Waves and Optics

Introductory Waves and Optics Worksheets and Solutions

Workshop Tutorials for Introductory Physics

WI1: **Simple Harmonic Motion**

A. Review of Basic Ideas:

Use the following words to fill in the blanks:
equilibrium, frequency, force, kinetic energy, potential, simple harmonic motion, friction, periodic, proportional, spring, driving, period, amplitude, kinetic, conserved, damped

Periodic Motion

What is periodic motion? The expansion of your lungs as you breathe, the pendulum of a grandfather clock, the back-and-forth motion of pistons in a car engine - all these are examples of motion that repeats itself over and over; ________ motion or oscillation. If the periodic motion is sinusoidal then it is called ______ _______ ________.

A body that undergoes periodic motion always has a stable ______ position. When it is moved away from this position a _____ pulls it back toward equilibrium. But by the time it gets there, it has picked up _____ _____, so it overshoots, stopping somewhere on the other side, and is again pulled back towards equilibrium. This force is ______ to the distance the body has been displaced from its equilibrium position and is written $F=-kx$. The minus sign tells you that the force is in the opposite direction to the displacement, and is directed towards the equilibrium position. The k is the _______ constant. Two simple examples are spring-mass systems and pendulums.

Oscillatory motion can be described by a _______, which tells you how long it takes per oscillation, and a ______, which is how many oscillations per second. The size of the oscillations is described by the _______.

When a mass on a spring oscillates it has _______ energy and elastic _______ energy and gravitational potential energy. The total energy is the sum of these and is _______. However, we know that if we start a spring oscillating, it will eventually stop, because of ______. This is known as ______ simple harmonic motion. To keep the spring oscillating we need to provide a _______force.

Discussion questions

Explain how a child on a swing fits the description of damped simple harmonic motion.
What do you need to do to keep the child swinging?

B. Activity Questions:

1. Oscillations of a spring-mass system

Two identical objects are attached to identical springs
If the mass of one of the objects is increased will there be any difference in the periods of the two systems? Explain your answer.
If one of the springs is replaced with one with a larger spring constant, how will this affect the period of oscillation?
If one spring is stretched more than the other, will the periods be the same?

2. Damped oscillations

Observe the oscillation of the spring when the attached object is immersed in water.
Draw displacement-time graphs for oscillations of the object in air and in water.
Investigate the damping of your knee joint by sitting on the edge of a bench and allowing it to swing freely.

3. Charting pendulum motion

Swing the pendulum so that it draws a line on the moving paper.
How would you describe the shape of the trace that it produces?
Write an equation to describe the trace drawn. Define all the symbols that you use.

C. Qualitative Questions:

1. Imagine you have a spring and you cut it into two pieces, one a third the length of the original spring and one two thirds the length of the original.

a. If you attach equal masses to each new spring, will the extension be the same for each spring? If not, will it be greater for the shorter or longer spring?

b. What can you say about the spring constants of the two new springs?

2. Bungy jumping is an increasingly popular sport, with a growing clientele of "adrenalin junkies" and an increasing number of facilities around the world.

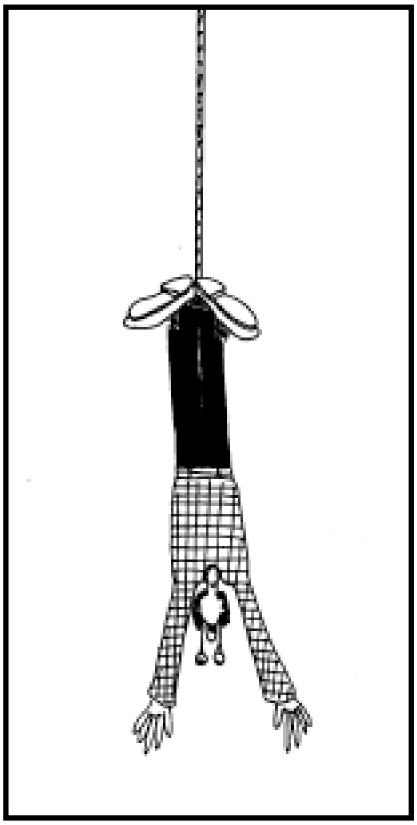
a. Plot a graph with displacement on the vertical axis and time on the horizontal axis for a bungee jump. Zero displacement corresponds to your final equilibrium position.

b. Mark on your graph the region which is approximately simple harmonic motion.

c. Mark on your graph the period and positions of maximum speed, zero speed, maximum acceleration and zero acceleration.

d. Do you momentarily stop at any position?

e. Some people's retinas become detached when they bungy jump. When is this most likely to happen?



D. Quantitative Question:

1. A bungy fish is a toy made out of balloons. It consists of a small balloon filled with sand which is wrapped in many layers of balloons to make a fish shape, and attached to a bungy cord also made out of balloons. A 100 g blue bungy fish is bobbing up and down with amplitude 6 cm and frequency 1 Hz. At time $t = 0$, when you first observe the bungy fish, it has a displacement of +6 cm from its equilibrium position.

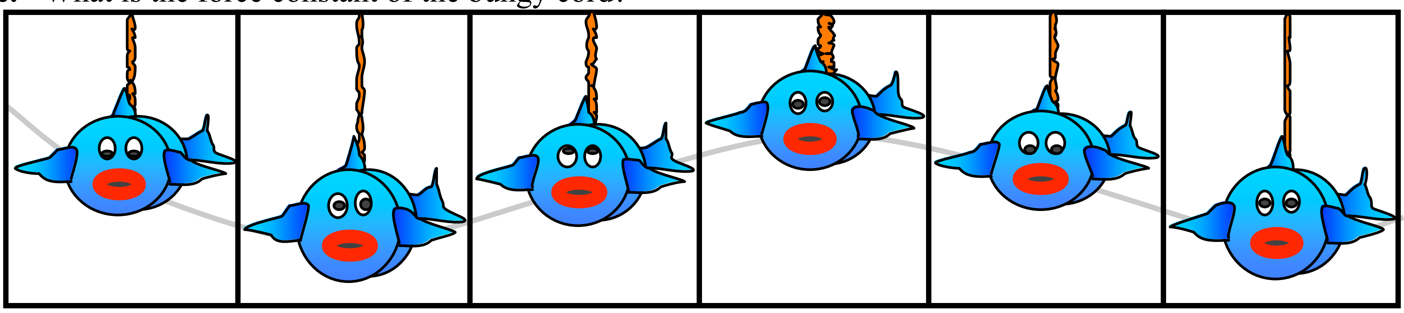
a. What is the angular frequency of the bungy fish?

b. Write down a formula giving the displacement of the bungy fish as a function of time.

c. Where is the bungy fish at time $t = 1$ s?

d. Where is the bungy fish at time $t = 0.1$ s?

e. What is the force constant of the bungy cord?



Workshop Tutorials for Introductory Physics

Solutions to WI1: **Simple Harmonic Motion**

A. Review of Basic Ideas:

Periodic Motion

What is periodic motion? The expansion of your lungs as you breath, the pendulum of a grandfather clock, the back-and-forth motion of pistons in a car engine - all these are examples of motion that repeats itself over and over; **periodic** motion or oscillation. If the periodic motion is sinusoidal then it is called **simple harmonic motion.**

A body that undergoes periodic motion always has a stable **equilibrium** position. When it is moved away from this position a **force** pulls it back toward equilibrium. But by the time it gets there, it has picked up **kinetic energy**, so it overshoots, stopping somewhere on the other side, and is again pulled back towards equilibrium. This force is **proportional** to the distance the body has been displaced from its equilibrium position and is written $F=-kx$. The minus sign tells you that the force is in the opposite direction to the displacement, and is directed towards the equilibrium position. The k is the **spring** constant. Two simple examples are spring-mass systems and pendulums.

Oscillatory motion can be described by a **period**, which tells you how long it takes per oscillation, and a **frequency**, which is how many oscillations per second. The size of the oscillations is described by the **amplitude**.

When a mass on a spring oscillates it has **kinetic** energy and elastic **potential** energy and gravitational potential energy. The total energy is the sum of these and is **conserved**. However, we know that if we start a spring oscillating, it will eventually stop, because of **friction**. This is known as **damped** simple harmonic motion. To keep the spring oscillating we need to provide a **driving** force.

Discussion questions

A child on a swing will oscillate back and forth, and if you plotted the child's position as a function of time you would find that it could be described by the equation $x = A\cos\omega t$, where A is the largest displacement from equilibrium and ω is the angular frequency of the motion. Without pushing, if the child just sits on the swing, they will come to a halt after a while. This is because they lose energy due to friction in the swings attachment to the support, and due to air resistance – hence the motion is simple harmonic, and damped. To keep the child swinging a driving force needs to be applied – they need to be pushed, or swing their legs to make themselves move.

B. Activity Questions:

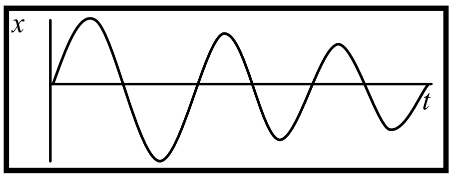
2. Oscillations of a spring-mass system

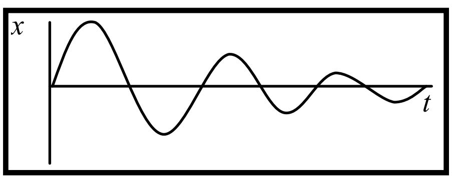
Two identical objects are attached to identical springs, hence they both have mass m attached to a spring with spring constant k, so the periods are the same and are equal to $T_1 = T_2 = 2\pi\sqrt{\frac{m}{k}}$.

If one of the springs has a bigger mass attached to it, the period will be longer; if $m_2 > m_1$ then $T_2 > T_1$
Changing the spring constant also changes the period, if $k_2 > k_1$ then $T_2 < T_1$
For simple harmonic motion the period is independent of amplitude, i.e. extension does *not* affect the period of oscillation.

2. Damped oscillations

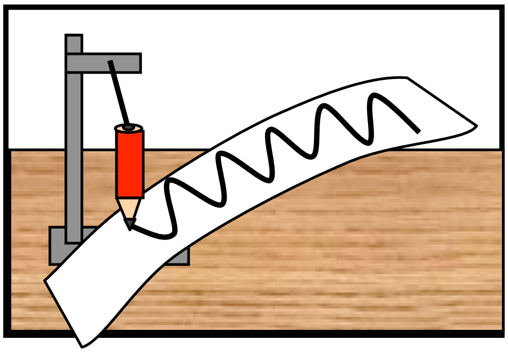
When the object is allowed to oscillate in air it takes a long time to stop, and the amplitude decreases very slowly. See top plot opposite. In water, the motion is strongly damped, and the oscillations decay and stop very quickly, as shown in the lower plot opposite.





Your knee joint is damped, as are all your joints. As you get older the damping usually increases as the joints are less lubricated.

3. Charting pendulum motion

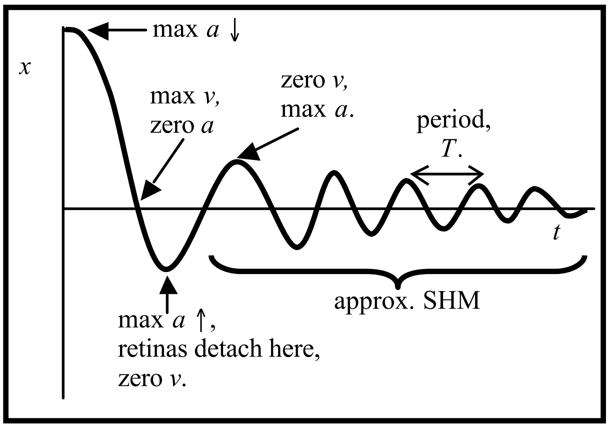


The line drawn is sinusoidal, and can be described by the equation $x = A\cos\omega t$, where A is the initial, and maximum, displacement, ω is the angular frequency of the motion and is equal to $2\pi f$ where f is the frequency of oscillation, t is the time, and x is the displacement at that time t.

