Waves & Optics

GCSE overview

isaacphysics.org
https://isaacphysics.org/pages/remote_learning

Waves

Waves carry energy or information without moving material from one place to another

Waves involve linked oscillations (repeating back-and-forth movements)

Waves can diffract (spread out on passing through a gap)

- Not noticeable if wavelength much smaller than gap

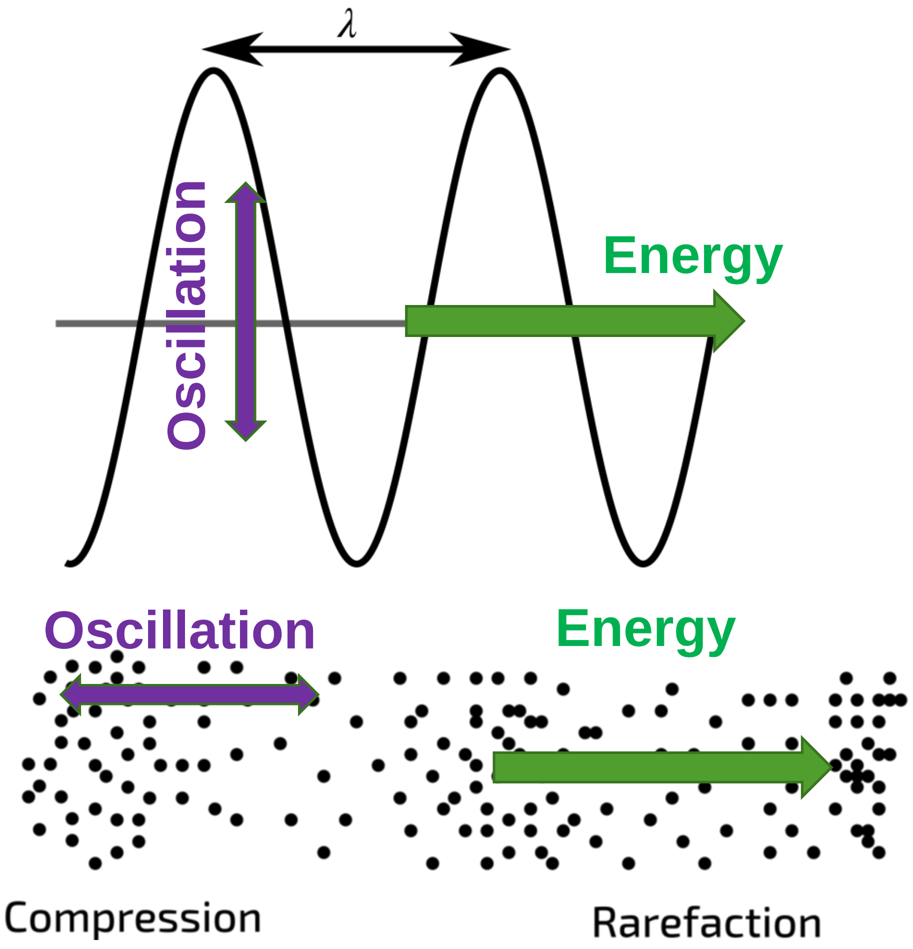
Transverse & longitudinal

In a transverse wave, the oscillations are at right angles to the direction in which the energy is transferred

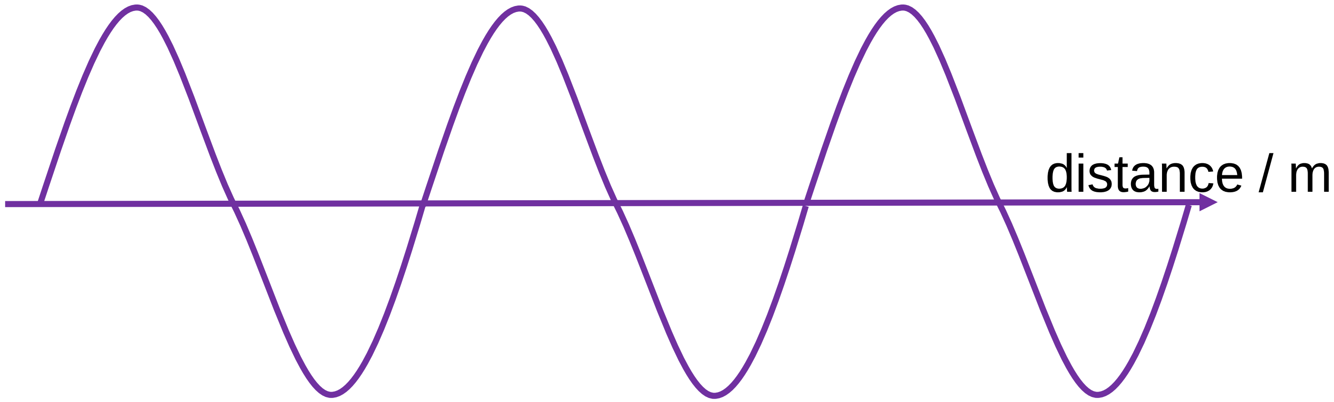
example: light, seismic P wave

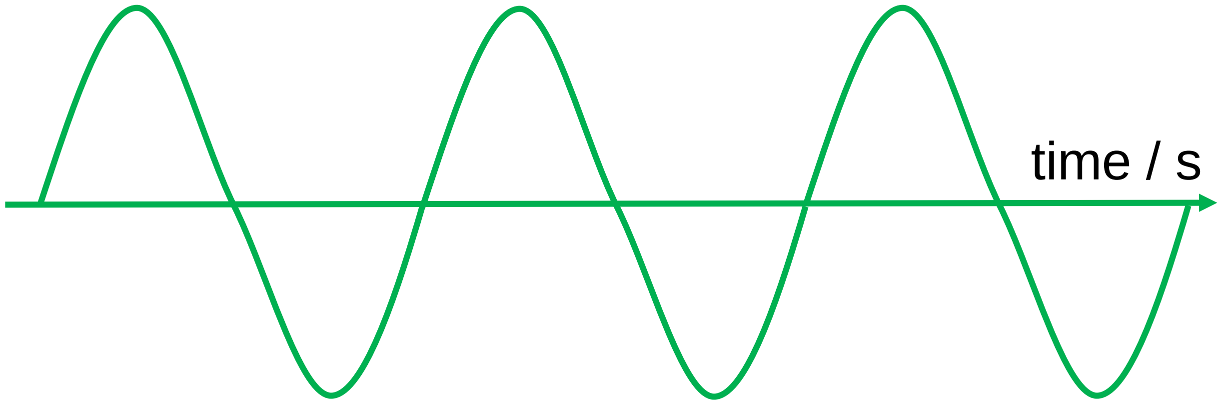
In a longitudinal wave, the oscillations are parallel to the direction in which the energy is transferred

example: sound, seismic S wave



Basic wave properties





Match the quantities

Symbol	Term		Meaning
λ	wavelength		number of waves passing you each second
T	time period		highest point on a wave
A	amplitude		distance from one peak to the next
f	frequency		lowest point on a wave
	peak		height of wave above the midpoint
	trough		the distance covered by a peak each second
v	speed		time for one wave to pass you

