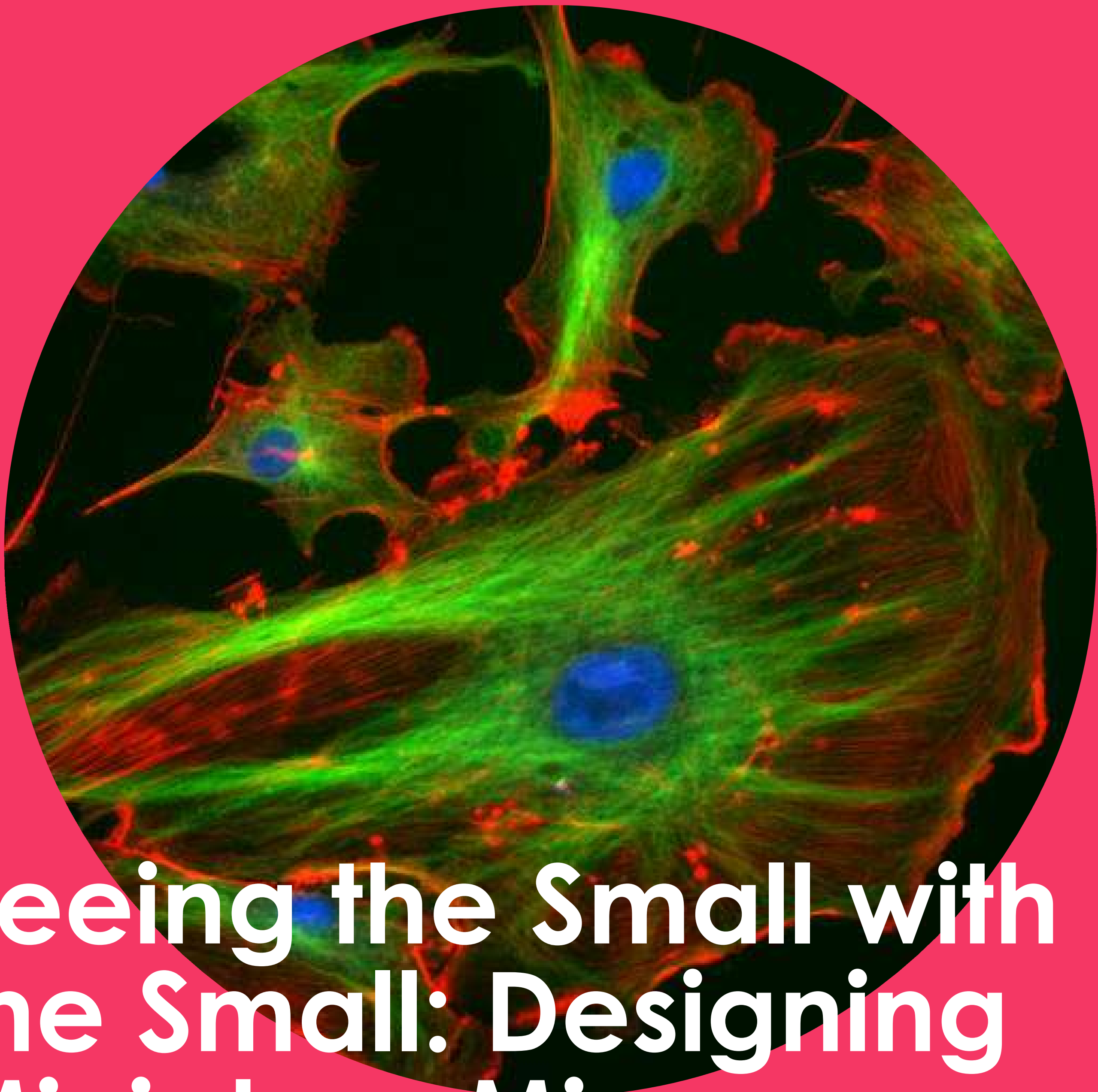
The Scholars Programme



Seeing the Small with the Small: Designing Miniature Microscopes for Medical Imaging

Key Stage 4 Programme

Pupil Name

Coursebook Designed by Gavrielle Untracht

Timetable and Assignment Submission

Timetable – Tutorials

Tutorial	Date	Time	Location
1 (Launch Trip)			
2			
3			
4			
5			
6 (Draft assignment feedback)			
7 (Final assignment feedback)			

Timetable – Homework Assignments

Homework Assignment	Description	Due Date
Tutorial 1	Baseline assessment	
Tutorial 2	The nature of light	
Tutorial 3	Properties of lenses	
Tutorial 4	Ray tracing	
Tutorial 5	Draft assignment	
Tutorial 6	Final assignment	

Assignment Submission – Lateness and Plagiarism

Lateness	
Submission after midnight on ________________	10 marks deducted
Plagiarism	
Some plagiarism	10 marks deducted
Moderate plagiarism	20 marks deducted
Extreme plagiarism	Automatic fail

KS4 Programme – Pupil Feedback Report

Grade	Marks	What this means
1st	70+	Performing to an excellent standard at A-level
2:1	60-69	Performing to a good standard at A-level
2:2	50-59	Performing to an excellent standard at GCSE
3rd	40-49	Performing to a good standard at GCSE
Working towards a pass	0-39	Performing below a good standard at GCSE
Did not submit	DNS	No assignment received by The Brilliant Club

Lateness	
Any lateness	10 marks deducted
Plagiarism	
Some plagiarism	10 marks deducted
Moderate plagiarism	20 marks deducted
Extreme plagiarism	Automatic fail

Name of PhD Tutor			
Title of Assignment			
Name of Pupil			
Name of School			
ORIGINAL MARK / 100		FINAL MARK / 100	
DEDUCTED MARKS		FINAL GRADE	

If marks have been deducted (e.g. late submission, plagiarism) the PhD tutor should give an explanation in this section:

Knowledge and Understanding

Critical Evaluation / Problem Solving

Structure and Presentation

Problem set

Overall Comments (participation, effort, resilience)

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Course Rationale

By enabling us to see cells, microscopes make it easier for doctors to diagnose diseases. But light can only reach a few millimetres into the body, so doctors need a special tool, called an endoscope, to image deeper organs. Endoscopes are essentially miniature microscopes made out of fibre optics. But how do microscopes work? How can we make sure that we're using a tool that lets us see what we want to see? What challenges exist that make endoscope design more difficult than microscope design? In this course, we will explore how endoscopes can help with medical diagnosis and how we can design tools to let us better understand and diagnose diseases.

The initial tutorial will be focused on introducing microscopy and endoscopy and their use in medical diagnosis. We will discuss different types of optical microscopes and how resolution and contrast determine the right microscope for a given application. Once students are comfortable with these topics, we will learn how to design a microscope that is optimized for a specific application using lenses and fibre optics. Finally, we will work towards the completion of a final assignment that includes a short essay-based response about how microscopy is useful in diagnosing disease and a problem set that walks through the steps of designing an optical fibre endoscope.

Group Discussions

How do you make the most of a group discussion?

The purpose of discussions is to allow everyone in the group to express their ideas and learn from each other. Often this will involve coming to a group decision about the issue under discussion, though they may of course 'agree to disagree' on certain points.

What we don't want in our tutorials:

Artwork by MiaHague.co.uk

Rules:

1. Pronounce clearly what you are saying
2. Use eye contact and facial expression to help to get your idea across or to support what someone else is saying
3. Speak in a way that is right for a discussion (more formal than a chat between friends)
4. Build on other people's ideas, and summarise your own views and the views of others when necessary
5. Give reasons to support your views and critically examine the views expressed by others
6. Organise the discussion and take turns with others
7. Listen carefully and respond to the views of others

Mark Scheme Table

Skills	1st (70-100)	2:1 (60-69)	2:2 (50-59)	3rd (40-49)	Mark /100
Knowledge and Understanding	○ Sophisticated understanding of the course material. ○ All the content included is relevant to the general topic and final assignment question – this shows clear thought about what to include. ○ Good evidence of independent thought. ○ Clear thought about unanswered or unexplored questions. ○ Very few factual mistakes. ○ Correct scientific language used, defined when it is useful to do so.	○ Good understanding of the course material. ○ Content included is usually relevant to the general topic and final assignment question. ○ Some evidence of independent thought. ○ Some attempt to think about unanswered or unexplored questions. ○ Very few factual mistakes. ○ Correct scientific language usually used, defined when it is useful to do so.	○ Mostly a good understanding of the course material. ○ Content included is usually relevant to the general topic and final assignment, but some may have been included without a clear reason. ○ Some evidence of independent thought. ○ Little attempt to address unanswered or unexplored questions. ○ Some factual mistakes. ○ Sometimes uses the correct scientific language but rarely includes definitions.	○ Some understanding of the course material. ○ Some of the content included is relevant to the general topic and final assignment, but some may have been included without a clear reason. ○ Little evidence of independent thought. ○ Does not attempt to address unanswered or unexplored questions. ○ Some factual mistakes. ○ Can use the key scientific language, but only uses this correctly occasionally and rarely include definitions.	
Critical Evaluation / Problem Solving	○ Always chooses research evidence that is related to and appropriate for the arguments made. ○ As well as describing the evidence, always explains its value or significance. ○ Often comments on how reliable the sources are, including potential limitations. ○ Evaluation is always clear, easy to follow and explained.	○ Often chooses research evidence that is related to and appropriate for the arguments made. ○ As well as describing the evidence; usually explains its significance. ○ Sometimes suggest why a source is/ is not reliable. ○ Evaluation is usually clear, easy to follow and explained.	○ Sometimes chooses research evidence that is related to and appropriate for the arguments made ○ Consistently describes evidence and sometimes attempts to explain its significance. ○ Can say if a source is reliable or not but does not always explain this. ○ Evaluation is not always clear, easy to follow, or explained.	○ Rarely chooses research evidence that is related to the arguments made. ○ Consistently describes evidence but does not always explain its significance. ○ Can say if a source is reliable or not but does not always explain this. ○ Evaluation is rarely clear, easy to follow, or explained.	

Structure and Presentation	- Introduction clearly outlines what the assignment will contain. - Organises ideas in paragraphs with a logical structure that makes it easy for the reader to follow. - Excellent answering of the question. - Conclusion summarises all of the main points clearly. - Where needed, includes the correct units. - Tables and graphs are labelled correctly, including titles and units. - Demonstrates an excellent understanding of referencing – all sources are cited in text and referenced in the correct format.	- Introduction outlines what the assignment will contain. - Organises ideas in paragraphs with quite a clear structure that makes it easy for the reader to follow. - Good answering of the question. - Conclusion summarises most of the main points clearly. - Where needed, includes the correct units. - Includes most of the appropriate labels for tables and graphs, including titles and units. - Demonstrates a good understanding of referencing – most sources are cited in text and referenced in the correct format.	- Introduction briefly outlines some aspects of the assignment. - Organises ideas in paragraphs, but their order could be more logical to make it easier for the reader to follow. - Attempts to address all aspects of the question. - Conclusion summarises some of the main points. - Includes units where needed, but with some errors. - Includes some of the appropriate labels for tables and graphs, including titles and units with occasional errors. - Demonstrates a developing understanding of referencing – some of sources are cited in text and referenced correctly, but with errors.	- Introduction mentions the main issue. - Usually organises ideas in paragraphs, but their order is not always easy for the reader to follow. - Does not address all aspects of the question. - Conclusion summarises some of the main points. - Often forgets to include the correct units. - Sometimes forgets to include the labels needed for tables and graphs, such as titles and units. - Has not or only occasionally attempts to reference.	
Overall mark for the written element (average of the 3 marks from the above criteria) /100					
Problem set mark /100					
Final mark *(Mark for written element + Problem set mark)* ÷ 2 /100					

Glossary of Keywords

Word	Definition
Microscope	
Endoscope	
Resolution	
Contrast	
Imaging depth	
Absorption	
Transmission	
Scattering	
Refraction	
Wavelength	
Amplitude	
Frequency	
Crest	

Trough	
Wavefront	
Photon	
Phase	
Index of refraction	
Total internal reflection	
Focus (focal point)	
Focal Length	
Numerical Aperture	
Convergence	
Divergence	
Collimated	
Spot size	
Depth of field	

List of Useful Formulas

Wavelength and frequency	$$f = \frac{c}{\lambda}$$	f = frequency c = speed of light = 3x10^8 m/s λ = wavelength
Law of reflection	$$\theta_i = \theta_r$$	θ_i = angle of incidence θ_r= angle of reflection
Index of refraction	$$n = \frac{c}{v}$$	n = index of refraction c = speed of light = 3x10^8 m/s v = speed of light in the material
Snell's law	$$n_1 \sin \theta_1 = n_2 \sin \theta_2$$	
Numerical aperture	$$NA = n \sin \theta \approx n \frac{D}{2f}$$	NA = numerical aperture D = lens or beam diameter f = focal length n = numerical aperture
Resolution (spot size)	$$s = \frac{4\lambda * f}{\pi * D} = \frac{0.61\lambda}{NA}$$	s = spot size f = focal length D = lens or beam diameter λ = wavelength NA = numerical aperture
Depth of Field	$$DOF = \frac{2 * \pi * (\frac{s}{2})^2}{\lambda}$$	DOF = depth of field s = spot size λ = wavelength

Image distance	$$\frac{1}{d_i} = \frac{1}{f} - \frac{1}{d_o}$$	d_i = image distance d_o = object distance f = focal length
Magnification	$$M = \frac{h_i}{h_0} = \frac{-d_i}{d_o}$$	M = magnification h_i = image height h_0 = object height d_i = image distance d_o = object distance

Units – An overview

In science, it is really important that units are included when reporting the answer to a question. Units are what allow us to use numbers to describe the world. Without units, science wouldn't make sense! All units in science are based on the standard international system of units (SI) and a set of prefixes that describe multiples and fractions of these units. Pay attention to these prefixes! Understanding them will be key to getting the correct answers in problem sets. Here is an overview of units that we will use in this course.

Length

The most common units we will use in this course. The SI unit for length is metres. Metres are very large compared with the sizes typically described in optics. We will most often use units of nanometres or micrometers.

Units of Length	Abreviation	Scale Factor
Metres	m	
Micrcometers	Microns, µm (note that µ is the greek letter 'mu')	1000000 µm = 1 m
Nanometres	nm	1000000000 nm = 1m

Frequency

Frequency describes how often something occurs per unit of time. The SI unit for time is seconds, so the SI unit of frequency is $\frac{1}{s}$ (per second). There is also a special name for this unit – Hertz (abbreviated Hz). You should use the unit Hertz to describe frequency.