C. Qualitative Questions:

1. Imagine you have a spring and you cut it into two pieces, one a third the length of the original spring and one two thirds the length of the original.
a. The more coils a spring has the easier it is to stretch it. The shorter spring, with only half as many coils, will not stretch as much as the longer spring when the same force is applied to it by hanging a mass on it.
b. The spring constant, k, is given by the extension, Δx, for a given applied force F: $F = -k\Delta x$ or $k = F/\Delta x$. For the same force the longer spring has a greater extension, therefore it has a smaller spring constant.

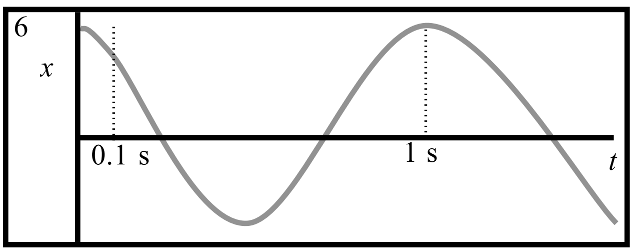
2. Bungy jumping is an increasingly popular sport.



a. See opposite.
b. See opposite, the region which is approximately simple harmonic motion is after the initial jump when you oscillate up and down before being untied.
c. See opposite. The speed is greatest as you pass through the equilibrium position, the acceleration is greatest as the maximum and minimum displacements.
d. You momentarily stop at the top and bottom of each oscillation. At these points your acceleration is maximum, and hence the force you experience will be maximum at these points.
e. When you jump you go head first, and the first minimum is where you are most likely to have your retinas detach, as this is where the acceleration and hence the force will be greatest.

D. Quantitative Question:

A 100 g bungy fish is bobbing up and down with amplitude 6 cm = 0.06 m and frequency 1 Hz. At time t = 0, when you first observe the bungy fish, it has a displacement of +0.06 m from its equilibrium position.
a. The angular frequency of the bungy fish is $\omega = 2\pi f = 2 \times \pi \times 1$ Hz $= 2\pi$ rad.s^{-1}.
b. The formula which describes simple harmonic is $x = A\cos(\omega t + \phi)$, where ϕ is the phase constant, A is the maximum displacement, $\omega = 2\pi f$ where f is the frequency, t is the time, and x is the displacement at time t. For the bungy fish: $x = 0.06$ m cos (2π rad.s$^{-1} \times t$)
When we first observe the bungy fish, at $t = 0$, it has its maximum displacement, $A = 6$ cm. Hence the phase angle is $\phi = 0$.



c. At $t = 1$ s, $x = 0.06$ m cos (2π rad.s$^{-1} \times 1$ s) = 0.06 m,
back to the maximum.
This makes sense because the frequency is 1 Hz, so the period is 1 s. The bungy fish will have performed one complete oscillation and returned to its starting point at $t = 1$ s.
d. At time $t = 0.1$ s, $x = 0.06$ m cos (2π rad.s$^{-1} \times 0.1$ s) = 0.049 m = 5 cm.

e. We can find the force constant, k, from the angular frequency using $\omega = \sqrt{\frac{k}{m}}$, which we rearrange to give $k = \omega^2 m = (2\pi \text{ rad.s}^{-1})^2 \times 0.1 \text{ kg} = 3.9 \text{ kg.s}^{-2}$.

Workshop Tutorials for Introductory Physics

WI2: **Waves**

A. Review of Basic Ideas:

Use the following words to fill in the blanks:
medium, travelling, travelling, energy, waves, velocity, period, oscillate, light, space, music, sound, wavelength, amplitude, people, standing

Waves

You are surrounded by ________ all the time. Everything you see and everything you hear, is actually a wave. The rods and cones in your eyes are sensitive to ________, which is a wave. The cilia in your cochlear respond to ________ waves which are vibrations in the air.

Some waves, like sound, need a ________ to propagate through, but electromagnetic waves, like light, don't. Which is why in ________ no-one can hear you scream, but they can see you scream.

Waves can be described by several quantities. The ________ is how long a single oscillation takes. The ________ is how far it is between peaks, the ________ is how fast the peaks travel and the ________ is how far from equilibrium the peaks are.

A wave is a disturbance in a material. The particles ________, but there is no net movement of matter. During a "Mexican wave" the disturbed particles are ________ and the disturbance travels around the venue. This is a ________ wave. Many waves you are familiar with, such as water waves, are travelling waves. Although there is no net movement of matter, waves do transmit _________.

Waves that stay in the same place are called ________ waves. These are easy to observe on strings. If you pluck a taut string you will get a standing wave. This is the basis of many musical instruments. The standing wave on the string causes a _________ wave in the air, which causes a standing wave on your ear drum, which is transmitted to the cochlear, which your brain interprets as _________.

B. Activity Questions:

1. Transverse waves
Examine the wave machine, and send a wave from the bottom to the top.
This is a torsional or "twisting wave". Explain why this is called a transverse wave.
How is it different to the transverses waves you are familiar with?

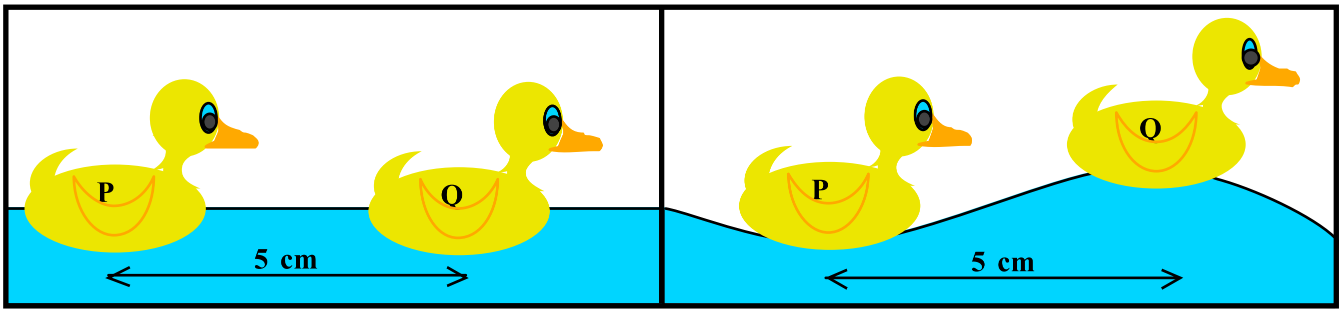
2. Longitudinal Waves
Send a wave along the length of the slinky.
Does the amplitude of the wave affect the speed at which it moves?
How can you change the wave speed?

3. Waves in rubber tubes
One tube is filled with water and the other with air.
Can you tell which is which by observing waves on these tubes?

4. Ripple tank I – making waves
Experiment with the different oscillators. What sort of shaped waves can you produce?
Using one oscillator and the stroboscope, try to measure the wavelength of the waves.
How does the wavelength change when you change the frequency of the oscillations?
Do you think the wave speed changes when you change the frequency?

C. Qualitative Questions:

1. Two rubber ducks, P and Q, are floating in the bathtub 5 cm apart (see below). You make waves by dropping things into the tub.



As the waves pass by the ducks you notice that when P is at its highest position, Q is at its lowest and vice versa.

a. What is the wavelength of the waves?

b. Can you make the waves travel faster by dropping in larger or smaller objects?

c. Can you make the waves travel faster by dropping in objects at a faster rate?

2. Many animals, such as scorpions and ant lions, use the movement of waves through the ground to find their prey. An animal moving along on the ground produces both a transverse travelling wave and a longitudinal travelling wave. The longitudinal waves travel faster than the transverse waves, and a scorpion can tell where an insect is by detecting the difference in arrival time for the two waves.

a. What is the difference between a transverse wave and a longitudinal wave?

b. For transverse waves transmitted through the ground, is the wave speed the same as the maximum speed of any part of the ground?

c. What about for longitudinal waves?

d. Why do longitudinal waves travel faster in the ground than transverse waves?

D. Quantitative Question:

Brent and Rebecca are trying to teach Barry the dog to jump over a rope. They each hold one end of the rope, keeping it stretched out taut. Brent suddenly jiggles the rope at his end sending a wave traveling along it towards Rebecca. The wave can be described the equation

$$y(x,t) = 0.02 \text{ m} \sin(63 \text{ m}^{-1}\, x - 2510 \text{ rad.s}^{-1}\, t)$$

a. What is the amplitude of this wave?

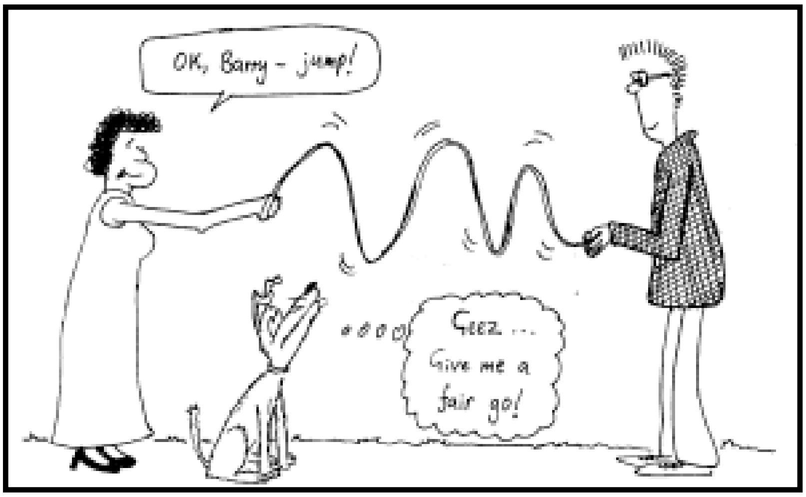
b. What is the wavelength of this wave?

c. What is the frequency of this wave?

d. What is the velocity of the wave?

When the wave reaches Rebecca it is reflected back along the rope towards Brent, without loss of amplitude.

e. Write the equation for this reflected wave.



Workshop Tutorials for Introductory Physics

Solutions to WI2: **Waves**

A. Review of Basic Ideas:

Waves

You are surrounded by **waves** all the time. Everything you see and everything you hear, is actually a wave. The rods and cones in your eyes are sensitive to **light**, which is a wave. The cilia in your cochlear respond to **sound** waves which are vibrations in the air.

Some waves, like sound, need a **medium** to propagate through, but electromagnetic waves, like light, don't. Which is why in **space** no-one can hear you scream, but they can see you scream.

Waves can be described by several quantities. The **period** is how long a single oscillation takes. The **wavelength** is how far it is between peaks, the **velocity** is how fast the peaks travel and the **amplitude** is how far from equilibrium the peaks are.

A wave is a disturbance in a material. The particles **oscillate**, but there is no net movement of matter. During a "Mexican wave" the disturbed particles are **people** and the disturbance travels around the venue. This is a **travelling** wave. Many waves you are familiar with, such as water waves, are travelling waves. Although there is no net movement of matter, waves do transmit **energy**.

Waves that stay in the same place are called **standing** waves. These are easy to observe on strings. If you pluck a taut string you will get a standing wave. This is the basis of many musical instruments. The standing wave on the string causes a **travelling** wave in the air, which causes a standing wave on your ear drum, which is transmitted to the cochlear, which your brain interprets as **music**.

B. Activity Questions:

1. Transverse waves

The torsional wave is a transverse wave because the direction of displacement of the particles (the rods) is perpendicular to the direction of travel of the wave. It is different to more familiar transverse waves, such as waves on a vibrating string, in that the displacement is due to twisting, and the amplitude would be described by an angle rather than a linear displacement.

twist

5. Longitudinal Waves

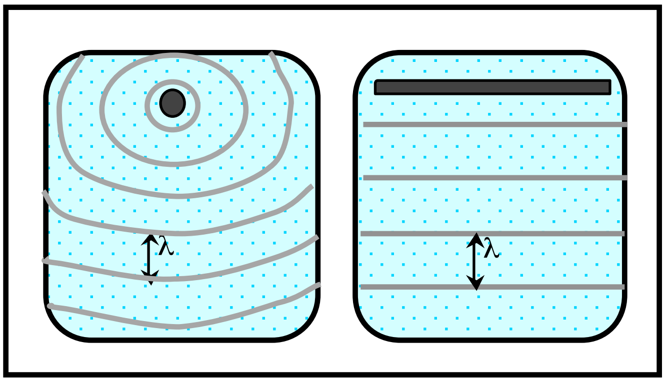
The amplitude of the wave does not affect the speed of the wave. The speed is determined by the medium it travels through, in particular it depends on the elastic and inertial properties of the medium, i.e. the tension and mass. You can change the wave speed on the slinky by stretching it more, and increasing the tension.