Match the quantities

Symbol	Term		Meaning
λ	wavelength		distance from one peak to the next
T	time period		time for one wave to pass you
A	amplitude		height of wave above the midpoint
f	frequency		number of waves passing you each second
	peak		highest point on a wave
	trough		lowest point on a wave
v	speed		the distance covered by a peak each second

Wave formulae

Number of waves made each second x time period = 1

$$f = \frac{1}{T} \qquad T = \frac{1}{f}$$

Speed = length of wave made each second

= number of waves made each second x wavelength

$$v = f\lambda \qquad f = \frac{v}{\lambda} \qquad \lambda = \frac{v}{f}$$

Practice with wave formulae

1. What is the frequency of the mains if T=0.020s?

2. What is the wavelength of a sound with f=440Hz if the speed of sound is 330m/s?

3. What is the frequency of a λ=3cm microwave if the speed is 3.0×10^8m/s?

Sonar & ultrasound

Ultrasound is a longitudinal wave, like sound, but with $f > 20\ 000$ Hz, so can not be heard

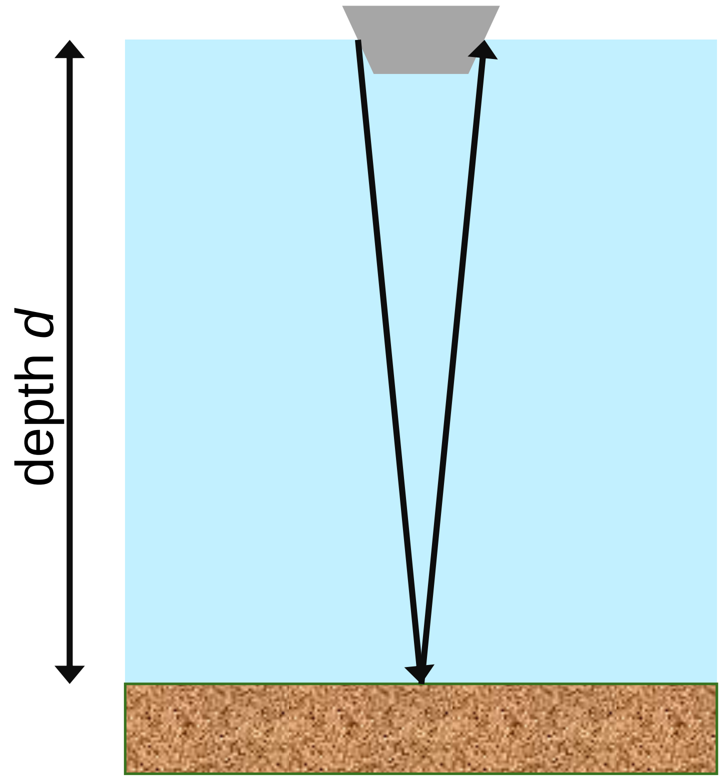
Speed of sound in water ≈ 1400m/s

In time t, pulse travels $2d$, so

$$2d = vt \qquad d = \frac{vt}{2}$$

Used in depth measuring, and antenatal scanning (non ionizing radiation)

High intensity ultrasound can also be used in medical treatments such as breaking up kidney stones



Sonar practice

Take the speed of radio waves to be $3.0x10^8$m/s, the speed of sound in air to be 330m/s, and in water/humans to be 1400m/s.

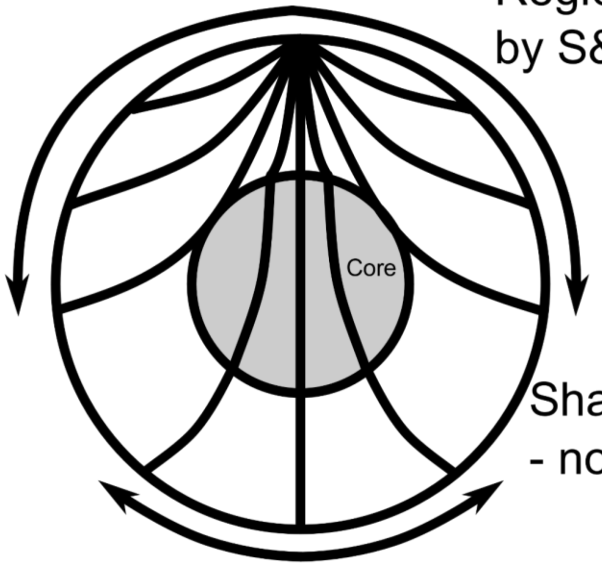
1. A sonar pulse reflects of the bottom of a sea channel and arrives back at the ship 0.029s after it was sent. How deep is the channel?

2. An ultrasound scan is measuring the size of a foetus's head. The pulse takes an extra 0.114ms to bounce of the back of the head rather than the front. How large is the head?

3. A radar pulse takes 69μs to reflect off an aircraft and return to the radar dish at the airport. How far away is the aircraft?

Seismic waves

Wave refracts as rock compressibility and density changes.
Wave can also reflect at boundaries.



	P-wave	S-wave
Speed	faster (≈7km/s)	slower (≈5km/s)
Type	longitudinal wave	transverse wave
Can travel in liquids?	yes (can pass core)	no

Seismic practice

Take the speed of S-waves near the surface of the earth to be 5km/s and the speed of P-waves to be 8km/s.

1. **If an earthquake occurs 40km away, how much time will it take the P wave to arrive? How much time will it take the S wave to arrive?**

2. **For the seismometer 40km from the focus, what is the delay between S wave and P wave?**

3. **How far away is an earthquake if the S wave arrives 9.0s after the P wave? (Hint: use your answer to q2)**

Electromagnetic waves

- Transverse waves
- Which can travel through vacuum
- Speed in vacuum = 3.0×10^8 m/s
- Involve oscillating electric and magnetic fields
- Have a wide variety of uses, and include visible light
- The higher the frequency, the more energy contained in each ‘parcel’ of light (photons).
- Very high frequency electromagnetic waves are ionizing.

Electromagnetic spectrum

Frequency		Wavelength
Low	Radio waves	Long
	Microwaves	2cm
	Infra-red radiation	10μm
	Visible light	0.4-0.7μm
	Ultra-violet radiation	0.1μm
	X-rays (from atom)	1 nm
High	Gamma (γ) rays (from nucleus)	Short

Ionizing

EM spectrum - uses

Band	Use
Radio	Broadcast (TV), aviation/shipping communication
Microwave	Mobile phone, satellite comms, navigation cooking, radar
Infra-red	heating (radiant heat), cooking (in grill/toaster), remote controls, fibre optic communications, night cameras
Visible	very many uses – take your pick...
Ultra-violet	hygiene, forgery detection, crime scene investigation, sun tanning lamps
X-ray	medical imaging, non-destructive testing in engineering
Gamma ray	radiotherapy, medical tracers

EM spectrum - hazards

Band	Hazard if over-exposed
Radio	
Microwave	frequency used in microwave oven causes heating
Infra-red	burns
Visible	
Ultra-violet	skin cancer
X-ray	hazards of ionizing radiation
Gamma ray	hazards of ionizing radiation

Light and matter

When light meets a surface, it may experience:

- Reflection – light bounces off
  - Specular reflection (as off mirror): bounces off at one angle only
  - Diffuse reflection (as off painted wall): bounces off at all angles
- Refraction – light passes through the surface, but with a change in speed
  - If light hits boundary diagonally, it will change direction
- Absorption – light does not pass through or reflect, and the surface is heated
  - pigmented (coloured) surfaces (including filters) will only absorb certain colours. Green leaves absorb red and blue light.