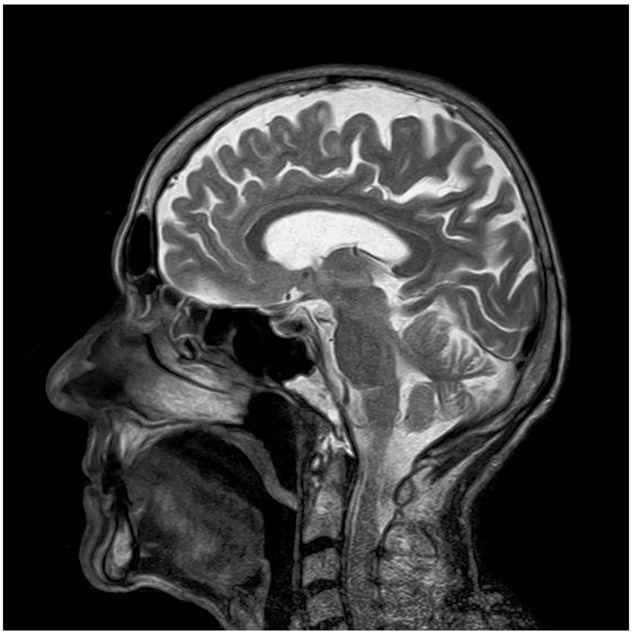
Angles

There are two common units for describing angles: degrees and radians. Radians are the SI unit for angles, so are typically used in science applications. When describing a full circle, the angle can be described as 360 degrees or 2π radians. To convert between radians and degrees, use the following formula: $\theta_{radians} = \theta_{degrees} * \frac{2\pi}{360}$. In this course, you may use either unit to describe angles as long as you specify what you're using.

Dimensionless Values

Some values we use in this course are reported without units. These values are called dimensionless values, and typically describe a ratio or relative value. The dimensionless values we will use in this course are numerical aperture and index of refraction.

Tutorial 1 – What is medical imaging?



What is the Purpose of Tutorial 1?

- To discuss how imaging is useful to diagnosis
- To learn about different types of medical imaging
- To introduce microscopes and endoscopes and why we need them
- To learn how **resolution** and **contrast** influence the choice of imaging technique
- To learn how contrast is based on the interactions between light and matter

Activity 1 – Mind map: Medical Imaging

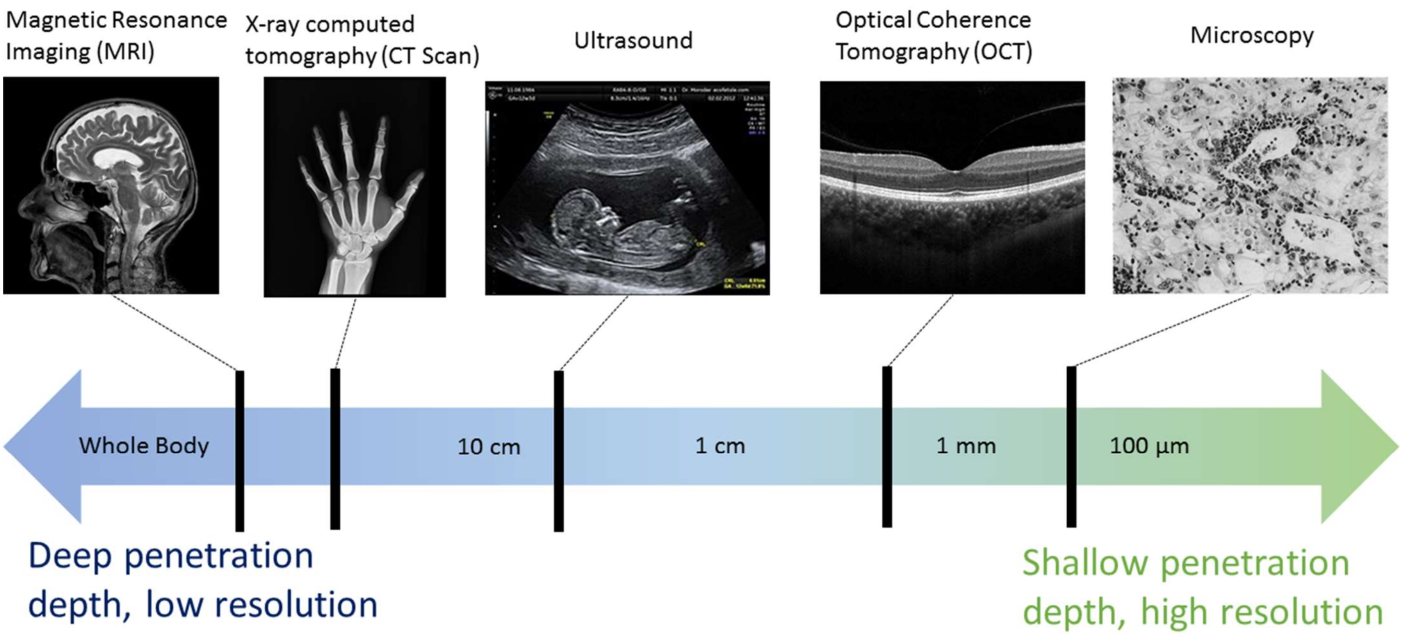
What do you think about when you hear the phrase "medical imaging?" Can you think of different types of medical imaging? When would each be useful? What factors would help you determine when to use different imaging techniques? How can imaging be useful for medical diagnosis?

Activity 2 – Discussion: Types of medical imaging

Medical imaging techniques can be classified by **imaging depth**, **resolution**, and **contrast**. Take a look at the diagram to learn a little bit about the most common medical imaging techniques.

Discussion questions:

- How do each of these techniques work?
- What are the advantages and disadvantages of each technique?
- What is the mechanism of **contrast** in each techniques?
- How are penetration depth and resolution related?
- What is a **microscope**, and why might we want to use one?
- What is an **endoscope**, and why might we want to use one?
- What type of contrast might exists on different scales of size in the body?



For the remainder of the course, we will be focusing on **optical imaging** techniques and microscopy. These techniques use visible or infrared light to generate **contrast** in images.

Why is imaging useful in medicine?

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Activity 3 – Discussion: How can light generate contrast in an image?

Light can generate **contrast** in an image based upon the different ways that light interacts with matter. There are four main ways that light interacts with matter: it can be **absorbed**, **transmitted**, **reflected**, or **scattered**.

Discussion questions:

- What does it mean when light is absorbed, reflected, transmitted or scattered?
- Can you think of some materials that interact with light in each of these ways?
- Is there any relationship between the colour of light and how it will interact with matter?
- Can we draw any connections between how vision works and how we might generate contrast in an image?

What does it mean for light to be **absorbed**? What is an example of something that absorbs light?

What does it mean for light to be **transmitted**? What is an example of something that transmits light?

What does it mean for light to be **reflected**? What is an example of something that reflects light?

What does it mean for light to be **scattered**? What is an example of something that scatters light?

How can these interactions between light and matter generate contrast in an image?

Baseline Assessment – Light interaction with matter

Part one: Written response.

Please answer the following question in essay format.

What sources of contrast exist in the body to generate images? (300 words)

First, describe in general how contrast is generated in images. You may want to focus on key words discussed in class including **absorption, transmission, reflection, and scattering**. Provide at least one specific example - Don't be afraid to be creative! Think about how light can interact with different parts of the body.

Second, use your own online research to investigate one imaging technique discussed in class. Describe briefly how it works and what the main source of contrast is. You may use the information on the next few pages to help you.

Don't forget to include a **bibliography**. A bibliography is a list of any books or websites that you used when writing your response.

Part two: Short answer questions

1. If light hits a mirror at an angle of 20 degrees, at what angle will it reflect from the mirror?

2. Does absorption depend on the colour of light? If so, how?

3. Does scattering depend on the colour of light? If so, how?

4. Can light focus to an infinitely small spot size? Why or why not?

5. Define the terms **amplitude** and **phase** in terms of how they describe a wave. You may use a drawing to help support your response.

6. Define the terms **resolution** and **contrast**.

7. True or False: Using ray tracing, I can determine the magnification of a lens. Explain your answer.

8. Solve the following equation for x:

$$X = \sin\frac{\pi}{2}$$

Submit your responses on VLE through Assignments → Baseline Assignments

The following information is reproduced from https://www.nhs.uk/conditions/mri-scan/

MRI scan

Magnetic resonance imaging (MRI) is a type of scan that uses strong magnetic fields and radio waves to produce detailed images of the inside of the body.

An MRI scanner is a large tube that contains powerful magnets. You lie inside the tube during the scan.

An MRI scan can be used to examine almost any part of the body, including the:

- brain and spinal cord
- bones and joints
- breasts
- heart and blood vessels
- internal organs, such as the liver, womb or prostate gland

The results of an MRI scan can be used to help diagnose conditions, plan treatments and assess how effective previous treatment has been.

What happens during an MRI scan?

During an MRI scan, you lie on a flat bed that's moved into the scanner.

Depending on the part of your body being scanned, you'll be moved into the scanner either head first or feet first.

The MRI scanner is operated by a radiographer, who is trained in carrying out imaging investigations. They control the scanner using a computer, which is in a different room, to keep it away from the magnetic field generated by the scanner.

You'll be able to talk to the radiographer through an intercom and they'll be able to see you on a television monitor throughout the scan.

At certain times during the scan, the scanner will make loud tapping noises. This is the electric current in the scanner coils being turned on and off.

You'll be given earplugs or headphones to wear.

It's very important to keep as still as possible during your MRI scan.

The scan lasts 15 to 90 minutes, depending on the size of the area being scanned and how many images are taken.

Read more about how an MRI scan is performed

How does an MRI scan work?

Most of the human body is made up of water molecules, which consist of hydrogen and oxygen atoms.

At the centre of each hydrogen atom is an even smaller particle called a proton. Protons are like tiny magnets and are very sensitive to magnetic fields.

When you lie under the powerful scanner magnets, the protons in your body line up in the same direction, in the same way that a magnet can pull the needle of a compass.

Short bursts of radio waves are then sent to certain areas of the body, knocking the protons out of alignment.

When the radio waves are turned off, the protons realign. This sends out radio signals, which are picked up by receivers.

These signals provide information about the exact location of the protons in the body.

They also help to distinguish between the various types of tissue in the body, because the protons in different types of tissue realign at different speeds and produce distinct signals.

In the same way that millions of pixels on a computer screen can create complex pictures, the signals from the millions of protons in the body are combined to create a detailed image of the inside of the body.

The following information is reproduced from
https://www.medicalnewstoday.com/articles/245491.php

Ultrasound Scan

How do ultrasound scans work?

Last updated Fri 23 June 2017
By Yvette Brazier
Reviewed by Debra Rose Wilson, PhD, MSN, RN, IBCLC, AHN-BC, CHT

An ultrasound scan uses high-frequency sound waves to create images of the inside of the body. It is suitable for use during pregnancy.

Ultrasound scans, or sonography, are safe because they use sound waves or echoes to make an image, instead of radiation.

Ultrasound scans are used to evaluate fetal development, and they can detect problems in the liver, heart, kidney, or abdomen. They may also assist in performing certain types of biopsy.

The image produced is called a sonogram.

Fast facts on ultrasound scans

Here are some key points about ultrasound scans. More detail is in the main article.

- Ultrasound scans are safe and widely used.
- They are often used to check the progress of a pregnancy.
- They are used for diagnosis or treatment.
- No special preparation is normally necessary before an ultrasound scan.

Concept

The person who performs an ultrasound scan is called a sonographer, but the images are interpreted by radiologists, cardiologists, or other specialists.

The sonographer usually holds a transducer, a hand-held device, like a wand, which is placed on the patient's skin.

Ultrasound is sound that travels through soft tissue and fluids, but it bounces back, or echoes, off denser surfaces. This is how it creates an image.

The term "ultrasound" refers to sound with a frequency that humans cannot hear.

For diagnostic uses, the ultrasound is usually between 2 and 18 megahertz (MHz).

Higher frequencies provide better quality images but are more readily absorbed by the skin and other tissue, so they cannot penetrate as deeply as lower frequencies.

Lower frequencies penetrate deeper, but the image quality is inferior.

How does it capture an image?

Ultrasound will travel through blood in the heart chamber, for example, but if it hits a heart valve, it will echo, or bounce back.

It will travel straight through the gallbladder if there are no gallstones, but if there are stones, it will bounce back from them.

The denser the object the ultrasound hits, the more of the ultrasound bounces back.

This bouncing back, or echo, gives the ultrasound image its features. Varying shades of grey reflect different densities.

The following information is reproduced from https://www.wonderopolis.org/wonder/how-does-an-x-ray-work#targetText=Today's%20x%2Dray%20machines%20produce,in%20an%20x%2Dray%20tube.&targetText=When%20x%2Drays%20come%20into,the%20beam%20passes%20through%20them.

X-ray Imaging

How does and x-ray work?

Have you ever wondered…

- How does and X-ray work?
- Who discovered the X-ray?
- How do X-rays help doctors?

What do penicillin, Super Glue and X-rays have in common? Their inventors all discovered them by accident!

In 1895, German physicist Wilhelm Roentgen was experimenting with electricity in a special tube. He wanted to find out how electricity would act in a vacuum. For that reason, Roentgen removed as much air from the tube as possible. That allowed electrons to move at a very fast pace through the tube.

As the electrons moved, they bumped into each other. They also ran into the glass of the tube and two special parts of the tube called the cathode and anode. What Roentgen didn't know was that, when these fast-paced electrons bumped into the tube's anode, they would send off a type of light that hadn't yet been discovered. This type of light is called an x-ray.

X-rays are a type of light ray, much like the visible light we see every day. The difference between visible light and x-rays is the wavelength of the rays. Human eyes cannot see light with longer wavelengths, such as radio waves, or light with shorter wavelengths, such as x-rays.

Soon, Roentgen noticed that a fluorescent screen in his lab started glowing while he conducted his experiment. While he knew fluorescent material normally glows when exposed to electromagnetic radiation, he was still surprised because heavy cardboard, which he thought would have blocked the radiation, surrounded the tube.

He began to experiment by placing different objects between the tube and the screen. No matter what he put between the two, the screen still glowed.

At one point, Roentgen placed his hand in front of the tube. When he did this, he saw a silhouette of his bones projected onto the screen.

Not only had Roentgen discovered x-rays, he saw firsthand (pun intended!) how they could become extremely helpful to medicine.

There's no doubt the x-ray machine is very useful to doctors. X-rays can pass through nonmetallic objects, including human tissues and organs. An x-ray machine is like a giant camera that allows doctors to see what is going on inside a patient without having to do surgery.

It took a long time for scientists to make the x-ray safe for medical use. Today's x-ray machines produce a stream of electromagnetic radiation that interacts with an anode in an x-ray tube. The x-rays made by this interaction are then directed toward the part of the body being examined. To reduce radiation exposure, x-ray machines aim the x-rays at only the focus area.

When x-rays come into contact with our body tissues, they produce an image on a metal film. Soft tissue, such as skin and organs, cannot absorb the high-energy rays, and the beam passes through them. Dense materials inside our bodies, like bones, absorb the radiation.

