# Unit 141: The Principles of Photonics

**Unit code:** R/503/0543

**QCF Level 3:** BTEC Nationals

**Credit value:** 10

**Guided learning hours:** 60

## Aim and purpose

Learners will develop an understanding of how light behaves as a wave and as a particle. Learners will develop skills to apply the laws of reflection, refraction and use different types of lenses for specified applications.

## Unit introduction

Photonics has played a major role in changing how we live. The ability to mass produce optic and electro-optic components and integrate them with powerful electronic computing devices has revolutionised many aspects of our lives, including consumer electronics, telecommunications, and the automotive and medical sectors. Broadly speaking, photonics covers the generation, manipulation, transmission and detection of light.

In many aspects of our daily lives we use devices which cover one or more aspects of photonics, for example CD/DVD players and LCD TVs. The need to understand the nature of light and basic optical principles is fundamental to understanding how electronic devices capture and process light and the information it represents.

This unit will give learners looking to work in photonics-related industries an understanding of the underlying principles which govern any optic system. This understanding can be used to interpret specifications and performance of imaging systems and the fundamental characteristics associated with them.

In this unit learners will develop an understanding of how light is produced and how it behaves as a wave and a particle. The unit covers interaction of light with lenses, mirrors, prisms, beam-splitters and diffraction-gratings. Paraxial formulae are used to analyse single lenses and combinations of lenses. Learners will analyse ray diagrams in terms of objects, images, focal lengths, focal points, focal planes, refraction, reflection and magnification. They will develop an understanding of the wave characteristic of light by exploring the principles of diffraction and interference. Learners will have the chance to construct measure and test optic systems to apply the principles they have learned.

## Learning outcomes

**On completion of this unit a learner should:**

1. Be able to apply the laws of reflection and refraction to different situations using appropriate terminology
2. Be able to use different types of lenses for specified applications
3. Understand the behaviour of light in terms of polarisation, diffraction and interference
4. Understand light in terms of the photon.

  

# Learning outcomes and assessment criteria

| Learning outcomes | | Assessment criteria<br>To achieve each outcome a learner must demonstrate the ability to: | |
|---|---|---|---|
| 1 | Be able to apply the laws of reflection and refraction to different situations using appropriate terminology | 1.1 | apply the laws of reflection to different situations |
| | | 1.2 | determine the refractive index and critical angle of optic media using appropriate equipment |
| | | 1.3 | apply the laws of refraction to different situations |
| 2 | Be able to use different types of lenses for specified applications | 2.1 | explain the functions of lenses for different applications in terms of their characteristics |
| | | 2.2 | graphically determine the image position, orientation and height for a convex lens with three different object positions (relative to focal point) |
| | | 2.3 | use formulae to calculate object distances, image distances, magnification and focal length for lenses |
| | | 2.4 | test a self-designed lens system consisting of at least two lenses to meet a given specification |
| 3 | Understand the behaviour of light in terms of polarisation, diffraction and interference | 3.1 | explain the polarisation of light with regard to electric and magnetic fields |
| | | 3.2 | explain the principles of diffraction |
| | | 3.3 | explain the principles of interference |
| 4 | Understand light in terms of the photon | 4.1 | explain how photons are produced by different sources of light |
| | | 4.2 | explain, in terms of photons, situations that cannot be accounted for by applying the wave theory of light. |

# Unit content

## 1 Be able to apply the laws of reflection and refraction to different situations using appropriate terminology

*Terminology*: velocity; wavelength; frequency; real image; virtual image

*Reflection*: angle of incidence = angle of reflection; ray diagrams; use of normals; critical angle; total internal reflection

*Refraction*: refraction of light at a dielectric boundary; Snell's law $n_r/n_i = \text{sine}(\theta_i)/\text{sine}(\theta_r)$; refractive index $n = \text{speed in vacuum/speed in medium}$

*Equipment*: lasers; optic components; beam-steering components; mirrors; prisms; mounting devices and their assembly

## 2 Be able to use different types of lenses for specified applications

*Characteristics of lenses*: lens types and shapes eg convex, concave, plano-convex

*Lens functions*: eg doublets, reduction of aberrations

*Ray diagrams*: eg for lenses, for various object positions; real and virtual images; object height and position; image height and position; focal length; focal plane

*Formulae*: Gaussian thin lens equation linking focal length with object and image position $1/f = 1/d_i + 1/d_0$; magnification factor $M = f_0/f_e$

