Physics, Astronomy & Mathematics

Outreach Demonstration Booklet

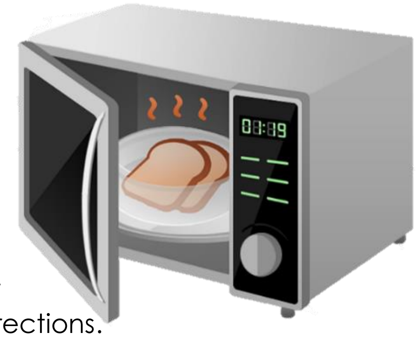
December 2019

Physics, Astronomy & Maths Demonstration & Activities

Contents

Measure the speed of light with a microwave

Introduction



In 1887, Michelson & Morley carried out an experiment to detect the "luminiferous aether". The logic at the time was that sound-waves travel through air, and waves travel through water, so shouldn't electro-magnetic waves (light!) also travel through some sort of material?

The experiment proved that the aether did not exist and that space was empty, by comparing the speed of light in two directions.

It was expected that the speed of light in the direction that the Earth travels around the Sun would be faster (e.g. the speed of light + the speed of the Earth) than the speed of light in the perpendicular direction. This is what we expect from our everyday experience - if a ball is thrown along a train carriage, it travels at the speed of the ball *plus* the speed of the train.

But the Michelson-Morley experiment proved otherwise. Whether you are stood still or stood on the Earth orbiting the Sun at 70,000 miles per hour, the speed of light is the same! The result of this breakthrough experiment stunned scientists, and lead to Einstein developing his theory of Special Relativity a few years later.

Method

You too can measure the speed of light, by simply using a microwave oven!

1. Remove the rotating plate
2. Add a (non-metallic) tray of a food that easily melts – such as cheese slices, chocolate or marshmallows.
3. After cooking on high power for 30-60 seconds, you will notice parts of the food has melted, while other parts haven't.
4. Measure the distance between the melted parts of the cheese. It should be about 12.2cm – that is our wavelength. The frequency of the microwaves is usually found on the back of the oven (2.45GHz).
5. Use: *Speed = frequency x wavelength* (or $C = f\lambda$ in shorthand maths) to calculate the speed of light to be 2.99 m/s.

TAKE CARE with units when multiplying these together!

Explanation

Interference patterns build up in a microwave oven. In some places the microwaves (which are just a type of light) bounce around the oven and cancel each other out – *destructive interference* – while in other places, the microwaves combine with each other – *constructive interference*. This is why microwave ovens need turn-tables to ensure food is evenly cooked.

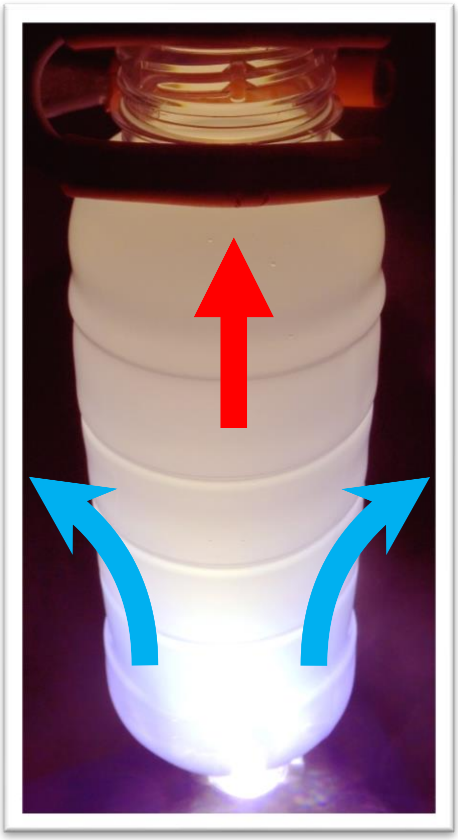
REMEMBER: This is the speed of light through air, which is essentially a vacuum. Light travels 1.333 times faster in vacuum than in water - we say water has a refractive index of 1.333.

Atmosphere in a bottle

Introduction

Why is the sky blue and the Sun red at sunset?

It is all to do with light scattering off air molecules. *Blue light bends best*, which is why the sky is blue – the blue component of Sun light is scattered around the sky as it passes through the atmosphere. The red component just goes straight through. This also explains why the Sun appears so red at sunset – the blue light is scattered away from the line of sight, up into the sky, leaving only the red light from the Sun left.



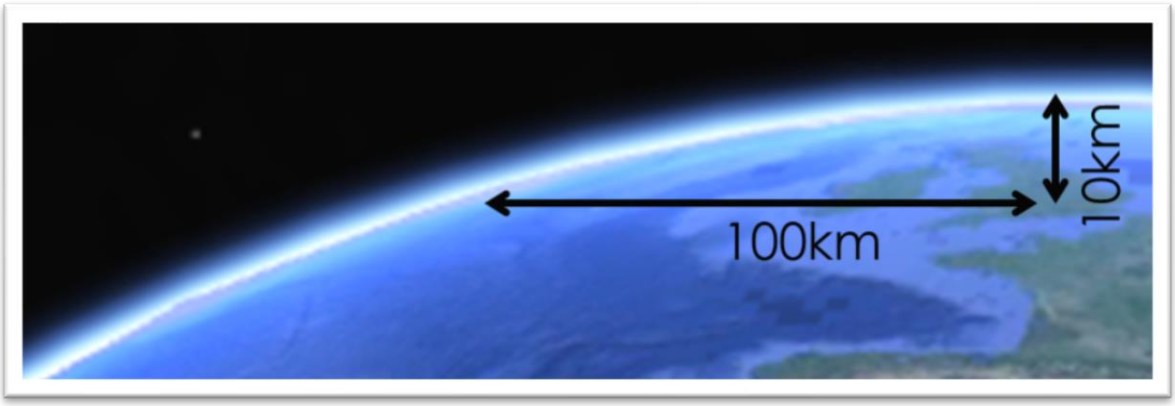
This is more pronounced at sunset, as sunlight is travelling through more atmosphere – 100km rather than just 10km (which is caused by the curvature of the Earth as shown below).

Method

This effect can be simulated in a plastic bottle. Simply add a few drops of milk to a bottle of water, and shine a light at the bottom – I use a bright bicycle light!

If you use a volunteer of a clamp to hold the bottle, you can see the blue light coming out of the sides and look down into the bottle and you see mainly red light (since all the blue light has been scattered away).

Note that it is worth experimenting with the amount of milk – I keep adding drops of milk, or pouring a bit away and adding more water, until I get the desired effect.



Polarised Light

Introduction

Polarisation is a property of light – it is the direction in which a wave of light oscillates. Surprisingly, the use of this property is widespread, predominantly in LCD TV's & monitors. In this activity we explore polarised light with some surprising and colourful results.

Equipment List

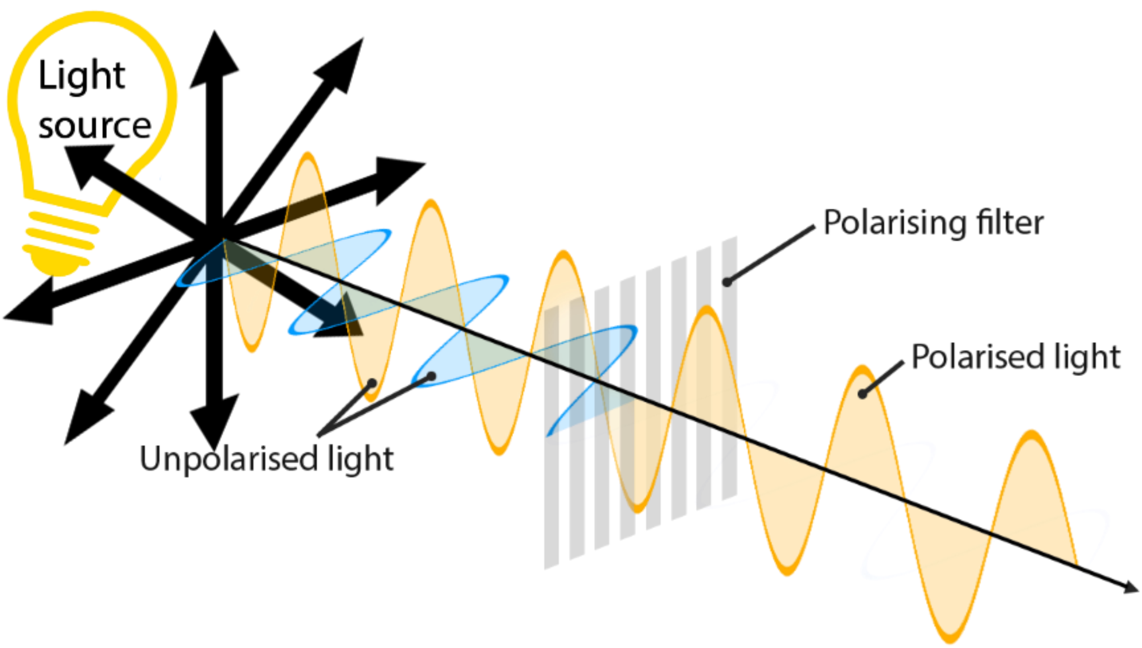
- ☐ Linear polarising filter x 2 (~£10-£15 per A4 sheet; alternatively, polarising sunglasses)
- ☐ Some of the following items to look at through polarised light:
  - Sellotape
  - Plastic beaker
  - Plastic ruler/protractor
  - glue sticks
  - cling film
- ☐ Light table (optional)
- ☐ Old computer monitor, with the polarising layer torn off (optional)

Workshop Overview

After introducing light and polarised light, we use it to show material stress points of various materials, how polarised light is used with computer monitors, and do some experiments with Sellotape (scotch tape).

