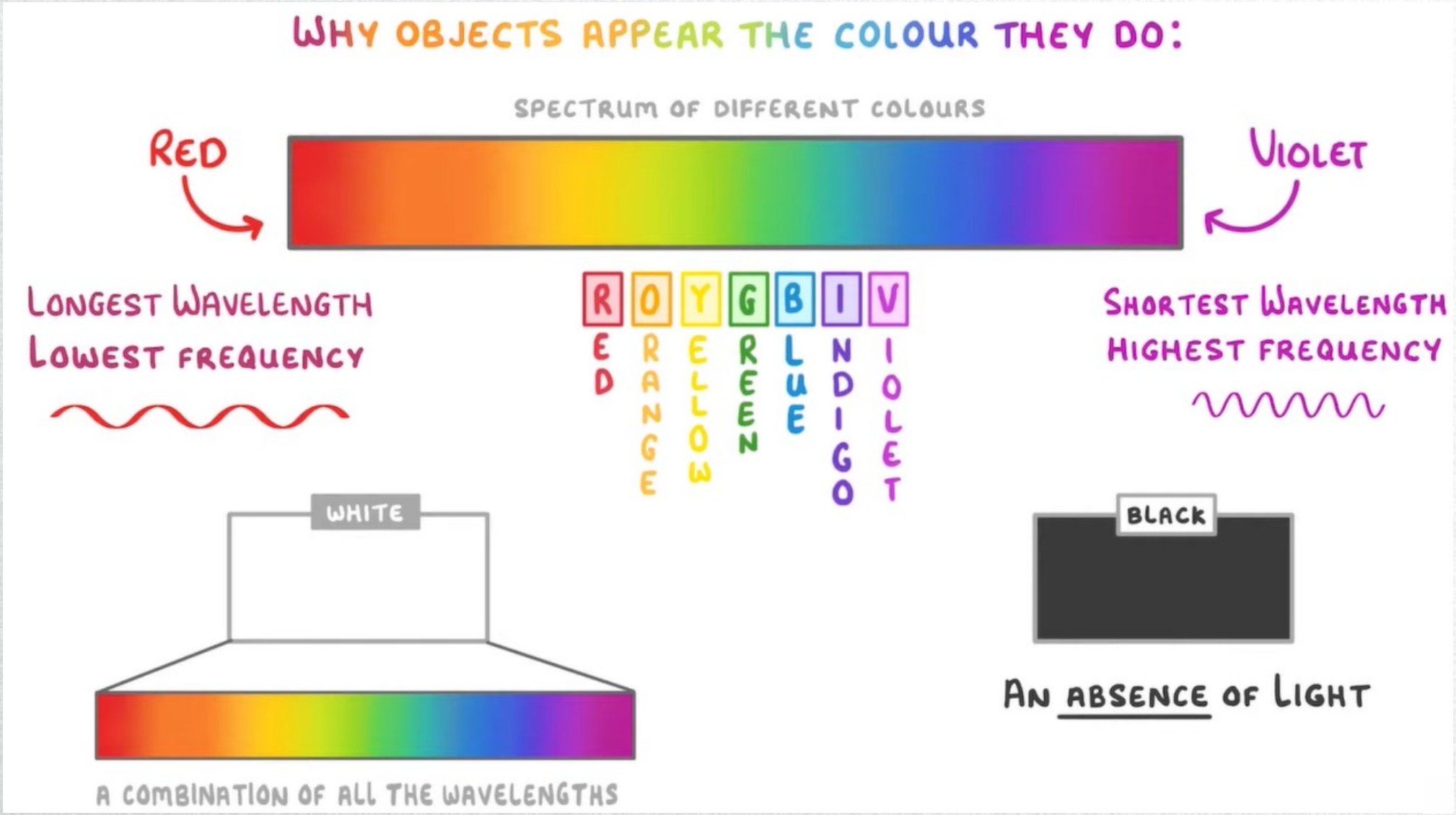
Infrared (IR)

- Infrared radiation is used for **heating** and to **monitor temperature:**
  - ✓ IR is also known as heat radiation. **Electrical heaters** radiate IR to keep us warm, and things like grills use IR to cook food.
  - ✓ **IR is given out by all objects** – the hotter the object, the more IR radiation it gives out.
  - ✓ The IR given out by objects can be detected in the dark of night by **night-vision** equipment. The equipment turns it into an electrical signal, which is displayed on a screen as a picture, allowing things which would otherwise be hidden in the dark to be seen.

