

AS and A LEVEL

Delivery Guide

PHYSICS B (ADVANCING PHYSICS)

H157/H557

For first teaching in 2015

Waves and quantum behaviour

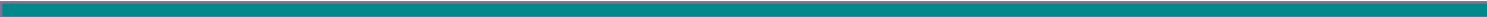



Version 2

AS and A LEVEL PHYSICS B

Delivery guides are designed to represent a body of knowledge about teaching a particular topic and contain:

- Content: A clear outline of the content covered by the delivery guide;
- Thinking Conceptually: Expert guidance on the key concepts involved, common difficulties students may have, approaches to teaching that can help students understand these concepts and how this topic links conceptually to other areas of the subject;
- Thinking Contextually: A range of suggested teaching activities using a variety of themes so that different activities can be selected which best suit particular classes, learning styles or teaching approaches.

If you have any feedback on this Delivery Guide or suggestions for other resources you would like OCR to develop, please email resources.feedback@ocr.org.uk

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Module 4: Understanding processes

This module provides progression from the application-oriented work in *Physics in Action*. *Understanding Processes* is organised around different ways of describing and understanding processes of change: motion in space and time, wave motion, quantum behaviour. It provides a sound foundation in the classical physics of mechanics and waves and takes the story further, touching on the quantum probabilistic view.

Physical variables are extended from scalars to quantities that add like vectors.

Either section may be covered first. Some teachers may wish to introduce work on vector addition from 4.2 before embarking on work on combining phasors.

The first section of the module is mainly about superposition phenomena of waves with a brief account of the quantum behaviour of photons. This is a rich field for practical physics and students will have many opportunities to extend their experimental and analytical skills. In addition, the topics provide a picture of the development of theories and understanding over time (HSW1, HSW2, HSW7). Quantum behaviour is discussed through considering possible photon paths, avoiding the wave/particle dichotomy.

Section 4.1 Waves and Quantum Behaviour

(a) Describe and explain:

- (i) production of standing waves by waves travelling in opposite directions
- (ii) interference of waves from two slits
- (iii) refraction of light at a plane boundary in terms of the changes in the speed of light and explanation in terms of the wave model of light
- (iv) diffraction of waves passing through a narrow aperture
- (v) diffraction by a grating
- (vi) evidence that photons exchange energy in quanta $E = hf$ (for example, one of light emitting diodes, photoelectric effect and line spectra)
- (vii) quantum behaviour: quanta have a certain probability of arrival; the probability is obtained by combining amplitude and phase for all possible paths
- (viii) evidence from electron diffraction that electrons show quantum behaviour.

(b) Make appropriate use of:

- (i) the terms: phase, phasor, amplitude, probability, interference, diffraction, superposition, coherence, path difference, intensity, electronvolt, refractive index, work function, threshold frequency.

(c) Make calculations and estimates involving:

- (i) wavelength of standing waves
- (ii) Snell's Law

(iii) path differences for double slits and diffraction grating, for constructive interference $n\lambda = d \sin\theta$ (both limited to the case of a distant screen)

(iv) the energy carried by photons across the spectrum, $E = hf$

(v) the wavelength of a particle of momentum p , $\lambda = \frac{h}{p}$

(d) Demonstrate and apply knowledge and understanding of the following practical activities (**HSW4**):

(i) using an oscilloscope to determine frequencies. **Links to 4.1a(i) PAG5**

(ii) determining refractive index for a transparent block. **Links to 4.1c(ii)**

(iii) superposition experiments using vibrating strings, sound waves, light and microwaves. **Links to 4.1a(i),b(i), c(i) PAG5**

(iv) determining the wavelength of light with a double-slit and diffraction grating. **Links to 4.1a(ii), a(v), c(iii) PAG5**

(v) determining the speed of sound in air by formation of stationary waves in a resonance tube. **Links to 4.1a(i), c(i) PAG5**

(vi) determining the Planck constant using different coloured LEDs. **Links to 4.1a(vi), c(iv) PAG6**

Learner Activity 1

Previous versions of this course were backed by the 'Advancing Physics' CD-ROM, which is no longer tailored to the course: it does, however, have a great many ideas for practical work, with clear instructions for students. The teachers' version also has lists of equipment for technicians. Many of the experiments and demonstrations are applicable to the new course.

The teachers' version also has worked solutions to nearly all the problems on the CD-ROM.

If you cannot get hold of the CD-ROM you will find that many of the experiments and worksheets are available on the Institute of Physics TAP (Teaching Advanced Physics) website <http://tap.iop.org/>.