Light & Polarised Light

Light is made up of tiny waves or packets of energy, which we call photons. We can see some of these photons with our own eyes. Blue photons with higher energy have a shorter wavelength, and red photons have less energy and a longer wavelength. It's weird, but we have to think of these packets of light as both a particle and as a wave.



This wave comes towards us in all directions – up and down (just like a drop of water on the beach), but also left & right and at all angles in between.

Polarising filters allow only light oscillating in a certain direction to pass through it. After light passes through a filter, it is polarised – that is, the light is only oscillating in a single plane.

Once light is polarised, it can serve a range of useful purposes, as we will now demonstrate.

Material Stress

Pass light through a polarising filter, then through the target plastic object (e.g. a plastic ruler), and finally through a second filter, and the stress points of the plastic target object will be clearly visible. The different colours are caused in a similar way to how a prism breaks up light – as the polarised light passes through ruler, it passes at different speeds and the wavelength of light is compressed the wavelength producing different colours

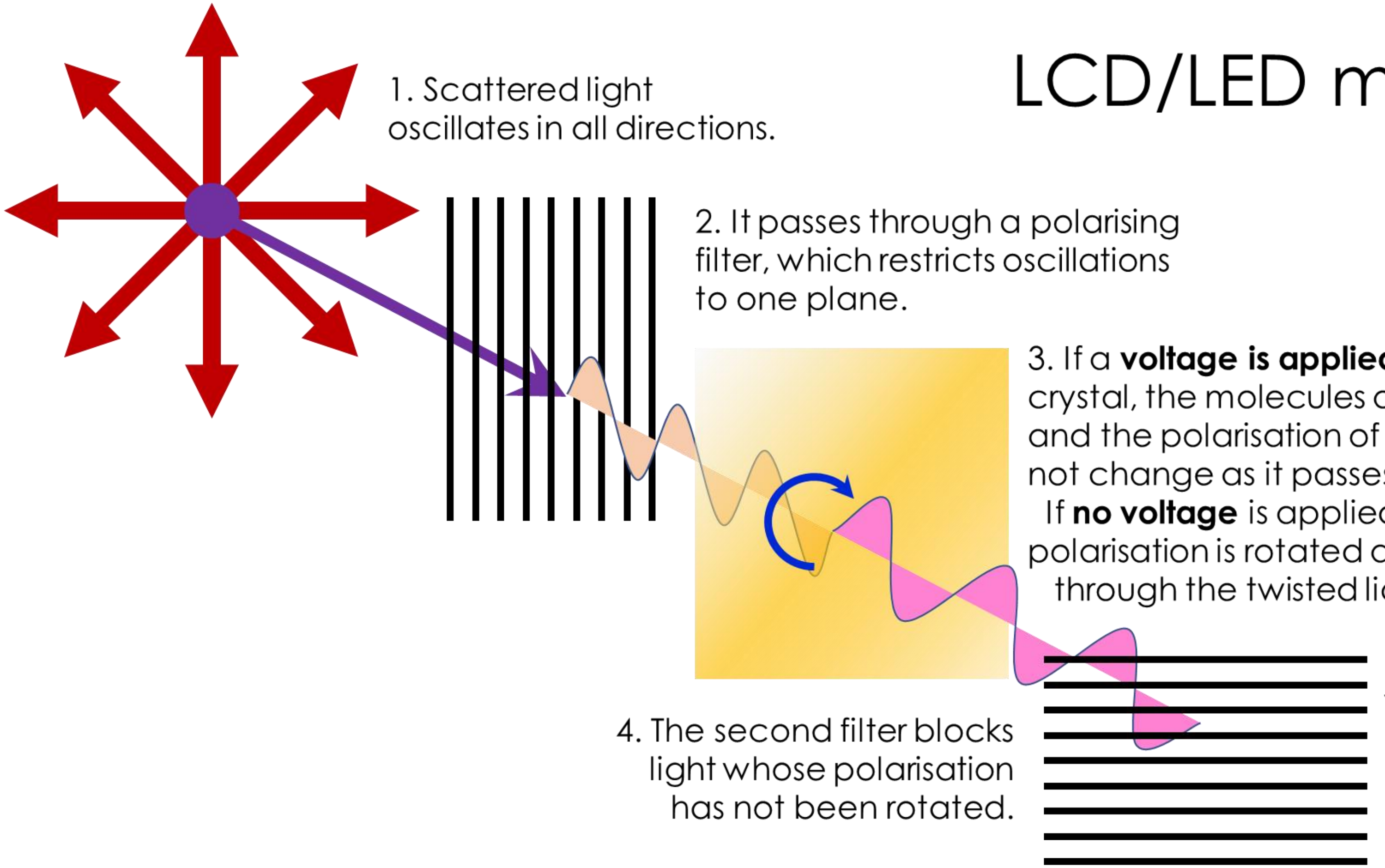
LCD monitors

Liquid-crystal display (LCD) monitors work using polarised light as follows.

1. White light from the back of the monitor passes through a sheet of linear polarizing filter.
2. That polarized light then passes through a layer of *liquid crystal* which can be organized in pixels (for a TV or computer monitor) or in a seven-segment display (calculators).
3. On the viewing side of the display, there is a second linear polarizing sheet, oriented at 90 degrees to the first.
4. The molecules are naturally twisted (helical), and so as the polarised light passes through them, it's polarisation is twisted by 90 degrees allowing them to pass through the second sheet. An LCD screen is naturally bright white as all the light is allowed through by default.
5. However, when a voltage is applied across a pixel, the molecules straighten out, and light can pass through without a change in polarisation. This light is then blocked by the second polarising filter on the front of the monitor and the pixel appears dark.
6. This allows the amount of white light passing through from the back to the front of the monitor to be electrically controlled. When voltage is applied, light is blocked by the front polarizer, and the pixel appears dark. With no voltage applied, the light gets straight through.
7. To get a colour image, red, green and blue filters are applied.
8. Intermediate voltages create intermediate rotation of the polarization axis and the pixel has an intermediate intensity.
9. So we see the colour of the pixel change with voltage. Similarly, a prism splits white light into different colours using the change in refractive index at the boundaries of the glass.

The use of polarization in the operation of LCD displays is immediately apparent to someone wearing polarized sunglasses - the monitor appears normal when you tilt your head one way, and black when you tilt your head another way!

LCD/LED monitors



A dramatic demonstration of how LCD monitors work can be achieved by removing the polarising filter from the front of a monitor. Once this is done, the screen appears white, as we see all the light coming through the liquid crystal, no matter which way the light is polarised. But by placing a polarising sheet in front, or wearing polarising sunglasses, the normal image reappears.

Sellotape demonstration

Sellotape works in much the same way as the liquid crystal in the monitor. Light passes through the first polarising filter and so is polarised in one direction. The Sellotape, depending on how it has been folded and so stretched, rotates the plane of polarisation one way or another. The second sheet of polarising blocks the light that is rotated one way, but allows the other to come through, producing dramatic colours differences depending on how the molecules in the Sellotape has been stretched. The polarising filter is essentially amplifying the contrast between polarised light that has been rotated one way, but not the other. The colours are caused by how much the Sellotape has been stretched, which changes the refractive index.

Magnetic Cannon / Gauss' Gun

Introduction

The first rule of the magnetic cannon is… Do not mention the word cannon or gun, in order to maintain the element of surprise!

This is just a nice (surprising) demonstration of momentum conservation, very similar to a Newton's Cradle.

Equipment List

- ☐ A strong (neodymium) magnet
- ☐ Steel ball bearings
- ☐ A track (e.g. electrical trunking, but any grove will do)

Demonstration Overview

A suggestion method for demonstrating the magnetic cannon is as follows:

1. Telle the audience what you have – a strong magnet and 5 non-magnetic steel ball bearings.
2. Place the magnet on the track.
3. Ask the audience what will happen if we roll a ball towards the magnet – will it attract or repel?
4. Get a volunteer to do that, and the ball will be attracted with quite a violent collision.
5. Do the same with a few more balls *on the same side*, asking what will happen each time. Point out that the collisions are getting weaker each time due to the magnetic field strength fading away with distance – actually, with distance squared. While this is all true, it is mainly a bit of distraction, to help push down expectations and so makes the cannon effect even more of a surprise.
6. Once we have 3 or 4 ball bearings on one side, ask the audience what will happen if we put a ball on the other side?
7. Get someone to do this.