*Lens system*: eg astronomical telescope, microscope

## 3 Understand the behaviour of light in terms of polarisation, diffraction and interference

*Polarisation of light*: electric and magnetic fields; types (circular, linear, elliptical); use of dichroic materials; analysis as a vector quantity $E$ wave; Malus' law applied to a series of polarising filters placed at an angle $\theta$ where $E = E_0\cos(\theta)$

*Diffraction*: wave model to predict diffraction at an aperture; Airy disc; Fraunhofer single-slit diffraction pattern; Huygens' principle; diffraction grating; $a\sin(\theta) = m\lambda$ for minima using small angle approximation; minima separation $y = m\lambda D/d$

*Interference of light*: principle of wave superposition; constructive and destructive interference; coherence of light sources; interference using Young's double-slit experiment; condition for maxima $d\sin(\theta) = m\lambda$ using small angle approximation; maxima separation $y = m\lambda D/d$; effects eg Newton's rings, oil films

## 4 Understand light in terms of the photon

*Sources of light*: stars (including the sun); incandescent; fluorescent tubes; lasers; LEDs

*Production of light*: the photon; quantisation of energy; Bohr's atomic model; lasers (stimulated emission)

*Situations*: production of laser light; line emission spectra (eg produced by sodium lamp, hydrogen lamp)

# Assessment and grading criteria

In order to pass this unit, the evidence that the learner presents for assessment needs to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria for a pass grade describe the level of achievement required to pass this unit.

| Assessment and grading criteria | | |
|---|---|---|
| **To achieve a pass grade the evidence must show that the learner is able to:** | **To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:** | **To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:** |
| **P1** apply the laws of reflection to different situations [IE1, TW1, TW2, TW4, SM2] | | |
| **P2** determine the refractive index and critical angle of optic media using appropriate equipment [IE1, TW1, TW2] | | |
| **P3** apply the laws of refraction to different situations [IE1, TW1, TW2, TW4, SM2] | | |
| **P4** explain the functions of lenses for different applications in terms of their characteristics | | |
| **P5** graphically determine the image position, orientation and height for a convex lens with three different object positions (relative to focal point) | | |
| **P6** use formulae to calculate object distances, image distances, magnification and focal length for lenses [TW1] | | |
| **P7** test a self-designed lens system consisting of at least two lenses to meet a given specification [IE1, IE2, IE4, IE6, CT1, CT5, TW1, TW2, TW4, SM2, SM3] | | **D1** evaluate the advantages and disadvantages of multi-lens systems |
| **P8** explain the polarisation of light with regard to electric and magnetic fields [IE1] | **M1** use Malus' law to determine light intensity of a series of polarising filters placed at varying angles | |
| **P9** explain the principles of diffraction [IE1] | **M2** explain the formation of diffraction patterns | |

| Assessment and grading criteria | | |
|---|---|---|
| **To achieve a pass grade the evidence must show that the learner is able to:** | **To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:** | **To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:** |
| **P10** explain the principles of interference [IE1] | **M3** explain the formation of interference patterns | **D2** analyse the effects of varying light/optical frequency, spacing, aperture size and intensity on a diffraction grating |
| **P11** explain how photons are produced by different sources of light [IE3] | | |
| **P12** explain, in terms of photons, situations that cannot be accounted for by applying the wave theory of light [IE1] | | |

**PLTS**: This summary references where applicable, in the square brackets, the elements of the personal, learning and thinking skills applicable in the pass criteria. It identifies opportunities for learners to demonstrate effective application of the referenced elements of the skills.

| **Key** | IE – independent enquirers<br>CT – creative thinkers | RL – reflective learners<br>TW – team workers | SM – self-managers<br>EP – effective participators |
|---|---|---|---|

# Essential guidance for tutors

## Delivery

It is important that Unit 4: Mathematics for Technicians has been delivered or is being delivered concurrently with this unit, to give learners the necessary mathematical skills. They will also need a basic level of computer skills to use any computer-based software.

The four learning outcomes are linked and the delivery strategy should ensure that these links are maintained. The unit should be delivered through a combination of theory lessons and demonstrations, reinforced through practical work in an optic laboratory. It is important that learners have a thorough understanding of optical devices if they are to be able to recognise, handle and select relevant components. The ability to handle optic components and mount pieces on an optic work-top is an important outcome for this unit.

Delivery could use paper-based or computer-based exercises for example calculating the object position and height in a ray diagram for a convex lens. Most centres will probably start with the paper-based methods used to draw simple ray diagrams for example convex lens with various object positions. It is likely that centres will then move on to real components, using optical bread boarding techniques.