6. Waves in rubber tubes

The tube filled with water is much heavier, and hence the waves travel more slowly along it as velocity decreases with increasing mass per unit length.

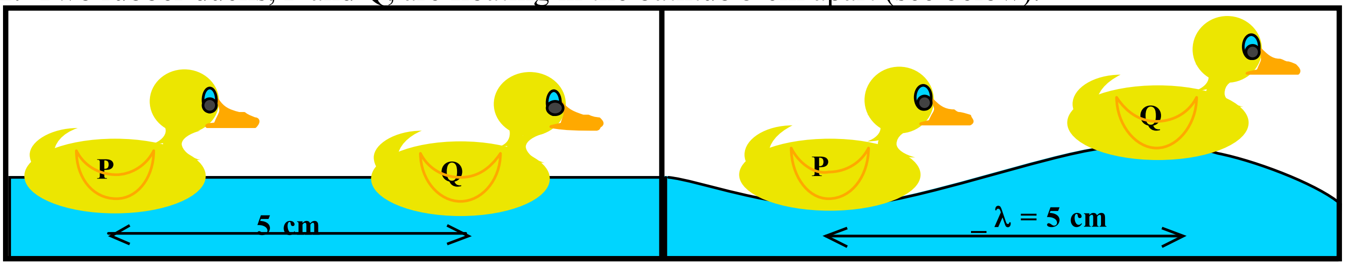
7. Ripple tank I – making waves

You should be able to produce circular wave fronts using the point oscillator, and plane waves using the long rod oscillator. Changing the frequency changes the wavelength, λ, of the waves produced, but does not affect the speed. The speed depends only on the medium, which is not changing.



C. Qualitative Questions:

1. Two rubber ducks, P and Q, are floating in the bathtub 5 cm apart (see below).



As the waves pass by the ducks you notice that when P is at its highest position, Q is at its lowest.

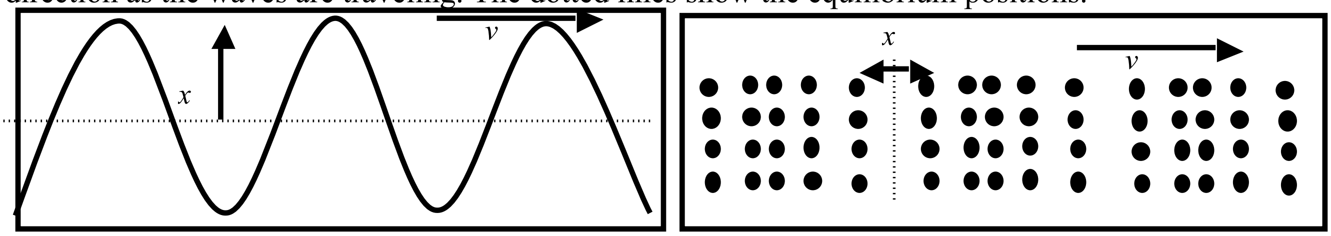
a. We know that the distance from peak to trough, which is _ a wavelength is 5 cm, therefore the wavelength of the waves must be 10 cm.

b. You can't make the waves travel by dropping in bigger objects. Bigger objects will give you bigger waves, but the wave speed depends on the properties of the medium, which is water.

c. Dropping in objects more frequently will increase the frequency, and decrease the wavelength, but will not affect the wave speed, as explained in part **b.**

2. An animal moving along on the ground produces both a transverse travelling wave and a longitudinal travelling wave.

a. In a transverse wave (below, left) the displacement of the medium is perpendicular to the direction the waves are traveling in. In longitudinal waves (below, right), the displacement of the medium is in the same direction as the waves are traveling. The dotted lines show the equilibrium positions.



b. The wave speed is not the same as the maximum speed of any particle, often the wave speed is much greater. The wave speed depends on the properties of the medium, the particle speed depends on the wave frequency and amplitude.

c. The same is true for longitudinal waves.

d. Wave speed is proportional to the elastic property over the inertial property. The inertial property (mass, density), has to be the same for both longitudinal and transverse waves in the ground – they're both traveling through the same medium. However the elastic property (tension), is greater for longitudinal waves – the particles can move up and down more easily than side to side, which requires compression. (Ground has a lower sheer modulus than compression.)

D. Quantitative Question:

Rebecca and Brent are trying to teach Barry to jump over a rope. Brent suddenly jiggles the rope at his end sending a wave traveling along it towards Rebecca. The wave can be described the equation $y(x,t) = 0.02 \text{ m} \sin(63 \text{ m}^{-1}\, x - 2510 \text{ rad.s}^{-1}\, t)$.

This is of the form $y(x,t) = A \sin(kx - \omega t)$

a. The amplitude of this wave is $A = 0.02$ m.

b. The wavelength of this wave is $\lambda = 2\pi/k = 2\pi / 63 \text{ m}^{-1} = 0.1 \text{ m} = 10$ cm.

c. The frequency of this wave is $f = \omega / 2\pi = 2510 \text{ rad.s}^{-1} / 2\pi = 400$ Hz.

d. The velocity of the wave is $v = f \times \lambda = 0.1 \text{ m} \times 400 \text{ s}^{-1} = 40 \text{ m.s}^{-1}$.

e. The reflected wave is identical to the transmitted wave but traveling in the opposite direction, hence it can be described by the equation $y(x,t) = A \sin(kx + \omega t) = 0.02 \text{ m} \sin(63 \text{ m}^{-1}\, x + 2510 \text{ rad.s}^{-1}\, t)$.

Workshop Tutorials for Introductory Physics

WI3: **Interacting Waves**

A. Review of Basic Ideas:

Use the following words to fill in the blanks:
diffraction, standing, sum, reflected, sound, echo, interference, superimposed, destructive, constructive, wavelength

Interacting Waves

Have you ever called out to someone and heard your voice come back to you? Maybe you were in the bush and there was a cliff nearby. The _______ waves that left your mouth were reflected off the cliff and came back to you as an _______. In the same way, when you pluck a guitar string you start the string vibrating and waves move down the string. The waves are _______ from the fixed end of the string and return along the string. In both cases the incoming and reflected waves occupy the same space and we say the two waves are ________ on each other.

This superposition of the waves results in interference. At any given point in space the resultant disturbance is the _______ of the individual disturbances of the two waves in question. At some places the two disturbances will add to give zero displacement - a point of _______ interference. At some places the waves will add to a maximum disturbance, a point of _______ interference. This superposition of waves and the resulting interference occurs for any type of waves – think what happens to your car radio when you pass under a transmission line. In this case there is interference between the electromagnetic radio waves from the station and electromagnetic waves from the transmission lines. Mobile phones have to be turned off in aeroplanes so they don't interfere with navigation signals.

In some cases when waves superimpose there is a regular interference pattern set up which has points of destructive and constructive interference that are constant in time. These are called _______ waves. Standing waves on violin strings and in the air columns of flutes and clarinets give notes of fixed frequency that are the bases of musical sounds.

Another strange property of waves, called _______, occurs when they bend around obstacles and move through narrow spaces. This diffraction is most noticeable when the obstacle or narrow space has a size of the order of the _______ of the wave. Hold two fingers very close together and up to the light. The light will diffract around your fingers and interfere. Can you see some fine lines between your fingers? This is an ________ pattern.

Discussion Question

You are sitting with your friends in a cafe which is very noisy. How would you design an environment in which you could hear conversations more easily.

B. Activity Questions:

1. Ripple tank

Use the long wave source to produce parallel wavefronts.
What happens when you put a small object in front of the wave?
What about a larger object?
What happens when these waves pass through a small gap in a barrier?
Explain your observations.

2. Interference

Observe the interference patterns with the HeNe laser and the double slits.
Why does this pattern occur?
What happens to the pattern on the screen as the slit width is changed?

3. Standing waves on a string.
What happens when you adjust the frequency?
Sketch the patterns formed by the string, noting the frequency at which they occur.
What happens when you change the tension in the string?

4. Chladni's plates.
Sprinkle sand or cork dust on the plates. With a well resined bow excite the plate by bowing with a long firm stroke at an edge. What do you observe? How many patterns can you form on a given plate?
Sketch one of the patterns you produce and label the nodes and antinodes.
Why are the patterns different on different plates?
Try damping a point on the edge of a plate while bowing. What do you observe and why?

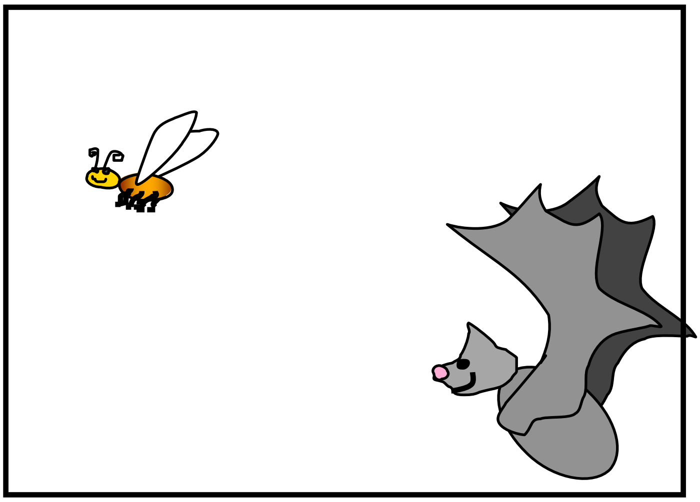
C. Qualitative Questions:

1. Why is it that if you hide behind something, such as a large tree, you cannot be seen, but if you make a noise you can still be heard?

2. Musicians often use tuning forks or electronic sound generators which produce a pure tone. They sound the pure tone, and at the same time play a note on their instrument, while listening for beats.
a. Explain how two notes can produce beats. Draw diagrams to help explain your answer.
b. How does beat production help a musician to tune their instrument? What does the musician do?

D. Quantitative Question:

You will need to estimate some sizes.
Waves are disturbed by and reflected from objects of similar size to, or larger than, their wavelength, while they simply pass by smaller objects. Many animals such as bats use echolocation to navigate and to hunt by. The hunter produces a sound which bounces off the prey and can then be detected by the hunter. What frequency would you expect the chirps of a hunting insectivorous bat to be?
Note : $v_{sound} \sim 340$ m.s^{-1} in air.



Workshop Tutorials for Introductory Physics

Solutions to WI3: **Interacting Waves**

A. Review of Basic Ideas:

Interacting Waves

Have you ever called out to someone and heard your voice come back to you? Maybe you were in the bush and there was a cliff nearby. The **sound** waves that left your mouth were reflected off the cliff and came back to you as an **echo**. In the same way, when you pluck a guitar string you start the string vibrating and waves move down the string. The waves are **reflected** from the fixed end of the string and return along the string. In both cases the incoming and reflected waves occupy the same space and we say the two waves are **superimposed** on each other.

This superposition of the waves results in interference. At any given point in space the resultant disturbance is the **sum** of the individual disturbances of the two waves in question. At some places the two disturbances will add to give zero displacement - a point of **destructive** interference. At some places the waves will add to a maximum disturbance, a point of **constructive** interference. This superposition of waves and the resulting interference occurs for any type of waves – think what happens to your car radio when you pass under a transmission line. In this case there is interference between the electromagnetic radio waves from the station and electromagnetic waves from the transmission lines. Mobile phones have to be turned off in aeroplanes so they don't interfere with navigation signals.