The main surprise originates from the speed of the ejected ball bearing. We don't really notice it, but within the last few millimetres, the ball bearing really accelerates towards the magnet. As with all collisions, the momentum from that speeding ball is passed on down the line to the ball bearing that is far enough away that it can easily escape, only feeling a weak magnetic field.

Get the audience to carry out their own experiments. What happens with one on each side, or two on one side and none on the other? The cannon only work when there is one more ball on the far side compared to the impact side, as some energy is lost in the collision (as heat & noise). Having additional balls on the impact side also works (if there is one more ball on the far side), but the ball doesn't get close enough to the magnet to be accelerated to high velocities, and so the ball is ejected at a much lower speed.

Inflatable Solar System

Introduction

The inflatable planets demonstration is mainly aimed at primary school children and provides a hands-on activity that provides them with a good sense of the basics of the solar system. It is divided into three parts, earth/sun, earth/sun/moon and the whole solar system.

NOTE: The inflatable planets puncture very easily, especially Saturn due to how the rings are attached to the planet. Do tell the kids that they are delicate, and that if anyone is caught throwing the planets around or doing anything else that could damage them, then we will remove them from the activity.

Equipment List

- ☐ Inflatable planets (Sun, Earth -> Pluto, Moon)
- ☐ Electric pump or people willing to blow them up!
- ☐ Ball Bearing ~ 5mm in diameter.
- ☐ Torch (with batteries)

Workshop Overview

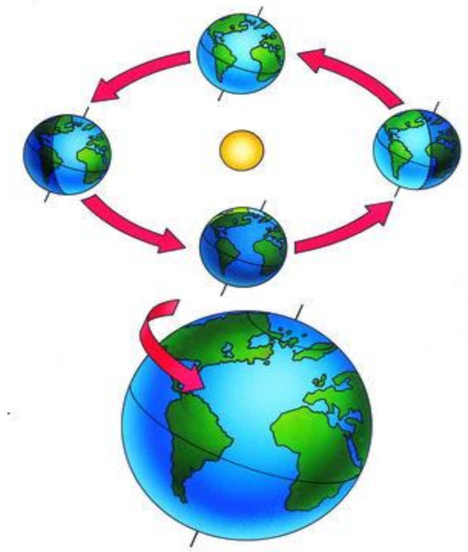
ACTIVITY		**Time**	**Σ**
Earth & Sun:	day/night, sizes, the seasons	10 min	10 min
Earth & Moon:	sizes, months, reflecting light from the sun, tidal locking	15 min	25 min
The Solar System:	names & order, overview, "scaled solar system"	40 min	65 min

Setup

- Inflatable planets either by mouth, foot pump or electrical pump. With the foot pump this should take under 30 minutes but can take much longer depending on how many people are available to help.

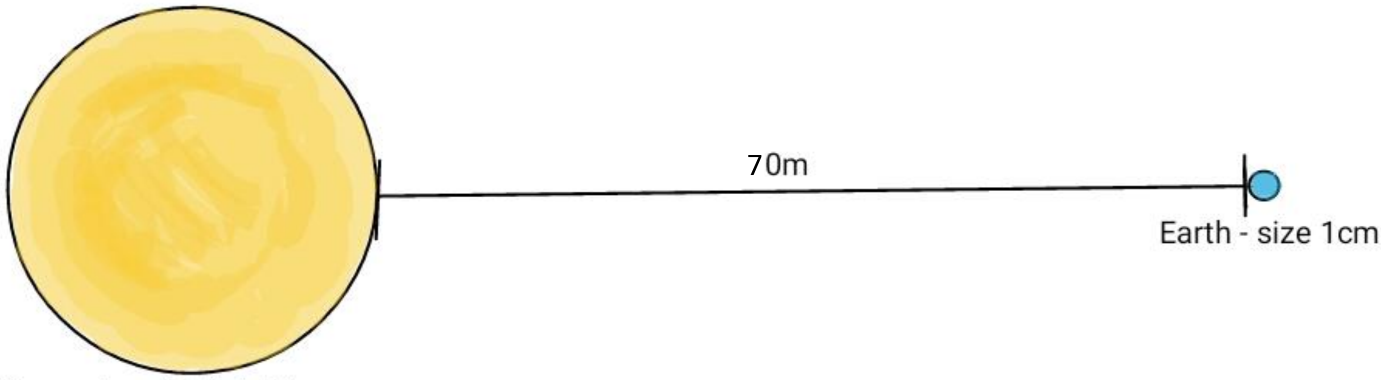
The Plan

- Duration – approx. 30 or 90 minutes
- ***Earth & Sun*** – approx. 10 minutes
    - With two volunteers holding the Earth and the Sun, demonstrate how the Earth goes around the Sun and discuss the how long this takes (e.g. a year), and how the Earth's rotation on its axis gives you day and night. It can be effective to use the torch to act as the Sun shining on the surface of the Earth, by having a third volunteer stand by the Sun and point it toward Earth with the classroom lights turned off.



    - *OPTIONAL*: Explain that the earth is tilted on its axis, which is why the Earth experiences seasons. During the Earth's yearly orbit of the Sun, for part of the time the North Pole is tilted toward the Sun, giving a northern summer. Six months later it is tilted away, giving it a northern winter. Summer in the north coincides with winter in the south.
    - Discuss the scale of the Sun to the Earth. Ask the class to guess if the Sun was actually the size of the inflatable Sun, how big the Earth would be and at what distance it would orbit. The Earth would be approximately 1cm across and would orbit around 70m away. Show the class the ball bearing (or a ball of Blu-tack) included in the equipment and let them know that the Earth fits into the Sun just over a million times.

      Note that on this scale, the next nearest star would be 16,000km away in Sydney, Australia!

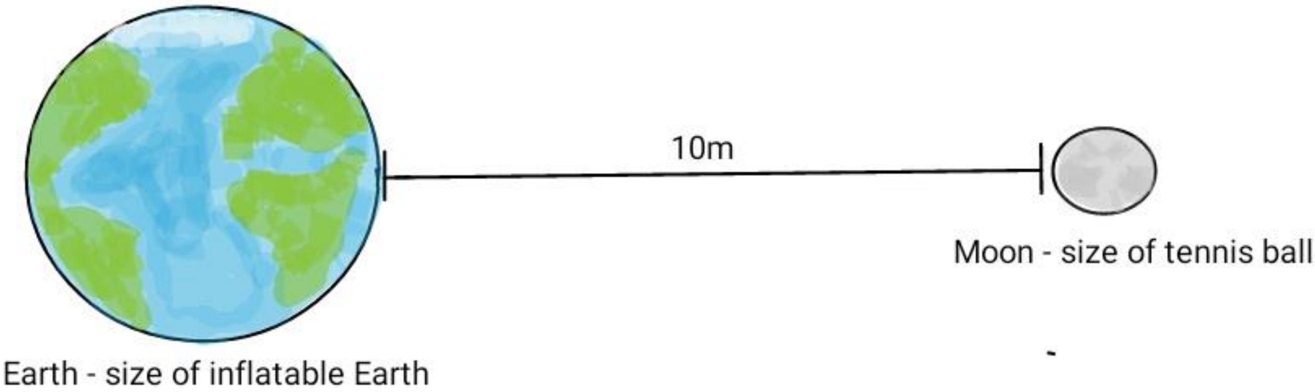


- ***Earth & Moon*** – approx. 15 minutes

    - With three volunteers holding the Earth, Sun and the Moon, and a fourth standing by the Sun with a torch to act as the light from the Sun.

    - Earth is approximately four times the size of the moon, separation is 30x earths diameter (can do this to scale probably)

    - Using the inflatable Earth, the Moon would be the size of a tennis ball and 10m away.



    - The Moon orbits the Earth every month – hence the name. To be exact, the synodic orbital period is 29.5 days.

    - Moon orbits the Earth 12 times a year (once every 29.5 days), with 11 days left over. So each month gets an extra day. However ancient people couldn't agree on which months got extra days, and that's why our calendar is a mess.

    - The Moon's "day" length (time to rotate once) is also 29.5 days, so this means the same side of the moon always faces the earth.

    - Talk about how the Moon reflects light from the Sun, doesn't radiate light itself. Move the Moon around the Earth in order to show how the phases of the moon happen. The torch may be useful here if you can make the classroom dark.

    - The gravitational pull of the Moon upon the Earth is small compared with the Sun. The effects the Moon's gravity causes the tides of the oceans on Earth. As the Moon's gravitational force pulls on the water of the oceans it causes 'bulges' in the ocean on both sides of the planet. Throughout the day as the Moon rotates the Earth the water 'bulges' in different parts of the planet.