Subtracting light

Primary colours of pigment are cyan, magenta & yellow.

Cyan has ink which removes red light from a beam

Magenta has ink which removes green light from a beam

Yellow has ink which removes blue light from a beam.

If white light passes a cyan filter, the red is removed, so it still has blue and green.

If you want to end up with blue light, you need to remove the green and the red, so you use a mixture of magenta and cyan to remove all but the blue. This mixture looks blue!

Absorption practice

What colour would the light be after...

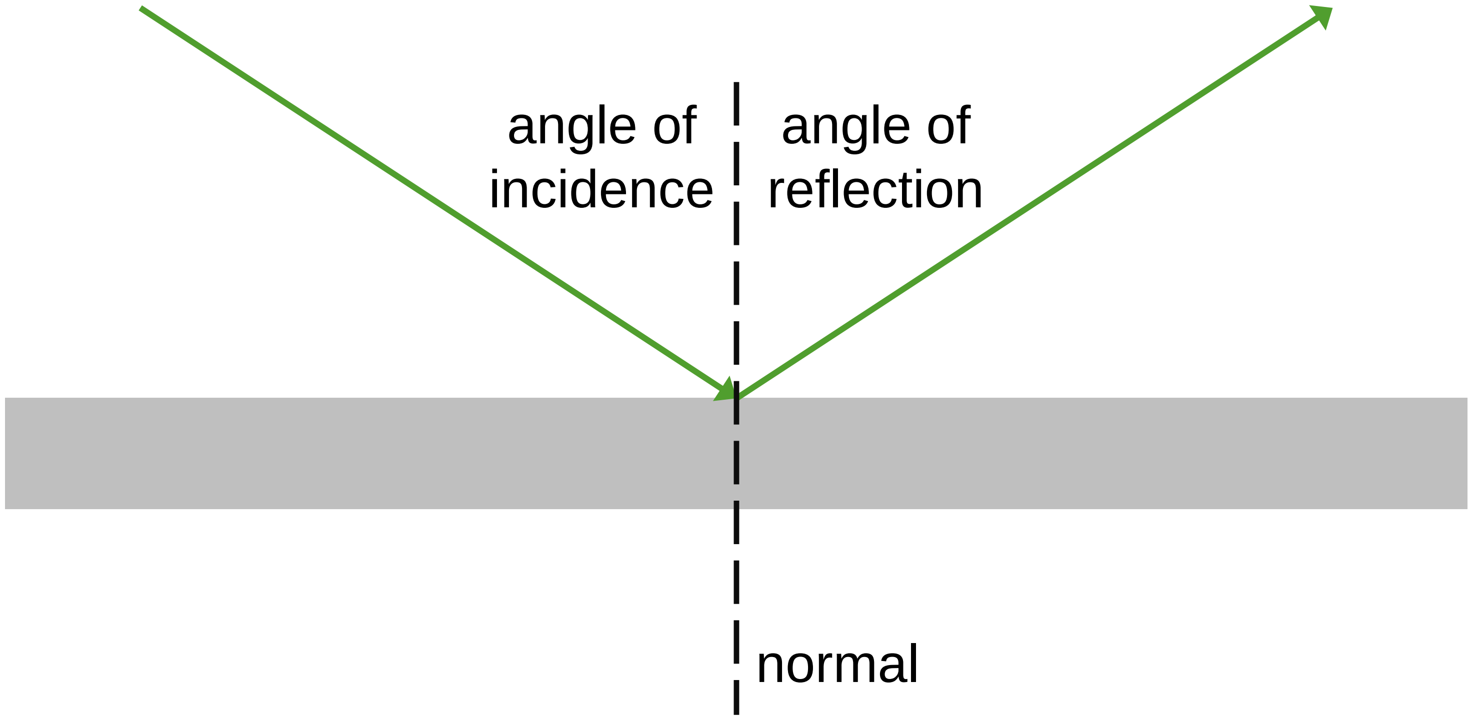
1. Initially white light has passed through a blue filter?

