Unit 127: Further Principles of Photonics

NQF Level 3: BTEC National

Guided learning hours: 60

Unit abstract

The modern world in which we now live has changed remarkably over recent years. Many aspects of our daily lives use devices that contain photonic devices - devices which generate manipulate and detect light.

This unit builds on the understanding of photonics that learners will have gained from *Unit 126: Principles of Photonics*. The unit will extend learners knowledge to cover more advanced topics on reflection, transmission, refraction and interference as well as their applications in industry. The unit starts by looking at photometry and the basic parameters of light. Learners will analyse complex ray diagrams, investigate the properties of polarised light and study and apply interference by looking at interferometry. Learners will need to solve transmission and refraction formulae and calculate the Brewster angle. Learners will have the chance to construct, measure and interpret an interferometer.

Learning outcomes

On completion of this unit a learner should:

1. Understand the theory of photometry and radiometry
2. Understand the principles of transmission and reflection of light at a boundary
3. Understand the interference of light and its applications
4. Understand the means of generating, transmitting, manipulating and detecting coherent light

Unit content

1 Understand the theory of photometry and radiometry

Radiometry and photometry: the solid angle steradian (sr); power per unit solid angle; perception of light by humans leading to the separation of a radiation source into luminous power and irradiated power; luminous power theory of lumens; lumens per square meter ie lux; lumens per solid angle (ie lumens/sr = candela); radiated power theory; irradiated power per unit area (ie irradiance = W/m^2); irradiated power per solid angle (ie watts/sr); colour perception; Newton's colour circle; hue, saturation and brightness

2 Understand the principles of transmission and reflection of light at a boundary

Transmission and reflection: Review of the basic theory, E and H waves, polarisation, transmission, refraction and reflection of light at a boundary, transmissivity and reflectivity of materials with differing refractive indices n1 and n2 where reflection coefficient r is given by the Fresnel equations:

$$r_{||} = \frac{\tan(\theta_i - \theta_t)}{\tan(\theta_i + \theta_t)} \qquad r_{\perp} = -\frac{\sin(\theta_i - \theta_t)}{\sin(\theta_i + \theta_t)}$$

The corresponding transmission coefficients are:

$$t_{||} = \frac{2\sin\theta_t \cos\theta_i}{\sin(\theta_i + \theta_t)\cos(\theta_i - \theta_t)} \qquad t_{\perp} = \frac{2\sin\theta_t \cos\theta_i}{\sin(\theta_i + \theta_t)}$$

Where θi = incident angle, θt = transmission angle; where I- and ||is the polarization of the incident light with the E field perpendicular and parallel respectively to the plane of incidence; plots of these curves to determine the polarizing or Brewster angle

3 Understand the interference of light and its applications

Interference: constructive and destructive interference of waves; path length; ray diagrams; boundary phase change conditions for 180° and 0° depending on relative refractive index; study of thin films; observe and interpret the results eg soap film, Newton's rings experiment, interference filters d=λ/2ncosß, quarter wavelength lens anti-reflection coatings, investigate the application of a thin film eg infra-red lens coatings to reduce losses, calculate the gain in transmission due to coatings as percentages where intensity is the amplitude squared, reflectivity or reflection coefficient r is the square of reflectance R ie $r = R^2 = ((n1-n2)/(n1+n2))^2$

4 Understand the principle means of generating, transmitting and manipulating coherent light

Generation of coherent light: review of light properties and introduce coherence, coherence length, monochromaticity, polarisation; characteristics of a laser/photo-diode, lasing action, stimulated emission; laser beam characteristics

Manipulation of a coherent light source: safely construct a series of optical components to manipulate a beam of coherent light, handling, assembling, mounting and aligning optical components, photo-diodes, lenses, beam steering, mirrors, polarising filters, beamsplitters, gratings, beam expanders, circular aperture, optical fibres as waveguides, total internal reflection, light detectors, power meters; use these components to build and analyse a complex optical system eg Michelson Interferometer, investigation of the Brewster angle, or similar complexity, apply interference theory to interferometry eg construct a Michelson interferometer or Mach-Zehnder interferometer to measure precise distance $d=m\lambda/2$ where m=number of fringes; Investigate an application of interferometry. Alternatively launch a coherent light source into a fibre-optic cable (waveguide), investigate fibre parameters eg loss per km, units of dB, construct a fibre system and take measurements of loss, power ratios

Grading grid

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

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 the learner is able to:**	**To achieve a distinction grade the evidence must show that the learner is able to:**
P1 discuss the nature of photometry and how is relates to radiometry P2 describe how light of differing polarisation is reflected at a boundary P3 determine the reflection coefficient for light reflecting at a boundary of differing refractive index P4 discuss the nature of a thin film using ray diagrams and phase changes to determine the resultant transmitted and reflected rays P5 discuss the benefits and applications of coating lenses P6 discuss the nature of light produced by a laser/photo-diode and what aspects make it suitable for interferometry P7 build or study a complex optical system containing at least 5 optical components and describe its operation P8 discuss the use of fibre optic cables and their operation.	M1 analyse a multi-layered coating and discuss its operation quantitatively M2 determine by experiment or analysis the Brewster angle for an incident light wave on a material of higher refractive index M3 build or analyse the operation of an interferometer or fibre optic systems and discuss a possible application.	D1 study the effect of multiple lens coatings and discuss the benefits relating to the lens type itself, the coating used and its intended use D2 discuss in detail the operation of an interferometer discussing the observed interference patterns and the components and parameters that affect the patterns produced.