OUP are also publishing new textbooks for the course, with additional resources available through their kerboodle platform.

<https://global.oup.com/education/content/secondary/series/advancing-physics-third-edition/?region=uk>

Below is a list of ideas for activities.

Learner Activity 2**Revising GCSE**

Some students may not yet have encountered the idea of waves and many will be vague about some of the concepts, so it is well worth devoting some time to covering the basics of wave motion.

Having done that, introduce the students to oscilloscopes. A Picoscope or data-logger with an oscilloscope function can be used as an alternative to a CRO, and these can be displayed on a data-projector: additionally they feature the ability to capture an event on a static display. Winscope is a free download using the sound card in a computer and there are several Oscilloscope apps which might familiarise the students with some of the techniques: 'Physics Oscilloscope', 'Agilent Oscilloscope' and 'iMSO' are all free.

Using an oscilloscope to measure frequency can range from the tedium of measuring the frequency of the a.c. output from a lab power supply to the chaos of getting the students to sing a steady note into a microphone: if using a PC-based oscilloscope it is easy to get a print-out of any waveform, which can be inserted into any student's notes.

Learner Activity 3**Production of standing waves by waves travelling in opposite directions**

Introduce this section by making standing waves using a rope, both with the end fixed and with the end allowed to move. Practise beforehand.

Then try as many of the following as you can:

Standing waves on a string (needs signal generator and vibration generator)

<https://spark.iop.org/sites/default/files/media/documents/episode-324-2-standing-waves-on-a-rubber-cord.doc.doc>

Standing waves in sound (needs signal generator, loudspeaker, microphone, oscilloscope)

<https://spark.iop.org/sites/default/files/media/documents/episode-324-5-standing-waves-in-sound.doc>

1 GHz standing waves (if you have R.F. apparatus)

<https://spark.iop.org/sites/default/files/media/documents/episode-324-8-a-stationary-1-ghz-wave-pattern.doc>

Standing waves in 2 and 3 dimensions (uses signal generator, vibration generator)

<https://spark.iop.org/sites/default/files/media/documents/episode-324-12-more-complicated-standing-waves.doc>

Resonance as such is not in this section, but measuring the speed of sound using a resonance tube should be attempted here. It is possible to use a sound editing program to produce a sound wave through a high-impedance loudspeaker connected to a laptop's sound card, so try this as a class experiment. Audacity is available as a free download and allows sound editing and production.

<https://www.audacityteam.org/>

Alternatively all of these might be made into a circus of experiments.

Measuring the speed of light using a microwave oven or measuring the speed of light through a fibre optic with a high speed oscilloscope (Picoscope copes with this) and kit such as the Lascell's fibre optic system (SciChem reference XOP850011).

<https://www.youtube.com/watch?v=cH9uHjJuANI>

Learner Activity 4**Interference of waves from two slits**

Try as many of these as possible. Interference in sound waves is difficult to show indoors because of many unwanted reflections, although setting up two signal generators and speakers at opposite ends of the classroom can produce areas of high and low sound experienced as you walk around the lab (not on the specification, but of interest is to demonstrate 'beats' with one signal generator marginally detuned, a principle used in piano tuning). It might be worthwhile to get hold of equipment to show this outdoors, e.g. a 'ghetto-blaster' with a CD of sine waves, or an iPhone or similar playing through portable speakers. There are several apps available to produce sine waves on an iPhone, e.g. 'Tunable'.

Interference in sound

<https://spark.iop.org/sites/default/files/media/documents/episode-321-1-hearing-superposition.doc>

Interference in a ripple tank

<https://spark.iop.org/sites/default/files/media/documents/episode-321-4-interference-patterns-in-a-ripple-tank.doc>

Interference in light; this is very easy to demonstrate using a home-made double slit and a laser.

<https://spark.iop.org/episode-321-interference-patterns>

Learner Activity 5**Refraction of light at a plane boundary in terms of the changes in the speed of light and explanation in terms of the wave model of light**

If you have well-disciplined students, try modelling refraction using students.

<https://spark.iop.org/sites/default/files/media/documents/episode-317-1-refraction-soldiers-walking-from-tarmac-onto-sand.doc>

You can set up a nice demonstration of 'invisibility' by dunking a boiling tube in a mixture of glycerol and water of the same refractive index as the glass, showing that a speed change is necessary for refraction. Set this up in advance: it takes a bit of messing about to get the mixture just right: it is, however, well worth the effort of doing so.

The standard method of measuring the refractive index of a block should be attempted: it can be made easier by using a suitable protractor printed on paper and even easier by using a hemispherical block.