    - Far side of the Moon is sometimes called the dark side of the Moon. This is wrong, half the time it's the light side! It's just that we never see it because the same side is always facing us.

- **The Solar System** - 40 minutes
    - With 10 volunteers, one for the Sun and nine for each of the other planets.
    - At this point, you can ask the class to try and name the planets and see if they can guess which planet each inflatable represents, and the order in which they are from the Sun.
    - Keep them guessing and encourage the class to interact. It is guaranteed that at least one kid will know this off by heart.
    - Once they're in order, talk about each planet quickly in turn.

I. **The Sun**

The Sun is a star, not a planet. As far as stars go it is fairly ordinary star of average size. Surface is around 6000 degrees; core is millions of degrees due to all that stuff being squashed down. Know this by its colour, blue stars are hotter, red stars are more cold (but still hot!)

II. **Mercury:**

Closest planet, small, orbits very fast (88 days), very hot (around 400C). No atmosphere or anything because it's so small it can't hold onto it, the sun just blew it all away. Full of craters because the atmosphere isn't there to protect it.

III. **Venus**

The hottest planet, further away than mercury but its thick clouds and atmosphere trap heat inside, like a greenhouse. This makes it even hotter than mercury. About 100 years ago it was thought that Venus was "earth's twin" and maybe had aliens. We know this isn't true now because it is so hot and there are huge clouds of acid, nothing could possibly live there.

IV. **Mars**

Two moons (Phobos, Demios, tiny). Most likely candidate for life, we have a robot called curiosity there finding out about its surface and maybe even finding signs of life. Smaller than earth and much colder, it's thought maybe when the solar system was much younger it could have been warmer and have liquid water, and on earth, where you find water you tend to find life, so we think maybe this applies to other planets too. It's red because the rocks contain lots of rust (Iron oxide).

V. **Jupiter**

60+ moons (Ganymede, Europa, Io, Callisto are biggest). The largest planet, so large that it is bigger than all the rest combined. Made mainly of gas, which swirls around it in bands (which is why it's stripy). Big hurricanes rage over its surface, the biggest of which, called "the big red spot" could fit 3 earths inside of it and has been raging for over 300 years. Imagine if thunderstorms on earth did that!

VI. **Saturn**

60+ moons (titan is the biggest moon in the solar system) the planet is like Jupiter but smaller, mainly made of gas. The cool part is the rings, which are made of tiny pieces of rock and ice, which is why they are so reflective. The ice is always crashing into each other which makes it crack apart, exposing new clean surfaces. Other planets have small ring systems but they aren't visible without a very powerful telescope.

VII. **Uranus**

27 moons. Orbits around on its side rather than spinning like a top it sort of "rolls". No one really knows how this happened. People used to think something hit it and made it tip over, but the weird thing is its moons ALSO orbit vertically, so this can't be right. So no one really knows

VIII. **Neptune**

13 known moons. Not much is known about it except it's a big blue gas planet, with occasional white clouds that move across its surface.

IX. **Pluto**

NOT A PLANET! After other large rocks were discovered beyond Pluto, in 2006 we came up with 3 criteria for a planet. 1) Be big enough to squash yourself into a round shape. 2) Orbit the sun, not anything else. 3) Clear your path of obstacles. Pluto doesn't pass this as debris exists in its orbit, two of which are called nix and hydra. So, it was renamed a dwarf planet. Two other factors that suggest it is not a planet are i) the rest of the planets all orbit in a plane, while Pluto's orbit is highly inclined; ii) Pluto's orbit is highly elliptical, whereas all the rest of the planets are almost circular.

- Explain that planets nearer the Sun move faster than ones further out (Kepler's Third Law) and have them WALK around the Sun in the middle to make a little solar system!

PLANET	**ORBITAL SIZE**	**ORBITAL SPEED**	**ORBITAL PERIOD**
Mercury	0.387 AU 0.307-0.466 AU	107 000 mph	88 days
Venus	0.722 AU 0.718-0.728 AU	78 350 mph	225 days
Earth	1.00 AU 0.98-1.01 AU	66 630 mph	365.25 days (1 year)
Mars	1.52 AU 1.38-1.66 AU	54 000 mph	687 days (1.9 years)
Jupiter	5.20 AU 4.95-5.46 AU	29 240mph	11.8 years
Saturn	9.58 AU 9.05-10.12 AU	21 640 mph	29.5 years
Uranus	19.2 AU 18.4-20.1 AU	15 290 mph	84.1 years
Neptune	30.1 AU 29.8-30.4 AU	12 250 mph	164.8 years
Pluto	39.5 AU 29.8-49.3 AU	10 700 mph	247.7 years

Orbital size is in Astronomical Units (mean & range). For a scaled solar-system, use the same numbers but different units e.g. meters (in an assembly hall) or feet (across a classroom).

- Take questions!

Background reading

- http://solarsystem.nasa.gov/planets/
- http://solarsystemfacts.net/
- "Wonder of the solar system" TV series, by Brian Cox.
- http://www.youtube.com/watch?v=4fuHzC9aTik

Modern-Day Uses

- Looking at planets inside our solar system and discovering new planets outside our solar system (exoplanets), can tell us more about the Earth, and what other kinds of worlds are out there for us to explore and visit. Research into other planets can spark new ideas for things we can do here on earth. Different types of satellites or learning how different weathers and climates work on other planets.

Careers

- The United Kingdom Space Agency (UKSA) plans to increase the current operating budget from £6Billion to £40Billion, and the number of jobs to 100,000. The European Space Agency (ESA) are also a large employer of people who want to make space related careers!
  www.gov.uk/government/organisations/uk-space-agency
  http://www.esa.int/ESA

Spectral Workshop

Introduction

Spectroscopy is one of the most powerful techniques employed in astronomy. We can't just fly to the sun in order to find out what it's made of, so how do we go about it? Fortunately, it turns out that hot objects give out a spectrum of different wavelengths of light. These spectra have discrete lines in them which can be used to identify the elements they are made up of. This workshop aims to show students how spectroscopy works, and why it is such an important tool in all types of astronomy.

Equipment List

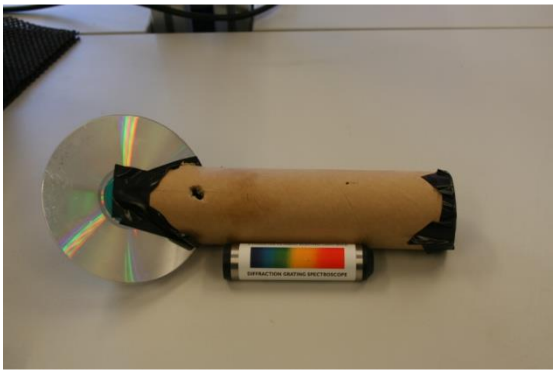
- ☐ Kitchen roll tube (one per group)
- ☐ CDs (one per group)
- ☐ Tape (one per group)
- ☐ Scissors (one per group)
- ☐ Prism
- ☐ 4 x Gas discharge tubes and power supplies
- ☐ 5 x Pocket spectrometers
- ☐ Laminates showing the spectra of different elements
- ☐ Digital camera, video capture equipment and laptop (optional)

Workshop Overview

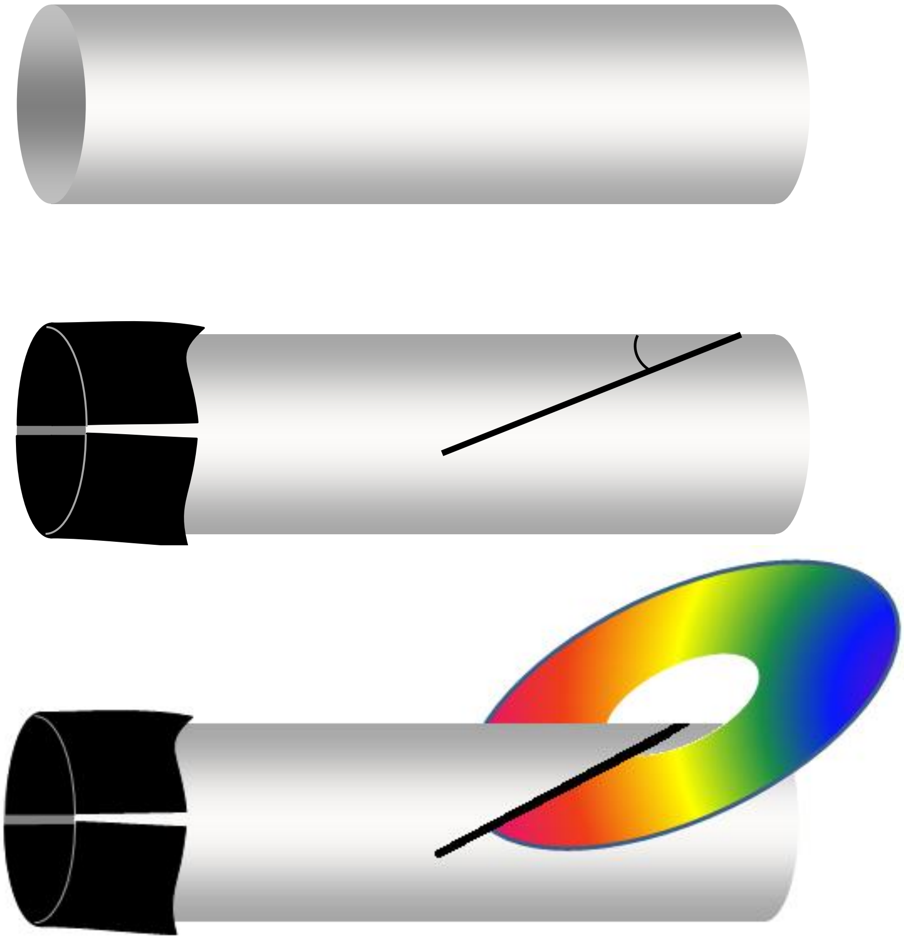
ACTIVITY	**Time**	
Introduction What is a spectrum, rainbows, quantized light?	10min	10min
DIY Spectrometer see plan for instructions, blue sky, light bulbs	20min	30min
Guess the gas Neon (red), Helium(orange), Hydrogen(purple), Mercury(blue)	20min	50min
Closing Talk Discovery of helium, redshift, big bang evidence, exoplanets	10min	60min