2. Initially red light has reflected off a red surface?

3. Initially green light has reflected off a blue surface?

4. White light passes through a green filter, then reflects off a white surface?

Specular Reflection



Law of reflection: angle of incidence = angle of reflection

Image in reflection - practice

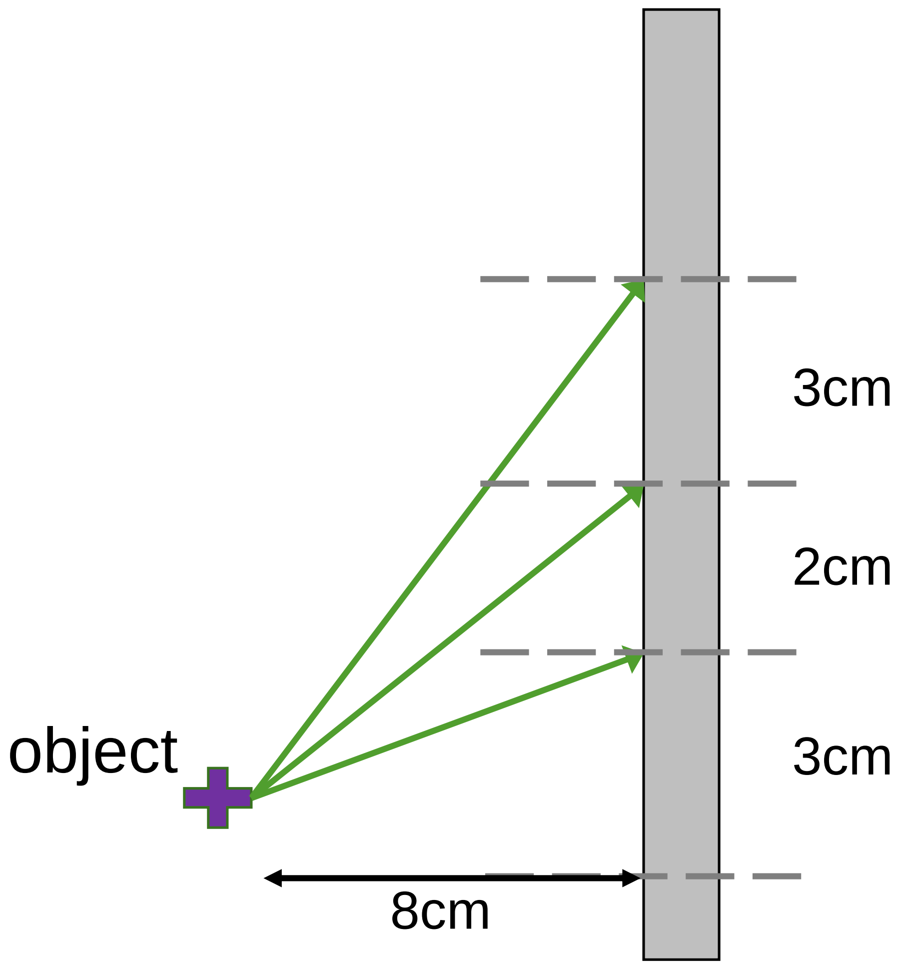
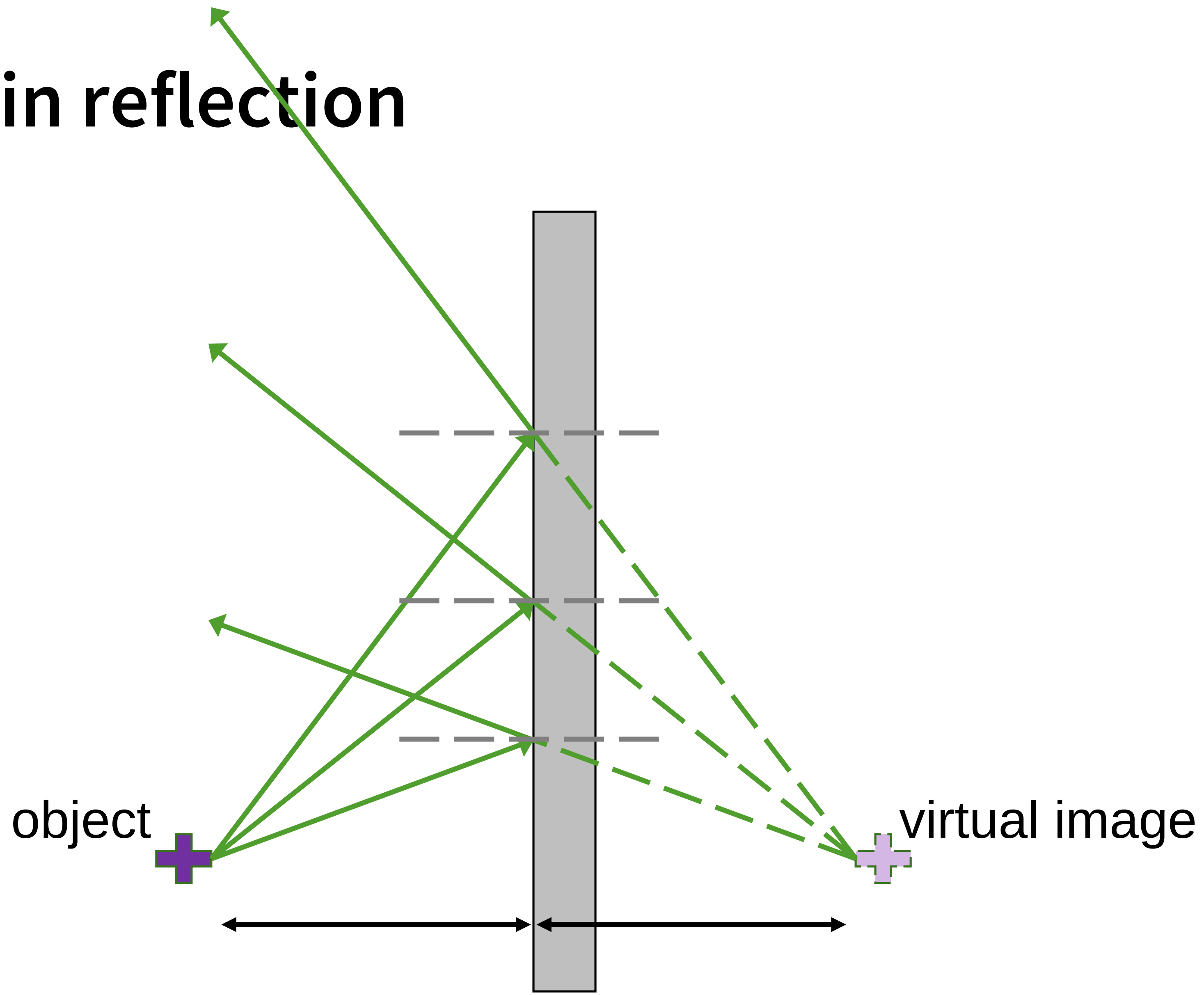
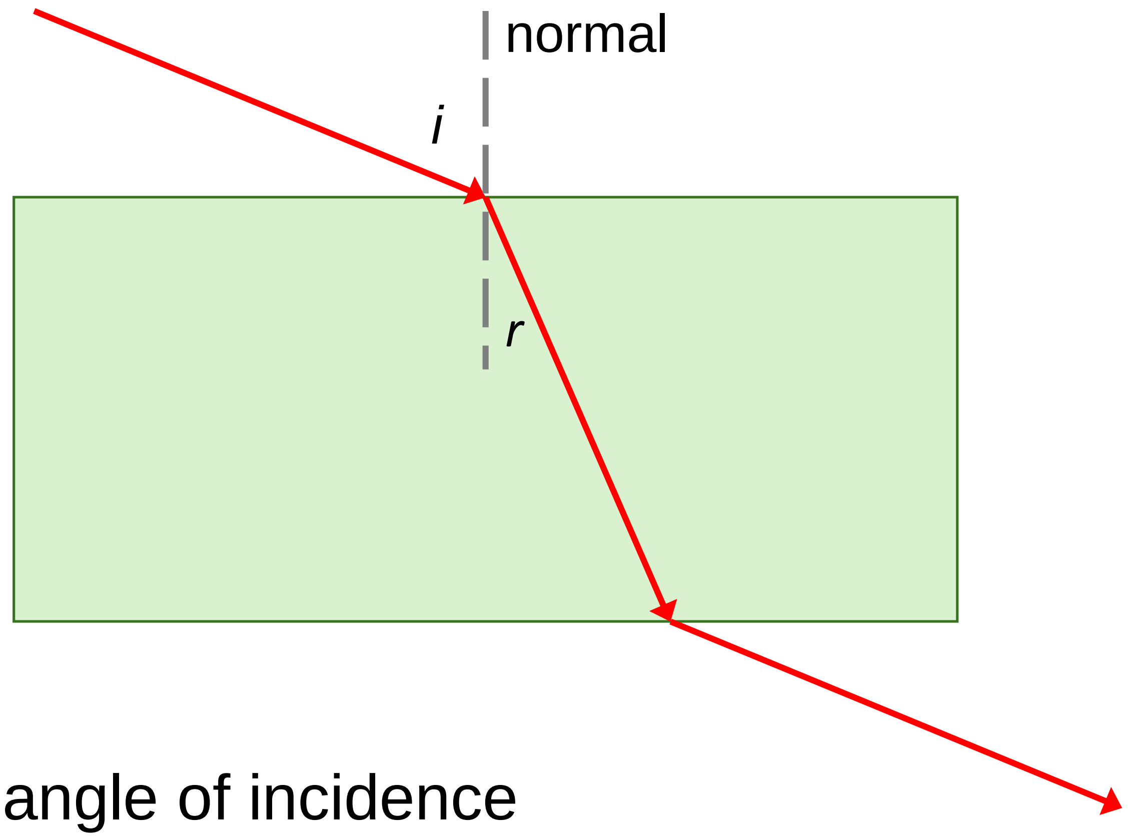