Learners should be given the opportunity to practise using the formulae identified in the unit content but they are not required to memorise them. However, they should be expected to select the most appropriate formulae to solve photonic problems. In addition, learners should have the confidence to transpose equations to meet their needs for example Snell's law. Clearly, the ability to transpose formulae is a mathematical skill and tutors will need to ensure that learners have appropriate support during both the delivery of this learning outcome and the unit as a whole.

Wherever possible, centres should enable learners to experience a range of equipment that reflect typical and current industry usage. It would not be appropriate to use only computer-based simulation packages. Tutors should ensure learners are aware of the safe use of optical sources and of their use in a laboratory/workshop and industrial setting.

For P1, examples of real and virtual images should be investigated, eg reflection in a bathroom mirror as an example of a virtual image; a real image can be projected onto a screen.

For P2, the determination of the critical angle of optic media will require the use of a light source, eg laser and a beam-steering assembly with the ability to measure angles accurately. Software simulations can be used as a less desirable alternative.

For P3, Snell's law should be studied using an analytical approach. The manipulation of the equation to determine the sine of an angle should be included. The case for the critical angle should be explained (ie sine $r = 1$). Learners should understand that when angles of incidence are greater than the critical angle, total internal reflection occurs. Examples should be discussed, eg looking upwards from underwater in a swimming pool and transmission of light in fibre-optic cables.

For P4, learners should investigate how the characteristics of lenses are used to fulfil different functions, eg reduction of aberrations in optical systems.

P5 should be delivered using a graphical method (ray diagrams) to explore real and virtual images formed by lenses. This exercise will allow learners to differentiate between a real and a virtual image and to see the change of image position as the object is brought in from 'infinity', ie beyond two times the focal length.

For P6, learners will need to gain a good grounding in the use and meaning of the thin lens equation. Graphical and analytical methods should be used to calculate object distances, image distances, magnification and focal length.

 

P7 allows learners to apply basic lens theory by designing a lens system, for example a simple telescope or microscope. Design principles, predicting the magnification and methods of testing a lens system should all be covered.

For P8, learners should understand that light is a transverse wave that consists of electric and magnetic fields and is an example of an electromagnetic wave that forms part of the electromagnetic spectrum. Learners should understand how light may be polarised. Learners should know what a dichroic material is and examples should be explored such as sunglasses with polarising filters.

P9 and P10 look at the principles of diffraction and interference, both constructive and destructive. Ray diagrams to explore path length differences, eg Fraunhofer diffraction and Young's double-slit interference pattern should be used to give learners a qualitative understanding of these phenomena. A laser could be used to demonstrate diffraction and interference. Where possible, learners should carry out experiments on Young's double-slit interference patterns and also diffraction gratings.

P11 is an introduction to the photon and how they are produced by different sources of light. Sources should include an incandescent source and the laser. For the incandescent source, learners will need to gain an understanding of Bohr's atomic model and how changes in the energy levels of the electrons in an atom lead to the production of photons. For lasers, learners will need to understand how light is produced by stimulated emission. Although it is not an assessment requirement, learners could consider the unique properties of laser light, eg coherence, monochromatic, narrow beam width.

For P12, situations that cannot be explained in terms of the wave theory of light include line emission spectra, which can be linked to Bohr's atomic model and the production of laser light.

M1 builds on the idea of polarisation in P8 to investigate how a series of polarising filters can be arranged and analysed to evaluate the transmitted wave's orientation and magnitude. This topic can be related to LCD TVs and linked to vector theory covered in other units. (Intensity or amplitude of the transmitted wave is sufficient for the analysis, where intensity is proportional to the amplitude squared.)

M2 builds on P9 and M3 builds on P10 to develop a quantitative understanding of the formation of diffraction and interference patterns using a single-slit to produce a diffraction pattern, followed by Young's double-slit experiment to produce an interference pattern. The patterns observed can be explained by applying the theory of constructive and destructive interference. The link between wavelength and fringe spacing should be predicted and measured. Ray diagrams should be used to derive the equations for the maxima (double-slit interference) and minima (single-slit diffraction) fringe separations. The use of small angle approximations is needed to simplify the final equations.

D1 could include a discussion of Galilean and Newtonian telescopes as well as the use of doublets and aspherics in modern imaging systems.

D2 explores the effect of different gratings on light and the resulting interference patterns as certain parameters are varied. Learners should carry out practical experiments to vary these parameters and observe the effects. Mathematical models of diffraction and interference should be used to give learners a thorough understanding of the observed effects.

Computer-based software packages for the analysis and simulation of optics could help to corroborate theoretical results; however tutors should ensure learners gain experience of carrying out practical laboratory work.