In some cases when waves superimpose there is a regular interference pattern set up which has points of destructive and constructive interference that are constant in time. These are called **standing** waves. Standing waves on violin strings and in the air columns of flutes and clarinets give notes of fixed frequency that are the bases of musical sounds.

Another strange property of waves, called **diffraction**, occurs when they bend around obstacles and move through narrow spaces. This diffraction is most noticeable when the obstacle or narrow space has a size of the order of the **wavelength** of the wave. Hold two fingers very close together and up to the light. The light will diffract around your fingers and interfere. Can you see some fine lines between your fingers? This is an **interference** pattern.

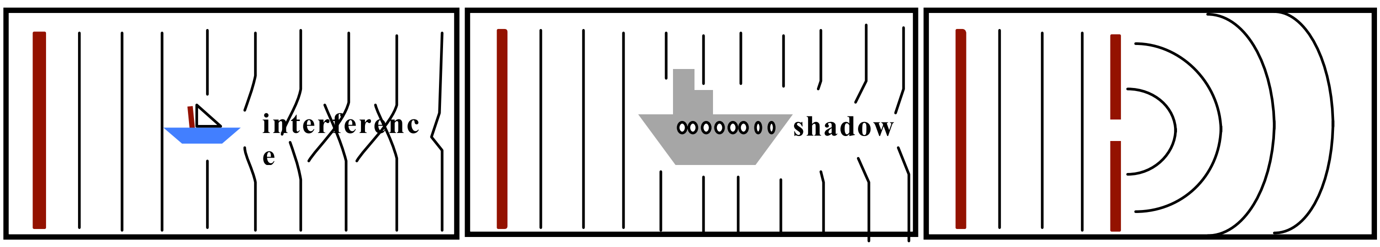
Discussion Question

You are sitting with your friends in a cafe which is very noisy. Often this is because the sounds people make are reflected off the walls and floors – particularly when the walls are hard surfaces. Rooms with tiles or floor baords are usually noisier than rooms with carpet. To make a room quiet, other than by getting everyone to stop talking, you would have sound absorbing surfaces, like carpet on the floor and walls.

B. Activity Questions:

1. Ripple tank

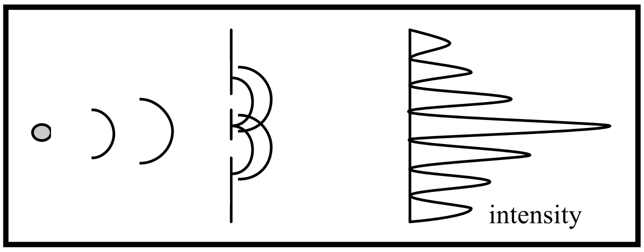
The waves will difract around a small object forming an inteference pattern where the waves from either side meet. Waves will be blocked by large objects, leaving a shadow or wake behind the object.
When plane waves pass through a narrow slit the slit acts as a point source, and semi-circular wave fronts are produced. You may also see an inteference pattern, due to diffraction effects at the edges of the slit. This is most commonly seen with light, for example try looking looking through at a light source through a pinhole in a piece of paper – you will be able to see maxima and minima.



2. Interference

The waves from the two slits interfere to give light and dark fringes, as shown opposite

The greater the slit separation, the closer together the fringes are.



3. Standing waves on a string.

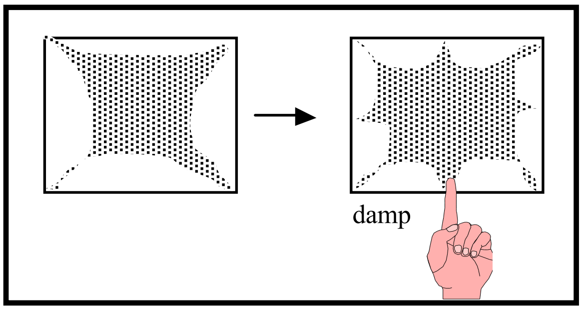
You should see nodes and antinodes when at the fundamental frequency, and multiples of the fundamental. Changing the tension changes the wave speed which changes the frequencies at which standing waves occur, as $v = f\lambda$, and the values of λ are fixed by the string length.

fundamental

first harmonic

4. Chladni's plates.

When you bow on the plate it will vibrate. The sand gathers in the nodes as it is shaken from the antinodes. The pattern depends on where you bow, and on the shape and size of the plate. Damping forces a node where you put your finger and the pattern changes.



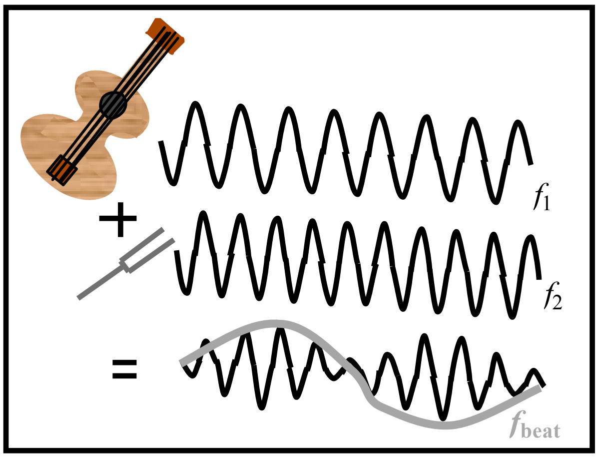
C. Qualitative Questions:

1. If you hide behind something, such as a large tree, you cannot be seen, but if you make a noise you can still be heard. This is because sound waves have wavelengths of a few centimetres to a few metres, so they diffract around objects likes trees. Visible light has a wavelength of around 500 nm, much much smaller than a tree trunk, so while the light can still diffract around the tree, it forms a shadow behind it. The light that reflects off you, that allows you to be seen by other people, cannot diffract enough to allow someone on the other side of the tree to see you. If visible light had wavelengths similar to the wavelength of sound, you wouldn't be able to hide behind trees.

2. Musicians often using tuning forks or electronic sound generators which produce a pure tone.

a. The beat frequency you hear from two notes is the difference between the frequencies of the two notes, $f_{beat} = f_1 - f_2$. The further apart the notes, the slower the beats.

b. Musicians tune their instruments by sounding a known note, for example with a tuning fork, then adjusting their tuning until the frequency from their instrument is the same and no beats can be heard.



D. Quantitative Question:

In air, sound waves travel at around 340ms^{-1}. An insect is a few millimetres long or less. Estimating the insect size to be 1mm long, the wavelength needs to be this or less, so the bat needs a frequency of

$f = v/\lambda \sim 340\ \text{ms}^{-1} / 0.001\text{m} \sim 340{,}000$ Hz.

This is well beyond the frequency threshold of human hearing, which is around 20 Hz to 20 kHz .

Workshop Tutorials for Introductory Physics

WI4: **Sound**

A. Review of Basic Ideas:

Use the following words to fill in the blanks:
Velocity, rigid, frequency, travelling, elastic, ultrasound, infrasound, elephants, amplitude, higher, Doppler, velocities, standing, medium, decreases, frequencies, longitudinal, water, vibrations

Sound

Sound waves are _____ waves. They require a _____ to propagate through, and the _____ at which they propagate depends on the _____ and inertial properties of the medium. Sound travels faster in more _____ mediums such as _____ and rock than it does in air.

A sound wave can be characterised by its pitch, which depends on the wave's _____, and its volume, which depends on the _____ of the wave.

When a guitar string is plucked or a violin string is bowed, _____ waves on the string reflect from the fixed ends and set up standing waves. These _____ of the string cause the air to vibrate, which is transmitted to our ears as sound waves. Travelling sound waves can also produce _____ waves in air columns, this is how woodwind instruments work.

Humans can hear frequencies in the range 20 Hz – 20 kHz, although this range usually _____ with age. Sound waves with frequencies above 20 kHz are called _____, and are used for medical imaging. Many animals also hear and use ultrasound. Sound waves with frequencies below 20Hz are called _____. While we can't hear infrasound, it can cause headaches. Earthquakes produce waves of infrasound, and _____use infrasound to communicate over long distances.

When a police car with its sirens blaring overtakes you on the road, you hear a range of _____. When it is coming towards you it sounds _____in pitch than it does after it has overtaken you. This is called the _____ effect. This effect is used to measure _____ of moving objects, for example a police radar detector uses the Doppler effect to tell if you are speeding, and bats use it to catch insects.

Discussion Question
In some science fiction movies, for example the Star Wars series, the explosion of a spaceship can apparently be heard in another spaceship, while both are in the vacuum of space. Is this possible?
Is there any way the explosion can produce sound inside the second ship?

B. Activity Questions:

1. Tuning forks and beats.
Listen to the beats when you tap the two tuning forks.
What happens when you adjust the frequency of one of the forks?
How do musicians use tuning forks to tune their instruments?

1. Resonance in a tube.
When the tube is the right length, the column of air inside it will resonate with the tuning fork. Vary the length of the air column in the tube to find the wavelength of the sound.
Can you think of a musical instrument which produces different notes by varying the length of an air column?

2. Look and listen

The CRO (cathode ray oscilloscope) draws a graph showing variations in amplitude with time (also used to measure heart rhythms).

Describe what happens to the sound you hear and the pattern on the CRO as the frequency is increased/ decreased? Remember that the audible frequency range is from 20Hz to 20 kHz.

What happens to the sound and the pattern as you turn the amplitude control?

3. Visualising Speech

A microphone is connected to an oscilloscope (CRO). As you speak into the microphone the pattern on the CRO depicts the sound waves generated by you.

How do these compare with the signals in (a). Is there more than one frequency?

How does the pattern change when you whistle, scream, sing a note, speak softly, speak loudly?

A wave appears on the screen if you lightly 'tap' the microphone. Explain why this happens.

C. Qualitative Questions:

1. Resonance is a remarkably useful phenomenon. For example, it is used to create images of body tissues using Magnetic Resonance Imaging, and to heat up food in a microwave. However resonance can also be quite destructive, and marching soldiers always break step crossing bridges, just in case they make the bridge collapse.

a. Explain how a wine glass can be shattered by a sustained note from an opera singer.

b. How is the shattering of a shop window by an explosion some kilometres away different to the shattering of the wine glass, and what sort of wave is involved in this case?

2. The outer ear canal is open to the air at one end and closed by the ear drum at the other end.

a. sketch the pressure distribution wave in the ear canal for the fundamental frequency.

b. sketch the displacement distribution wave in the ear canal for the fundamental frequency and write the wavelength in terms of the length l of the ear canal.

c. sketch the displacement distribution waves in the ear canal for the next two resonant frequencies and write the wavelengths in terms of l.

D. Quantitative Question:

Your local council is considering a proposal to locate a new airport near your house. A representative of the company has claimed that it will only increase ambient day time noise by 3dB, and night time noise levels by 6dB. What factor increases in sound level do these increases correspond to?

Workshop Tutorials for Introductory Physics

Solutions to WI4: **Sound**

A. Review of Basic Ideas:

Sound

Sound waves are **longitudinal** waves. They require a **medium** to propagate through, and the **velocity** at which they propagate depends on the **elastic** and inertial properties of the medium. Sound travels faster in more **rigid** mediums such as **water** and rock than it does in air.

A sound wave can be characterised by its pitch, which depends on the wave's **frequency**, and its volume, which depends on the **amplitude** of the wave.

When a guitar string is plucked or a violin string is bowed, **travelling** waves on the string reflect from the fixed ends and set up standing waves. These **vibrations** of the string cause the air to vibrate, which is transmitted to our ears as sound waves. Travelling sound waves can also produce **standing** waves in air columns, this is how woodwind instruments work.

Humans can hear frequencies in the range 20 Hz – 20 kHz, although this range usually **decreases** with age. Sound waves with frequencies above 20 kHz are called **ultrasound**, and are used for medical imaging. Many animals also hear and use ultrasound. Sound waves with frequencies below 20Hz are called **infrasound.** While we can't hear infrasound, it can cause headaches. Earthquakes produce waves of infrasound, and **elephants** use infrasound to communicate over long distances.