Image in reflection



Refraction

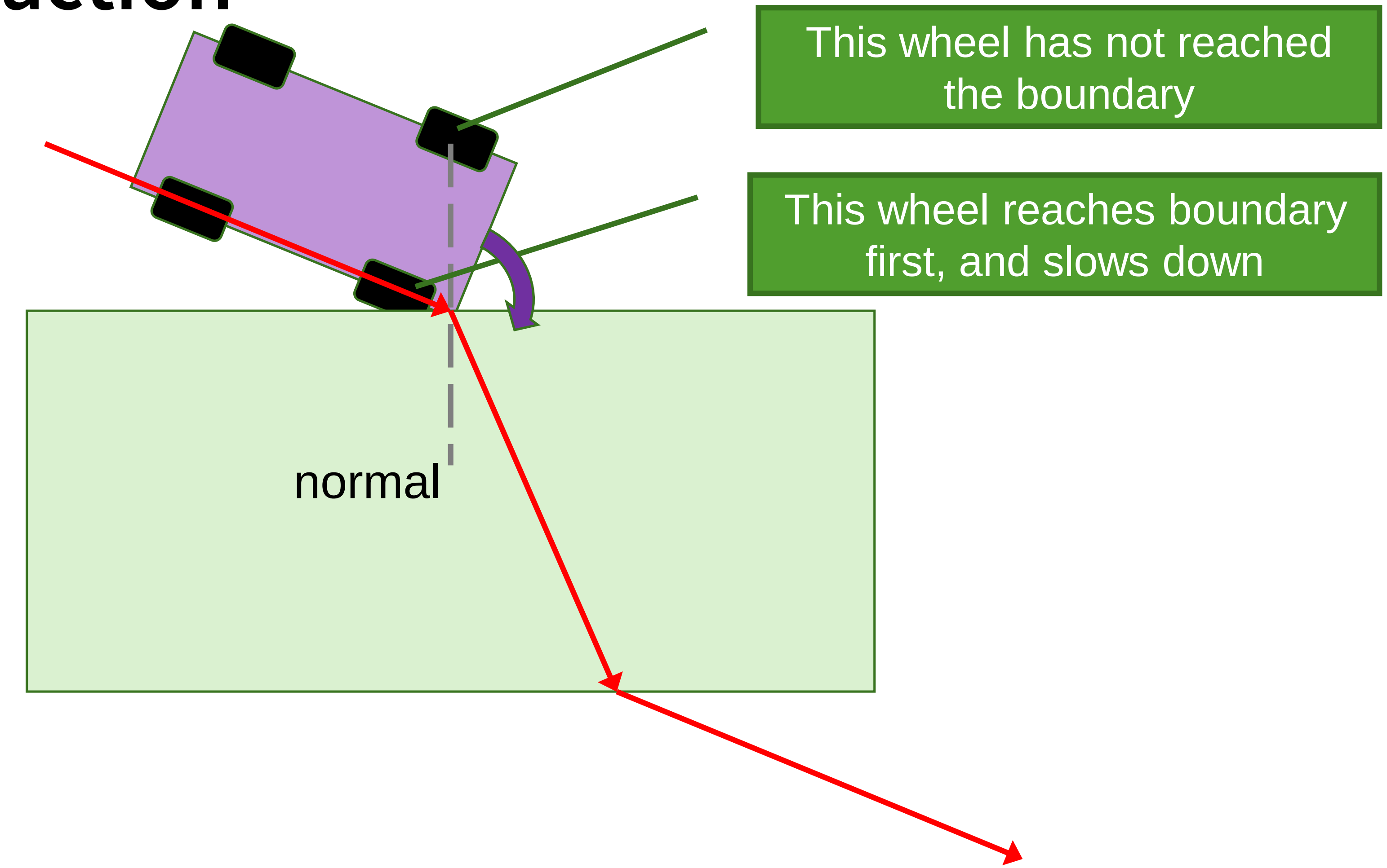


Faster
Away

Slower
Towards

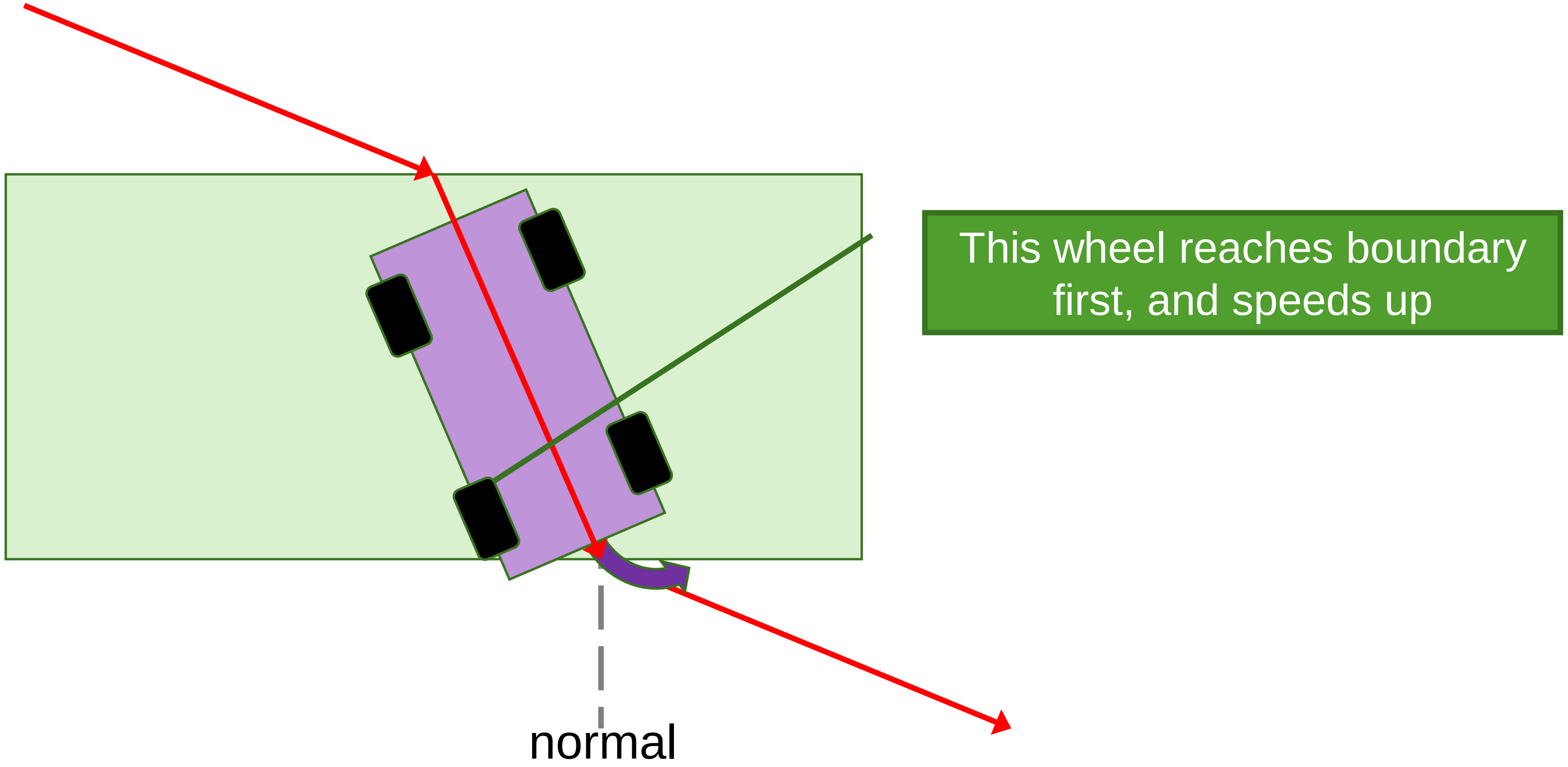
i = angle of incidence
r = angle of refraction