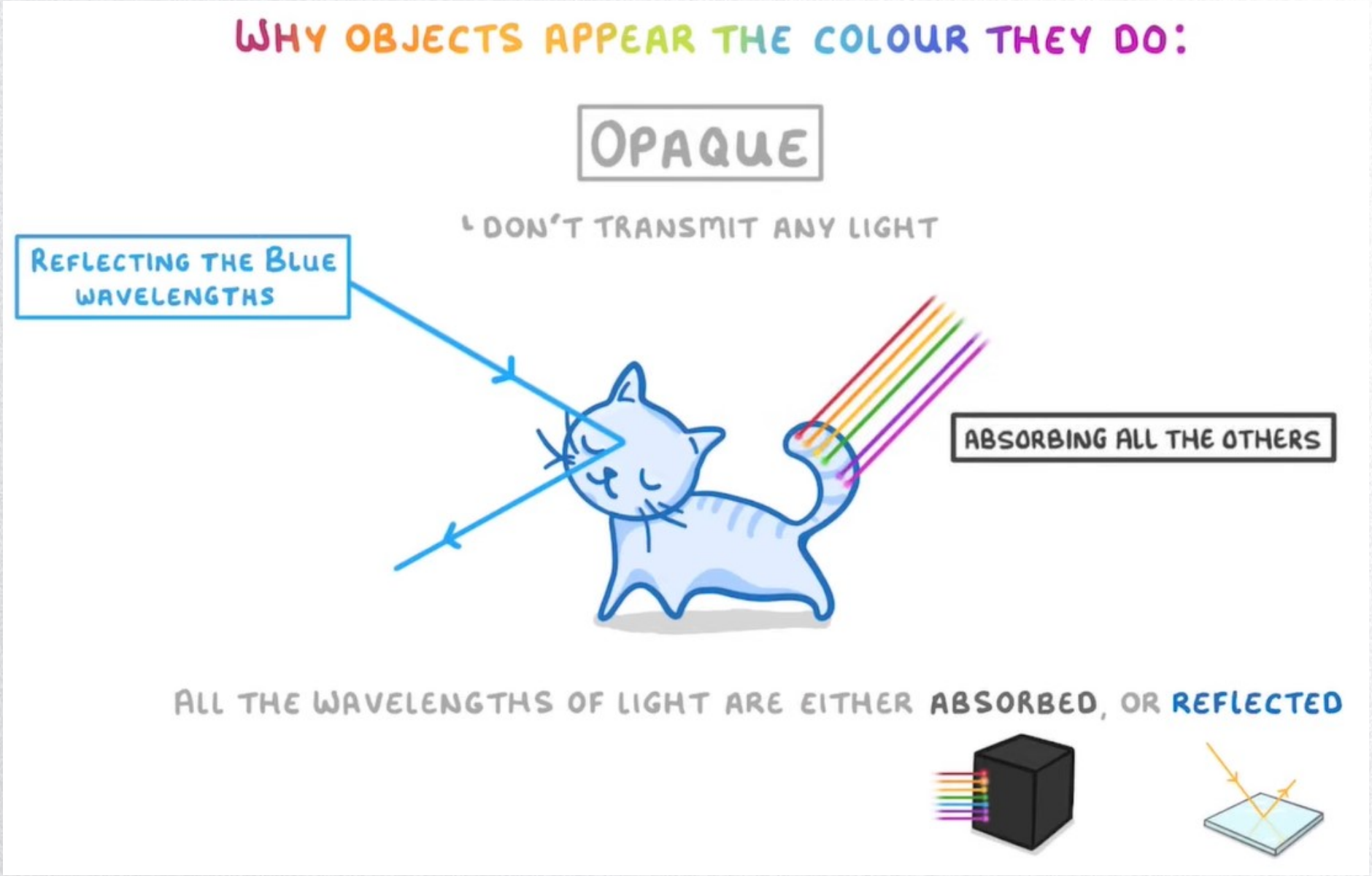
Microwaves & Infrared (IR)