When a police car with its sirens blaring overtakes you on the road, you hear a range of **frequencies.** When it is coming towards you it sounds **higher** in pitch than it does after it has overtaken you. This is called the **Doppler** effect. This effect is used to measure **velocities** of moving objects, for example a police radar detector uses the Doppler effect to tell if you are speeding, and bats use it to catch insects.

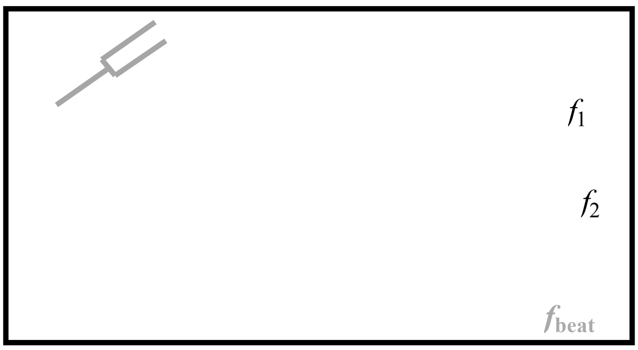
Discussion Question

In some science fiction movies, for example the Star Wars series, the explosion of a spaceship can apparently be heard in another spaceship, while both are in the vacuum of space. This is not possible, as sound needs a medium to travel through. However you would still be able to see the explosion.
The only way the explosion could produce sound inside a second ship is if bits of the exploded ship collided with the second ship. However this rarely seems to happen in movies.

B. Activity Questions:

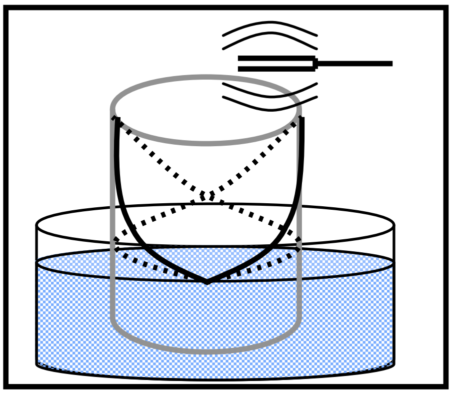
1. Tuning forks and beats.

The beat frequency you hear from two notes is the difference between the frequencies of the two notes, $f_{beat} = f_1 - f_2$. The closer the frequencies and hence the notes, the slower the beats.
Musicians tune their instruments by sounding a known note, for example with a tuning fork, then adjusting the tuning of their instrument so the beat frequency decreases until the beats stop. When the beats stop, the note from their instrument is the same as the tuning fork.



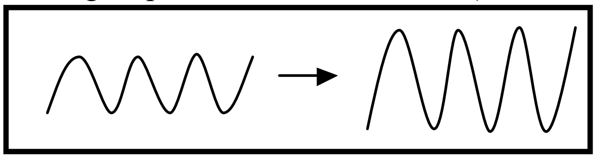
2. Resonance in a tube.

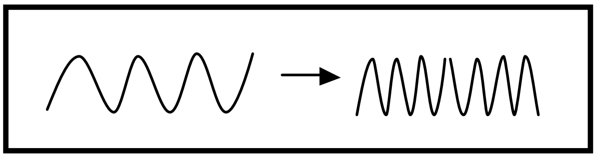
When the tube is the right length, the air column inside it will resonate with the tuning fork, producing a louder sound. See diagram opposite. A trombone produces different notes by varying the length of the air column inside it.



3. Look and listen

Increasing amplitude increases volume (below left), increasing frequency increases pitch (below right).





4. Visualising Speech

The microphone has a diaphragm (transducer) that converts vibrations in the air (sound) into an electrical signal. If this diaphragm is vibrated by other means it still produces an electrical signal.

You should see a complicated wave-form, because when you speak you produce many frequencies simultaneously. A whistle gives an approximately sinusoidal signal.

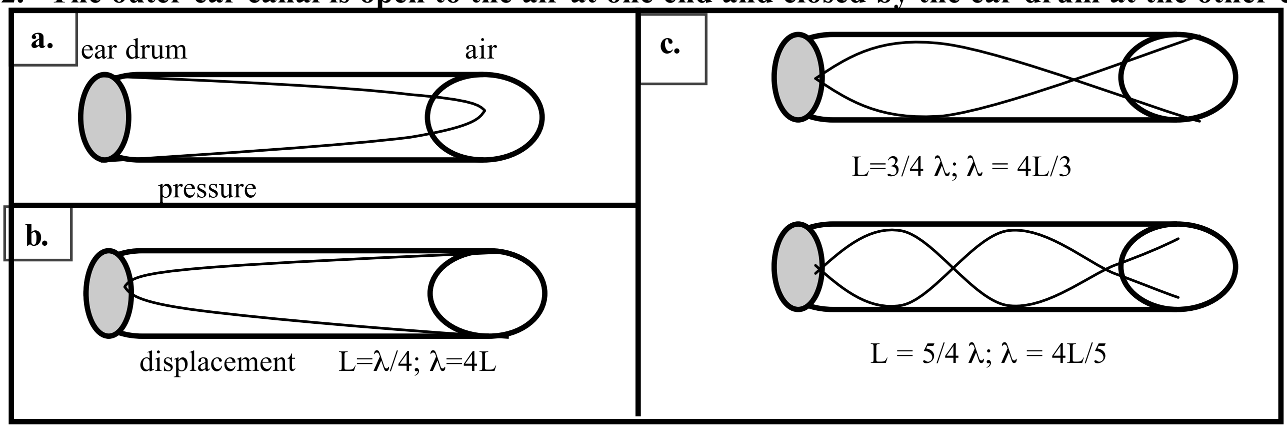
C. Qualitative Questions:

1. Resonance is a remarkably useful phenomenon, but can also be quite destructive.

a. A wine glass may shatter if the frequency is right because the sound waves set up standing waves in the glass at the resonant frequency, which causes it to dramatically shake apart. The frequency needs to be just right, but the intensity (volume) can be quite low.

b. When an explosion shatters a window, the window is shattered by a shock wave, which transmits a large amount of energy in a very short time. This is not due to resonance.

2. The outer ear canal is open to the air at one end and closed by the ear drum at the other end.



D. Quantitative Question:

Your local council is considering a proposal to locate a new airport near your house. A representative of the company has claimed that it will only increase ambient day time noise by 3dB, and night time noise levels by 6dB. An increase of 3 dB is equivalent to doubling the sound intensity, so it is a substantial increase. However the way we are sensitive to sound is not linear, but logarithmic, so 3 dB would generally not make much difference. An increase of 6 dB is equivalent to doubling intensity and then doubling it again, a four fold increase. Normal night time levels are around 10 dB, so this is quite a large increase, and would definitely be noticeable.

Workshop Tutorials for Introductory Physics

WI5: **The Electromagnetic Spectrum**

A. Review of Basic Ideas:

Use the following words to fill in the blanks:
night, sun, heat, 3×10^8 m.s^{-1}, spectrum, blue, rods, cones, electromagnetic, butterflies, microwaves, sound, wavelengths, visible, red, cows, ultraviolet, grey

Light and the Electromagnetic Spectrum

Have you ever stopped to think how it is that the information on this sheet reaches you? The answer lies with the waves that reflect off the sheet and into your eyes. These waves are electromagnetic in nature and your eyes respond to a particular range of frequencies – the visible segment of the electromagnetic _______.

Radio waves, _______, infrared radiation, visible light, ultraviolet, x-rays, gamma rays are just some of the common members of the electromagnetic spectrum. All these _______ waves have the same nature – they are comprised of oscillating electric and magnetic fields. Electromagnetic waves travel (propagate) at a constant speed of _______ in a vacuum. These waves do not need a medium, unlike _______ waves they can move through a vacuum. The energy the earth receives from the sun is electromagnetic in nature and comes to us through space.

What then is the difference between the different parts of the spectrum? The answer is that different parts have different frequencies and so different _______ but they all travel with the speed of light.

Humans are sensitive to only a very small part of the electromagnetic spectrum. With our eyes we detect ________ light, and with our skin we can detect infrared radiation, or ________. Human retinas have four types of detector cells, three types of ________ for colour vision, and the ________. The rods are very sensitive and are used mainly for spotting movement in the peripheral vision and for ______ vision. The rods don't tell different colours apart, which is why everything looks sort of _______ at night.

The three types of cones are sensitive to different wavelengths, or colours, one to blue, one to green and one to red. The sensitivities overlap so that we can see light from the ________ end of the spectrum, around 400 nm, to the ________, around 700 nm. We are most sensitive to the green/yellow around 550 nm, which is now being used on emergency vehicles such as fire engines rather than the traditional red. This is also the frequency at which the ________ radiates the most light.

Some animals don't have colour vision at all, such as ________ and dogs. Others have very different colour vision, such as insects. Bees are sensitive to ________, and many ________ see infrared.

Discussion Question

Can Superman really use x-ray vision? What would he need to be able to see with x-rays?

B. Activity Questions:

1. Speed of Light

Microwave the marshmallows to find the speed of light!
Read the frequency of the microwave radiation produced from the back of the microwave.
Microwave the marshmallows, watching carefully, and stopping the oven when they first begin to melt.
Measure the distance between melted bits to find the wavelength, and use this to calculate the speed of light.
Warning – very hot! Do not touch the molten marshmallows!

2. Prism
Shine the light through the prism.
What do you see going into the prism?
What do you see coming out?
Which is refracted (bends) more – light of long or short wavelength?

3. Change the colour of your fruit (or See the World through Rose Coloured Glasses)
Look at the banana with the red glasses. What do you see?
How does it look through the green glasses?
What about the apples? How do they look through the different glasses?

4. Sunset in a jar
Look at the light transmitted through the top of the beaker.
What do you notice about its colour?
What do you notice about the light coming out the sides of the beaker?
Explain the difference in these colours.
Explain why the sky on Earth is blue. What colour do you think the sky is on Mars? Why?

C. Qualitative Questions:

1. Rebecca and Brent are sitting inside watching TV one evening when Brent notices a lightning flash. A few moments later they hear a peal of thunder. Brent says they'd better go bring the washing in off the line because there's a storm coming. Rebecca's says to wait until the next ad' break. "hmm…" say's Brent, as he listens to the next peal of thunder, "that storm is getting pretty close, the thunder was only a second after the lightning".
"How can you tell?" asks Rebecca, as the first drops of rain start to fall…
How can Brent tell that the storm is getting closer? Explain your answer.

2. When some people go shopping for clothes they try to look at the clothes in natural light, for example in the doorway of a shop. Why do you think they do this? Why do you think expensive clothing shops rarely use fluorescent lighting in their fitting rooms?

D. Quantitative Question:

FM radio stations broadcast signals which have frequencies in MHz, for example 106.5 MHz.
a. Find the wavelength of the signal broadcast by this station.
AM radio stations broadcast in the "medium wave" range, which is much lower frequency than FM stations.
b. Which radio station in Sydney broadcasts a signal with a wavelength of 521 m?
There are two ways in which radio stations transmit signals to your car radio – one is AM or amplitude modulation, the other is FM or frequency modulation.
c. Draw a diagram showing the difference between amplitude modulated and frequency modulated waves.

Workshop Tutorials for Introductory Physics

Solutions to WI5: **The Electromagnetic Spectrum**

A. Review of Basic Ideas:

Light and the Electromagnetic Spectrum

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Radio waves, **microwaves**, infrared radiation, visible light, ultraviolet, x-rays, gamma rays are just some of the common members of the electromagnetic spectrum. All these **electromagnetic** waves have the same nature – they are comprised of oscillating electric and magnetic fields. Electromagnetic waves travel (propagate) at a constant speed of $\mathbf{3 \times 10^8\ m.s^{-1}}$ in a vacuum. These waves do not need a medium, unlike **sound** waves they can move through a vacuum. The energy the earth receives from the sun is electromagnetic in nature and comes to us through space.

What then is the difference between the different parts of the spectrum? The answer is that different parts have different frequencies and so different **wavelengths** but they all travel with the speed of light.