Refraction

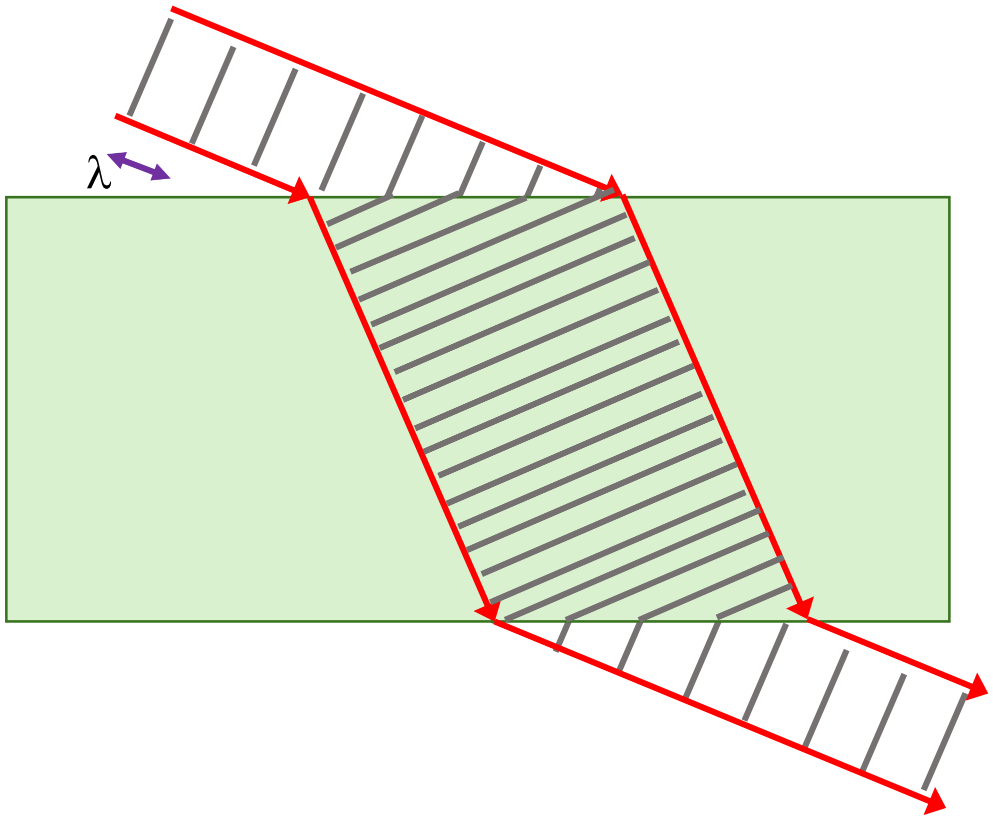


This wheel has not reached the boundary
This wheel reaches boundary first, and slows down
normal

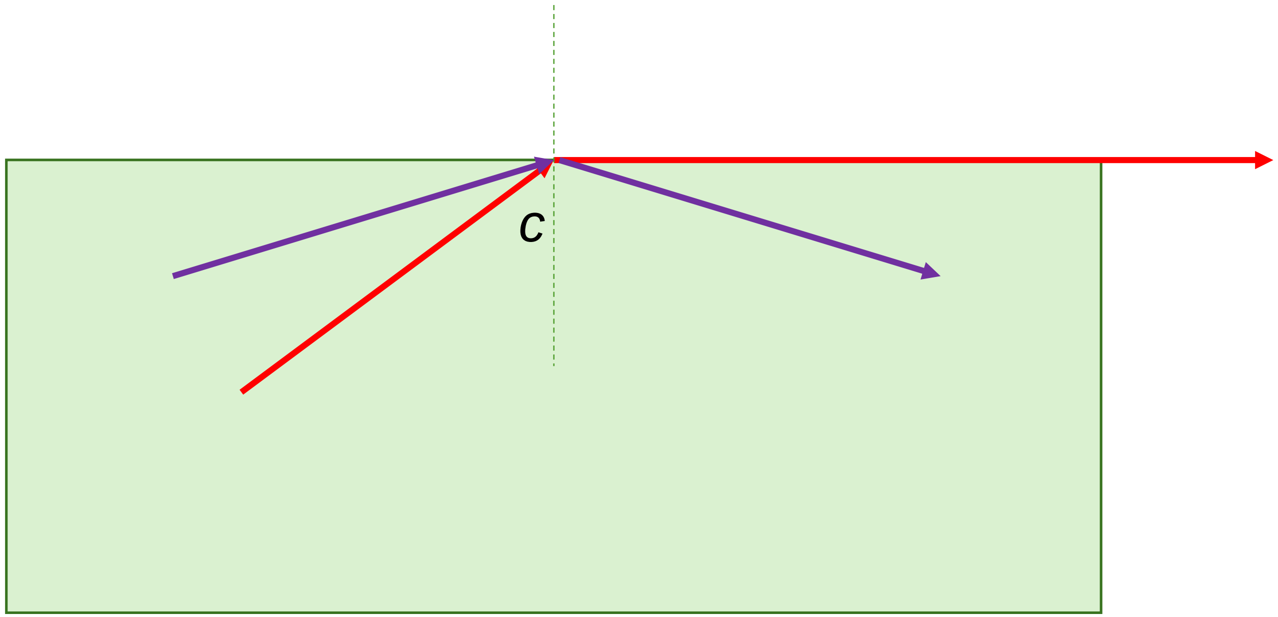
Refraction



Refraction wavefronts



Total Internal Reflection



Where light hits a boundary

- from the inside of the material
- above the critical angle

Refraction practice

Of the materials mentioned here, light goes fastest in air, then water, then petrol, then glass, and slowest in cubic zirconia.