Measuring refractive index <https://spark.iop.org/sites/default/files/media/documents/episode-317-2-measuring-refractive-index.doc>

Learner Activity 6**Diffraction of waves passing through a narrow aperture**

Diffraction in a ripple tank https://www.youtube.com/watch?v=KSig_EalFrw

Diffraction of microwaves <https://www.youtube.com/watch?v=UXv1vPxEBIE>

Learner Activity 7**Diffraction by a grating**

This can readily be shown using a laser and a set of diffraction gratings. If you have lasers of different colours then the effect of different wavelengths may be observed. Use Blu-tack or similar to fix the grating into the laser beam. It is not necessary to make use of a beam-spreading lens and subsequent re-focussing.

Measuring the wavelength of light using a diffraction grating <https://spark.iop.org/sites/default/files/media/documents/episode-322-2-measuring-the-wavelength-of-laser-light.doc>

Using a CD as a diffraction grating <https://spark.iop.org/sites/default/files/media/documents/episode-322-5-using-a-cd-as-a-reflection-grating.doc>

Learner Activity 8**Evidence that photons exchange energy in quanta $E = hf$ (for example, one of light-emitting diodes, photoelectric effect and line spectra)**

An experiment using different LEDs is the most direct way of achieving this, but, if you have a spectrometer and a gas-discharge lamp, then demonstrate line emission spectra (show a continuous spectrum first).

There were commercial photoelectric effect kits available and, if you have one of these, it should be possible to demonstrate stopping potential and work function fairly easily. This apparatus seems no longer to be on sale in the UK.

LED experiment https://spark.iop.org/sites/default/files/media/documents/episode-501-4-relating-photon-energy-to-frequency_0_0.doc

Line spectra

Photoelectric effect <https://spark.iop.org/episode-502-photoelectric-effect>

There is a nice applet from the University of Oregon displaying emission and absorption spectra of the elements: you may have to allow it as a special exception in your Java settings. <http://jersey.uoregon.edu/vlab/elements/Elements.html>

Learner Activity 9**Quantum behaviour: quanta have a certain probability of arrival; the probability is obtained by combining amplitude and phase for all possible paths**

A series of photographs showing double slit interference patterns as first one photon then increasing numbers of photons arrive is available at:

<http://www.animations.physics.unsw.edu.au/jw/light/youngs-experiment-single-photons.html>

Another link of interest is on Wikibooks at:

http://en.wikibooks.org/wiki/A-level_Physics_%28Advancing_Physics%29/Light_as_a_Quantum_Phenomenon

with a link to a fuzzy photograph.

Learner Activity 10**Evidence from electron diffraction that electrons show quantum behaviour**

Electron diffraction may be demonstrated easily using Teltron tubes (Available from 3B Scientific, Philip Harris at least) – read the instructions carefully because the electron diffraction tube has slightly different electrical connections from the other tubes in the set. Before showing this, show diffraction halos using visible light: if you use LEDs as the light source you can also show the effect on the diffraction pattern when using different wavelengths. <https://www.3bscientific.co.uk/index.html>

Diffraction of light <https://spark.iop.org/sites/default/files/media/documents/episode-506-2-diffraction-of-light.doc>

Electron diffraction <https://spark.iop.org/sites/default/files/media/documents/episode-506-1-diffraction-of-electrons.doc>

Learner Activity 11

PAG 5 and PAG 6 practical activities: OCR has produced the following relevant [suggested practical activities](#) for the practical endorsement:

PAG 5.1 - Determining the wavelength of light with a diffraction grating

PAG 5.2 - Determining the speed of sound in air using a resonance tube

PAG 5.3 - Determining frequency and amplitude of a wave using an oscilloscope

PAG 5.4 - Using diffraction from a CD as a means to determine wavelength

PAG 6.1 - Determining the Planck constant using LEDs

PAG 6.2 - Experiments with light

PAG 6.3 - Experiments with polarisation

If you can get one of the Advancing Physics CD-ROMs to work on your OS, then this will afford an excellent supply of problems intended to develop the concepts needed for this section. If this is not possible, then explore <http://tap.iop.org> which has a good selection of material from the CDs.

Other than this, the Internet is not well supplied with suitable problems for the course. If you wish to use questions from past papers, the OCR [website](#) has a good selection of these, including papers from previous versions of the specification, many of which have questions which are relevant to the new specification. [ExamBuilder](#) offers a very useful database of A Level questions from which you may select a single topic and look at, or print out, as many of the questions as you wish.