Humans are sensitive to only a very small part of the electromagnetic spectrum. With our eyes we detect **visible** light, and with our skin we can detect infrared radiation, or **heat**. Human retinas have four types of detector cells, three types of **cones** for colour vision, and the **rods**. The rods are very sensitive and are used mainly for spotting movement in the peripheral vision and for **night** vision. The rods don't tell different colours apart, which is why everything looks sort of **grey** at night.

The three types of cones are sensitive to different wavelengths, or colours, one to blue, one to green and one to red. The sensitivities overlap so that we can see light from the **blue** end of the spectrum, around 400nm, to the **red**, around 700nm. We are most sensitive to the green/yellow around 550nm, which is now being used on emergency vehicles such as fire engines rather than the traditional red. This is also the frequency at which the **sun** radiates the most light.

Some animals don't have colour vision at all, such as **cows** and dogs. Others have very different colour vision, such as insects. Bees are sensitive to **ultraviolet**, and many **butterflies** see infrared.

Discussion Question

Humans are not sensitive to light in the x-ray region of the spectrum. However, Superman is not technically human, so he might have receptors to x-rays. However, natural light from the sun and artificial light does not contain x-rays, so there wouldn't be any normally for Superman to see. He would need a source of x-rays to shine through things to use his x-ray vision.

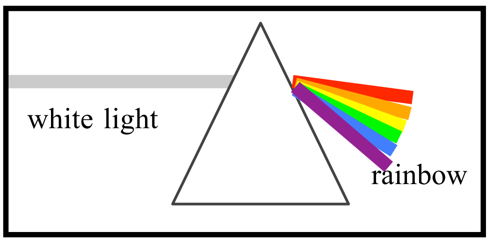
B. Activity Questions:

1. Speed of Light

The melted patches occur at antinodes in the standing wave pattern inside the microwave. The distance between two antinodes is _λ. The speed of light can then be found using $c = \lambda f$, where the frequency, f, is read off the compliance plate on the back of the microwave.

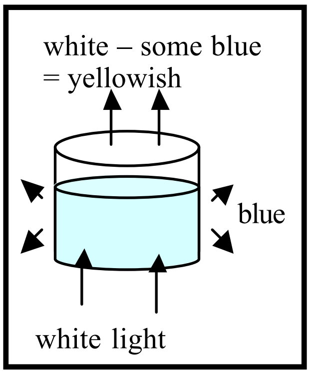
2. Prism

When light moves from air into the prism the light is refracted or bent, and it is bent again as it leaves the prism. The prism has a refractive index which varies for different wavelengths. The refractive index is greater for shorter wavelengths, and hence the blue component of the incident white light bends more than the red component.



3. Change the colour of your fruit (or See the World through Rose Coloured Glasses)
When white light falls on an object some of the light is reflected and some is absorbed. What we see is the reflected light, so the colour of the object is the colour of the light that it reflects. Looking through red glasses you will still see red objects as red, but objects that reflect no red light appear black. Hence a red apple looks almost normal, but a green apple looks black. A yellow banana looks reddish but very dark, because it reflects some red light, but not much.

4. Sunset in a jar
The milky water scatters the blue light more than other colours, so you should be able to see a faint blue tinge to the light coming from the sides of the beaker. This is like a very small but condensed version of the atmosphere scattering the light from the sun. The sky on Earth is blue because we are seeing light scattered by the atmosphere. If you looked directly at the sun (which you should never do!) it would look yellow, like the light coming out the top of the beaker. The sky on Mars (and the moon) is black because there is no atmosphere to scatter any light – hence in the daytime you would see the sun, and other stars.



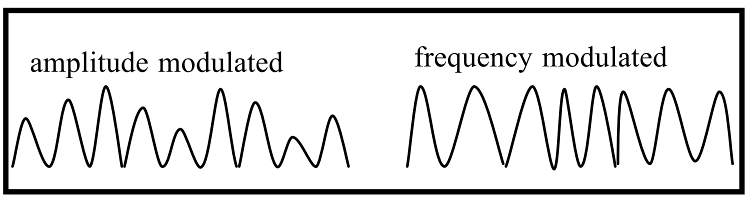
C. Qualitative Questions:

1. Rebecca and Brent are sitting inside watching TV one evening when Brent notices a lightning flash. A few moments later they hear a peal of thunder. When there is a storm, lightning and thunder are emitted at the same time and from the same source. The lightning, which is light waves, travels much faster (around 3 _ 10^{8} m.s^{-1}) than thunder which is a sound wave (and travels at around 3 _ 10^{2} m.s^{-1}). So the light reaches Brent and Rebecca sooner than the sound. If the storm is far away the time difference between the arrival of the two is large. As the storm gets closer, the distance traveled by both waves is less, so the time difference gets smaller, and when the storm is right overhead the time difference is no longer noticeable. Brent has noticed that the time difference is getting smaller, so the storm is getting closer. If the time difference was getting greater the storm would be moving away.

2. When some people go shopping for clothes they try to look at the clothes in natural light, for example in the doorway of a shop. Natural light is close to white light, it contains all the different colours in the visible spectrum. Fluorescent light does not have as much red in it as sunlight, so clothes look different in fluorescent light to natural light or incandescent light. Many people find they look "less attractive" in fluorescent light because it is a "harsh" light. This is because it does not contain much red, and pink skin tones usually look healthier than pale white tones. If people feel they look less attractive when trying on clothing, they are less likely to buy it, hence expensive stores tend to use incandescent lights even though they are more expensive to run.

D. Quantitative Question:

FM radio stations broadcast signals which have frequencies in MHz, for example 106.5MHz.
a. To find the wavelength of the signal broadcast you use the relationship $c = \lambda f$. We know that the frequency is $f = 106.5 \times 10^{6}$ Hz, and $c = 3.0 \times 10^{8}$ m.s^{-1}, so:
$\lambda = c/f = 3.0 \times 10^{8}$ m.s^{-1} / 106.5×10^{6} Hz = 2.8 m.
b. A wavelength of 521 m gives $f = c/\lambda = 3.0 \times 10^{8}$ m.s^{-1} / 521 m = 576×10^{3} s^{-1} = 576kHz.
This is ABC radio national in Sydney.
c. See diagram opposite.
An FM signal carries information in the way the frequency varies, while the amplitude remains constant. An AM signal carries the information in the variation of the amplitude, while the frequency stays the same.



Workshop Tutorials for Introductory Physics

WI6: **Reflection and Refraction**

A. Review of Basic Ideas:

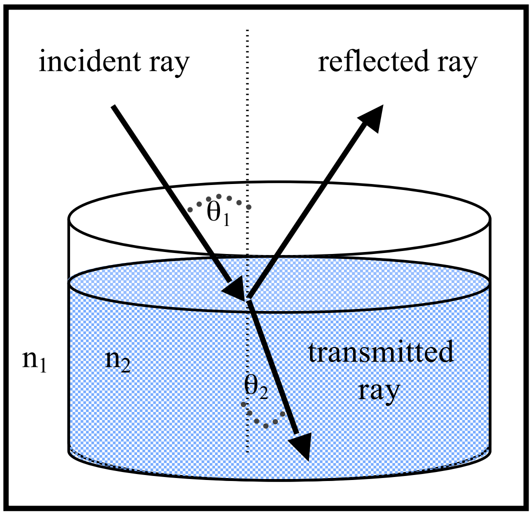
Use the following words to fill in the blanks:
refracted, speed, rays, reflected, reflection, transmitted, shallower, incidence, bends, perpendicular

Reflection and Refraction of Light

When you look into the surface of a swimming pool, often you can see both the bottom of the pool and your own _______. When light hits any surface, in this case the surface of the water, there is usually some light reflected, some light absorbed and some which is _______ into the underlying medium. To see your reflection, light reflected from you must have bounced or reflected off the surface. To see the bottom of the pool some light has travelled through the air-water interface to the bottom of the pool where again some light is reflected and the rest absorbed. The _______ light then passes back up through the water – air interface and into your eyes.

You may also have noticed that swimming pools always look _______ than they really are. To understand why this is we use the laws of reflection and refraction of light and we model light as _______ travelling in straight lines. Imagine a line perpendicular to the water-air interface at the point of incidence of the incoming ray. The angle between the perpendicular and the incident ray (the angle of _______) and the angle between the perpendicular and the reflected ray (the angle of reflection) are equal. This is the law of reflection.

The law of refraction, which tells us how light _______ as it moves from one medium to another, is defined in terms of a quantity known as the refractive index.



The refractive index of a material depends on the _______ of light in that material. It is the ratio of the speed of light in a vacuum to the speed of light in the medium and so is always greater than 1. Once again imagine a line perpendicular to the water-air interface at the point of incidence of the incoming ray. The angle of incidence, θ_1, is the angle between the incident ray and the _______. The angle of refraction, θ_2, is the angle between the perpendicular and the _______ ray in the new medium (water in this case). Call the air medium 1, with refractive index n_1 and water medium 2 with refracrive index n_2. The law of refraction states that $n_1\sin\theta_1 = n_2\sin\theta_2$. The greater the ratio of n_2 to n_1, the more the light will bend when it enters medium 2.

B. Activity Questions:

1. Prism

Shine the light through the prism.
What do you see going into the prism?
What do you see coming out?
Which is refracted (bends) more – light of long or short wavelength?
Sometimes after rain or when there is a break in the clouds you may see a rainbow. On a sunny day if you stand with the sun behind you , you can make a rainbow by spraying a mist of water from a hose.
Draw a diagram showing how the rainbow is formed by the droplets of water.

2. Bent pencil
Why does the pencil appear to be bent?
Draw a diagram showing how the light is bending in this case.

3. Losing your marbles
Pour the liquid into the container with the marbles in it.
Why do they appear to disappear?
What can you conclude about the refractive index of the marbles and the liquid?

4. Total internal reflection
Shine the light into the cable.
Can you see the light through the sides of the cable?
Where is the light going, and why?

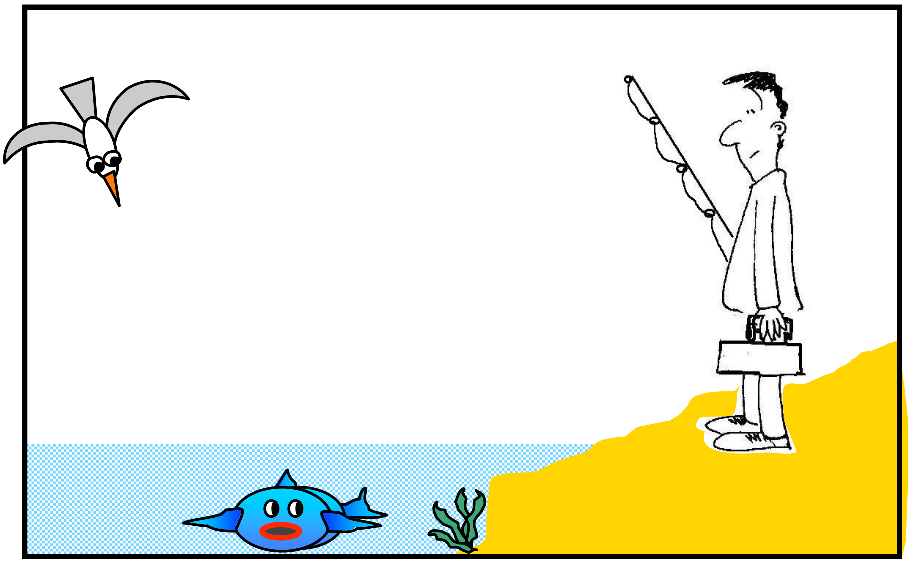
C. Qualitative Questions:

1. Have you ever noticed that swimming pools and rock pools by the ocean seem shallower than they actually are? Inexperienced snorkelers sometimes try to reach out and grab fish drifting past, believing them to be much closer than they actually are.
Consider an object lying on the bottom of a swimming pool. Draw a diagram the path of a light ray coming from an object at the bottom of a swimming pool into your eye. Use your diagram to explain why the object seems closer than it really is.