Centres are encouraged to relate theory to real engineering applications wherever possible. Industrial visits or work experience could be used to support learning and give learners an appreciation of the industrial applications of optical principles.

It is essential that learners are given full training in health and safety before using any photonics equipment. Learners should never use a laser source unsupervised. It is recommended that only low-power lasers are used during practicals and demonstrations. Any laboratory should be assessed by a laser safety officer in addition to any normal health and safety certification.

Note that the use of 'eg' in the content is to give an indication and illustration of the breadth and depth of the area or topic. As such, not all content that follows an 'eg' needs to be taught or assessed.

## Outline learning plan

The outline learning plan has been included in this unit as guidance and can be used in conjunction with the programme of suggested assignments.

The outline learning plan demonstrates one way of planning the delivery and assessment of this unit.

| Topic and suggested assignments/activities and assessment |
|---|
| *Whole-class teaching*:<br>• explain the term Photonics<br>• introduction to unit content, scheme of work and method of assessment<br>• introduction to photonics equipment<br>• outline health and safety procedures when using laser equipment |
| *Whole-class teaching*:<br>• explain terminology, symbols and units for velocity, frequency, wavelength and types of images<br>• use computer simulation of wave motion to show amplitude, frequency and wavelength<br>• explain the law of reflection and demonstrate the use of ray diagrams to produce real and virtual images<br>• explain and demonstrate critical angle and total internal reflection |
| *Individual learner activity:*<br>• apply the law of reflection |
| *Whole-class teaching:*<br>• explain the refraction of light at a dielectric boundary, refractive index of an optic media and velocity<br>• explain Snell's law<br>• discuss critical angle and total internal reflection |
| *Individual learner activity:*<br>• explain the refraction of light at a dielectric boundary<br>• calculate the refractive index of optic media<br>• determination of the critical angle by measurement<br>• determination of the angle of refraction and critical angle using Snell's law |

| Topic and suggested assignments/activities and assessment |
|---|
| **Preparation for and carrying out Assignment 1: Reflection and Refraction**<br>**Recap Safe Use of Lasers and Use of Photonics Equipment** (P1, P2 and P3) |
| *Whole-class teaching:*<br>• demonstrate types of lens and shapes<br>• explain the use of refraction by a lens and its focal length<br>• explain the application of lenses to correct visual impairments and the reduction of aberrations<br>• use a computer to simulate the eye as a lens and simulate visual impairments showing how these may be corrected using a lens |
| *Individual learner activity:*<br>• determine the focal length of a lens by practical measurement<br>• explain spherical and chromatic aberrations in lenses |
| *Whole-class teaching:*<br>• explain real and virtual images<br>• use computer simulations to explain ray diagrams applicable to both convex and concave lenses<br>• demonstrate the three ray method to determine the image height and distance for different object positions |
| *Individual learner activity:*<br>• draw real and virtual images using a convex lens<br>• use ray diagrams to determine the image position, orientation and height for a convex lens with different object positions |
| *Whole-class teaching:*<br>• use Gaussian thin lens equations and determine magnification factor |
| *Individual learner activity:*<br>• transposition of Gaussian lens equation<br>• use graphical and analytical methods to determine object distance, image distance, magnification and focal length for different types of lenses |
| *Whole-class teaching:*<br>• explain how a convex lens can be used as magnifying glass<br>• explain how lenses can be combined to produce a microscope and an astronomical telescope<br>• explain selection of telescope lens parameters for a given specification |
| *Individual learner activity:*<br>• determine the magnification factor of a simple magnifying glass<br>select suitable lenses to meet a given magnification factor for a telescope<br>• test a simple telescope to determine experimentally the lens spacing and magnification |
| **Preparation for and carrying out Assignment 2: Lenses** (P4, P5, P6, P7 and D1) |
| *Whole-class teaching:*<br>• explain light as an electromagnetic wave which is part of the electromagnetic spectrum<br>• explain light as a transverse wave consisting of electric and magnetic fields |