The Plan

- Introductory talk: - Duration approx. 10minuets
  - Ask what a spectrum is, who's heard of them? Famous example being a rainbow
  - How are rainbows formed? Show them using prism
  - Explain that when electrons around an atom fall from a higher energy state to a lower energy state, they emit the difference in energy as a packet of light – a photon.
  - Likewise, an electron can absorb a photon to push it up an energy level.
  - Show picture of suns spectrum and show how there are tiny "gaps" in the spectrum, which can be used to work out what it is made of.
  - Talk about how the gaps form: electrons in the solar atmosphere absorb specific wavelengths (the ones that let them transition between energy levels) so that light doesn't pass through, creating a black gap.



- Spectrometer DIY: - duration approx. 20min
  - Help them make the first cut into the cardboard tube at approx. 30 degrees, and about ¾ of the way down the tube. Then let them do the rest themselves. They should look something like the following diagram when they're done.



- Once the students are done building (or ruining) their spectrometers, give out pocket spectrometers to any groups that have ruined their stuff, but try to fix them if possible.

- Mystery Gases: - duration approx. 15 minutes
  - Hand out the worksheets & pens, and unveil the lamps. Explain that their task is to compare the spectra they can see in their DIY spectroscopes with the laminated sheets to work out what gases are in the lamps. The gases are as follows: **Neon (red), Helium (orange/pink), Hydrogen (purple), Mercury (blue).**
  - Once they've all looked at each lamp, get them to look at a light bulb if there's one in the room, and go through the answers. If you have it with you, use the good spectrometer attached to the camera via the adapter and project the spectra on to the screen to confirm the results.
  - Stress that science is mainly about making observations and then writing down what you see. Explain how helium was discovered through this technique when we pointed a spectrometer at the sun.

- Closing talk: - duration approx. 10minutes.
  - When spectroscopes were pointed at stars, we worked out they were made of hydrogen and a new element, helium. It was guessed that galaxies were also made up of stars, and therefore H and He but when we pointed spectroscopes at them, we found they did indeed have the same spectra, but shifted towards the red end of the spectrum by some amount.
  - It turned out this is because of the DOPPLER EFFECT (can talk about how an ambulances siren drops in pitch as it passes you), for light specifically it is called redshift. When you do this for lots of galaxies, it appears that they are all flying away from us in various directions. This means that at some point in the past, everything used to be much closer together, i.e. spectroscopy has given us a good piece of evidence for how the universe came about!

- One more recent use of spectroscopy is used to discover exoplanets (planets orbiting other stars). When a planet passes in front of its star, we can point a spectroscope at it and work out what its atmosphere is made of. Starlight filters through the atmosphere of the planet and gains additional lines which can then be analysed here on Earth. The spectrum on the laminated card shows a prominent peak at around 585nm, which corresponds to orange light. This peak is actually part of the signature of sodium.

Applications

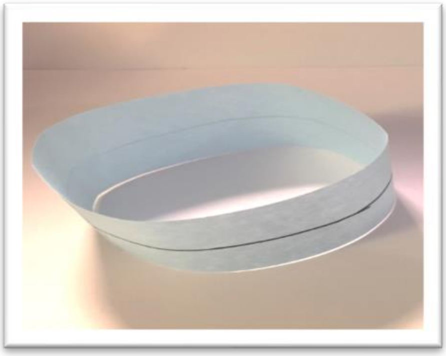
- Astronomy: finding out what distant celestial objects are made from. By taking the ratio of hydrogen and helium can estimate a star's age
- Exoplanets: their atmospheric content can be found which gives us an idea of what kind of planet they are.
- Chemical analysis. If you don't know what a chemical is, burning it and using a spectrometer on the flames can give you a clue as to its constituent elements.
- Background notes – see: http://chemistry.bd.psu.edu/jircitano/periodic4.html

Modern-Day Uses

- Remote sensing
- ALL astronomy (e.g. Cosmological redshifts)
- Industrial precision manufacturing

The Magical Möbius Strip!

Let's explore some interesting surfaces, which can be made from a sheet of paper.

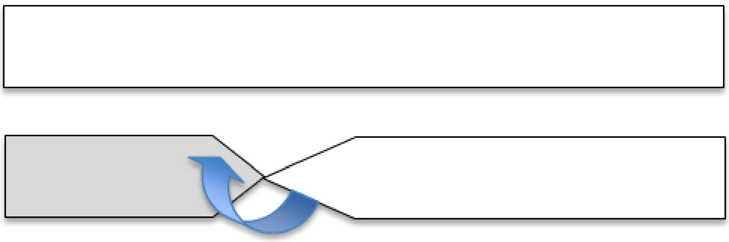


Take a strip of paper and tape the two opposite ends together.

You have just created a surface, called a

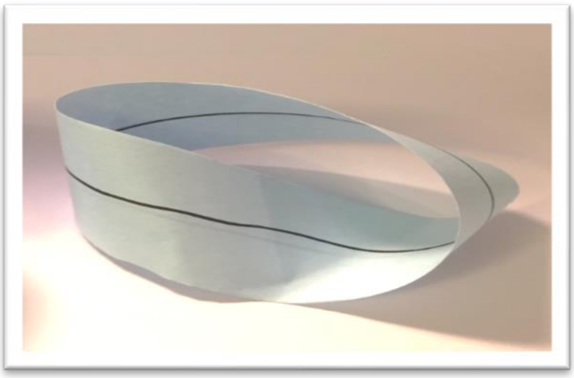
Cylinder

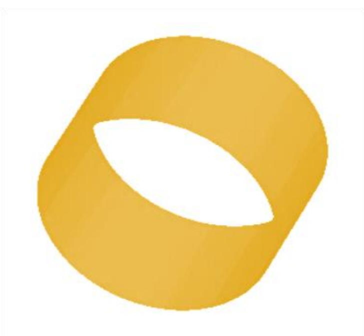
Take another strip of paper, put a twist into the strip by turning one end through half a turn, and then join the two ends together.



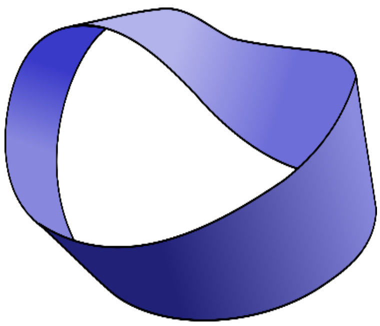
This surface is called a

Möbius Strip





What differences are there between these two surfaces?



Experiments

Can you predict what happens when we cut along these surfaces?

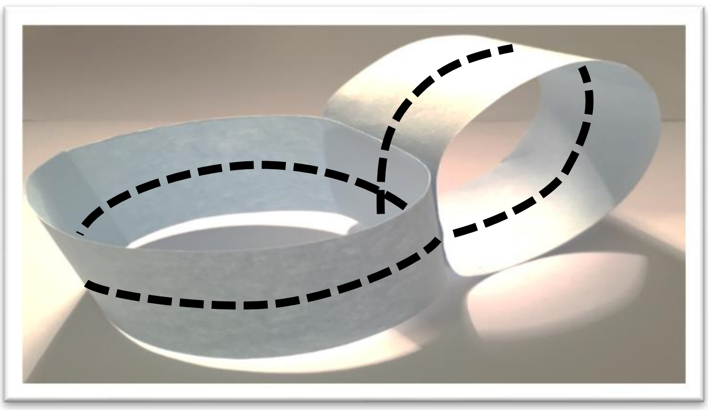
1. Draw a line along the centre of both surfaces.