2. It is possible to see the sun or even a distant boat on the ocean when it is below the physical horizon. Explain, using a diagram, how this is possible.

D. Quantitative Question:

The picture below shows a fish and the fisherman who is hoping to catch him. It is a calm clear day and the surface of the water is perfectly smooth. The refractive index of water is 1.33.
a. What is the critical angle for the air-water interface?
b. Draw a diagram showing what the fish sees.



Workshop Tutorials for Introductory Physics

Solutions to WI6: **Reflection and Refraction**

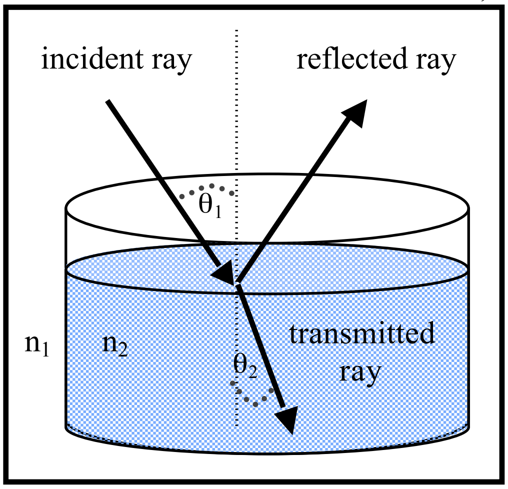
A. Review of Basic Ideas:

Reflection and Refraction of Light

When you look into the surface of a swimming pool, often you can see both the bottom of the pool and your own **reflection**. When light hits any surface, in this case the surface of the water, there is usually some light reflected, some light absorbed and some which is **transmitted** into the underlying medium. To see your reflection, light refelcted from you must have bounced or reflected off the surface. To see the bottom of the pool some light has travelled through the air-water interface to the bottom of the pool where again some light is reflected and the rest absorbed. The **reflected** light then passes back up through the water – air interface and into your eyes.

You may also have noticed that swimming pools always look **shallower** than they really are. To understand why this is we use the laws of reflection and refraction of light and we model light as **rays** travelling in straight lines. Imagine a line perpendicular to the water-air interface at the point of incidence of the incoming ray. The angle between the perpendicular and the incident ray (the angle of **incidence**) and the angle between the perpendicular and the reflected ray (the angle of reflection) are equal. This is the law of reflection.

The law of refraction, which tells us how light **bends** as it moves from one medium to another, is defined in terms of a quantity known as the refractive index.

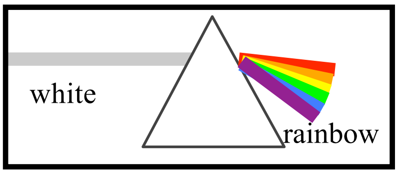


The refractive index of a material depends on the **speed** of light in that material. It is the ratio of the speed of light in a vacuum to the speed of light in the medium and so is always greater than 1. Once again imagine a line perpendicular to the water-air interface at the point of incidence of the incoming ray. The angle of incidence, θ_1, is the angle between the incident ray and the **perpendicular**. The angle of refraction, θ_2, is the angle between the perpendicular and the **refracted** ray in the new medium (water in this case). Call the air medium 1, with refractive index n_1 and water medium 2 with refracrive index n_2. The law of refraction states that $n_1\sin\theta_1 = n_2\sin\theta_2$. The greater the ratio of n_2 to n_1, the more the light will bend when it enters medium 2.

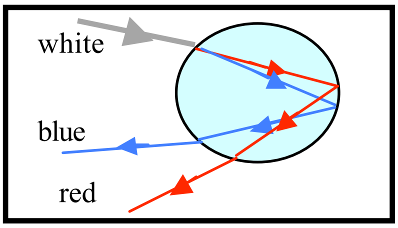
B. Activity Questions:

1. Prism

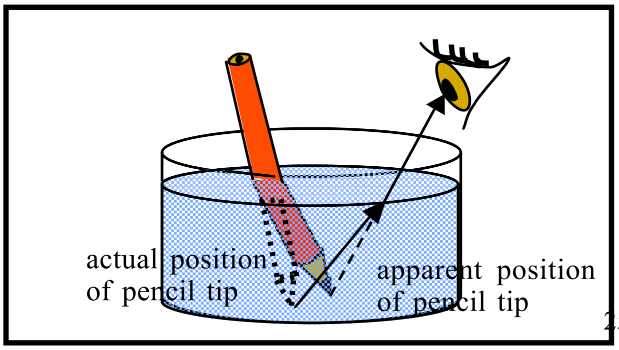
When light moves from air into the prism the light is refracted or bent, and it is bent again as it leaves the prism. The prism has a refractive index which varies for different wavelengths. The refractive index is greater for shorter wavelengths, and hence the blue component of the incident white light bends more than the red component.



This is how rainbows are produced, the raindrops act as prisms, but the light doesn't just pass through the drops, it is reflected off the back surface of the drop and comes out the front separated into different wavelengths.



2. Bent pencil



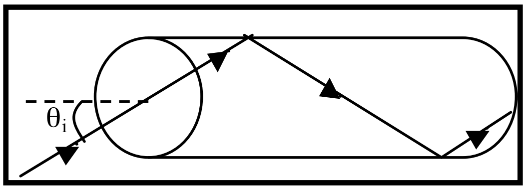
The light from the pencil is refracted when it passes from the water into air, bending away from the normal as it moves from high to low refractive index. The light coming from the pencil tip appears to be coming from the apparent pencil tip as shown opposite.

3. Losing your marbles

The refractive index of the marbles and the liquid is the same, so light passing through the beaker will not be bent as it moves from water to marble to water again. If the marbles are transparent, they will be invisible in the liquid.

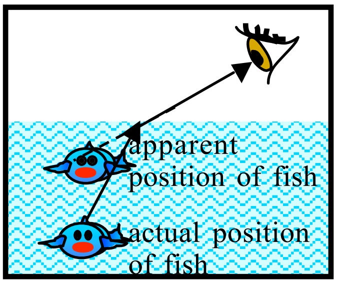
4. Total internal reflection

The light ray that enters the cable is totally internally reflected provided the incident angle, θ_i, is greater than the critical angle. Light is trapped inside the cable and almost none gets out the sides.

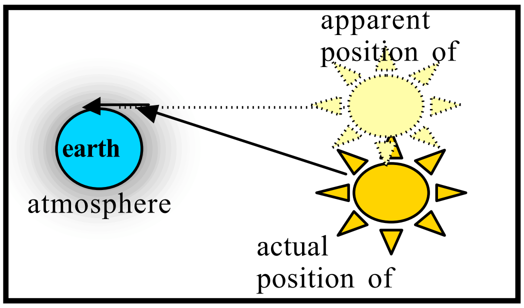


C. Qualitative Questions:

1. Light travelling from one medium into another is bent or refracted. When the medium it is entering has a higher refractive index than the one it is leaving, it is bent away from the normal to the surface. Water has a higher refractive index than air, so this is what happens when light reflects off a fish, passes through the water's surface and into your eye. The apparent position of the fish is closer than its actual position, and the ratio of the apparent depth to the actual depth is equal to the ration of the refractive indices; $d_{apparent} / d_{actual}.= n_{air} / n_{water.}$

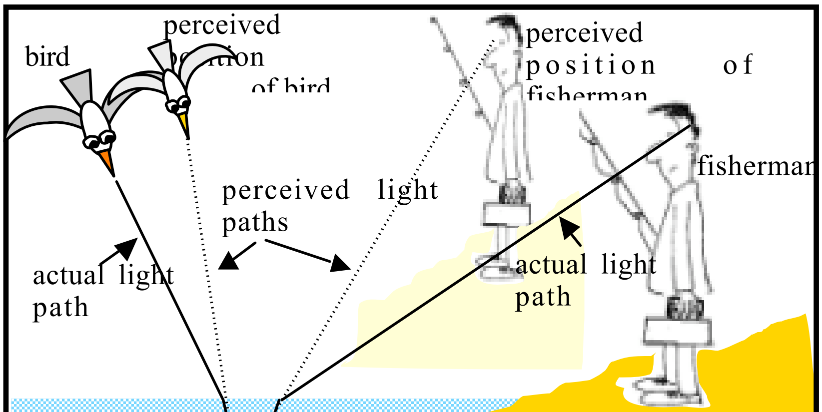


2. The Earth is surrounded by the atmosphere, which extends a few hundred kilometres into space. When a ray of light enters the atmosphere it is refracted, or bent, by the atmosphere.
When light travels from a medium with lower refractive index to one with higher refractive index the light is bent towards the normal to the surface of the new medium. See diagram opposite. When the sun is below the physical horizon, it may still be visible because the light it emitts is refracted, so its apparent position is above the horizon.



D. Quantitative Question:

It is a calm clear day and the surface of the water is perfectly smooth. Refractive index of water is 1.33.
a. The critical angle for the air water interface can be found using Snell's law: $n_1\sin\theta_1 = n_2\sin\theta_2$. The critical angle is when total internal reflection occurs, ie the fish would only see a reflection from the surface of the water, and not anything outside the water. This occurs when $\theta_1 = 90^o$, so:
$n_1\sin\theta_1 = n_2\sin\theta_2$, or $1\_\sin(90^o) = 1.33\_\sin\theta_2$, which gives $\sin\theta_2 = 1/1.33$, and $\theta_2 = 49^o$. Any rays with incident angle greater than 49^o never make it to the fish.



b. See diagram. Light coming from the bird and the fisherman is diffracted, or bent, making them appear higher up and further away than they actually are. Some fish, such as angler fish, allow for this effect. Angler fish can accurately spit a stream of water at an insect a few feet above the water, allowing for diffraction.

Workshop Tutorials for Introductory Physics

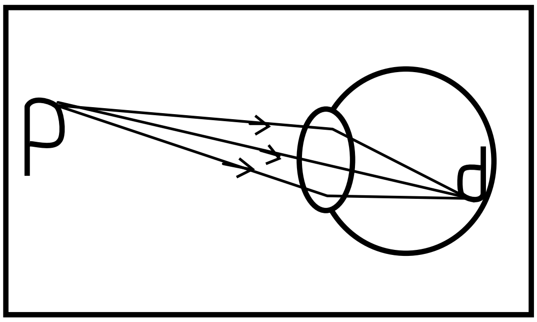
WI7: Lenses and Mirrors

A. Review of Basic Ideas:

Use the following words to fill in the blanks:
enlarged, stars, diverging, sharp, retina, focal, optical, magnified, focused, virtual, converges

Seeing clearly - glasses, telescopes and microscopes
Most people will need glasses at some time in their life. Why do we need glasses and what do they do?

The eye is a special _______ instrument. The front of the eye acts as a lens and bends light as it passes through it. This way an image of the object we are viewing is formed on the _______. Think about one letter of the print in front of you. Light enters your eye from each part of the letter. Your eye bends the light so that all the light from one point on the letter is focused onto one point of the retina. The light from each part of the letter is thus _______ on the retina and an image of the letter is formed.



Why do we need glasses? Because often the inbuilt lens in our eye cannot bend the light exactly the right amount to form a _______ image on the retina. If you are longsighted you can't see objects that are close to you. Light rays from a close object have a larger angle cone of light and hence need to be bent more to focus on the retina. If your eye cannot bend the light enough you need a lens that _______ the light rays. The power of the lens, or its ability to focus, is related to the _______ length of the lens, which depends on the curvature of the sides of the lens and the material from which it is made.

Short sighted people have the opposite problem – their eyes bend the light too much and they have trouble seeing things a long way off.

So long sighted people need converging (convex) lenses, while short sighted people need _______ (concave) lenses.

Optical instruments, such as microscopes and telescopes, have a series of lenses usually with the aim of providing a ________ image of the original object. For instance a telescope gives a magnified image of distant _______, while a microscope gives a magnified image of a very small object that is quite close. The image may be real as in a slide projector, or _______ as in a magnifying glass. In a projector light actually passes through the image and is projected on a screen. A virtual image is one where the light only appears to come from the image. A good example of a virtual image is the enlarged image you see through a magnifying glass. Light is bent as it passes through the magnifying glass to your eye so that it appears to have come from an _______ image but the path of the light is just from the print through the lens to your eye. The image is a virtual one.