| Topic and suggested assignments/activities and assessment |
|---|
| *Individual learner activity:*<br>• investigation of the sections of the electromagnetic spectrum<br>• calculate frequency and wavelength for various electromagnetic waves within the electromagnetic spectrum |
| *Whole-class teaching:*<br>• demonstration using an overhead projector and Polaroid filters to show polarisation of light<br>• explain how light is polarised in terms of its electric and magnetic fields<br>• explain the types of polarisation and the relationship between the electric and magnetic fields<br>• explain the use of dichroic materials in polarising filters used in sunglasses and liquid crystal displays<br>• use computer simulation to demonstrate the difference between polarised light and non-polarised light<br>• use computer simulation to show polarised light and the use of polarising filters |
| *Individual learner activity:*<br>• outline safety procedures when using class 2 lasers<br>• carry out practical measurements of light intensity after a polarising filter |
| *Whole-class teaching:*<br>• explain Malus' law and light as a vector quantity<br>• explain Malus' law applied to a series of polarising filters |
| *Individual learner activity:*<br>• calculate light intensity using Malus' law after a series of polarising filters are set at various angles<br>• practical measurement of light intensity after a series of polarising filters are set at various angles |
| **Preparation for and carrying out part of Assignment 3: Polarisation** (P8 and M1) |
| *Whole-class teaching:*<br>• demonstrate diffraction patterns<br>• explain diffraction of light using Huygens' principle<br>• demonstrate computer simulated Fraunhofer single-slit diffraction patterns<br>• explain diffraction using ray diagrams and formula for minima separation (using small angle approximation)<br>• explain the use of diffraction gratings |
| *Individual learner activity:*<br>• use computer simulation to model Huygens' principle of diffraction using wave fronts<br>• use computer simulation to model Fraunhofer single-slit diffraction patterns<br>• investigate the effect of varying the slit size and wavelength of light on a Fraunhofer single-slit diffraction pattern<br>• use small angle approximation to determine diffraction parameters, such as minima separation and difference in path length |

| Topic and suggested assignments/activities and assessment |
|---|
| *Whole-class teaching:*<br>• explain and demonstrate the principles of wave superposition<br>• explain coherence of light sources and demonstrate constructive and destructive interference patterns<br>• demonstrate computer simulated Young' s double-slit interference pattern<br>• demonstrate coherence and interference fringes using a Michelson Interferometer<br>• explain interference using ray diagrams and formula for maxima separation using small angle approximation |
| *Individual learner activity:*<br>• use computer simulation to model principles of wave superposition and coherence of light sources<br>• use computer simulation to model constructive and destructive interference<br>• investigate the effects on Young's double-slit interference pattern of varying the slit separation, distance to screen and wavelength of light<br>• use computer simulation to investigate coherence and fringe separation<br>• use small angle approximation to determine interference parameters, such as maxima separation and difference in path length |
| **Preparation for and carrying out part of Assignment 4: Diffraction and Interference** (P9, P10, M2 and M3) |
| *Whole-class teaching:*<br>• explain the production of light, natural and artificial<br>• explain Bohr's atomic model, energy levels and the production of photons |
| *Individual learner activity:*<br>• use a worksheet to identify and list sources of light (natural, artificial and reflected)<br>• demonstrate incandescent lamps and lasers light<br>• use a computer simulation of Bohr's atomic model to show the emission of photons with changes of electron energy levels |
| *Whole-class teaching:*<br>• explain the acronym 'LASER' and the production of photons by stimulated emission<br>• explain the characteristics of laser light<br>• recap Bohr's atomic model and production of photons<br>• explain line emission spectra for sodium and hydrogen lamps<br>• explain the construction of a simple ruby laser and the production of laser light |
| *Individual learner activity:*<br>• use computer simulations to model the production of photons by stimulated emission<br>• use computer simulation to model the characteristics of laser light (coherence, monochromatic and narrow bandwidth)<br>• use a direct vision spectroscope to view line emission spectra produced by sodium and hydrogen lamps<br>• use computer simulations to model line emission spectra produced for different gases<br>• use computer simulations of a simple ruby laser to model the production of laser light |
| **Preparation for and carrying out Assignment 5: Photons** (P11 and P12) |

## Assessment

Much of the evidence for the pass criteria can be generated through practical experimentation with real components.

It is likely that at least five assessment instruments will be required for this unit. If practical work and tests are also used then the total number of pieces of assessed work could be more than this. This should be considered carefully so that it does not place an unduly high assessment burden on learners or the tutor.

Wherever possible, practical work should lead to a final product that can be handed in for assessment at the end of the session without a further need for report writing. This will help ensure authenticity of evidence and also keep the assessment activities short, sharp and relevant.

Centres should combine any tests with practical hands-on experience of real optic systems and components. This could be achieved by learners building prototype optic systems on breadboards according to values they determined theoretically. This will allow learners to build the optic system and check theory against actual results through measurement. Centres need to ensure that sufficient product evidence is available for the optic systems being used/developed and the formulae selected/used to determine the required values.

For P1, learners could produce ray diagrams to show the laws of reflection being applied to different situations. These diagrams should show the formation of real and virtual images.

For P2, learners could produce a report of experiments carried out to determine the refractive index and critical angle of optic media.