Which way will light bend when passing diagonally from

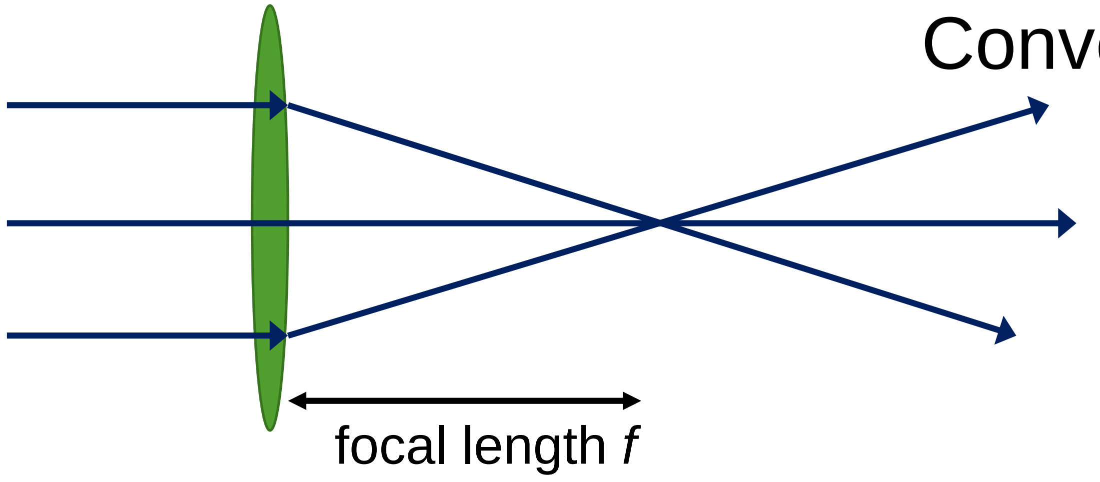
1. Air into cubic zirconia?

2. Petrol into water?

3. Glass into air?

4. Water into glass?

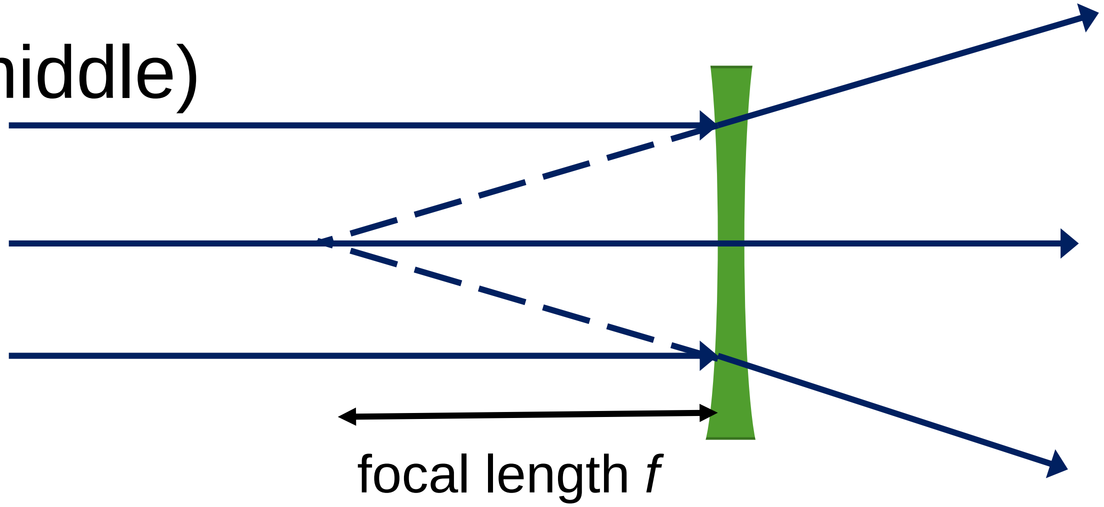
Lenses



Convex lens (thickest in middle)

$$\text{Power (D)} = \frac{1}{\text{focal length (m)}}$$

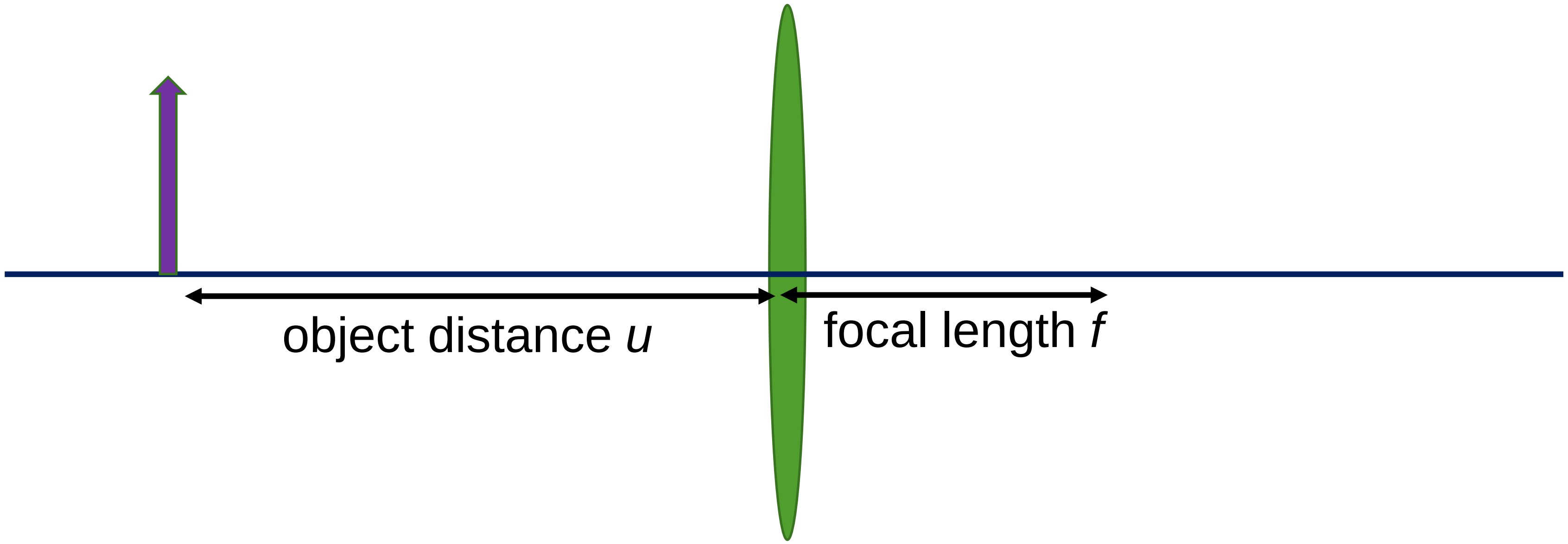
Concave lens (thinnest in middle)