What do you discover?

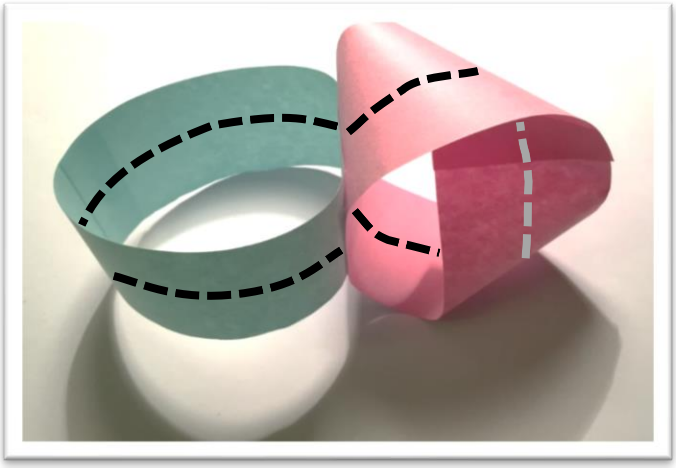
2. Now cut along this line - cut both the **cylinder** and the **Möbius strip** in half. What is the result?

3. Make another **Möbius strip**, but this time make your cut $^{1}/_{3}$ of the way from the edge of the strip. Is the result the same as before?

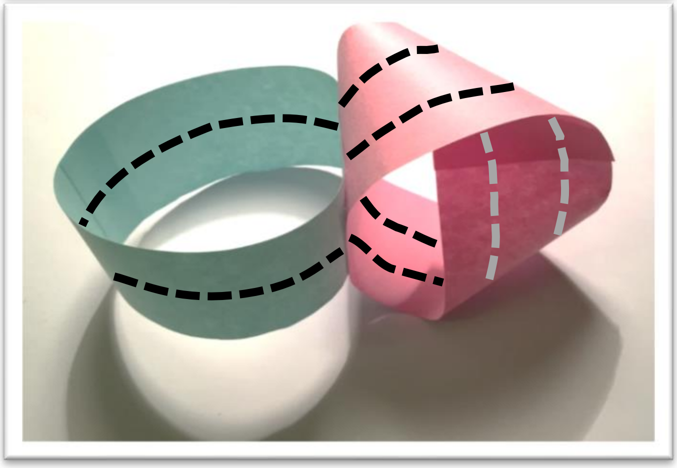
4. Make **two cylinders**. Tape them to each other at right angles. Your result should look like a twisted figure 8. What do you think you will end up with after you cut both strips down the middle (lengthwise)? Now cut down the middle of each loop, you will need to make two cuts to complete this step.



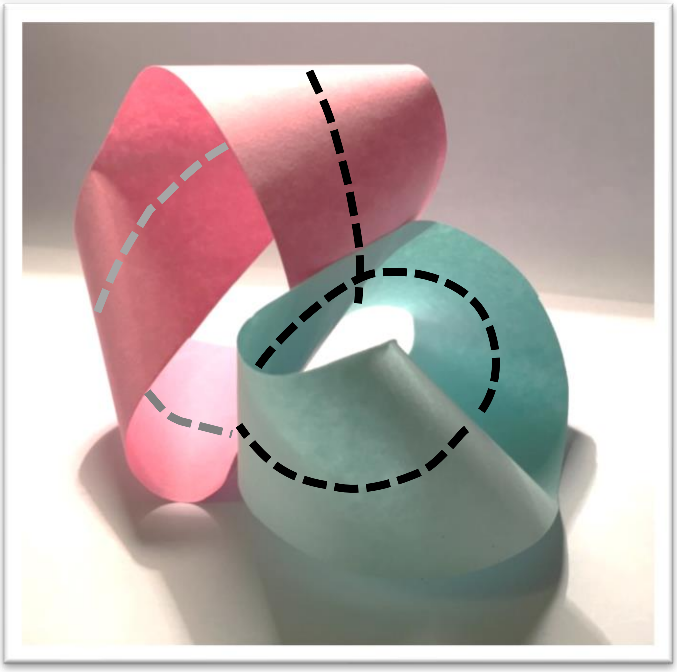
5. Make **one** **Möbius strip** and **one** **cylinder**; tape them to each other at right angles. Now cut them both down the middle, you will need to make two cuts to complete this step. What result are you expecting to get?



6. Follow the instructions for part 5 as above, but this time start cutting the **Möbius strip** **1/3** of the way along the length of the strip, then cut the cylinder in half.



7. Make **two** **Möbius strips**; the two strips need to be twisted in opposite directions, (i.e. the two strips should be mirror images of each other). Now tape the strips together at right angles. Finally, cut along the middle of the strips, cutting right over the taped part where the two strips are fixed together.

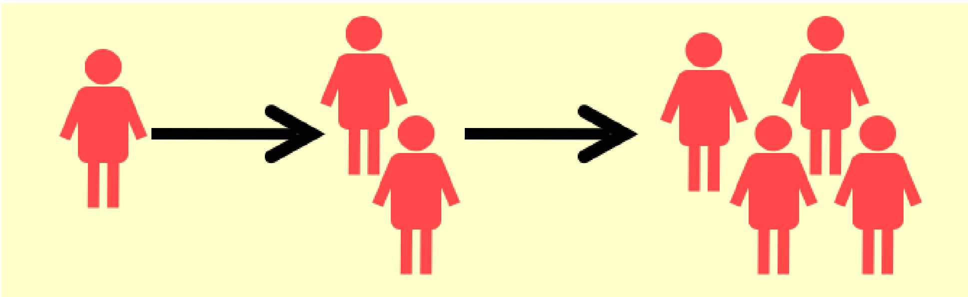


The Infection Game

Introduction

The objective of this game is to help students understand the concept of multiplying by zero and plotting graphs, through studying the spread of an endemic infection. This game simulates the spread of a disease; the interaction that drives it is represented by multiplication of numbers.

All students are assigned number 1, except for one student who is assigned with 0 (this represents the first infected person). In each round, students are required to pair with someone and note down the product of their numbers; this will now be the ***NEW number*** *for* ***BOTH students*** *in the next round. The process is repeated for 10-20 rounds (depending how large the group is), with each result being noted in individual record sheets. Due to repeated multiplication, the more rounds are played, the more products will result in 0, simulating the spread of infection.*
(In a group of 50-60 participants, you should find that by round 9 the vast majority of the population will be infected.)



Mathematical skills involve sketching and interpreting graphs (fitting curves through data points), determining patterns of behaviour over time. At least 30 participants are required to generate a clear pattern of behaviour. To make this game more interesting, do not share the background information mentioned above with students. The aim of the game is to let the students discover the structure for themselves.

Equipment List

Individual Worksheets

- *Individual Record Sheet - Form A*
- *Individual Record Sheet - Form B*
- *Class Record Sheet*
- *Individual Graph Sheet - Form C*

Other resources

- *PowerPoint slides*
- *Pre-made spreadsheet to generate graphs*

Workshop Overview

ACTIVITY

Activity		**Time**	∑
Introduction	Brief discussion about spread of diseases & mathematics behind it (PPT slide 1) Introductory video (PPT slide 2) Recap multiplication exercise (PPT slide 3)	10min	10min
Instructions	Hand out student worksheets Forms A and B, and pens Explain the rules of the game (check lesson plan) Display instructions on board (PPT slide 4)	5min	5min
Game 1	Students exchange numbers for 8-10 minutes Ask leading questions (check lesson plan) Collect results, fill in the *Class Record Sheet*	15min	25min
Discussion	Divide students into small groups, up to 10 people in each Quick discussion of the previous stage, their thoughts Graph plotting	10min	10min
Results	Student's graphs are compared with the graphs of the actual results Discussion of the outcome (check lesson plan for leading questions)	10min	15min

Game 2	Divide students into two groups (countries) "Fly" and "scan" one student at a time across the room	15min	25min

Set up

- Bring up the power point on a projector.
- Have the worksheets ready to hand out for the game. Alternatively hand them out at the start of the session.

The Plan

Introduction 10 minutes

- Start the session by introducing the topic in simple words, using the PowerPoint slides:
  (slide 1)
- *Mathematics is used to predict the future. In this activity, we will see how Mathematicians try to understand and predict the spread of diseases.*
- Play the introductory video (it will help students understand the concept behind the spread of an endemic, bringing everyone to the same level on the topic). (slide 2)
- Before moving on to the game, ensure that students are familiar with the concept of multiplication, including multiplying a number by zero. Run a quick test by asking simple multiplication questions. (slide 3)

Instructions 5 minutes

- Prior to starting the game, you should mention that secrecy is very important.
- Distribute *Individual Record Sheets - Forms A and B*, ensuring that only **one** student is given the *Form A*, this will be your infected participant; and the rest of the students are given *Form B* (uninfected participants).
- Put up the slide with instructions for students, (for the duration of the rounds). Explain the following rules of the game, without revealing the main concept of the game.