Much like camera film, the X-ray film develops depending on which areas were exposed to the X-rays. Black areas on an x-ray represent areas where the x-rays have passed through soft tissues. White areas show where denser tissues, such as bones, have absorbed the x-rays.

Have you ever had an x-ray? They're commonly used to see broken bones. Doctors might also order an x-ray when trying to figure out why you don't feel well. But rest assured! X-rays are nothing to be nervous about. They don't hurt at all. Instead, they help doctors find ways to make you feel better.

Tutorial 2 – Microscopes and Light

What is the Purpose of Tutorial 2?

- To learn how to use a microscope
- To learn how to measure magnification and resolution of your microscope
- To learn about how discuss light in different ways

Activity 1 – Using a microscope

For this activity, you will be provided with a small microscope and some prepared slides. Look at the slides with your 'naked eye' and also with the microscope. Choose one slide, and draw a picture of what you see with and without the microscope.

Naked Eye	With Microscope

Discussion questions:

- What kinds of things can we see with a microscope that we can't see by eye?
- What sources of contrast exist in these images?
- After using a microscope, why do you think a microscope might be useful for medical diagnosis?
- What are the important parameters that need to be controlled when adjusting a microscope?

Activity 2 – Resolution and magnification of a microscope

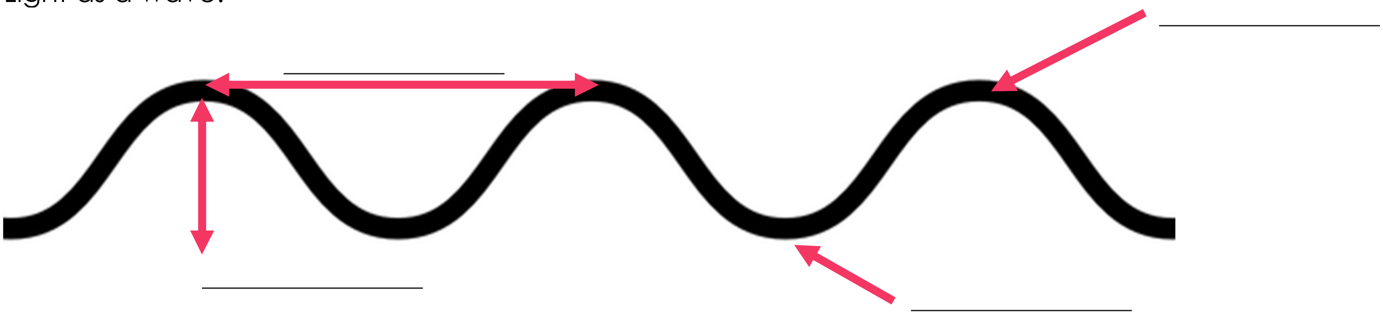
In this activity, you will learn how to measure the resolution and magnification of your microscope. The **resolution** is defined as the minimum separation between two points that can be distinguished in an image, but it is effectively the smallest thing that we can see with our microscope. The **magnification** is the ratio between the actual size of an object and the size that it appears in our image. Can we increase the magnification of an image using digital zoom?

The magnification of the image on the screen is: ____

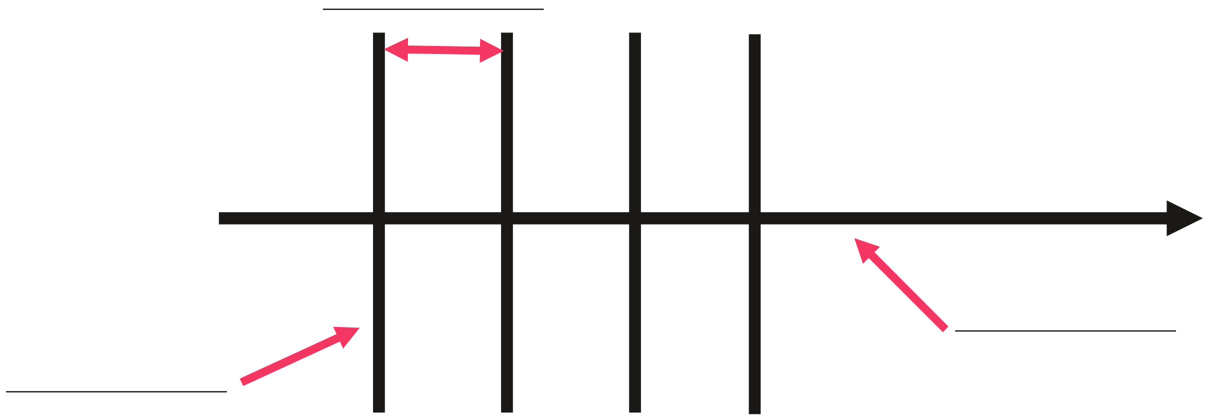
The resolution of the image is: ____

Activity 3 – Discussion: How do we talk about light?

Label the diagrams below based on our discussion in class.
Light as a wave:



Light as a Ray:



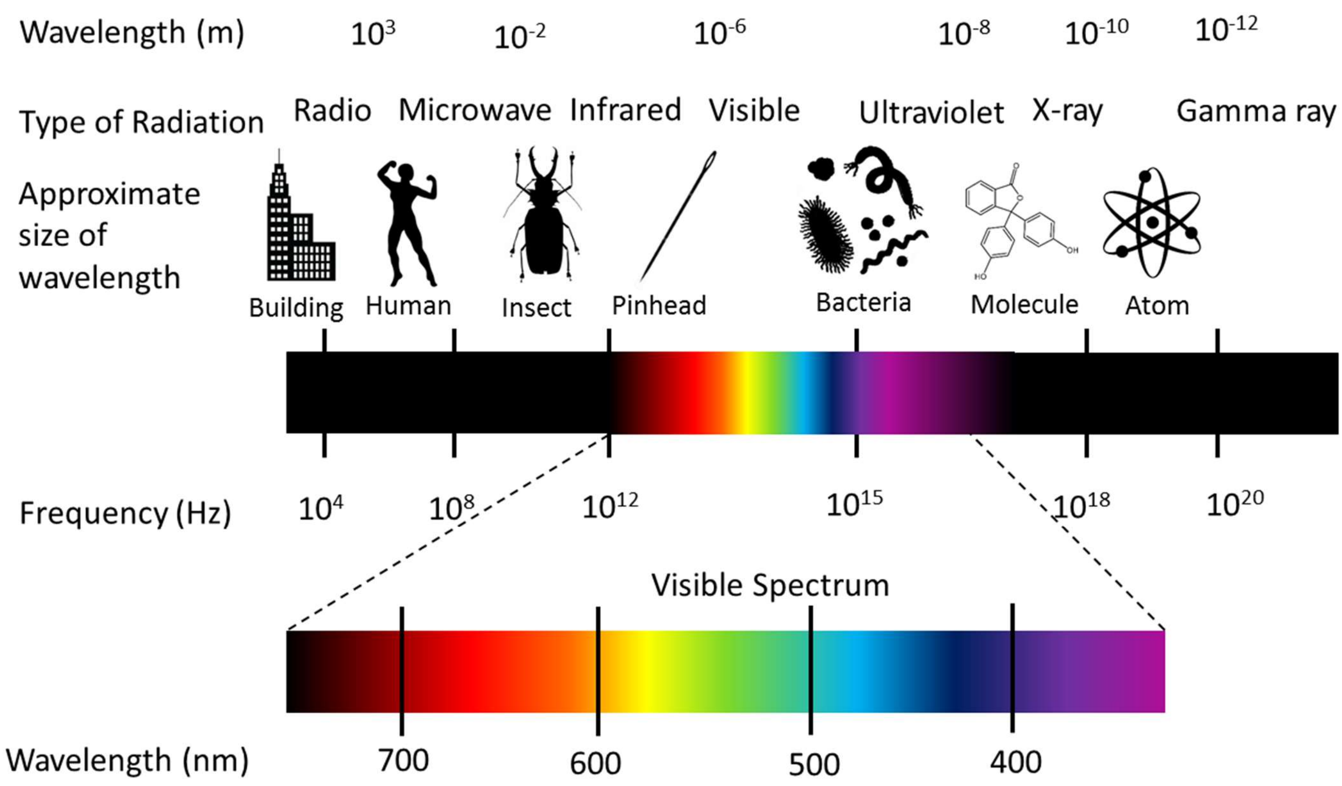
Light as a Particle:

A particle of light is called a __________. The position along the wave is called the __________.

Discussion questions:

- Some people describe light as a ray, some people describe light as a particle, and some people describe light as a wave. How are each of these good models of the behaviour of light? How are they bad models? When does each model apply best?
- Can light focus to an infinitely small spot?
- What is the difference between laser light and light coming from a light bulb?

Visible light is part of the electromagnetic spectrum



The frequency and the wavelength of light are two different ways of thinking about how quickly the light waves are moving. They are related to the speed of light by the following formula:

$$f = \frac{c}{\lambda}$$

We usually use f to represent the frequency, c to represent the speed of light, and λ (the Greek letter 'lambda') to represent wavelength.

Tutorial 2 Homework assignment – The nature of light

Part 1: Is light a wave, a ray, or a particle?

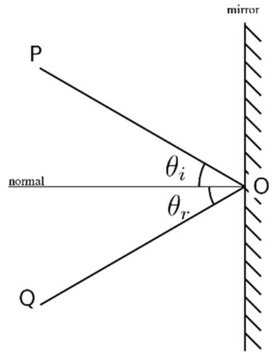
Explain how light can be described as a wave, a ray, and a particle. Use specific terms that we talked about it class to support your argument. (500 words)

Part 2: Read the description of reflection and refraction and answer the following questions.

Reflection, refraction, and total internal reflection

Reflection

We already know that light will reflect when it hits a smooth, shiny surface, but can we predict how it will reflect? For example: If you hold a mirror at an angle, what will you see? We can predict the angle light will reflect at using the law of reflection.



The law of reflection:

$$\theta_i = \theta_r$$

The angle of incidence is equal to the angle of reflection.

These angles are measured relative to the normal. The normal is a line perpendicular to the surface of the mirror.

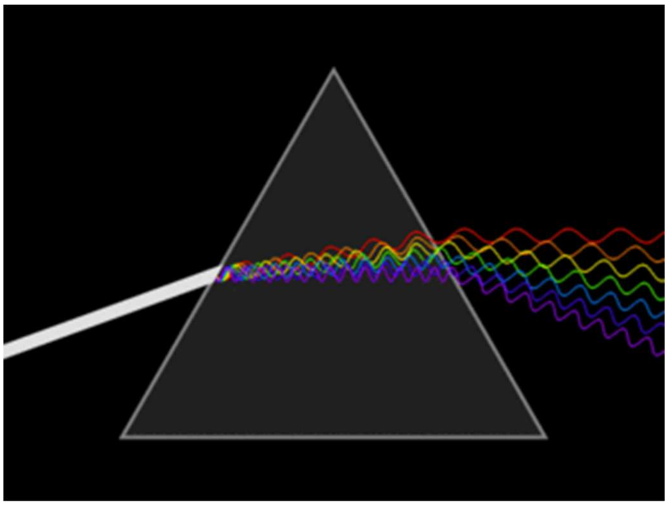
Refraction

Nothing travels faster than the speed of light in vacuum, but is the speed of light always the same? Light travels different speeds when it travels through different materials! When light travels through a material, it travels slower than the speed of light in vacuum. Think about going for a run on concrete versus running through sand; running in sand is more difficult, so you slow down – the same thing happens with light! The amount light slows down is determined by a property of the material called the **index of refraction**, often labelled as ‘n’. The speed of light is usually label ‘c,’ and ‘v’ is the speed of light in a material.

$$n = \frac{c}{v}$$

Another way of thinking about the index of refraction is that it is the ‘optical density’ of a material, or how dense that material is for light to travel through.

In addition to slowing down, light that travels across a boundary between two materials will bend when it is transmitted. The amount that it bends depends on the index of refraction and the colour of the light. Blue light will bend more than red light in a material with the same index of refraction. This is why a prism splits light into its component colours! This phenomenon is called **refraction**. Refraction is also the reason why a straw in a glass of water appears bent – the light bends when it passes through the boundary.



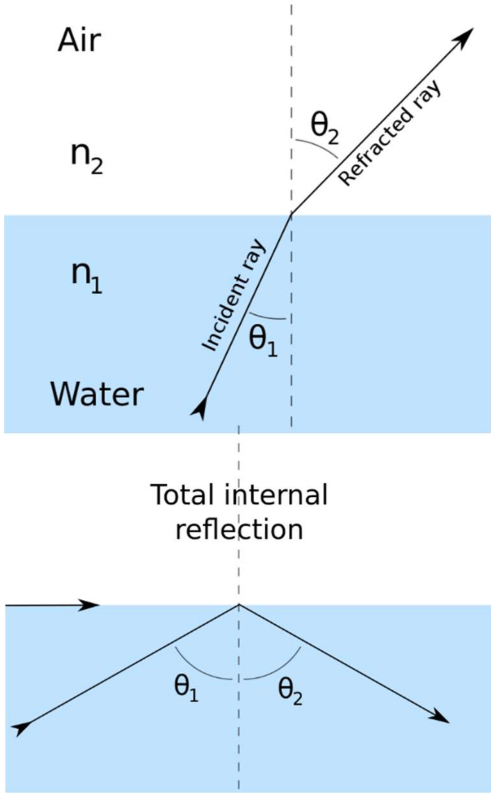
Understanding refraction is really important for understanding how a microscope works because refraction is what causes a lens to focus light! So, how can we know how much light will bend? We can use the law of refraction, also called Snell’s law.

Snell's law:

$$n_1 \sin\theta_1 = n_2 \sin\theta_2$$

In this equation, n refers to the index of refraction in each of the two materials, and θ refers to the angle the light hits the boundary measured relative to a line perpendicular to the boundary.

Notice that there is a special case of Snell's law. Since the sine function has values limited between 0 and $\frac{\pi}{2}$, there exists the possibility that θ_2 is undefined if $n_2 < n_1$. This occurs in the case where θ_1 is larger than a certain value, called the critical angle. When the angle of incidence is larger than the critical angle, it isn't refracted at all – it's reflected! This phenomenon is called **total internal reflection**.



Questions:

1. What is the law of reflection?

2. Define the term 'index of refraction'?

3. What law lets us calculate how much light will bend when it enters a new material?

Tutorial 3 – Lenses: How do they work?

What is the Purpose of Tutorial 3?