Revising GCSE

Some students may not yet have encountered the idea of waves and many will be vague about some of the concepts, so it is well worth devoting some time to covering the basics of wave motion. Introduce the concept of phase early to avert criticism from more capable students that this has been covered before. Many students will need help with the idea of a sine wave, though the equation $y = a \sin(2\pi ft - kx)$ is not required.

If you introduce phasors early in the section, then go on to use them in explaining the phenomena studied, you may avoid students thinking that they have seen all this before, albeit in a format suited to GCSE.

Introduce the apparatus *en masse*, concentrating on waves rather than the details of each piece of equipment (e.g. ripple tanks, signal generators, loudspeakers, microphones, oscilloscopes – a Picoscope interfaced with a data-projector is a considerable asset here, microwave apparatus, GHz e.m. wave kit, lasers, LEDs). Take the opportunity while doing this to cover the fundamental properties of each wave, e.g. mechanical/electromagnetic, transverse/longitudinal. A circus of simple experiments might be useful to allow students to learn how to use the equipment and to be advised of any inherent risks.

Production of standing waves by waves travelling in opposite directions

Having briefly discussed echoes, go on to deal with standing waves, initially in practice, leading to the underlying theory. It is a lot easier to produce standing waves than it is to explain how they occur: you might explore the possibilities of drawing waves moving in opposite directions and superposing them, but a decent animation can achieve wonders. Daniel A. Russell, Graduate Program in Acoustics, The Pennsylvania State University has some useful animations which could be incorporated into any presentation, though the mathematics is worth avoiding at this stage.

<https://www.acs.psu.edu/drussell/demos.html>

Introduce phasors early in this topic so that students feel they are learning something new while revising wave ideas, and use this concept to explain standing waves and superposition effects in diffraction and interference.

Interference of waves from two slits

It is well worth downloading a suitable graphic for this, unless you are expert in drawing concentric circles. Wikimedia has a suitable one.

https://commons.wikimedia.org/wiki/File:Two_Slit_Interference_2500nm_wl_0.1mm_d_close_up.png

Path differences for double slits, for constructive interference $n\lambda = d \sin\theta$ (limited to the case of a distant screen). The inference is that $\lambda = dx/D$ is not required.

Refraction of light at a plane boundary in terms of the changes in the speed of light and explanation in terms of the wave model of light

Snell's Law

Diffraction of waves passing through a narrow aperture

Wikipedia has some useful animated gifs and graphics you might insert into any presentation, though the mathematical analysis is probably worth avoiding at this stage.

http://en.wikipedia.org/wiki/Diffraction#Single-slit_diffraction

By considering a diffraction pattern as being due to interference of wavelets from different parts of the wavefront travelling through a slit, you can use phasors to show how this results in the diffraction pattern. There is no suggestion in the specification of needing to know formulæ for diffraction, though it does occasionally crop up in examination questions, where it is supplied in the text.

Diffraction by a grating

Path differences for diffraction grating, for constructive interference

$n\lambda = d \sin\theta$ (limited to the case of a distant screen)

Drawing concentric circles is likely to be a challenge here as well and the internet is not particularly helpful.

Evidence that photons exchange energy in quanta $E = hf$ (for example, one of light-emitting diodes, photoelectric effect and line spectra)

For the photoelectric effect, a knowledge of threshold frequency and work function is required, so some numerical problems featuring these would be useful.

Teaching Advanced Physics has these.

<https://spark.iop.org/episode-502-photoelectric-effect>

When dealing with line spectra it is worth subverting the examiners' trick of quoting energy levels in electronvolts by practising the conversion to joules. *Teaching Advanced Physics* has some suitable questions dealing with $E = hf$.

<https://spark.iop.org/episode-501-spectra-and-energy-levels>

Quantum behaviour: quanta have a certain probability of arrival; the probability is obtained by combining amplitude and phase for all possible paths

This is where phasors really come into their own. Make sure that students can add phasors as vectors and relate the probability to the square of the resultant phasor amplitude.

Evidence from electron diffraction that electrons show quantum behaviour

Practise $\lambda = h/p$, together with $E = hf$ and $c = f\lambda$.

Teaching Advanced Physics has some relevant questions here.

<https://spark.iop.org/episode-506-particles-waves>

It is quite entertaining to calculate your own wavelength to explain why diffraction effects are negligible when you enter the room through the doorway.

There is a delightful passage in one of George Gamow's 'Mr Tompkins' books in which Mr. Tompkins is being chased by a quantum tiger: when he hides in his tent, the tiger diffracts through the opening and fills the tent: only by opening the tent-flap wide and thereby reducing the diffraction is Mr. Tompkins safe. (George Gamow, *Mr. Tompkins in Wonderland*, chapter 'Quantum Jungle': somewhat dated in approach, but well worth reading).