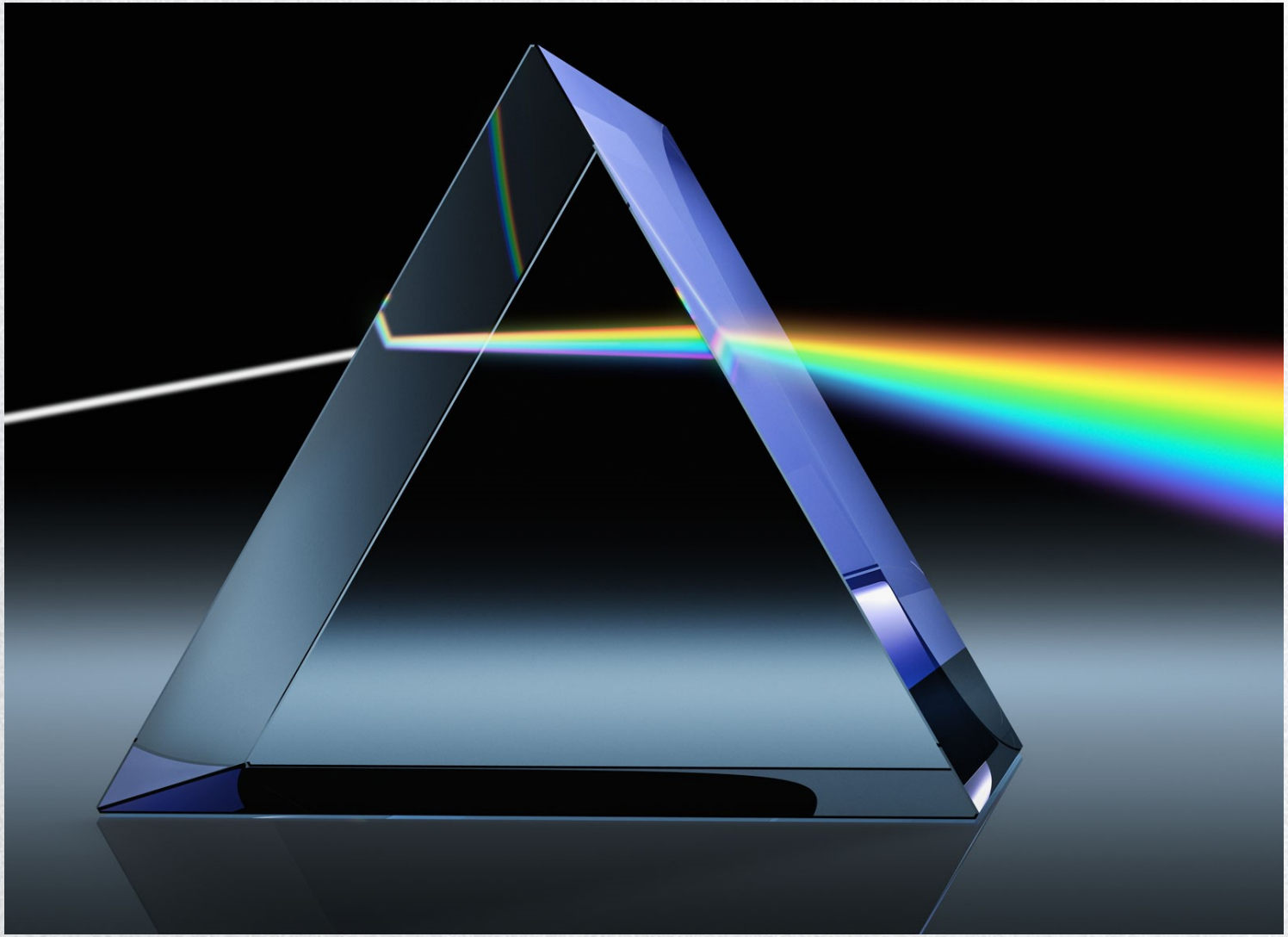
Visible light



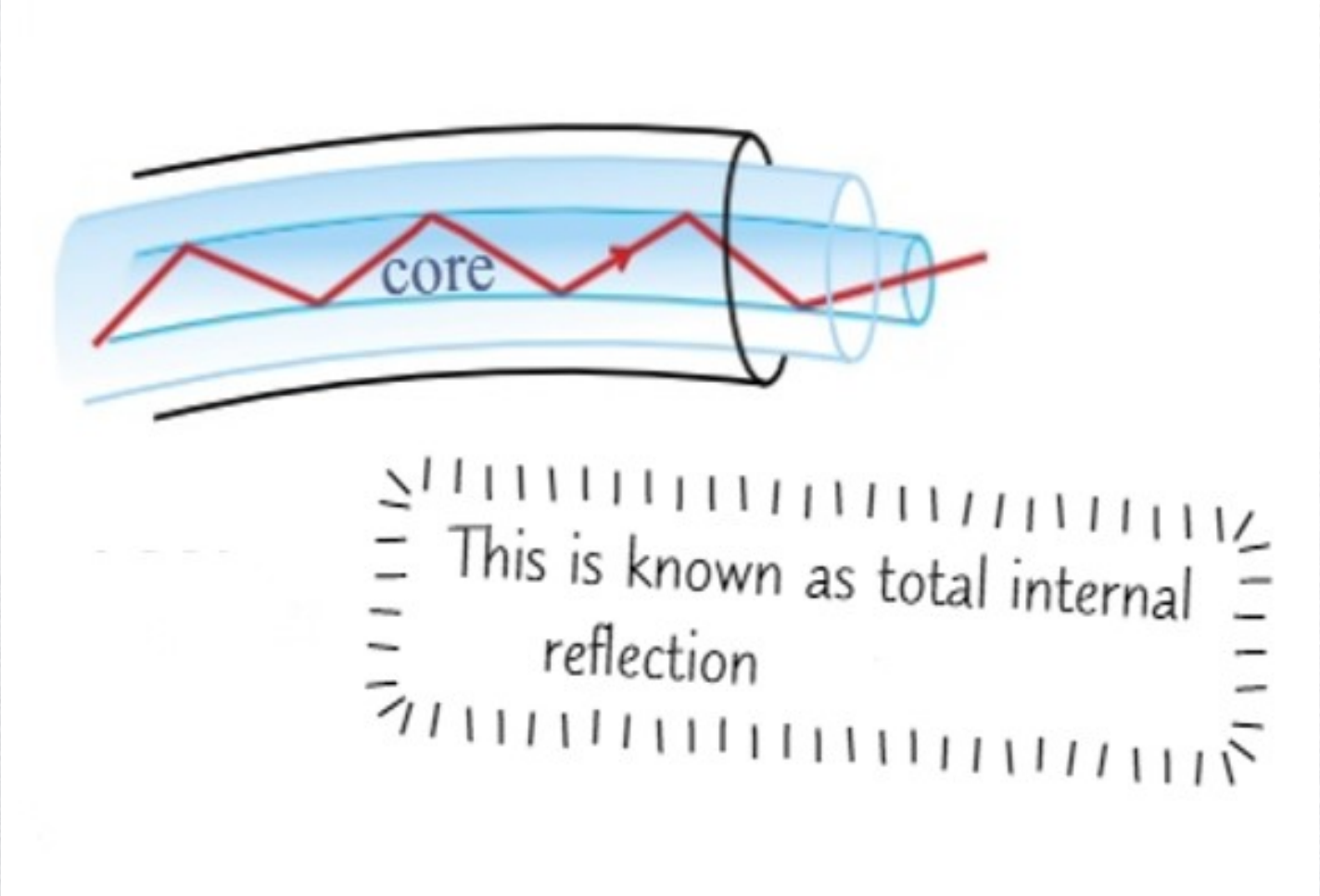
Visible light



White light & Dispersion



Light signals

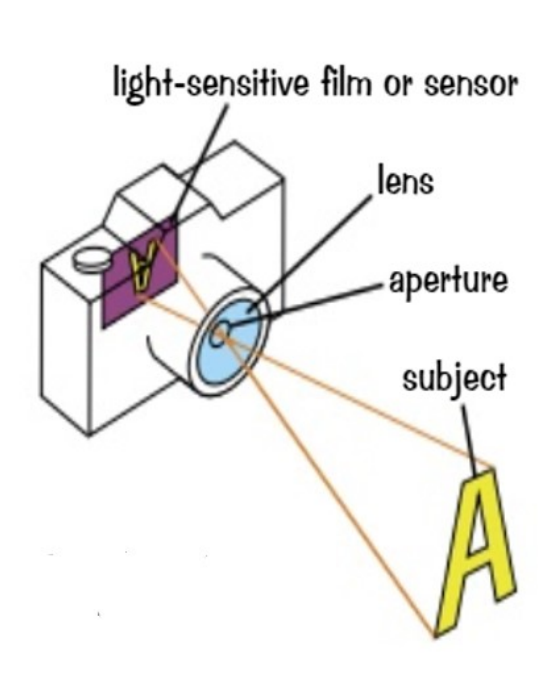


Light signals

Light signals can travel through optical fibres:

1) *As well as using it to look at things around us, visible light can be used for communication using optical fibres – which carry data over long distances as pulses of light.*
2) *Optical fibres work by bouncing waves off the sides of a very narrow core.*
3) *The pulse of light enters the fibre at a certain angle at one end and is reflected again and again until it emerges at the other end.*