For P3, learners should apply the laws of refraction to different situations and show all relevant calculations.

For P4, learners should explain the functions of different types of lens and how these are used in different applications for example reduction of aberrations.

For P5, learners could produce ray diagrams to graphically determine the image position, orientation and height for a convex lens with three different object positions (relative to focal point).

For P6, learners could show calculations using the thin lens equation to find object distances, image distances and focal length for convex and concave lenses. Calculations should include an optic system that uses a minimum of two lenses. Calculations must also include the determination of magnification.

For P7, learners should be given a specification for an optic system consisting of at least two lenses. Learners should design, build and test the system. Evidence could be in the form of a report that discusses whether the tests show that the system meets the required specification and could include tutor observation of the tests or photos/video of testing in action.

For P8, learners should explain how light is polarised in terms of its electric and magnetic fields.

The evidence for P9 and P10 will be descriptive and learners need to provide a basic explanation of the principles and concepts of light as a wave to explain diffraction and interference. This should include the ideas of interference, both constructive and destructive. Use of ray diagrams to explore path length differences, for example Fraunhofer diffraction and Young's double-slit interference pattern, should be used to give a qualitative understanding of these phenomena.

For P11, learners should explain how light is produced in sources such as the sun by changes to the energy levels of electrons. Reference to Bohr's atomic model should be included. Learners should also explain how light is produced by a laser in terms of the photon.

For P12, learners should explain two different situations that cannot be accounted for by applying the wave theory of light, for example line emission spectra and the production of laser light.

For M1, learners should provide evidence of being able to use Malus' law by carrying out appropriate calculations.

For M2 and M3, learners should build on P9 and P10 by giving a mathematical explanation of diffraction and interference patterns. Learners should apply the theory of constructive and destructive interference to Young's double-slit experiment and the link between wavelength and fringe spacing should be derived using representative ray diagrams. Learners should also be able to derive equations for the maxima (double-slit interference) and minima (single-slit diffraction) fringe separations. Use of small angle approximations is needed to simplify the final equations.

For D1, learners could produce a report that evaluates the advantages and disadvantages of multi-lens systems. This evaluation should be based on the theory that has been covered within the unit and observations made through practical experiments. Examples may include an evaluation of Galilean and Newtonian telescopes as well as the use of doublets and aspherics in modern imaging systems.

For D2, learners should predict the effect of different gratings on light and the resulting interference patterns as certain parameters are varied. This may follow practical work where learners have had a chance to vary these parameters. The analysis should draw on mathematical models of diffraction and interference and show a thorough understanding of the observed effects.

## Programme of suggested assignments

The table below shows a programme of suggested assignments that cover the pass, merit and distinction criteria in the assessment and grading grid. This is for guidance and it is recommended that centres either write their own assignments or adapt any Edexcel assignments to meet local needs and resources.

| Criteria covered | Assignment title | Scenario | Assessment method |
|---|---|---|---|
| P1, P2 and P3 | Reflection and Refraction | A mixed activity consisting of three tasks. The first being to describe, using ray diagrams, the laws of reflection with examples of real and virtual images.<br>The second a practical activity requiring learners to determine the refractive index and critical angle of optic media by experimentation.<br>The third requiring learners to use Snell's law to determine angles of refraction and the critical angle for total internal reflection for optic media. | A report containing written responses to the descriptive task, tabulated results, graphs for the practical activity and calculations for the theoretical analysis using Snell's law.<br>A brief conclusion on the results obtained should be included for the practical activity, together with an observation sheet signed by the tutor. |
| P4, P5, P6, P7 and D1 | Lenses | A mixed activity consisting of five tasks. The first being to explain the function, parameters and applications of different types of lenses.<br>The second a practical activity requiring learners to determine graphically the image orientation and height for a convex lens with three object positions.<br>The third a practical activity requiring learners to use Gaussian lens formula to determine object distance, image distance, focal length and magnification factor for a convex lens.<br>The fourth a practical activity requiring learners to design and test a multi-lens system to meet a given specification for a telescope manufacturing company.<br>The fifth activity requires learners to evaluate the benefits and disadvantages of a multi-lens system. | A report containing written responses to the descriptive task, ray diagrams, tabulated results for the practical activity, calculations and tabulated results for the use of Gaussian lens formula.<br>In addition, a report for the design and testing of a multi-lens system with diagrams, calculations, tabulated results for theoretical and measured parameters, together with an observation sheet for this practical activity signed by the tutor.<br>The inclusion of an evaluation of the benefits and disadvantages in the report would cover the distinction criteria. |