Also worth a look at are Russell Stannard's 'Uncle Albert' books (*The Time and Space of Uncle Albert*, *Black Holes and Uncle Albert*, and *Uncle Albert and the Quantum Quest*, especially, in this case the last one), target audience 11–16 but another quirky source.

Many wave phenomena are strikingly beautiful and the effects of superposition are not intuitive, so this can be an opportunity to conjure some of the magic of physics within your students. An internet search should produce some vivid graphics of ripples and light diffraction and interference, many of which may be included in any teaching presentation: there is, of course, no substitute for stunning demonstrations.

Here are a few:

Interference on the sea <https://www.flickr.com/photos/tholub/5343533062/in/gallery-physic-sclassroom-72157625109662093/>

Diffraction haloes <http://epod.usra.edu/blog/2009/12/refraction-and-diffraction.html>

More diffraction haloes http://ukazy.astro.cz/upload/20071229RadomirVondra_Ha1.jpg

Brocken Spectre <http://weeklysciencequiz.blogspot.co.uk/2012/09/brocken-specter.html>

Diffraction haloes are all over the place: round every street light on a misty night, round traffic lights seen through a misted window, round the Moon on clear, frosty nights; and they are simplicity itself to show in the laboratory.

A CD or DVD acts as a reflection grating and it may be worth devoting half an hour or so to allowing students to investigate this – old CDs and DVDs litter the prep room. <https://spark.iop.org/sites/default/files/media/documents/episode-322-5-using-a-cd-as-a-reflection-grating.doc>

Diffraction of sound is so much a part of normal life that it needs to be pointed out what is actually occurring: if you are loud and brave, stand outside the laboratory door singing to demonstrate it. Showing interference of sound is more tricky, especially indoors where there are many unwanted reflections, but it is used in motor-bike and car silencers and in 'silence areas' by using rapid microprocessors to send a sound wave 180° out of phase with incident sound. Microphones for use in noisy environments connect two microphones in antiphase so that the background noise cancels: the speaker uses just one of the microphones to transmit.

Radio waves diffract over obstacles in the environment: this is even used intentionally to transmit commercial radio.

Radio propagation by diffraction over an obstruction <http://www.smeter.net/propagation/diffrac1.php>

Suitable graphic at the foot of this page http://www.schoolphysics.co.uk/age14-16/Wave%20properties/text/Diffraction_/index.html

Using diffraction with radar <http://www.radartutorial.eu/07.waves/wa08.en.html>

Standing waves are found in most musical instruments, the timbre of the notes produced being affected by the relative intensities of the harmonics present.

They are also found in microwave ovens, hence the need for the turntable (or the rotating paddle in early versions) to ensure even heating.

They occur in optical cavities, optical waveguides, lasers and in interferometry using optical flats.

They can occur in the atmosphere, finding a use for gliders, and in fast-moving rivers.

Standing waves on fibres can be used in sensors to indicate variations in frequency and phase.

Wave-particle duality is fundamental to the operation of electron microscopes and to neutron diffraction, which is used in determining the atomic structure of materials. It is also the starting point for wave mechanics leading to the theory of quantum tunnelling, essential to the operation of the tunnelling diode and other solid-state devices.

http://en.wikipedia.org/wiki/Electron_microscope

http://en.wikipedia.org/wiki/Neutron_diffraction

http://en.wikipedia.org/wiki/Tunnel_diode

Refraction is, of course, fundamental to the theory of lenses, in optical instruments and spectacles. Total internal reflection can explain the action of optical fibres, though this is not specifically required by the specification.

Other industrial applications include ultrasonic cleaning, ultrasonic cutting, ultrasonic machining, metal forming, metal welding.

http://en.wikipedia.org/wiki/Ultrasonic_cleaning

http://en.wikipedia.org/wiki/Ultrasonic/sonic_driller/corer

http://en.wikipedia.org/wiki/Ultrasonic_machining

<http://www.powerultrasonics.com/content/ultrasonic-metal-forming>

http://en.wikipedia.org/wiki/Ultrasonic_welding

Medical applications of ultrasound are mainly for visualizing internal organs (or objects, such as babies), but it has also been used to break up kidney stones, and possibly gall stones (lithotripsy).

http://en.wikipedia.org/wiki/Medical_ultrasonography

<http://en.wikipedia.org/wiki/Lithotripsy>

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