4) *Optical fibres are increasingly being used for telephone and broadband internet cables. They are also used for medical purposes to see inside the body without having to operate.*

Visible light



Visible light is also useful for photography

1) Cameras use a lens to focus visible light onto a light-sensitive film or sensor.
2) The lens aperture controls how much light enters the camera.
3) The shutter speed determines how long the film or sensor is exposed to the light.
4) By varying the aperture and shutter speed (and also the sensitivity of the film or the sensor), a photographer can capture as much or as little light as they want in their photography.

Ultraviolet (UV)

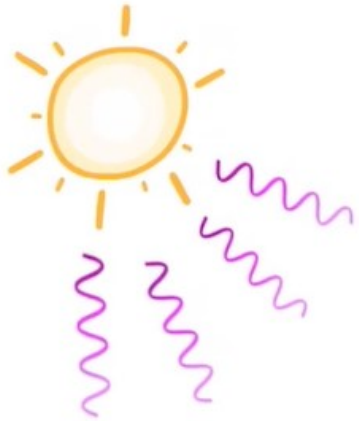
Ultraviolet is used in fluorescent lamps

1) Fluorescence is a property of certain chemicals, where ultraviolet radiation (UV) is absorbed and then visible light is emitter. That's why fluorescent colors looks so bright – they actually emit light.
2) Fluorescent lights use UV radiation to emit visible light. They're safe to use as nearly all the UV radiation is absorbed by a phosphor coating on the inside of the glass which emits visible light instead.
3) Fluorescent lights are more energy-efficient than filament light bulbs.
4) The sun also emits a lot of UV radiation – it can cause damage to skin cells.

Ultraviolet (UV)

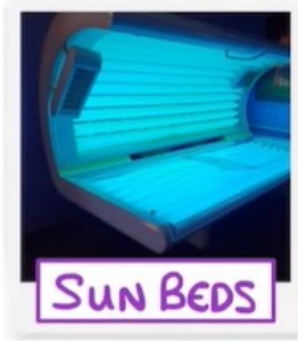
RADIO WAVES	MICRO WAVES	INFRA RED	VISIBLE LIGHT	ULTRA VIOLET	X-RAYS	GAMMA RAYS
$10^{4}m - 1m$	$10^{-2}m$	$10^{-5}m$	$10^{-7}m$	$10^{-8}m$	$10^{-10}m$	$10^{-15}m$