| Criteria covered | Assignment title | Scenario | Assessment method |
|---|---|---|---|
| P8, M1 | Polarisation | A mixed activity consisting of two separate sections covering the three topics.<br><br>The first section being Polarisation which consists of two tasks. The first task requires learners to explain the polarisation of light with respect to the electric and magnetic fields.<br><br>The second task is a mixed activity with both practical and theoretical content. The first activity requires learners to measure the light intensity through a series of polarising filters set at different angles. The second requires learners to determine using Malus' law the light intensity through the series of polarising filters used in the practical activity. | A report with appropriate diagrams containing written responses to the descriptive task.<br><br>A written report for the second task should include tabulated results for the practical activity together with calculations and tabulated results for the use of Malus' law. A brief conclusion comparing the measured and theoretical results should be included, together with an observation sheet for the practical activity signed by the tutor. |
| P9, P10, M2 and M3 | Diffraction and Interference | The second section covers both diffraction and interference and consists of three tasks. The first task requires learners to explain the principles of diffraction using a Fraunhofer single-slit model and Young's double-slit interference model using the concept of light as a wave.<br><br>The second requiring learners to derive the equations from theoretical principles using ray diagrams and apply these equations to determine parameters for both single-slit diffraction and double-slit interference.<br><br>The third is a practical activity requiring learners to investigate and analyse the effect on different gratings on light and the interference patterns produced. | A report with appropriate diagrams containing written responses to the descriptive task, together with ray diagrams, equations and calculations for the theoretical application.<br><br>A written report for the practical activity showing tabulated results for changing grating parameters, together with a mathematical analysis of the observed effects. An observation sheet for the practical activity signed by the tutor. |
| P11, P12 | Photons | An activity which consists of two tasks. The first task requiring learners to explain how photons are produced by various light sources.<br><br>The second task requiring learners to use particle theory to explain two difference situations that cannot be accounted for by applying wave theory. | A written report containing a labelled diagram of Bohr's atomic model to explain the production of photons by changes of electron energy levels for various sources of light. In addition, to explain the production of photons by stimulated emission for the production of laser light and photons as part of line emission spectra. |

## Links to National Occupational Standards, other BTEC units, other BTEC qualifications and other relevant units and qualifications

This unit forms part of the BTEC Engineering sector suite. This unit has particular links with:

| Level 1 | Level 2 | Level 3 |
|---|---|---|
| | | Mathematics for Engineering Technicians |

This unit covers some of the knowledge and understanding associated with the SEMTA Level 3 National Occupational Standards in Mechanical Manufacturing Engineering, particularly:

- *Unit 165: Building Optical Systems*
- *Unit 168: Following Clean Room/Clean Work Area Protocols*.

## Essential resources

It is essential that learners have access to a well-equipped photonics laboratory with up-to-date resources and instruments such as light sources, lasers, photo-diodes, lenses, beam-splitters, prisms, mirrors, optic breadboards, associated mounting and alignment equipment, digital and analogue multimeters, function generators and oscilloscopes.

With the increased use of computer-based methods for simulation, centres are strongly advised to consider the provision of suitable hardware and software.

### Employer engagement and vocational contexts

Much of the work for this unit can be set in the context of learners' work placements or be based on case studies of local employers. Further information on employer engagement is available from the organisations listed below:

- Work Experience/Workplace learning frameworks – Centre for Education and Industry (CEI -University of Warwick) – www.warwick.ac.uk/wie/cei/
- Learning and Skills Network – www.vocationallearning.org.uk
- Network for Science, Technology, Engineering and Maths Network Ambassadors Scheme – www.stemnet.org.uk
- National Education and Business Partnership Network – http://www.iebe.org.uk/
- Local, regional Business links – www.businesslink.gov.uk
- Work-based learning guidance – www.aimhighersw.ac.uk/wbl.htm
- Integrating Work Based Learning into Higher Education: A Guide to Good Practice – uvac.ac.uk/publications

## Indicative reading for learners

### Textbooks

Born M and Wolf E – *Principles of Optics* (Cambridge University Press, 1999) ISBN 9780521642224

Fischer R F – *Optical System Design* (McGraw-Hill Professional; 2nd Edition, 1 March 2008)
ISBN 9780071472487

Hecht E – *Optics* (Pearson Education, 2003) ISBN 9780321188786

Kingslake R – *Lens Design Fundamentals* (Academic Press, 2nd Edition, 25 January 2010)
ISBN 9780123743015

Smith W J – *Modern Optical Engineering: The Design of Optical Systems* (McGraw-Hill Professional; 4th Edition, 1 January 2008) ISBN 9780071476874

 