- To learn about **reflection** and **refraction** and how to model how light will behave in a material
- To learn how lenses interact with and shape light
- To learn how to measure the focal length of a lens
- To learn about how **focal length** determines **resolution**

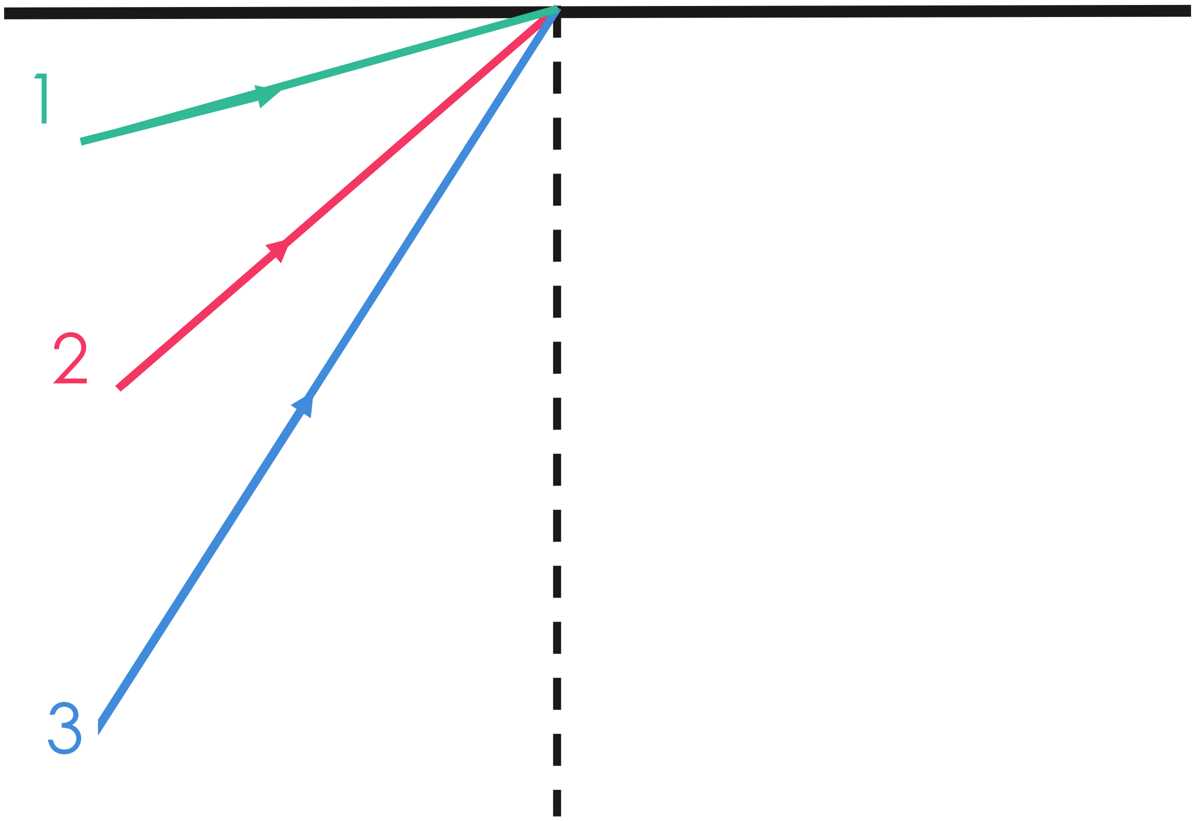
Activity 1 – Homework Reflection

What is the most interesting thing you learned about reflection and refraction from the homework assignment?

Activity 2 – Reflection and Refraction: Theory and practice

Use the diagram below to prove the law of reflection.

1. Hold the mirror along the thick black line across the page
2. Shine a light along each of the coloured lines on the left side of the page. Draw a line indicating the direction of the reflected ray on the right side of the page.
3. Use the protractor to measure the angle of incidence and the angle or refraction for each colour. Record your measurements in the table.
4. Do your measurements prove the law of reflection?



	Angle of Incidence	Angle of Reflection
Position 1		
Position 2		
Position 3		

What is total internal reflection and under what conditions will it occur?

Activity 3 – How do lenses work?

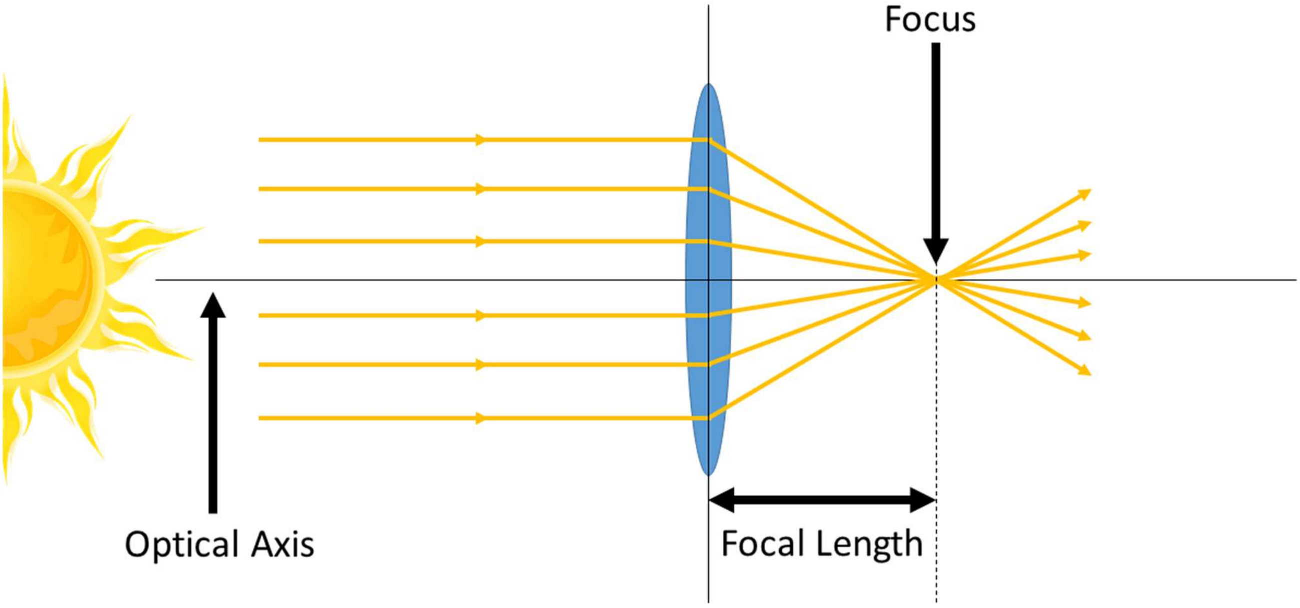
What is a lens? A lens is a curved piece of transparent material that causes light rays to converge or diverge by means of refraction.

For this activity, you will be given several lenses to play with. Try looking at a pen or pencil through the lens. What happens if you adjust the distance between the lens and the pen? What if you adjust the distance between the lens and your eye? Do you observe any trends? How can we figure out where to place the lens in order to get the best image?

Activity 4 – Focal length of a lens

If a light source is far away, like the sun, we can estimate that all of the rays of light coming from that source are parallel. When light rays are parallel, we say that they are **collimated**. When parallel rays of light are incident on a lens, all the rays **converge**. The location where the light converges is called the **focus**. Beyond the focus, the light rays will **diverge**. The distance between the focus and the lens is called the **focal length.** We can use this fact to measure the focal length of a lens. The focal length is an important parameter to know in order to determine where to place your lens in relation to your object and your eye.

For this activity, you can use the room lights as your distant light source since the distance from the table to the lights will be much larger than the focal length of the lens. When the lens is positioned so that the screen (for this experiment, the table) is at the focus, the image formed by the lens will appear sharp.

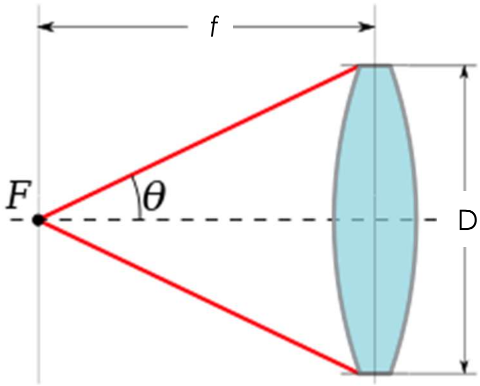


Measuring focal length

1. Hold the lens parallel to the table. You should see a bright spot on the table.
2. Note the shape of the room lights. Adjust the distance between the table and the lens until the bright spot is the same shape as the light and the edges are sharp.
3. Use a ruler to measure the distance between the table and the lens – this distance is the focal length!

I have measured the focal length of my lenses to be:

Another important parameter to know about your lens is the **numerical aperture.** The numerical aperture tells us the range of angles over which the lens can accept light. It is important because it determines the minimum **spot size** that we can achieve with that lens.



The numerical aperture (NA) is defined as:

$$NA = n \sin\theta \approx n\frac{D}{2f}$$

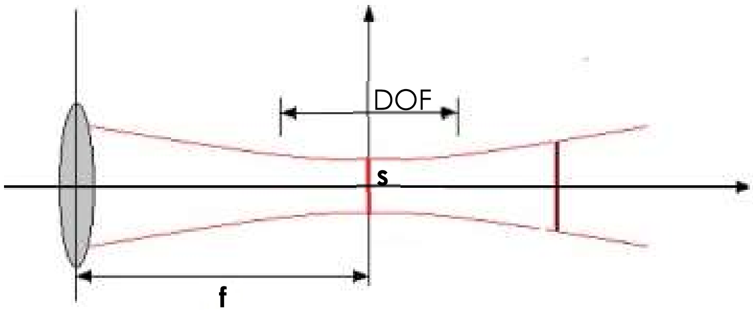
Where n is the index of refraction of the material that the light is focusing into.

The **resolution** (s) of an image formed by this lens is the minimum distance that two spots must be separated in order to distinguish them as two separate objects. The resolution of an image formed by a particular lens is:

$$s = \frac{4\lambda * f}{\pi * D} = \frac{0.61\lambda}{NA}$$

Note that D here doesn't always refer to the diameter of the lens. It will refer to the diameter of the beam if the beam is smaller than the diameter of the lens.

If we were to focus a laser beam using this lens for a fluorescent microscope, this value would also be the minimum beam diameter, or **spot size** (also called the diffraction-limited spot size), we could focus the laser beam to.
Since we know that a lens will not focus a laser beam to an infinitely small spot, how would this look?

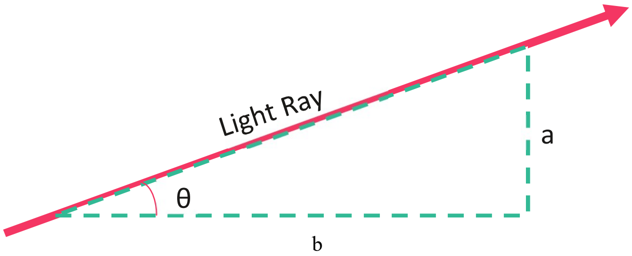


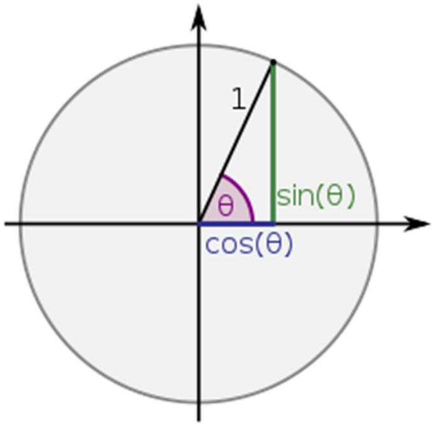
The **depth of field** (DOF) tells us over what distance our light will be focused if we use the lens to focus a laser beam. In a wide-field image, the DOF tells us what range of information in the image will be in focus. The DOF depends on the spot size and the wavelength of light.

$$DOF = \frac{2 * \pi * (\frac{S}{2})^2}{\lambda}$$

Triangle Geometry – An overview

What does the expression $\sin\theta$ mean in Snell's law and the numerical aperture formula? Sine is one of three special mathematical functions that gives us information about an angle. The other two functions are called cosine and tangent. These functions are useful in optics because they can give us information about the direction that a ray of light is travelling. They are defined based on the geometry of a right triangle – we can always draw a right triangle next to a ray of light to help us define the direction. Θ is the Greek letter 'Theta', which is often used in science to represent an angle in many different equations.



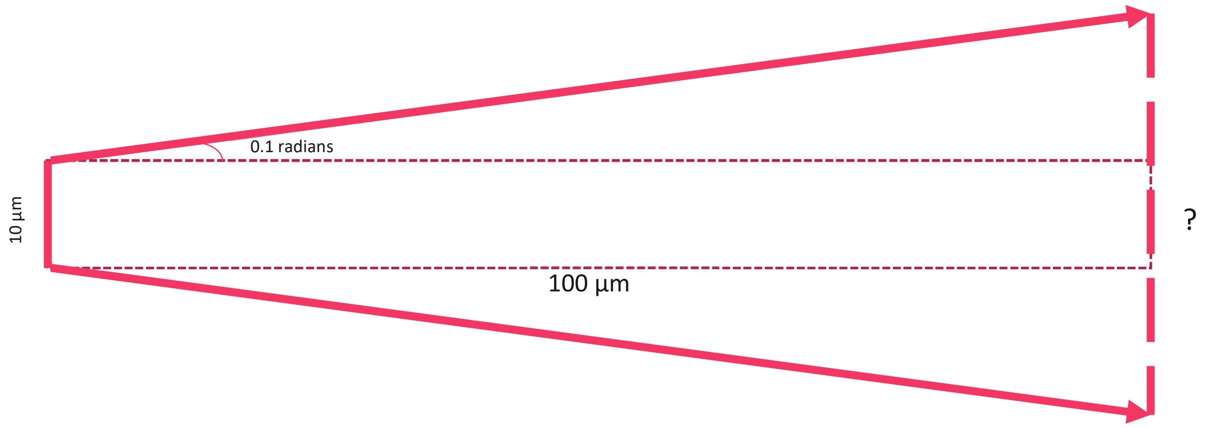


Sine and cosine can be explained by placing a right triangle inside of a circle. Imagine that your ray of light is coming from the centre of a circle and has a length of 1. At the point where your ray intersects with the circle, the x coordinate is $\cos\theta$ and the y coordinate is $\sin\theta$. The tangent is special because it tells us about the *slope* of the ray; the equation for tangent is the same as the equation for the slope of a line: $\tan\theta = \frac{a}{b}$. The easiest way to work with these functions is to use your calculator.

Most often, these functions are used with angles in a special unit called radians. A full circle is 2π radians, just like a full circle is 360 degrees! To convert from radians to degrees, we can use the following formula: $\theta_{radians} = \theta_{degrees} * \frac{2\pi}{360}$.

In optics, we are typically dealing with really small angles, so we can make some assumptions about the value of the sine and tangent functions. For $\sin\theta < 0.25$ and $\tan\theta < 0.25$, we can assume that $\sin\theta = \theta$ and $\tan\theta = \theta$. This is called the *small angle approximation*.