└ SHORTER WAVELENGTH THAN VISIBLE LIGHT



└ SUN TAN

└ SUN BURN

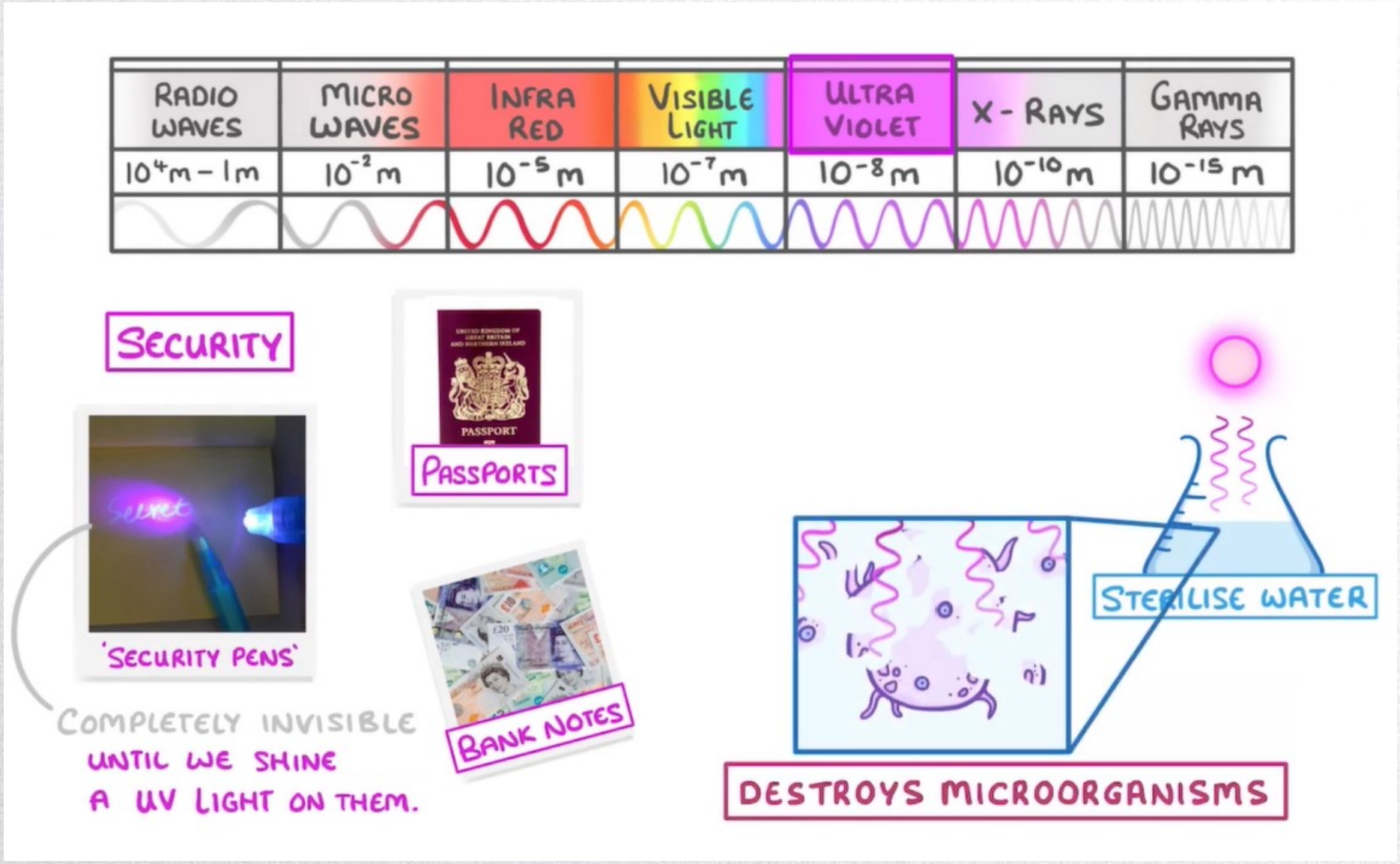


FLUORESCENCE

- ULTRAVIOLET LIGHT IS ABSORBED
  - ENERGY RE-EMITTED AS VISIBLE LIGHT

EMITTING LIGHT

Ultraviolet (UV)



Ultraviolet – Security

Ultraviolet – Security

Ultraviolet – Security

Ultraviolet – Security

Ultraviolet – Security

X-rays

X-rays let us **see inside things**

1) X-rays are used to **view the internal structure** of objects and materials, including our bodies – which is why they're so useful in medicine.
2) To make an x-ray image, x-rays are directed through the object or body onto a detector plate. The brighter bits are where fewer x-rays get through. This is a **negative image**.
3) Radiographers in hospitals take **x-ray photographs** to help doctors **diagnose broken bones** – x-rays pass easily through flesh but not through denser material like bones or metal.
4) Exposure to x-rays can cause **mutations** which lead to **cancer**, so radiographers and patients are protected as much as possible by **lead aprons and shields**, and exposure to the radiation is kept to a minimum.