## Delivery of personal, learning and thinking skills

The table below identifies the opportunities for personal, learning and thinking skills (PLTS) that have been included within the pass assessment criteria of this unit.

| Skill | When learners are … |
|---|---|
| **Independent enquirers** | solving problems by applying the laws of reflection and refraction to different situations<br>solving problems by calculating the refractive index and critical angle of optic media<br>identifying questions to answer and carrying out research by testing a self-designed lens system<br>exploring issues from different perspectives ie wave versus particle nature of light |
| **Creative thinkers** | exploring possibilities and trying out alternatives when testing a self-designed lens system |
| **Reflective learners** | |
| **Team workers** | collaborating with others to apply the laws of reflection and refraction to different situations and work towards common goals<br>achieving results by determining the refractive index and critical angle of optic media in practical work<br>working in a team to reach common goals by determining object distances, image distances, magnification and focal length for lenses in practical work<br>collaborating with others showing fairness and consideration to reach agreements when testing a self-designed lens system |
| **Self-managers** | using initiative to organise time and resources and demonstrate perseverance when testing a self-designed lens system. |
| **Effective participators** | |

Although PLTS are identified within this unit as an inherent part of the assessment criteria, there are further opportunities to develop a range of PLTS through various approaches to teaching and learning.

| Skill | When learners are … |
|---|---|
| **Independent enquirers** | planning and carrying out research using Malus' law to determine light intensity of a series of polarising filters<br>exploring diffraction patterns using a single-slit and Young's double-slit experiments<br>considering the different applications of multi-lens systems to evaluate advantages and disadvantages<br>exploring the effects on interference patterns when varying parameters for diffraction gratings in practical work |
| **Creative thinkers** | |
| **Reflective learners** | |

| Skill | When learners are … |
|---|---|
| **Team workers** | working towards common goals by using Malus' law to determine light intensity of a series of polarising filters<br>reaching agreements and showing consideration to others when observing diffraction patterns using a single-slit and Young's double-slit experiments<br>collaborating with others to analyse the effects when varying parameters on a diffraction grating. |
| **Self-managers** | |
| **Effective participators** | |

## Functional Skills – Level 2

| Skill | When learners are … |
|---|---|
| **ICT – Use ICT systems** | |
| Select, interact with and use ICT systems independently for a complex task to meet a variety of needs | producing a report for the self-designed lens system |
| **Use ICT to effectively plan work and evaluate the effectiveness of the ICT system they have used** | |
| Manage information storage to enable efficient retrieval | producing a report for the self-designed lens system |
| Follow and understand the need for safety and security practices | producing a report for the self-designed lens system |
| Troubleshoot | |
| **ICT – Find and select information** | |
| Select and use a variety of sources of information independently for a complex task | |
| Access, search for, select and use ICT-based information and evaluate its fitness for purpose | |
| **ICT – Develop, present and communicate information** | |
| Enter, develop and format information independently to suit its meaning and purpose including:<br>• text and tables<br>• images<br>• numbers<br>• records | producing a report for the self-designed lens system |
| Bring together information to suit content and purpose | producing a report for the self-designed lens system |
| Present information in ways that are fit for purpose and audience | producing a report for the self-designed lens system |
| Evaluate the selection and use of ICT tools and facilities used to present information | testing a self-designed lens system using simulation software |
| Select and use ICT to communicate and exchange information safely, responsibly and effectively including storage of messages and contact lists | |

| Skill | When learners are … |
|---|---|
| **Mathematics** | |
| Understand routine and non-routine problems in a wide range of familiar and unfamiliar contexts and situations | solving problems for different situations using photonic equations |
| Identify the situation or problem and the mathematical methods needed to tackle it | recognising the relevant parameters and formulae to be applied to given situations |
| Select and apply a range of skills to find solutions | selecting and applying photonic equations to solve given problems |
| Use appropriate checking procedures and evaluate their effectiveness at each stage | checking the results of calculations to ensure they are correct |
| Interpret and communicate solutions to practical problems in familiar and unfamiliar routine contexts and situations | |
| Draw conclusions and provide mathematical justifications | |
| **English** | |
| Speaking and listening – make a range of contributions to discussions and make effective presentations in a wide range of contexts | speaking with and listening to peers and supervisors to establish an understanding of photonic principles and applications in engineering |
| Reading – compare, select, read and understand texts and use them to gather information, ideas, arguments and opinions | selecting, reading and using appropriate information sources for different situations regarding photonics |
| Writing – write documents, including extended writing pieces, communicating information, ideas and opinions, effectively and persuasively | taking notes and solving problems to communicate accurate solutions effectively |

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