$$\text{Power (D)} = -\frac{1}{\text{focal length (m)}}$$

Lens image 1

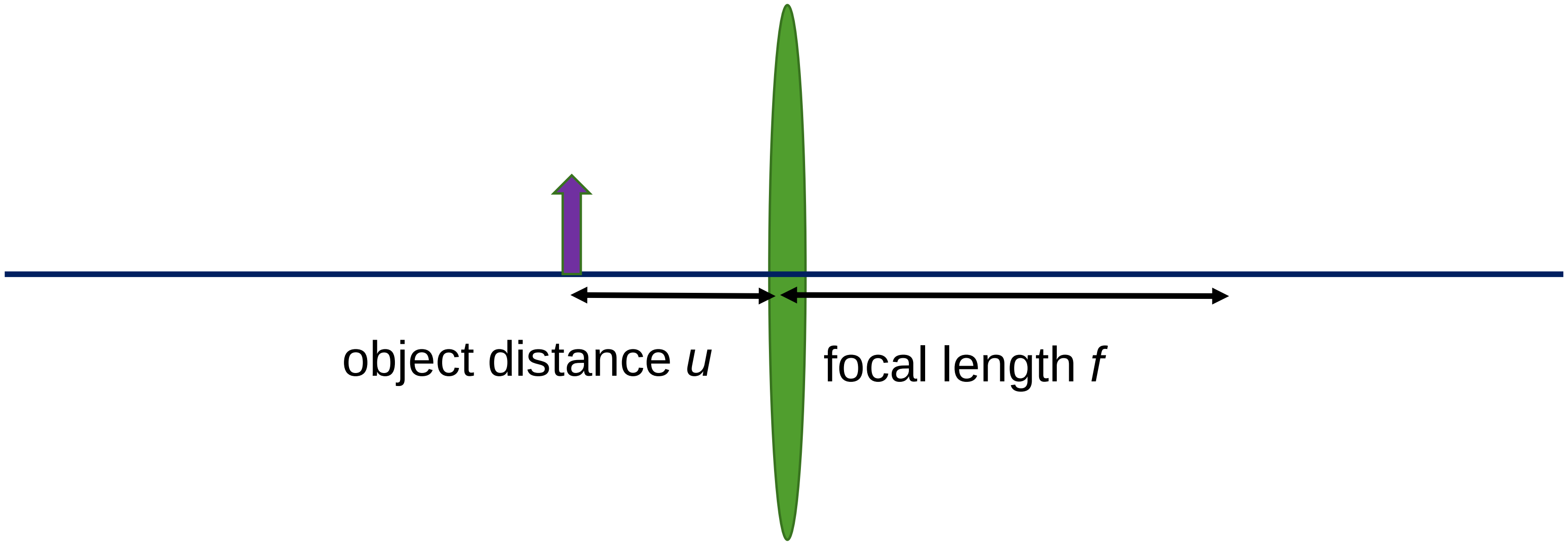
Convex lens: real image



If drawing, use u=10cm, f=5cm, put the lens in the middle of the paper and draw the object 7cm high

Lens image 2

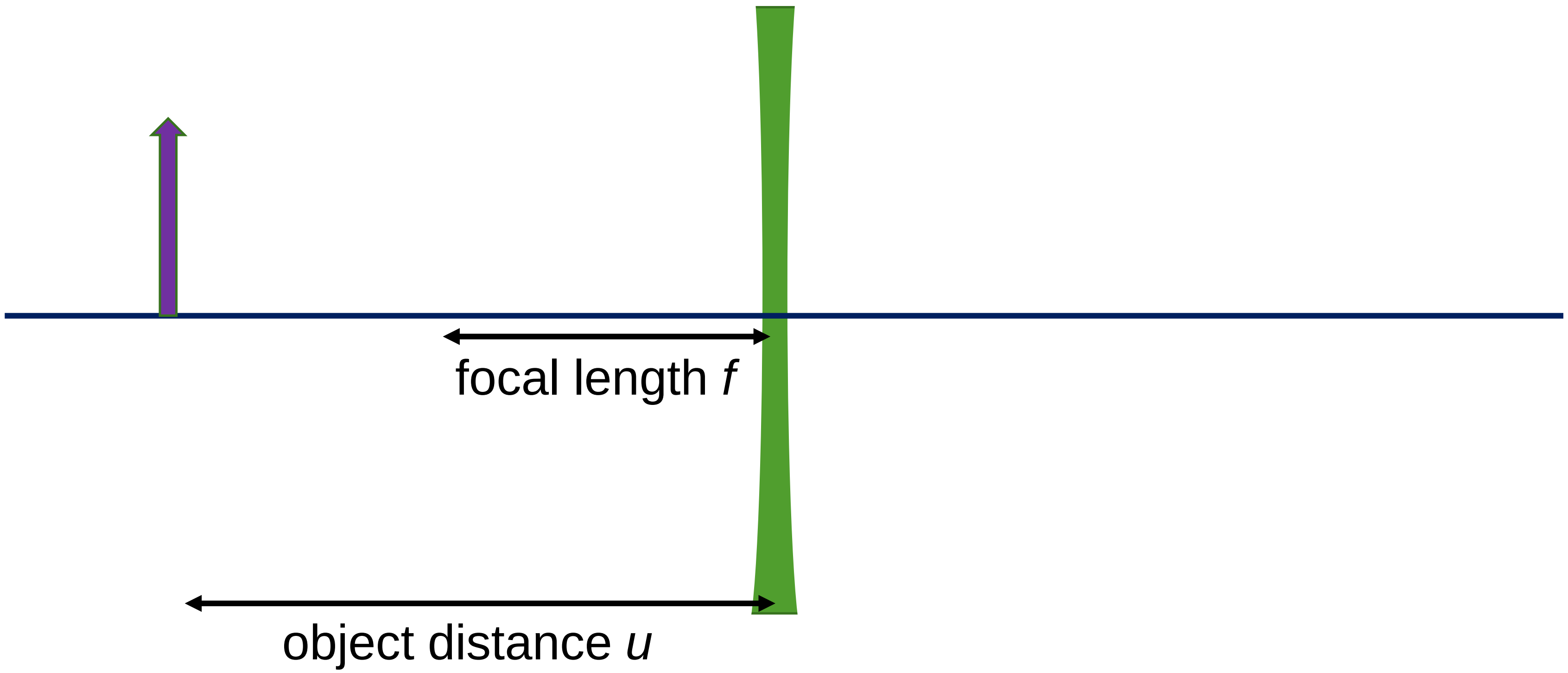
Convex lens: virtual, magnified image



If drawing, use u=5cm, f=10cm, put the lens in the middle of the paper, and draw the object 4cm high

Lens image 3

Concave lens: virtual, diminished image



If drawing, use u=12cm, f=8cm, put the lens in the middle of the paper, and draw the object 7cm high

Image summary

Lens	Object distance	Image type	Image size
Concave	Any	Virtual, erect	Diminished
Convex	$u > 2f$	Real, inverted	Diminished
	$u = 2f$	Real, inverted	Same size
	$f < u < 2f$	Real, inverted	Enlarged
	$u = f$	No image – parallel beam produced	
	$u < f$	Virtual, erect	Enlarged

u = object distance (object to lens)
f = focal length

Links

GCSE Topic Revision

https://isaacphysics.org/pages/gcse_topic_index#gcse_revision

Consolidation Programme

https://isaacphysics.org/pages/summer_programmes_2021