Rules of the Infection Game

- You have all been given a sheet to record your individual results of the game. Write your name down in the top right corner.
- Each one of you has been allocated a secret number, which is displayed on the first line of your record sheet.
- The game will run for several rounds. In each round find another student, and quietly tell each other your numbers.
- Multiply your two numbers together, and write down the result on the next line of your record sheet. This will be your new number for the next round.
  For example, if your secret number is a 2 and the other student has a 3, you will both get 2x3=6, so 6 is your number for the next line and the next round.
- Continue to do this until we ask you to stop, or when you have reached the end of your sheet. Please sit down once you have finished.

Game Play 15 minutes

- Start the game; allow up to ten minutes for students to repeatedly exchange numbers, you may need to allocate less or more time, depending on the size of the group.
- When the time is up, ask students to look at the last result on their record sheets (that number should be zero for most of the participants). Ask who had the number **zero** as their ***first entry*** to raise their hand (one person), then ask who had the number **zero** as their ***last entry*** to raise their hands (more or less everyone). You should tell students that it is really important to think about how the

Fill in the *Class Record Sheet as follows:*
*(*results will be used in the final stage of the game to plot two curves)

Fill in the **TOTAL** Number of Zeros column:
- Ask students to raise hands if they had zero as an entry for round one
- Note down this number; repeat the process for each round

To fill in the Number of **NEW** Zeros column you do not need to ask students to reveal their results, instead:
- In the first cell, note the number of students that were initially assigned the number 0 (infected)
- Work backwards, noting down the differences between the cells of the **TOTAL** Number of Zeros column. For example: for round 1 record the difference between the **TOTAL** Number of Zeros in round 1 and the START
- Repeat for each row in the table

number of zeros increased from only one to such a high number; they will need to discuss it later on in the game.

- **Collection of Data**
  Your table should look similar to the following example. Small counting errors will not affect the overall outcome. Do not reveal the collected figures until the final stage of the game.

Class Record Sheet
The Infection Game

ROUND	Number of NEW Zeros	TOTAL Number of Zeros
START	1	1
1	1	2
2	2	4
3	4	8
4		

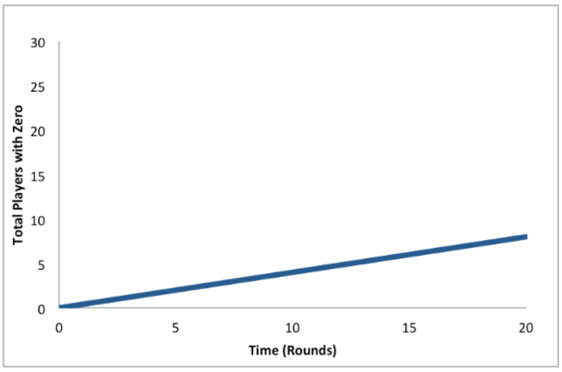
Group Discussions 10 minutes

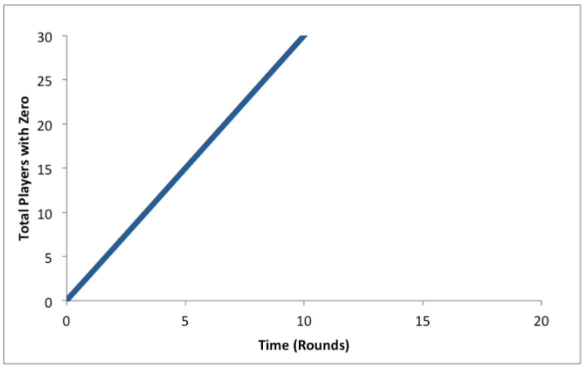
Divide students into small groups of up to 10 children. Distribute *Individual Graph Sheet - Forms C and D*, which will be used to plot graphs.

- **Total Number of Infections** - (use *Form C* for this task)
  - The aim is to encourage each group to discuss how the total number of zeros in each round changes as the game progresses. Do this by asking the following questions:
  - *We know that only one person had number zero in the first round, and by the time we reached the final round most of you had zero as the resulting number.*
    - *What does the growing number of zeros represent?* It is the spread of the infection.
    - *Do you think it is possible for the whole group to get infected? Yes, no, why?*
    - *How many steps did it take for most of the group to get infected? E.g. the number of rounds played.*
    - *What if we had more people participating in the game, do you think it would take more or less time for the infection to spread? Yes, no, why?*
    - *At what point do you think the spread of infection stops?* This is when all the participants have zero as their number, so everyone is infected.
  - By now your group should have determined that the total number of infected students increases with each round, until there are no more students left who can still contract the disease.

- **Plotting the graph**

    - Start by asking the students whether they know what a graph is, and what you put on it (data). Draw a mock graph and ask them what the two perpendicular lines are called (axes).
    - Ask the students what the graph would look like if, at each interval, you went up by the same increment (a diagonal line).
    - Then draw two graphs that look like this:



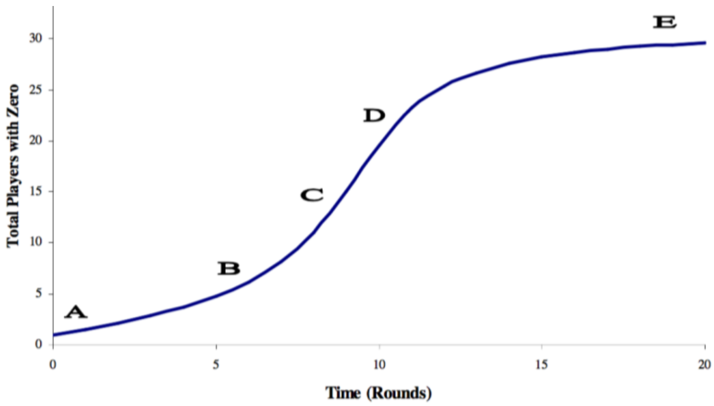


    - Ask them which one would mean the infection was spreading slowly (left), and which quickly (right).

- **Now ask students to plot the total number of infections (number of those with a zero) against rounds.**

- Lead them in the right direction by pointing out that the spread of infection starts off slowly, and increases quickly - get them to recall how many students stood up and walked across the room when counting up the results of the game.
- Their resulting graph should have a similar shape as in the figure. Do not reveal the shape of the graph; it is important for students to work as a group to understand the behaviour of the infection for themselves, and to explain their reasoning behind it.

What pattern are you seeing?

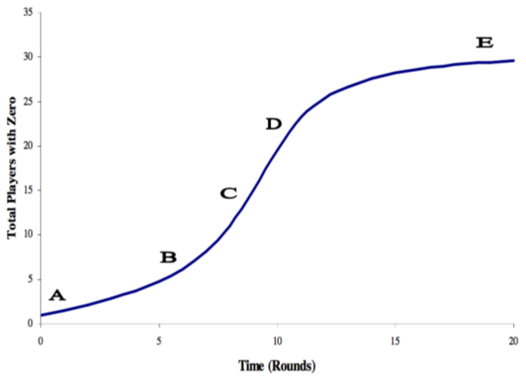


- Think about the initial steps, the overall shape of the graph.

Comparison of Results 10 minutes

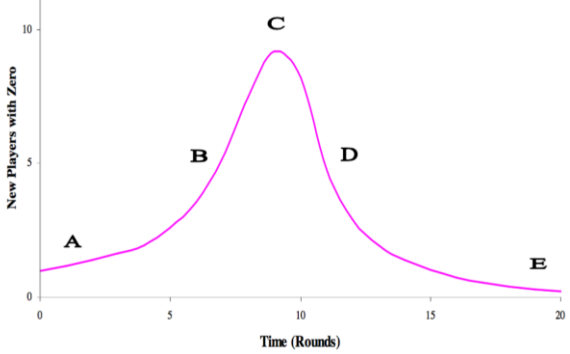
- In this section you should reveal to all groups the two graphs generated by the spreadsheet using the *Class Record Sheet* results collected earlier. Ask students to compare their own graphs to the ones generated by the spreadsheet.

- Take a couple of minutes to talk about the two results, ask how their prediction graphs differ to the ones displayed. Briefly talk about what happens at each region, for example:



  - **A** - initial spread of infection, starts off slowly because only a few students are infected to begin with.
  - **B** - increasing growth, more and more students get infected in each round of the game.
  - **C** - infection continues to spread, the curve changes its direction rapidly going up in an S shape.
  - **D** - the spread of infection slows down, because most of the students are already infected.
  - **E** - the infection does not spread anymore, because everyone is infected by this point.

- **Change of Infection Rate** (NEW Zeros in each round)
  - Now we will look at the rate of infection spread, by considering only newly infected students in each round.