We can use this information to calculate how a beam expands as it travels. For example: Let's say that we have a laser beam with a diameter of 10 μm that is diverging at an angle of 0.1 radians (0.1 radians ≈ 5.7 degrees). What will be the diameter of the beam after it travels 100 μm?



Since the angle 0.1 radians is small, we can say that $\tan\theta = \theta = 0.1$, which means that the slope of the ray is 0.1. Using the slope formula, $\tan\theta = \frac{a}{b}$, we can say that the radius of the beam will increase by $\mathrm{a} = \mathrm{b} * \tan\theta = 100 * 0.1 = 10\ \mu m$. Therefore, the new beam diameter after travelling 100 μm will be 30 μm.

Tutorial 3 Homework assignment – Properties of lenses

1. I have a lens with a focal length of 200 mm and a diameter of 250 mm. What is the numerical aperture of this lens (n = 1 for air)? (Hint: use the equation for NA)

2. How will the answer to question 1 change if I submerge the lens in water (n=1.33)?

3. I've reduced the diameter of my lens to 50 mm. What is the new NA in air? In water?

4. I shine a beam of light with a wavelength of 700 nm through my lens. The beam has a diameter of 50 mm. What will be the diameter of the spot in air? In water? (Hint: Use the equation for resolution)

5. Will the answer to question 4 be different if I use the 50 mm diameter lens or the 250 mm diameter lens?

6. What will be the depth of field of the focused light in air? In water? (Hint: use the equation for DOF)

Tutorial 4 – Lenses and Ray Tracing

What is the Purpose of Tutorial 4?

- To learn about how ray tracing can be used to model lenses
- To observe that a microscope is just 1-2 lenses combined
- To use a camera obscura to understand how lenses for images

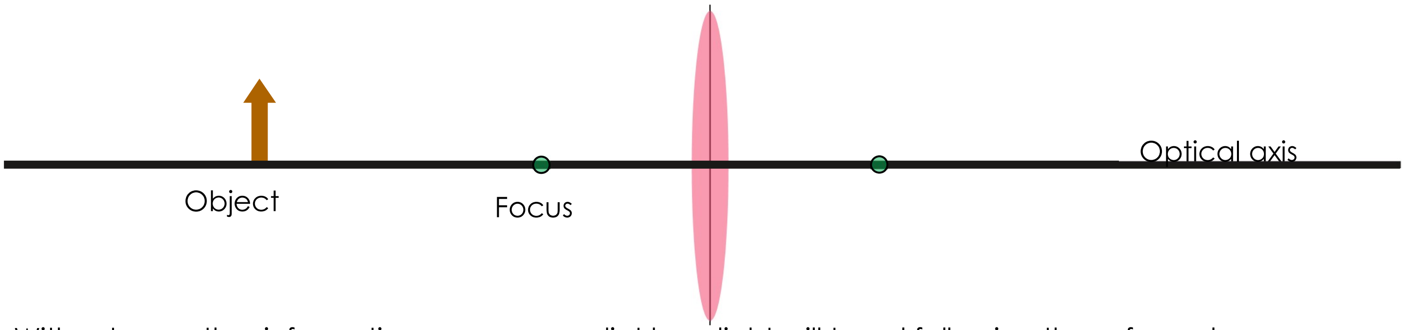
Activity 1 – Questions

Write down at least one question you have based on the course material so far. Ask your partner the question. Can you answer their questions?

Activity 2 – Introduction to ray tracing

So, now that we know the focal length of our lens, where should we put it in relation to the object and screen? **Ray tracing** is a technique to figure out where to put your lens in order to make sure that you see a focused image. You can also use ray tracing to determine the **magnification** of your image.

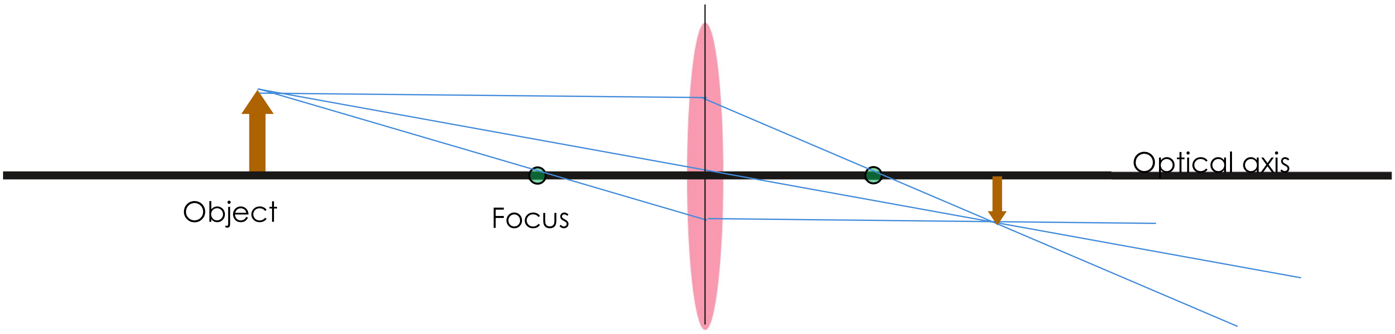
Start with a vertical line representing the position of your lens. Draw a horizontal line through the centre of your 'lens' – this is called the **optical axis.** Note the focal length of the lens by drawing a dot at the correct distance on both sides of the lens. Draw an arrow representing the height and position of your object.



Without any other information, we can predict how light will travel following these four rules.

1. Rays travelling through the centre of the lens will pass through without bending.
2. Rays travelling parallel to the optical axis will refract through the focal point
3. Rays travelling from the focal point will refract so that it is parallel to the lens
4. Rays parallel to a ray that passes through the centre of the lens will intersect the ray through the centre at a distance from the lens equal to the focal length.

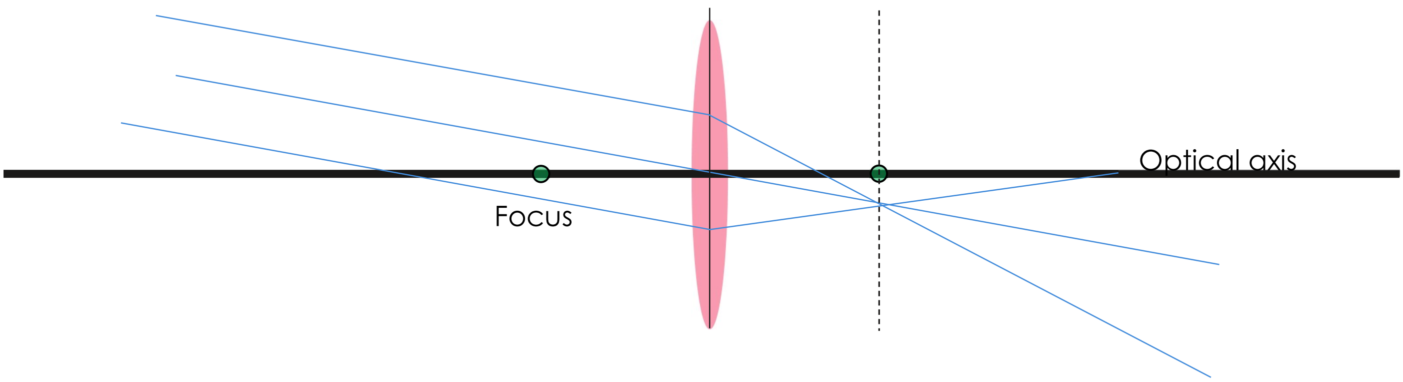
In most cases, you can use the first three rules to draw three **principle rays**.



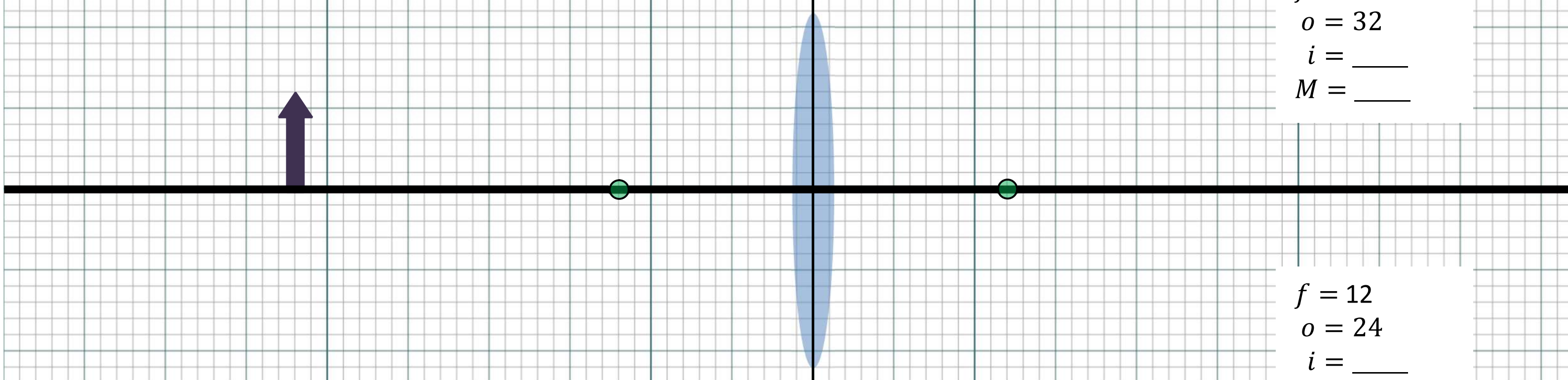
The three rays will intersect at a point that represents the tip of the image! You can measure the relative height of the object and the image.

If the rays appear to diverge, try extending the lines back toward the object – they may converge on the same side of the lens as the object! If the image is on the opposite side of the lens as the object, this is called a **real image**. If the image is on the same side of the lens, it is called a **virtual image**. A virtual image cannot be projected onto a screen, but you may still be able to see it. For example, a flat mirror forms a virtual image; the image appears to be inside the mirror even though the light isn't actually coming from within the mirror. The large image you see with a magnifying glass is also a virtual image.

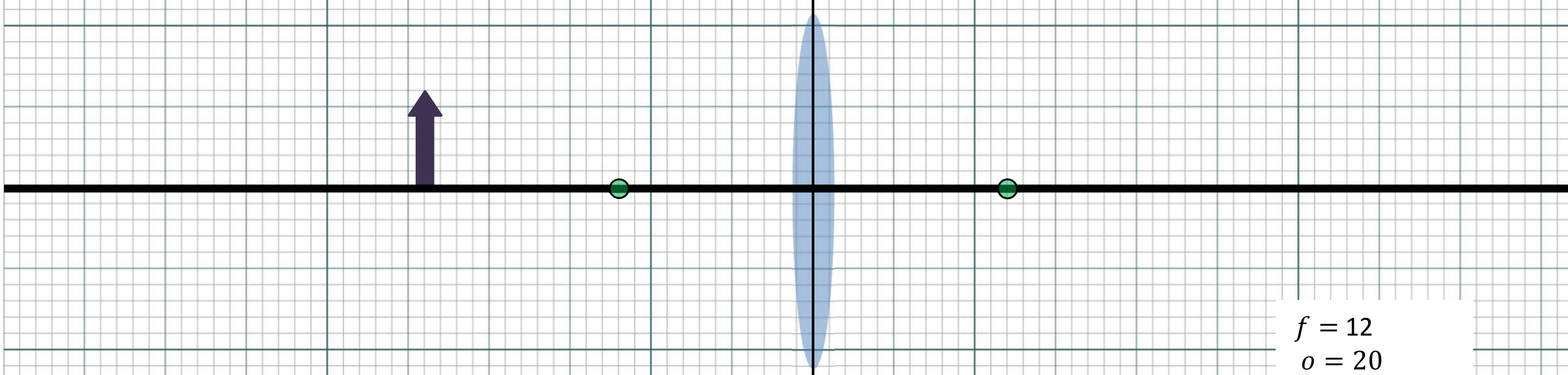
Rule 4 lets us determine what happens when parallel rays go through a lens.



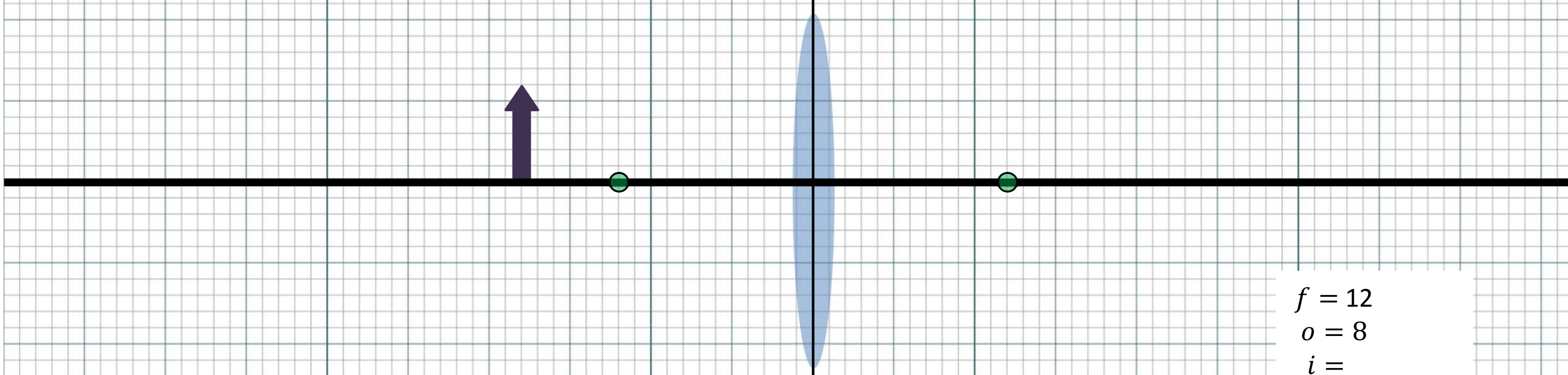
$f = 12$
$o = 32$
$i =$ _____
$M =$ _____



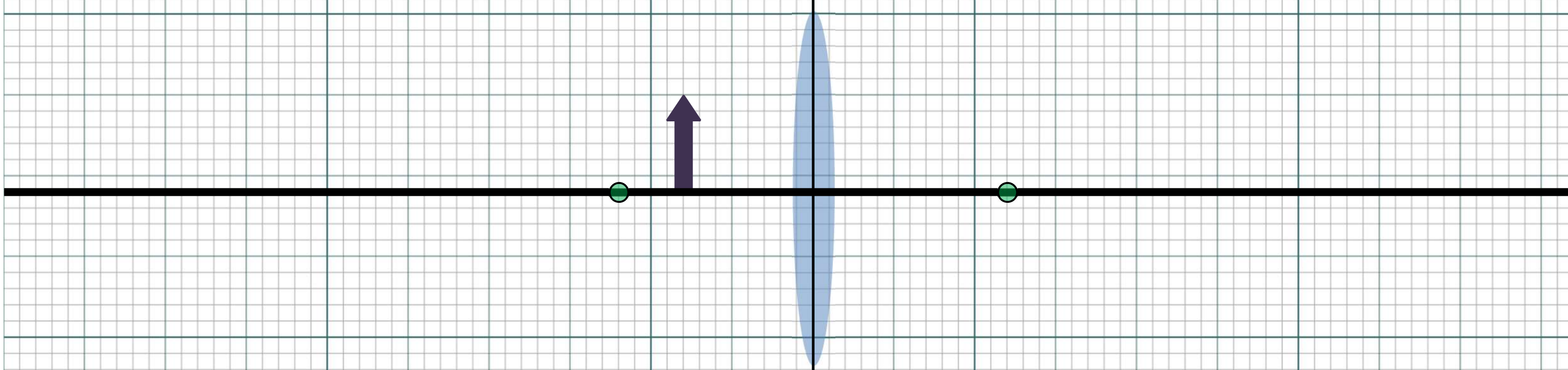
$f = 12$
$o = 24$
$i =$ _____
$M =$ _____



$f = 12$
$o = 20$
$i =$ _____
$M =$ _____



$f = 12$
$o = 8$
$i =$ _____
$M =$ _____



Activity 3 – Discussion: Should we use multiple lenses in our microscope design?