Discussion Question:
In the book *Lord of the Flies* by William Golding there is character called Piggy, who wears glasses. He uses them to start a fire, so that the group of boys stranded on the island can cook and stay warm. Later in the book he gets into a fight and his glasses are smashed. He then has trouble seeing because he is extremely short sighted. Why does this not make sense, given what you know about optics?.

B. Activity Questions:

1. Lenses – concave and convex
Observe how the different lenses change the direction of the light rays.
Feel the different shapes and relate the shapes to the effect of the lens.
Which ones are converging? Which ones are diverging?

2. Lenses – finding the focal length of a convex lens
Hold the lens up to the window and hold a piece of paper behind it (on the other side of the lens from the window). Move the paper until you get a sharp image of the world outside the windows (or distant object such as a tree).
What is the focal length of the lens?

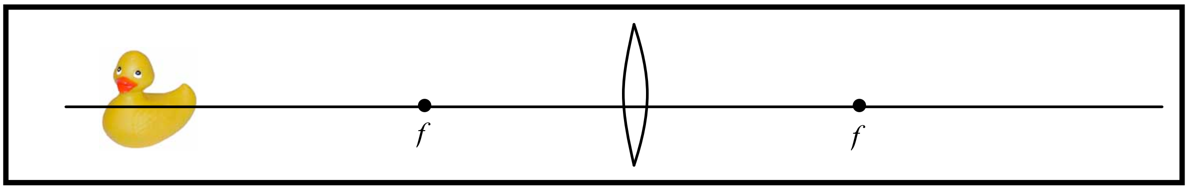
3. Half a lens
Hold the lens up so that an image of the light is formed on a piece of paper.
Predict what will happen if half the lens is covered with another piece of paper.
Now get someone else to cover half the lens.
What happens to the image? Was your prediction correct?
Explain your observations.

4. Right angled mirrors
Look at your image in the mirror.
What do you notice when you move your hands?
How is this different to a single mirror?

C. Qualitative Questions:

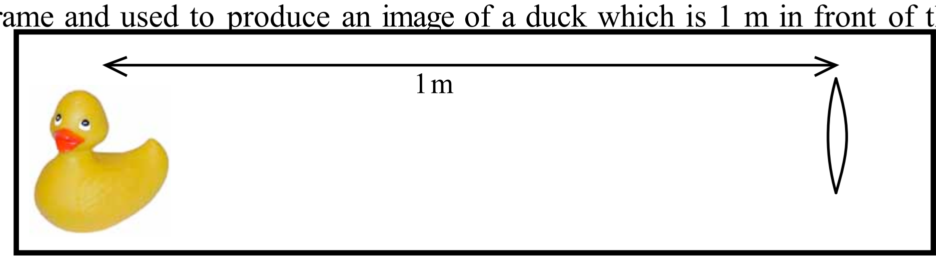
1. You want to buy a mirror to put in the inside of your closet door so you can check how you look in the morning before setting off to uni, but you don't want to spend a lot of money getting a bigger mirror than you actually need.
a. How big a mirror would you need to just be able to see yourself from top to toe?
b. At what height should the mirror be mounted?
c. Why are left and right reversed in a mirror but not up and down?

2. Sketch a ray diagram for the situation shown and describe the image (size, orientation, real or virtual).



D. Quantitative Question:

The first handheld spectacles were in use at least 700 years ago. It took another hundred years for someone to invent a way of attaching them to the head, however wearing them in public was considered bad taste until quite recently. Optometrists write prescriptions with the lens strength measured in diopters, D. A diopter is the reciprocal of the focal length; $D = 1/f$.
a. A pair of glasses has lenses with strength 1.5 D. What is the focal length of these lenses?
One lens is pulled out of the frame and used to produce an image of a duck which is 1 m in front of the lens. (See figure.)



b. Use the lens formula to locate the image.
c. What sort of image is this?

(Hint: Is the light actually coming from where the image appears to be?)

Workshop Tutorials for Introductory Physics

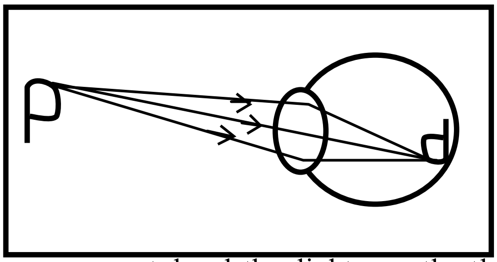
Solutions to WI7: Lenses and Mirrors

A. Review of Basic Ideas:

Seeing clearly - glasses, telescopes and microscope

Most people will need glasses at some time in their life. Why do we need glasses and what do they do?

The eye is a special **optical** instrument. The front of the eye acts as a lens and bends light as it passes through it. This way an image of the object we are viewing is formed on the **retina**. Think about one letter of the print in front of you. Light enters your eye from each part of the letter. Your eye bends the light so that all the light from one point on the letter is focused onto one point of the retina. The light from each part of the letter is thus **focused** on the retina and an image of the letter is formed.



Why do we need glasses? Because often the inbuilt lens in our eye cannot bend the light exactly the right amount to form a **sharp** image on the retina. If you are longsighted you can't see objects that are close to you. Light rays from a close object have a larger angle cone of light and hence need to be bent more to focus on the retina. If your eye cannot bend the light enough you need a lens that **converges** the light rays. The power of the lens, or its ability to focus, is related to the **focal** length of the lens, which depends on the curvature of the sides of the lens and the material from which it is made.

Short sighted people have the opposite problem – their eyes bend the light too much and they have trouble seeing things a long way off.

So long sighted people need converging (convex) lenses, while short sighted people need **diverging** (concave) lenses.

Optical instruments, such as microscopes and telescopes, have a series of lenses usually with the aim of providing a **magnified** image of the original object. For instance a telescope gives a magnified image of distant **stars**, while a microscope gives a magnified image of a very small object that is quite close. The image may be real as in a slide projector, or **virtual** as in a magnifying glass. In a projector light actually passes through the image and it is projected on a screen. A virtual image is one where the light only appears to come from the image. A good example of a virtual image is the enlarged image you see through a magnifying glass. Light is bent as it passes through the magnifying glass to your eye so that it appears to have come from an **enlarged** image but the path of the light is just from the print through the lens to your eye. The image is a virtual one.

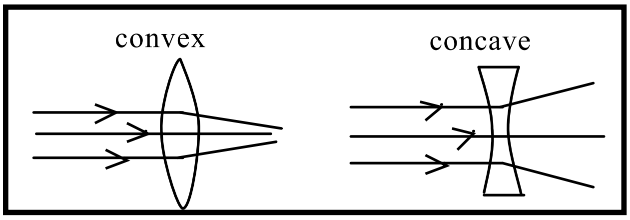
Discussion Question:

Corrective lenses for shortsightedness (myopia) are diverging or concave lenses. Diverging lenses form a virtual image behind the lens, and hence cannot be used to focus light at a point to start a fire. Piggy and his friends should not have been able to cook, or Piggy must have been long sighted.

B. Activity Questions:

1. Lenses – concave and convex

Convex lenses are converging lenses, and concave lenses are diverging lenses. See diagram opposite.



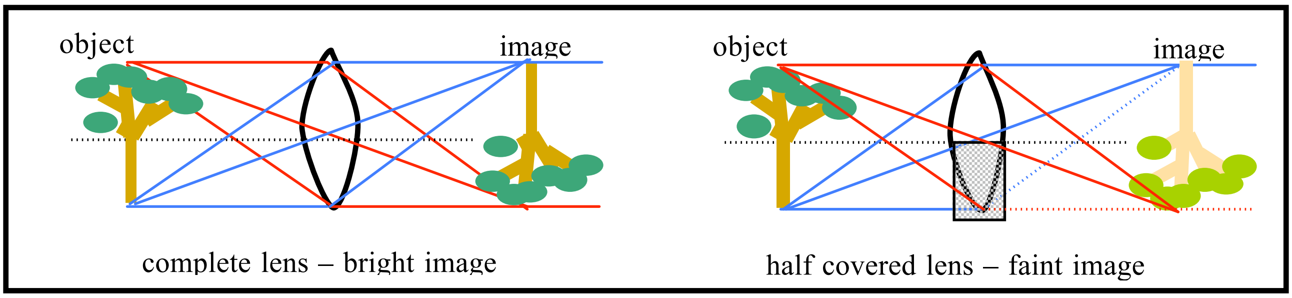
2. Lenses – finding the focal length of a convex lens

Hold the lens up to the window and hold a piece of paper behind it (on the other side of the lens from the window). Move the paper until you get a sharp image of the world outside the windows (or distant object such as a tree). When you have a sharp image, you measure the distance between the lens and the image (paper). This distance is the focal length of the lens.

(Using $\frac{1}{f} = \frac{1}{o} + \frac{1}{i}$, and $o = \infty$ so that $\frac{1}{o} = 0$, gives $f = i$)

3. Half a lens

When you cover half the lens you get a fainter image. Effectively you are cutting out half the light rays, but they still produce an entire image.



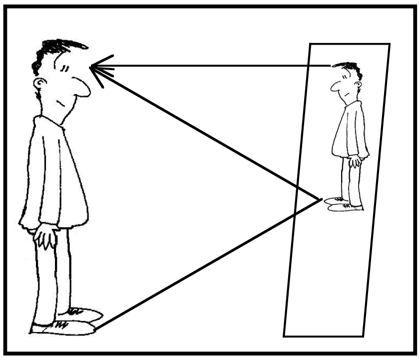
4. Right angled mirrors

Look at your image in the mirror.

The right angled mirror does not reverse your reflection, so when you move your hand left, you see it move to the left in your reflection. In a single mirror, left and right are reversed.

C. Qualitative Questions:

1. You want to buy a mirror but you don't want to spend a lot of money getting a bigger mirror than you actually need.

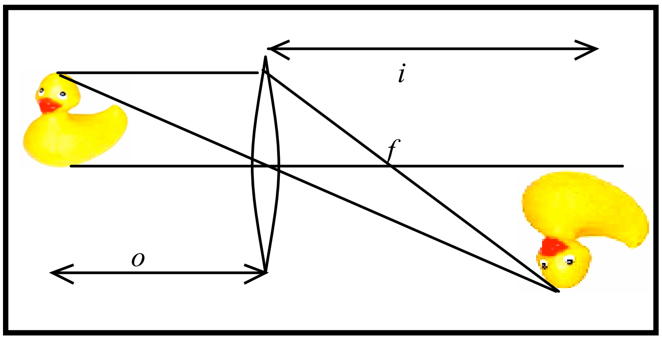


a. The angle of reflection is equal to the angle of incidence, so a ray coming from your toes to your eyes reflects off the mirror at half your height. The lower half of a full length mirror only shows the floor. A mirror only needs to be half your height, so you can see all of yourself, plus a little bit to allow for your eye height being a little less than your full height.

b. The mirror should be mounted so that the top is level with the top of your head.

c. In your reflection left and right seem to be reversed, but not up and down. This is because of the way we define left and right as relative to ourselves, not our surroundings. For example, "towards the wall" and "away from the wall" are not reversed, just as up and down are not reversed. Up and down are defined externally, usually relative to the ground. It is important to know how your coordinate systems are defined, and whether they change as you move!

2. See diagram opposite. The image produced is real, inverted and magnified.



D. Quantitative Question:

Optometrists write prescriptions with the lens strength measured in diopters, D. A diopter is the reciprocal of the focal length; $D = 1/f$. A pair of glasses has lenses with strength 1.5 D.

a. The lens has a strength of 1.5 diopter, so it has a focal length of 1/1.5 = 0.66m.

b. Using $\frac{1}{f} = \frac{1}{o} + \frac{1}{i}$ where f = 0.66 m and o = 1 m, we get an image distance of 2 m.

c. This is a real image, if you put a screen where it appears to be, there would be light on the screen.