Gamma radiation

Sterilizing medical equipment

1) Gamma rays are used to sterilize medical instruments by killing all the microbes.
2) This is better than trying to boil plastic instruments, which might be damaged by high temperatures.

Sterilizing food

1) Food can be sterilized in the same way as medical instruments – again killing all the microbes.
2) This keeps the food fresh for longer, without having to freeze it or cook it or preserve it some other way.
3) The food is not radioactive afterwards, so it's perfectly to eat.

Summary: EM waves

Region	Frequency (Hz)	Wavelength range (m)	Descriptions
radio waves	$10^5 - 10^{10}$	$10^4 - 10^{-2}$	- EM oscillation produced by electric circuits - Received by aerial and used in communication
microwaves	$10^{10} - 10^{11}$	$10^{-2} - 10^{-3}$	- Used for rapid heating in microwave - Used to communicate with satellites, i.e. mobile phones
infrared	$10^{11} - 10^{14}$	$10^{-3} - 10^{-6}$	- All hot objects produce infrared - Used for night googles, burglar alarms (since all humans emit infrared)
visible light	10^{14}	10^{-7}	- Produced by very hot objects such as the Sun - Detected by the eye - Used in optical fibre communication
ultraviolet	$10^{15} - 10^{17}$	$10^{-7} - 10^{-9}$	- Causes fluorescence in some materials - Used with sunbeds to produce sun tan
X-rays	$10^{17} - 10^{19}$	$10^{-9} - 10^{-11}$	- Blackens photographic film - Used in diagnosis (x-ray scan) - Dangerous in high doses
gamma rays	$10^{19} - 10^{22}$	$10^{-11} - 10^{-14}$	- Produced in nuclei radioactive elements - Used in medical diagnosis but dangerous in high dosage

Discoverer of EM waves

Type of EM wave	Discoverer	Year
infrared	William Herschel	1799
ultraviolet	Johan Wilhelm Ritter	1801
radio waves	Heinrich Hertz	1887
X-rays	Wilhelm Rontgen	1895
gamma rays	Henri Becquerel	1896

Typical uses of EM

radio waves	radio and television transmissions, astronomy, radio frequency identification (RFID)
microwaves	satellite television, mobile phones (cell phones), microwave ovens
infrared	electric grills, short range communications such as remote controllers for televisions, intruder alarms, thermal imaging, optical fibers
visible light	vision, photography, illumination
ultraviolet	security marking, detecting fake bank notes, sterilizing water
X-rays	medical scanning, security scanners
gamma rays	sterilizing food and medical equipment, detection of cancer and its treatment

Typical uses of EM

Many important systems of communications rely on EM radiation including:
(a) **Mobile phones (cell phones)** and wireless internet use microwaves because microwaves can penetrate some walls and only require a short aerial for transmission and reception
(b) **Bluetooth** uses radio waves because radio waves pass through walls but the signal is weakened on doing so
(c) **Optical fibres (visible light or infrared)** are used for cable television and high-speed broadband because glass is transparent to visible light and some infrared; visible light and short wavelength infrared can carry high rates of data

Harmful effects of EM waves

microwaves	internal heating of body cells
infrared	skin burns
ultraviolet	damage to surface cells and eyes, leading to skin cancer and eye conditions
X-rays	mutation or damage to cells in the body
gamma rays	mutation or damage to cells in the body

Uses of EM Waves

Study question:

Suggest one advantage of using gamma rays to sterilize medical instruments instead of boiling them.

Uses of EM Waves

Study question:

Suggest one advantage of using gamma rays to sterilize medical instruments instead of boiling them.

Gamma rays are less likely to damage some types of plastic instruments than boiling.

Uses of EM Waves

Electromagnetic radiation has many uses.

Draw a line from each use to the type of radiation it requires.

use	type of radiation
detecting an intruder at night	radio waves
communicating by satellite for a telephone	microwaves
detecting broken bones in the body	infra-red
	visible light
	ultraviolet
	X-rays
	gamma rays

[3]

[Total: 3]

Uses of EM Waves

Answer	Marks
→ infra-red → microwaves → X-rays	3