Discussion Questions:

- Do you notice any trends when solving the ray tracing problems?
- Can you determine a formula for the image distance given the object distance and focal length?
- Can you determine a formula for the magnification of the lens?
- What trends did you observe about the behaviour of lenses in the ray tracing problems?
- A microscope is defined as a system of one or more lenses used to magnify an image. What are some reasons we may want to use multiple lenses in our microscope design?

What are the equations we can use to calculate image distance and magnification?

Why might we want to use two lenses in our microscope design?

Note: To do ray tracing with multiple lenses, first determine the size and location of the image from the first lens. Then, use the image as the object for the second lens.

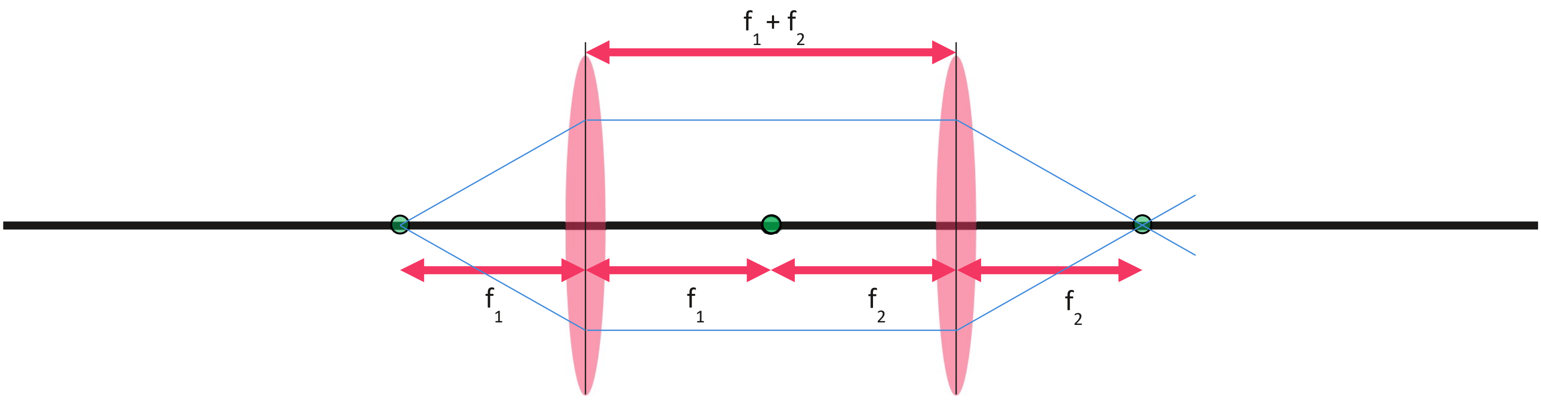
Ray Tracing Cheat Sheet

Position of Object	Beyond 2f	At 2f	Between 2f and f	At f	Between f and lens
Type of Image	Real	Real	Real	No Image	Virtual
Orientation	Inverted	Inverted	Inverted	No Image	Upright
Height	Smaller	Equal to Object Height	Bigger	No Image	Bigger

The 4f optical system

The 4f optical system is a particular way of arranging lenses. It is one of the most common ways to arrange lenses when multiple lenses are used. The name 4f comes from the fact that the arrangement is 4 focal lengths long. Some of the reasons why this arrangement is used are beyond the scope of this course, but the 4f system has the benefit of being particularly easy to model.

In order to build a 4f system, two lenses are required. Let's say that the first lens has a focal length of f_1 and the second has a focal length of f_2. The lenses should be arranged so that the separation between the two lenses is $f_1 + f_2$. The object should be placed a distance of f_1 from the first lens. Using the 4th rule of ray tracing, we know that if an object is placed at the focal point of a lens, the rays coming from that object will be parallel after passing through the lens. This means that the rays between the two lenses will be parallel! It also means that the image will be formed at a distance of f_2 from the second lens. The magnification of the image in a 4f optical system is the ratio between the focal lengths of the two lenses: $= \frac{f_2}{f_1}$.



Activity 4– How do lenses form images? Build a camera obscura to find out!

What is a camera obscura?
A camera obscura is a special type of pinhole camera with a lens. It allows us to view an image from a single lens projected through the pinhole onto a screen.

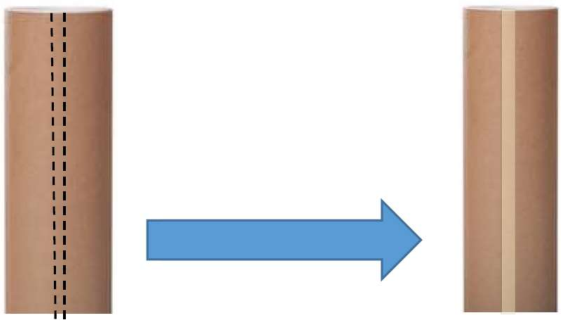
The pinhole acts like the pupil in your eye – it only allows light that has been scattered directly from the objects in the image to pass through. Rejecting light that has been scattered multiple times allows a clear image to be formed. A pinhole is often used to limit the amount of light collected by a lens; in a confocal microscope, a pinhole is used to select only photons that come from the focus of the lens. This allows us to image only a thin slice of our sample!

How to make a camera obscura:

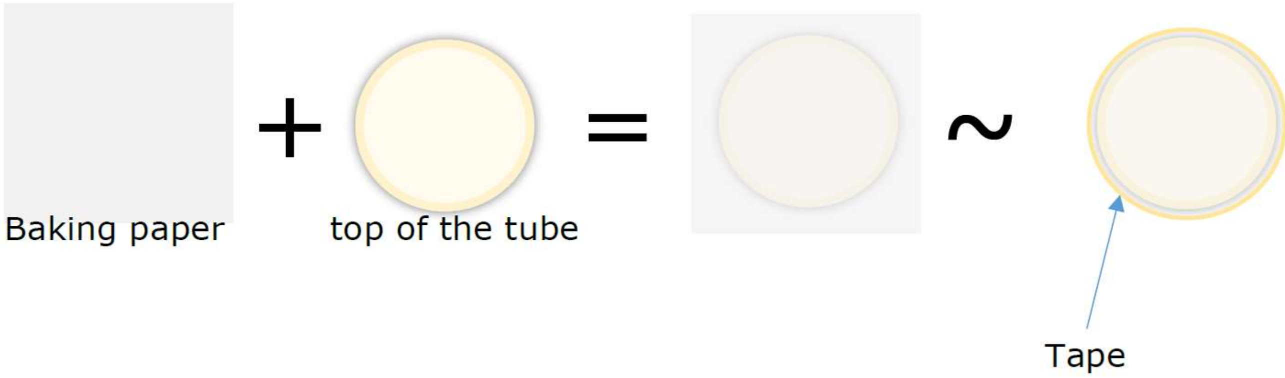
Supplies:
A cardboard tube
A lens – The focal length of my lens is ________.
Tape
Baking paper
Flat Cardboard

1. Cut the tube so that you have one 30 cm piece and one 15 cm piece.

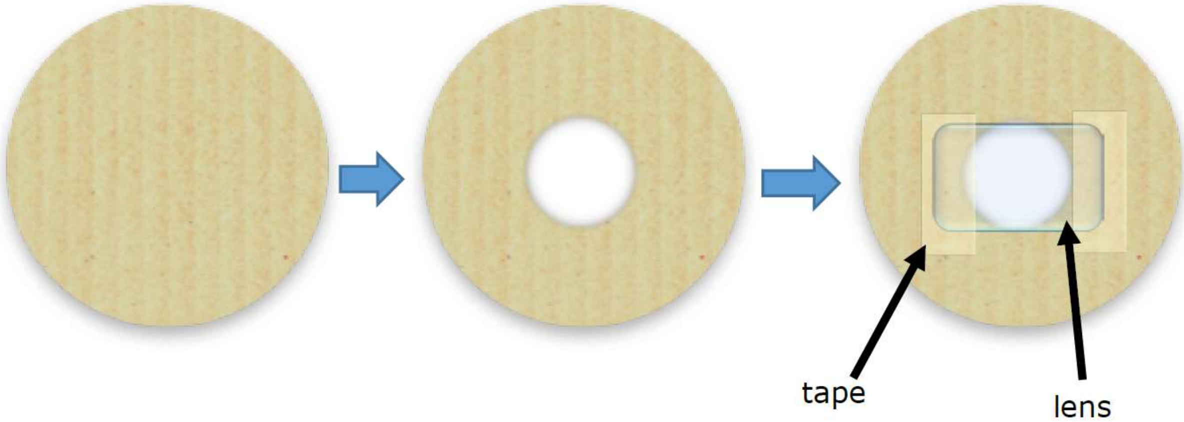
2. Cut a strip about 1 cm wide from the smaller tube and tape it closed to make a tube with a smaller diameter. You should be able to fit the shorter tube inside the longer tube.



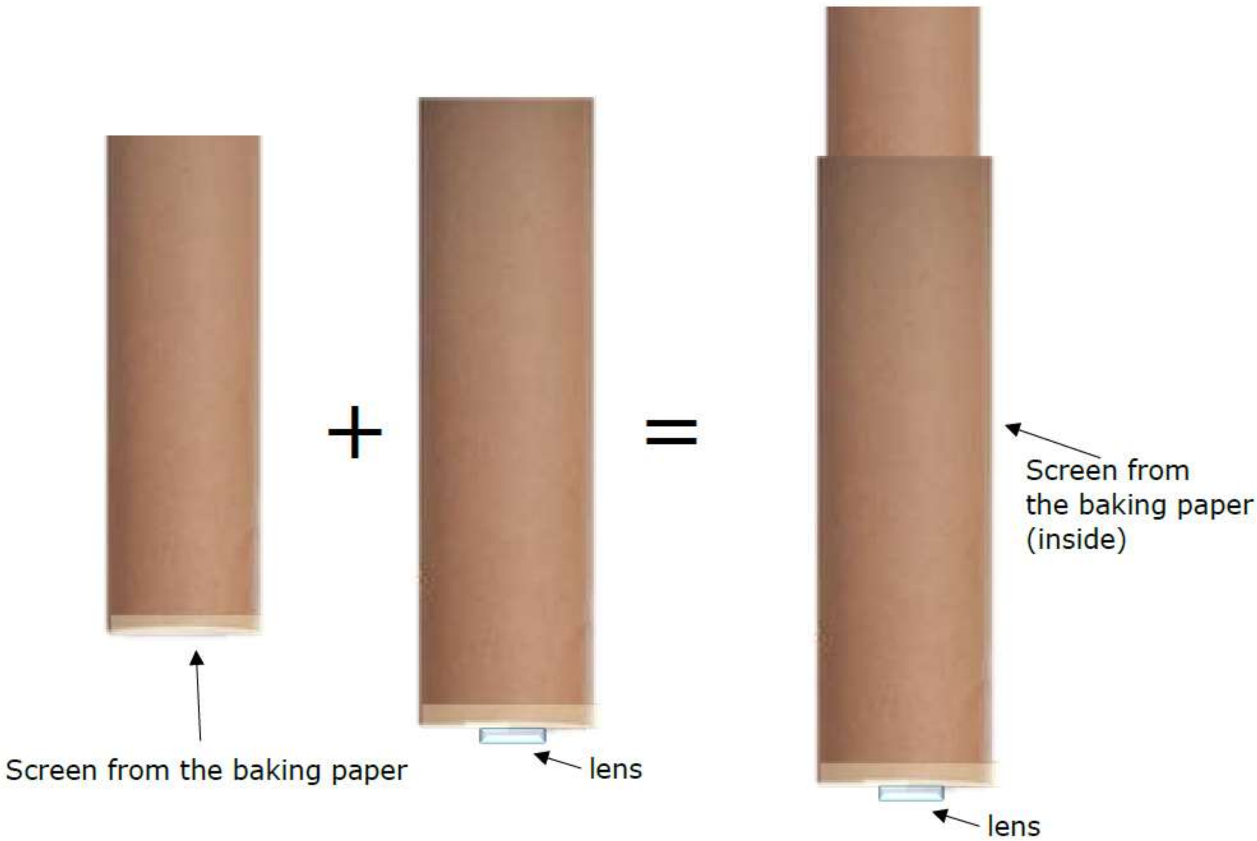
3. Cut out a square of baking paper bigger than the diameter of the small tube. Tape the baking paper over one end of the thinner tube to make a flat screen.



4. Cut out a circle from the flat cardboard with a diameter equal to the diameter of the wider tube. Cut a hole in the middle of the cardboard a bit smaller than the lens (it doesn't have to be perfect). Tape the lens to the cardboard and the cardboard to the top of the tube.