  - **A** - similarly to previous graph, the spread of infection starts off slowly, and then increases rapidly, as more students become infected.
  - **B** - the number of infected students is still increasing, but at a slower rate.

- **C** - the maximum number of infected students is reached, so the curve changes its direction, this is our turning point.

- **D** - the number of newly infected students in now declining, because less and less students can get infected.

- **E** - no more newly infected students, because everyone is already infected.

- **To end the session, ask students how things might change if:**

  - *You started with more than one infected person?*
    Each infected person passed on the disease to a different number of people? So instead of only infecting one other student in each round, one student could infect 2 or 3 other students. What outcome will this lead to?

Game Play - Second Game 10 minutes

- *This extension to **The Infection Game** is based around the idea of international jet-travel, the aim of which is to show students how diseases spread across countries. As well as highlighting the use of Mathematics in disease spread, we also show the influence of Physics by introducing the concept of thermal cameras to students. By playing this game students will learn how outbreaks of diseases can be controlled.*

- **Slide 5 - Thermal Camera Introduction**

- **Slides 6 and 7 – Instructions**

- Separate the students into two groups (countries) where everyone starts sitting down; the two groups should be on opposite sides of the room.

- **Step 1**
  - Randomly choose a student to stand up and "fly" them across the room to the other country - this is your infected student.

- **Step 2**
  - Upon arrival, the infected child selects two more students to stand up and shakes hands with them, so they are now also infected and should remain standing.

- Repeat **Steps 1 and 2** for 3 rounds, so there are some infected people in both countries.

- *Notify students that we are experiencing an outbreak of disease and in order to control it we introduce the thermal camera.*

- Now repeat the previous steps by randomly selecting another student, they can be infected (already standing) or still uninfected (sitting down).

- "Scan" them, if we decide that they are:
  - **not infected**, they will "fly" across and sit down
  - **infected**, then they will not be allowed to board their plane and leave the country, so they will need to remain in their group

- Provide infected students who weren't allowed to board flights with treatment/quarantine cards, so they no longer can pass the disease to uninfected students

- Repeat for a few rounds, so it is clear to students that the number of infected people is not increasing, and therefore we have managed to control the outbreak.

- **Discussion:**
  - *Was the spread of infection in the first game faster or slower than in the second game?*
  - *How many steps (flights) did the disease take to infect (some) people in both groups (countries)?*
  - *What difference does it make if each person infects 3 people instead of 2?*
  - *What if the groups were bigger?*

Possible Extension to the Game

If there is spare time at the end, the game could be extended in the following ways:

Start with **two infected individuals** instead of just one. Follow the lesson plan as above. When distributing the Individual Record Sheets, ensure **two** students are given *Form A*, and the rest are given *Form B.*

The aim of this extension is for students to discover that the rate of infection will be twice as fast if initially there are two infected students. It will only take half as many rounds before the whole population gets infected, and hence the duration of the game will also be halved.

Take Down

Collect the used worksheets or ask the students to dispose of them at the end of the session.

Modern-Day Uses

- The model helps us understand the spreading of diseases
- Helps us understand how quickly diseases can spread
- We can see the impact of quarantining

Background reading

It can be useful to look at the spread of disease as it can have potentially lethal effects on the population.

Careers

There are quite a few jobs that require the use of mathematical modeling and fitting. You can work for the government as well as private sector companies looking at the control of infectious diseases

Name___________________________

Individual Record Sheet
Form A

1. You start the game with a secret number allocated to you personally (your secret number is written below, next to the word **START**).
2. Once the game starts, pick another student and quietly exchange numbers. On your own, secretly **MULTIPLY** the two numbers and write the product on the next line. Now this is your new number.
3. Repeat the process by selecting another student each time, until you have finished the table or have been asked to stop.

ROUND	NUMBER
START	**0**
Round 1	
Round 2	
Round 3	
Round 4	
Round 5	
Round 6	
Round 7	
Round 8	
Round 9	
Round 10	
Round 11	
Round 12	
Round 13	
Round 14	
Round 15	
Round 16	
Round 17	
Round 18	
Round 19	
Round 20	

Name____________________________

Individual Record Sheet
Form B

1. You start the game with a secret number allocated to you personally (your secret number is written below, next to the word **START**).
2. Once the game starts, pick another student and quietly exchange numbers. On your own, secretly **MULTIPLY** the two numbers and write the product on the next line. Now this is your new number.
3. Repeat the process by selecting another student each time, until you have finished the table or have been asked to stop.

ROUND	NUMBER
START	1
Round 1	
Round 2	
Round 3	
Round 4	
Round 5	
Round 6	
Round 7	
Round 8	
Round 9	
Round 10	
Round 11	
Round 12	
Round 13	
Round 14	
Round 15	
Round 16	
Round 17	
Round 18	
Round 19	
Round 20	

Class Record Sheet
The Infection Game

Fill in the TOTAL Number of Zeros column:
1. Ask students to raise hands if they had zero as an entry for round one
2. Note down this number; repeat the process for each round

Fill in the Number of NEW Zeros column:
1. In the first cell, note the number of students that were initially assigned the number 0 (infected)
2. Work backwards, noting down the differences between the cells of the TOTAL Number of Zeros column
3. Repeat for each row in the table

ROUND	Number of **NEW** Zeros	**TOTAL** Number of Zeros
START	**1**	**1**
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		
11		
12		
13		
14		
15		
16		
17		
18		
19		
20		

Name__________________________

Individual Graph Sheet
Form C

Total Number of Students with **Zero** (Infected)

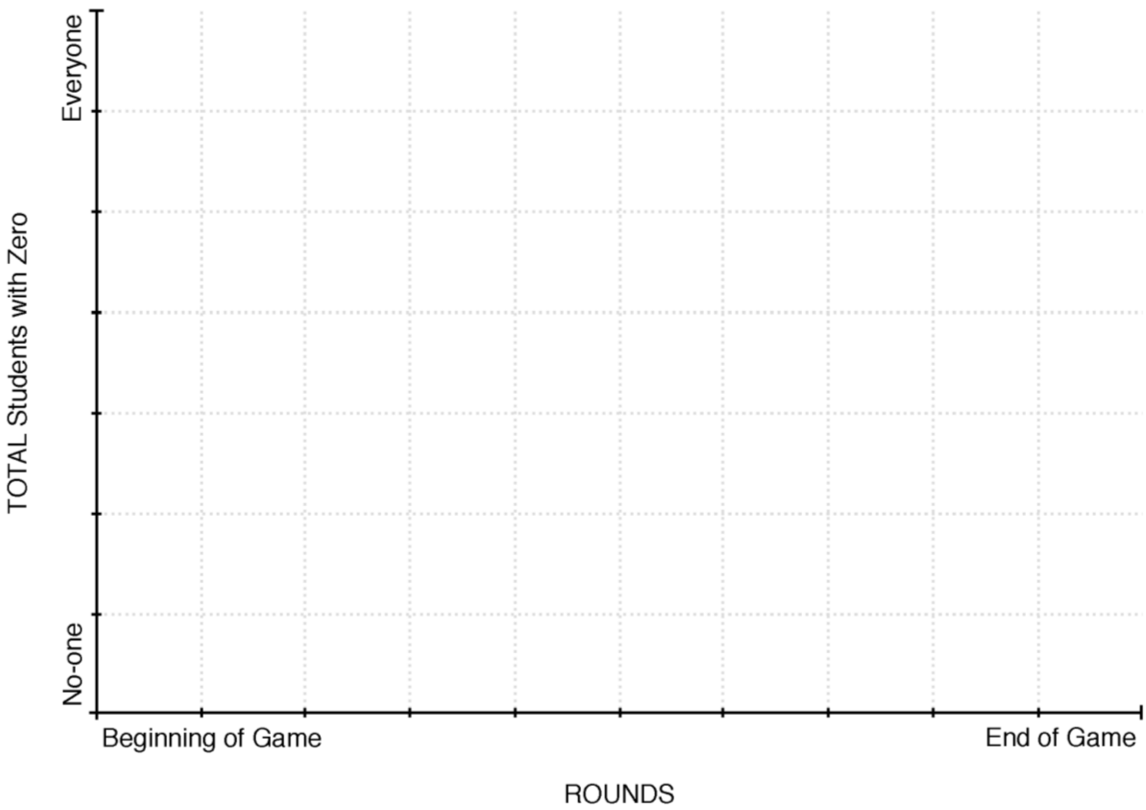
Answer the following questions:

What does the growing number of zeros represent?

Do you think it is possible for the whole group to get infected?

At what point do you think the spread of infection stops?

1. Make a sketch showing how you think the total number of zeros changed as the game progressed.
2. Share your ideas with the group.



Appendix: Activity Heading

Introduction

All the activities in this booklet should be presented in this format.

Equipment List

- ☐ Some items:
  - Sub item 1
  - Sub item 2
- ☐ More items (optional)
- ☐ Even more items

Workshop Overview

And so on…