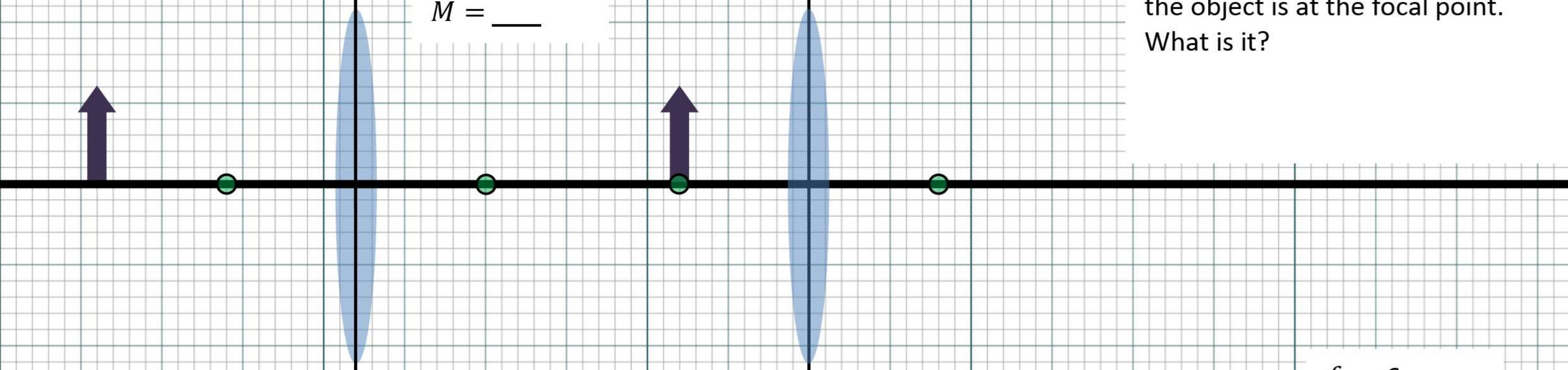
5. Place the smaller tube into the larger tube with the baking paper screen facing towards the lens. Adjust the distance from the lens to the screen to get a nice focused image.



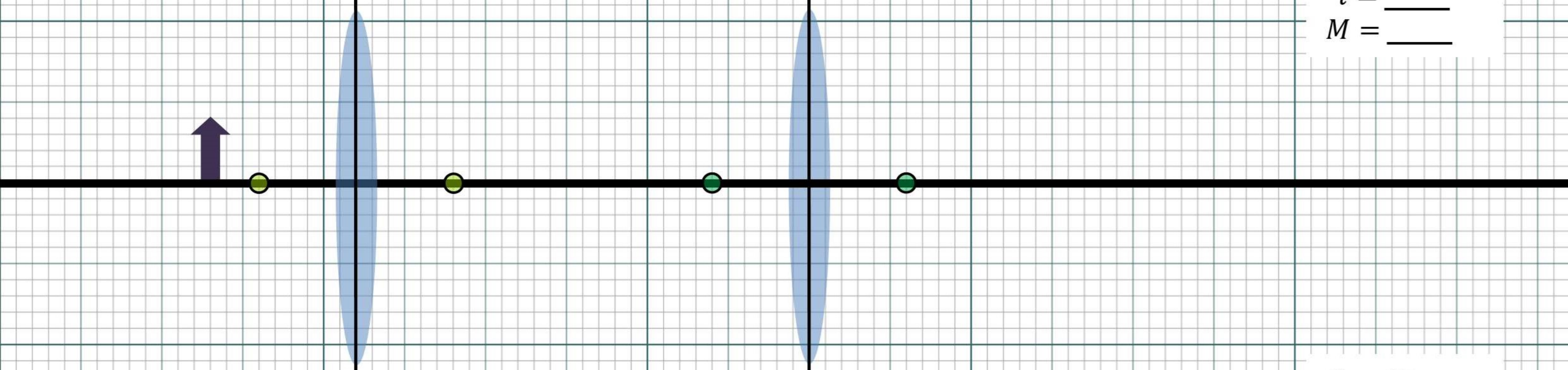
Tutorial 4 Homework assignment – Ray tracing (Problem Set)

$f = 8$
$o = 16$
$i =$ ___
$M =$ ____

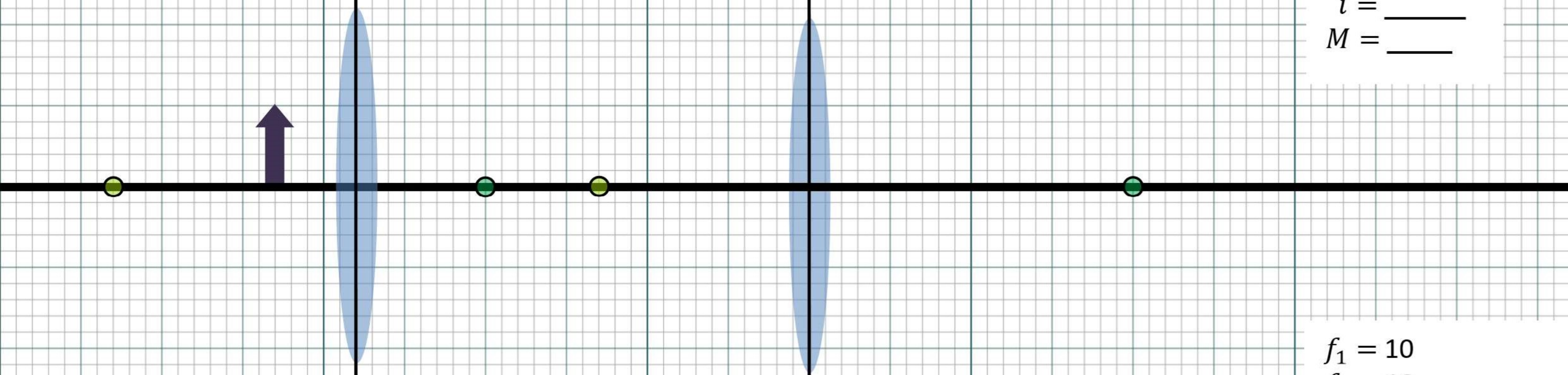
$f = 8$
$o = 8$
Something weird happens when the object is at the focal point. What is it?



$f_1 = 6$
$f_2 = 6$
$o = 9$
$i =$ _____
$M =$ _____

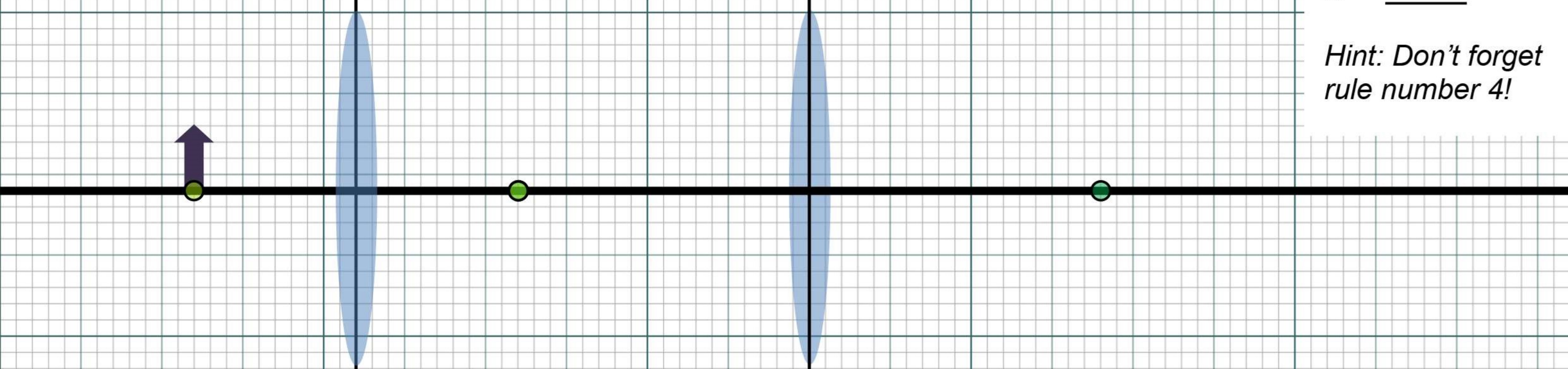


$f_1 = 15$
$f_2 = 20$
$o = 5$
$i =$ ______
$M =$ _____



$f_1 = 10$
$f_2 = 18$
$o = 10$
$i =$ ______
$M =$ ______

Hint: Don't forget rule number 4!



Tutorial 5 – Types of microscopes and endoscopes

What is the Purpose of Tutorial 5?

- To learn about difference between bright field and fluorescence microscopes
- To discuss different endoscope designs
- To summarise review any concepts from previous lectures
- To introduce and discuss the final assignment

Activity 1 – Check your knowledge

Let's see how well we recall some key concepts from previous tutorials. This is not a test! It is an opportunity to help determine what topics we should review before the final assignment.

1. A ray of light traveling through air (n = 1) crosses a boundary into water (n = 1.33) at an angle of 45 degrees to the water surface. At what angle will the light travel when it is in the water? What will be the speed of light in water? Writing the relevant equations is sufficient – you do not need to use a calculator to determine the exact numerical answer.

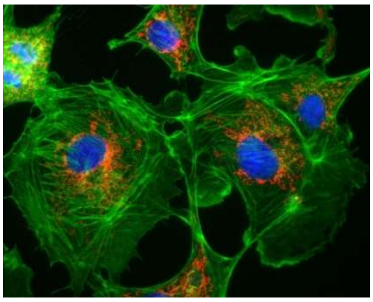
2. Is all light visible? Why or why not. Use the word **wavelength** in your response.

3. Define the terms **resolution** and **contrast**.

4. A candle is 15 cm away from a lens with a focal length of 3 cm. How far will the image be from the lens? What will be the magnification? What is the numerical aperture?

Activity 2 – Types of light microscopes

Bright field Microscope

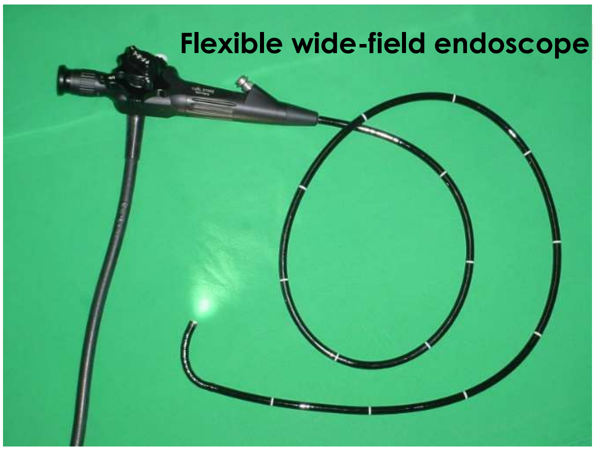


Fluorescence Microscope

There are two main types of light microscopes: bright field microscopes and fluorescence microscopes.

What is the difference between these two types of microscopes?

Activity 3 – Discussion: types of endoscopes



Some endoscopes are made with bulk lenses, and some are made entirely with fibre optics. What are the advantages and disadvantages of each of these options?

Activity 4 – What is the final assessment and what do I have to do?

Final Assessment

Part one: Designing an Endoscope **(50 marks)**

Jane wants to design an endoscope that will help her with diagnosing breast cancer. She knows that she wants a resolution of at least 2 μm (2 μm or less) to be able to accurately determine the boundaries between healthy and cancerous tissue. She plans to start by building her endoscope with bulk lenses. She plans on using an imaging technique called autofluorescence imaging, which is a fluorescence microscopy technique. Autofluorescence relies on substances that naturally exists in the body and fluoresce when exposed to a certain wavelength of light. The substance that Jane wants to excite is sensitive to light of 532 nm. The endoscope will be composed of two lenses: L1 will collimate a beam coming from an optical fibre and L2 will focus the beam to the desired spot size when it exits the endoscope.

1. Is 532 nm light visible? If so, what colour is it? What is the frequency of 532 nm light? **(3 Marks)**

2. In order to achieve a spot size of 2 μm, what will be the required numerical aperture of L2? You can round your answer to 2 decimal points. **(3 Marks)**

3. What will be the depth of field of images acquired with this endoscope? **(3 Marks)**

4. Jane would like the beam to have a diameter of 200 μm in the collimated region. What should be the focal length of L2? Note that the beam is focusing in air, and the index of refraction if air is 1. **(4 Marks)**

5. To deliver light to her endoscope, Jane will be using an optical fibre. The beam coming out of the fibre has a diameter of 50 μm and a numerical aperture of 0.22. What will be the angle of divergence of the light exiting this fibre? Remember that the index of refraction for air is 1. You may give your answer in radians or degrees. **(3 Marks)**

6. How far should L1 be placed from the end of the fibre to allow the beam to expand to a diameter of 200 μm? You can round your answer to the nearest whole number. What should be the focal length of L2 so that it will collimate the light coming from the fibre? Why? **(5 Marks)**

7. What should the separation be between L1 and L2? Choose the separation to create a 4f system. **(3 Marks)**

8. Create a ray tracing diagram that shows how the tip of the optical fibre is imaged to the focus of the endoscope. Use the graph paper provided. Don't worry if you can't portray some of the values exactly. **(9 Marks)**

Jane fabricated her endoscope based on your design, but she made a mistake! She accidentally placed the optical fibre 200 μm away from L1.

9. Using the equation for image distance, how far away from L2 will the focus of the endoscope be? **(4 Marks)**

10. Using the equation for magnification, what would we expect the new spot size to be? Will the image be upright or inverted? **(4 Marks)**

11. Draw another ray tracing diagram that describes the endoscope that was fabricated. **(9 Marks)**

Part two: Essay Question **(50 Marks)**

Explain how endoscopes can be designed for a specific application and why this is important.
(1000 words)

- Describe what an endoscope is and discuss the advantages and disadvantages compared with using a table-top microscope.
- Are endoscopes useful for medical diagnosis? How?
- Compare and contrast some common endoscope designs.
- What criteria are important to consider when choosing the right tool for the job? Why?
  You should discuss the choice of imaging technique, contrast and resolution appropriate for a specific application. You should also mention any trade-offs in design choices, for example: how does numerical aperture link probe size and resolution?

Essay writing reflection

Use the checklist below to reflect on your essay writing ability at the moment. Read the statements for each skill and then tick the box that most closely fits how you currently feel about your ability to do that skill.

You will use this to help your PhD tutor give you feedback in your next tutorial. They will give you specific advice on how to improve these areas in relation to your draft assignment so be completely honest.

<table>
<tr><th colspan="3">Addressing the question</th><th colspan="3">Using evidence</th></tr>
<tr><td colspan="3">I can…
identify what the title or question is asking me to do
select relevant information from the course to answer the title or question
explain why the information I have used is relevant</td><td colspan="3">I can…
select evidence that supports my points
link evidence to my points and ideas
clearly and convincingly explain how my evidence supports my points
use references</td></tr>
<tr><td colspan="3">I feel…</td><td colspan="3">I feel…</td></tr>
<tr><td>Confident</td><td>Partially confident</td><td>Not confident</td><td>Confident</td><td>Partially confident</td><td>Not confident</td></tr>
<tr><td>☐</td><td>☐</td><td>☐</td><td>☐</td><td>☐</td><td>☐</td></tr>
<tr><th colspan="3">Developing an argument</th><th colspan="3">Critical evaluation</th></tr>
<tr><td colspan="3">I can…
include a point of view or position in response to the title or question
develop and explain my point of view
argue why my point of view or position is correct</td><td colspan="3">I can…
ensure I analyse events and information rather than just describe them
assess the relevance and significance of the ideas and examples I am writing about</td></tr>
<tr><td colspan="3">I feel…</td><td colspan="3">I feel…</td></tr>
<tr><td>Confident</td><td>Partially confident</td><td>Not confident</td><td>Confident</td><td>Partially confident</td><td>Not confident</td></tr>
<tr><td>☐</td><td>☐</td><td>☐</td><td>☐</td><td>☐</td><td>☐</td></tr>
<tr><th colspan="3">Structuring</th><th colspan="3">Use of language</th></tr>
<tr><td colspan="3">I can…
arrange my points in to a logical order
write paragraphs that focus on one idea or point each
write an introduction that explains how I will deal with the issues of the essay
write a conclusion that sums up my main points</td><td colspan="3">I can…
minimise spelling, punctuation and grammar errors
ensure my writing makes the meaning clear and easy to follow
write using and appropriate tone and level of formality</td></tr>
<tr><td colspan="3">I feel…</td><td colspan="3">I feel…</td></tr>
<tr><td>Confident</td><td>Partially confident</td><td>Not confident</td><td>Confident</td><td>Partially confident</td><td>Not confident</td></tr>
<tr><td>☐</td><td>☐</td><td>☐</td><td>☐</td><td>☐</td><td>☐</td></tr>
</table>

Tutorial 6 – Draft assignment feedback and reflection

What is the Purpose of Tutorial 6?

- To received feedback on your draft assignment
- To reflect on your essay writing skills
- To identify practical ways to improve your assignment

What three things can you now do to improve your assignment and your essay writing ability?

1

2

3

Tutorial 7 – Final assignment feedback and reflection

What is the Purpose of Tutorial 7?

- To receive feedback on final assignments.
- To write targets for improvement in school lessons.
- To reflect on the programme including what was enjoyed and what was challenging.

Final assignment feedback

What I did well…	What I could have improved on…
• • •	• • •

My target for future work is…

Reflecting on The Scholars Programme

What did you most enjoy about The Scholars Programme?
•   •   •

What did you find challenging about the programme?	How did you overcome these challenges?
• • •	• • •

Appendix 1 – Referencing correctly

When you get to university, you will need to include references in the assignments that you write, so we would like you to start getting into the habit of referencing in your Brilliant Club assignment. This is really important, because it will help you to avoid plagiarism. Plagiarism is when you take someone else's work or ideas and pass them off as your own. Whether plagiarism is deliberate or accidental, the consequences can be severe. In order to avoid losing marks in your final assignment, or even failing, you must be careful to reference your sources correctly.

What is a reference?

A reference is just a note in your assignment which says if you have referred to or been influenced by another source such as book, website or article. For example, if you use the internet to research a particular subject, and you want to include a specific piece of information from this website, you will need to reference it.

Why should I reference?

Referencing is important in your work for the following reasons:

- It gives credit to the authors of any sources you have referred to or been influenced by.
- It supports the arguments you make in your assignments.
- It demonstrates the variety of sources you have used.
- It helps to prevent you losing marks, or failing, due to plagiarism.

When should I use a reference?

You should use a reference when you:

- Quote directly from another source.
- Summarise or rephrase another piece of work.
- Include a specific statistic or fact from a source.

How do I reference?

There are a number of different ways of referencing, and these often vary depending on what subject you are studying. The most important to thing is to be consistent. This means that you need to stick to the same system throughout your whole assignment. Here is a basic system of referencing that you can use, which consists of the following two parts:

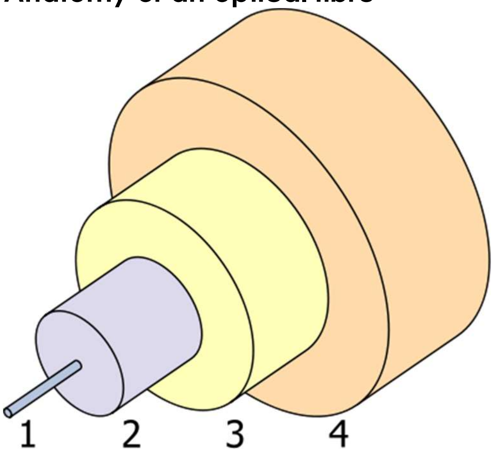
- **A marker in your assignment**: After you have used a reference in your assignment (you have read something and included it in your work as a quote, or re-written it your own words) you should mark this is in your text with a number, e.g. [1]. The next time you use a reference you should use the next number
    - e.g. [2].
- **Bibliography**: This is just a list of the references you have used in your assignment. In the bibliography, you list your references by the numbers you have used, and include as much information as you have about the reference. The list below gives what should be included for different sources.
- **Websites** – Author (if possible), title of the web page, website address, [date you accessed it, in square brackets].
    - e.g. Dan Snow, 'How did so many soldiers survive the trenches?', http://www.bbc.co.uk/guides/z3kgjxs#zg2dtfr [11 July 2014].
- **Books** – Author, date published, title of book (in italics), pages where the information came from.
    - e.g. S. Dubner and S. Levitt, (2006) *Freakonomics*, 7-9.
- **Articles** – Author, 'title of the article' (with quotation marks), *where the article comes from* (newspaper, journal etc.), date of the article.
    - e.g. Maev Kennedy, 'The lights to go out across the UK to mark First World War's centenary', Guardian, 10 July 2014.

Appendix 2 – Challenge Activities

How do fibre optics work?

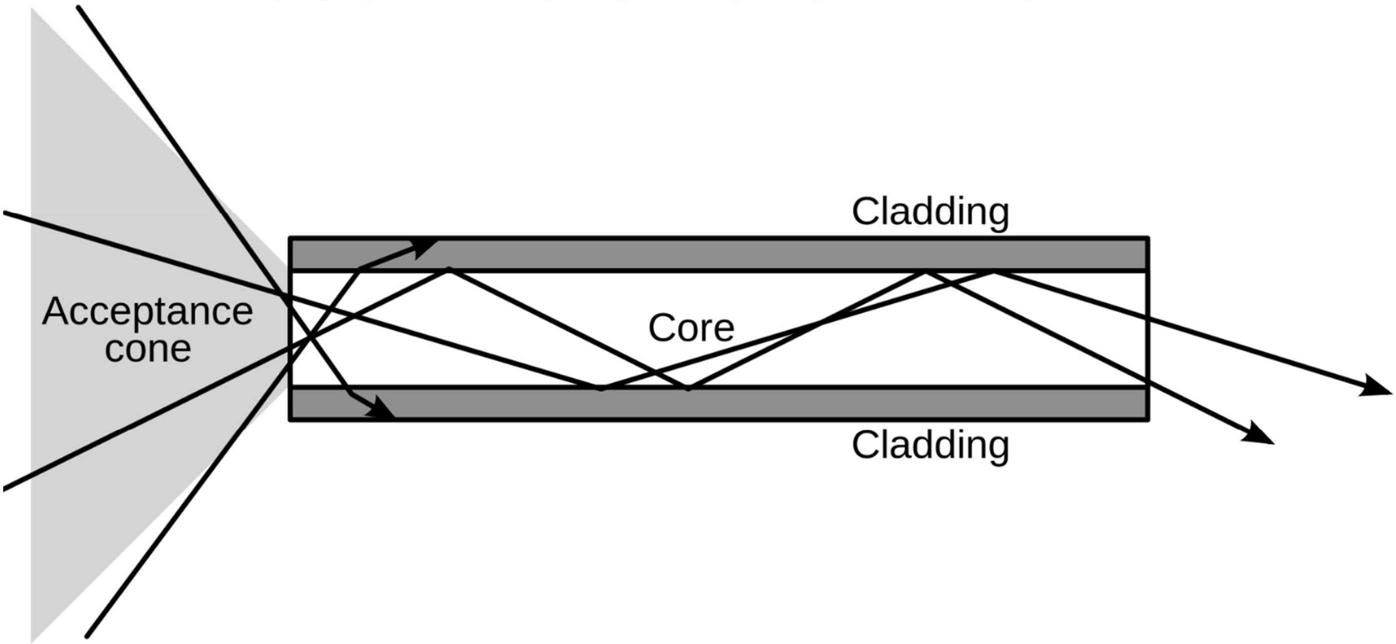
In this activity we will learn about how fibre optics work.

Anatomy of an optical fibre



	Name	Material
1	Core	Silica (glass)
2	Cladding	Doped Silica
3	Protective Coating	Acrylic or plastic
4	Jacket	Rubber

You can model the propagation of a ray of light along an optical fibre using total internal reflection.



For optical fibres, the **numerical aperture** tells us about how the light will diverge when it exits the fibre. It also tells us what the convergence angle of light needs to be in order to enter the fibre (labelled acceptance cone in the image above). It is based on the difference in the refractive index between the **core** and the **cladding** of the fibre.

$$NA_{fibre} = n\sin\theta = \sqrt{n_{core}^2 - n_{cladding}^2}$$

Remember that the index of refraction of the cladding must be less than the index of refraction of the core. Why?

____

____

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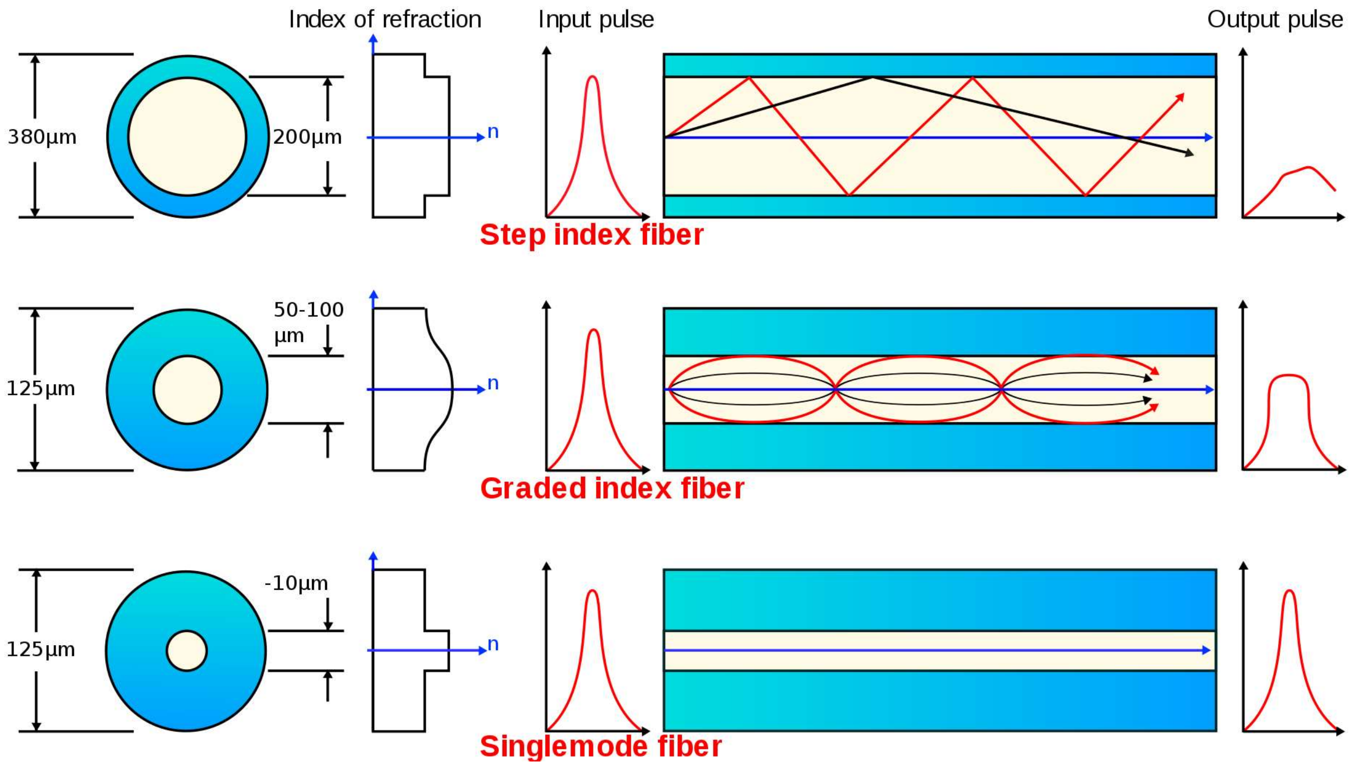
____

In order for total internal reflection to occur, the light must hit the cladding at a very large angle. What would happen if the light hit the cladding at too small of an angle?

Types of optical fibres



Fibre Type	Analogy in Free Space	Description
Step-index fibre		
Gradient-index fibre		
No-core fibre		

Is it possible for total internal reflection to occur in no-core fibre? Why or why not?

Reading Scientific Journals

At university some assignments will require you to read scientific journals. Scientific journals are special publications where researchers publish fist hand accounts of experiments and results. The articles must contain *original work*. Scientific journal articles typically start with an abstract; an abstract is a summary of the important results in the paper. Usually, it is a good idea to first read the abstract to get an idea of the important points in a paper. Below is an abstract from a scientific journal article about the design of a fibre optic endoscope. The first few pages of the article are included here on the next few pages.

Read through the abstract below. Underline any words that you learned in this course. Circle any words that you do not know.

Y. Qiu, Y. Wang, K. D. Belfield, and X. Liu, "Ultrathin lensed fiber-optic probe for optical coherence tomography," Biomed. Opt. Express 7, 2154-2162 (2016)

Abstract:

We investigated and validated a novel method to develop ultrathin lensed fiber-optic (LFO) probes for optical coherence tomography (OCT) imaging. We made the LFO probe by attaching a segment of no core fiber (NCF) to the distal end of a single mode fiber (SMF) and generating a curved surface at the tip of the NCF using the electric arc of a fusion splicer. The novel fabrication approach enabled us to control the length of the NCF and the radius of the fiber lens independently. By strategically choosing these two parameters, the LFO probe could achieve a broad range of working distance and depth of focus for different OCT applications. A probe with 125µm diameter and lateral resolution up to 10µm was demonstrated. The low-cost, disposable and robust LFO probe is expected to have great potential for interstitial OCT imaging.

What is the important advance that the authors are reporting in this article?

What else do you notice looking at the front page of the article?

Ultrathin lensed fiber-optic probe for optical coherence tomography

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*xliu@njit.edu

Abstract: We investigated and validated a novel method to develop ultrathin lensed fiber-optic (LFO) probes for optical coherence tomography (OCT) imaging. We made the LFO probe by attaching a segment of no core fiber (NCF) to the distal end of a single mode fiber (SMF) and generating a curved surface at the tip of the NCF using the electric arc of a fusion splicer. The novel fabrication approach enabled us to control the length of the NCF and the radius of the fiber lens independently. By strategically choosing these two parameters, the LFO probe could achieve a broad range of working distance and depth of focus for different OCT applications. A probe with 125μm diameter and lateral resolution up to 10μm was demonstrated. The low-cost, disposable and robust LFO probe is expected to have great potential for interstitial OCT imaging.

OCIS codes: (110.4500) Optical coherence tomography; (060.2350) Fiber optics imaging; (170.2150) Endoscopic imaging.

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Notes

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