Essential guidance for tutors

Delivery

It is important that both *Unit 4: Mathematics for Technicians* and *Unit 126: Principles of Photonics* have been delivered or are being delivered concurrently with this unit to give learners the necessary prerequisite knowledge.

Each of the four learning outcomes of this unit are linked and the delivery strategy should ensure that these links are maintained. Learning outcome 1 is the most likely starting point for delivery, as it will establish much of the underpinning knowledge and skills required for the remaining learning outcomes. The unit could be delivered through a combination of theory lessons and demonstrations, reinforced through practical work in an electrical science laboratory/workshop. It is important that learners have a thorough understanding of lenses if they are to be able to recognise, handle and select relevant components.

Learners should be given opportunities to practise using the formulae identified in the unit content but are not required to memorise them. However, they should be able to select the most appropriate formulae to determine the required values. In addition, learners should have the confidence to transpose equations to meet their needs (eg use Snell’s law). Clearly, the ability to transpose formulae is a mathematical skill and tutors will need to ensure that appropriate support is provided 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 reflects typical and current industry usage. It would not be appropriate to only use computer-based simulation packages. Tutors should ensure the safe use of optical sources and an awareness of their use in a laboratory/workshop and industrial setting.

The use of computer-based software packages for analysis and simulation of optics together with practical laboratory work will help to corroborate theoretical results.

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

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.

Assessment

Much of the evidence for the pass criteria can be achieved by practical experimentation with real components and/or computer-based software packages, where appropriate.

During practical experiments time should be spent to ensure learners know how to safely handle optical components. Extra emphasis should be placed on the safe use of photodiodes. Only low power diodes should be used (<1mw) as well as following good laboratory practice.

It is likely that at least four 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 even more than this. This should be carefully considered 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 further need for report writing. This will help control authenticity of evidence and also keep the assessment activities short, sharp and relevant.

The nature of photometry should be explored initially to distinguish the perception of visible radiation by humans and how this relates to radiometry. A discussion of this topic makes up the P1 assessment. Use of SI fundamentals relating to energy and the associated parameters for light should be included.

P2 should recall the E H waves studied in *Unit 126: Principles of Photonics* and learners will need to show an understanding of the differing reflection and transmission characteristics at a boundary, depending on the kind of polarisation of the incident light. Use of ray diagrams will help in the explanation. This could be combined with P3 to apply the Fresnel equations to determine the reflection and transmission coefficients. A more advanced analysis would include M2 to determine the Brewster angle and incident ray. A plot of reflected amplitude vs incident angle for parallel and perpendicular polarisation should be drawn ideally from experimental measurements.

P4 and P5 look at the theory of thin films and lens coatings. Thin films can be observed (eg oil on water) and ray diagrams used to explain the observations. Reference to spectacles and cameras could be useful. Ray diagrams can show graphically the effect of a lens coating. Particular attention needs to be draw to the thickness of a coating and the wavelength as well as any phase changes the reflected ray undergoes. Use of constructive and destructive interference to show the resultant reflected and transmitted wave. The coating materials and their refractive index should be included.

The evidence for P6 will be descriptive and requires learners to provide basic explanations of the principles and concepts of a laser and emissions causing a coherent set of photons to be produced. Some explanation of why laser light is special should be given (monochromatic, coherent, narrow beam etc).

P7 should ideally be a practical-based exercise which looks at the operation of an optical system, eg to measure refraction. This should draw on several topics learned previously. Discussion of the building of the system and setting up and testing should be included as well as the measurements made. Use of industry standard mounts and components is recommended.

P8 should be a brief introduction to the use of fibre optic cables. For centres wanting to provide this as an alternative to interferometry, M3 can be used to develop an experimental assessment for learners wishing to specialise in fibre optics and their application.

M1 relates to the use of multi-layered coatings on a surface. This can be an extension of P5 and used more complex ray diagrams to show the effects. The need for multi-layer coatings and an example of its application should be included.

M2 is best completed by experiment but can be done by analysis and use of spreadsheets to process results. It can be used as an extension to P3 and leads to the determining by experiment or calculation of the Brewster angle. Some discussion of what this angle represents should also be included.

M3 builds on experience gained in P7 and should ideally be a practical based exercise which looks at the operation of an interferometer. This should draw on several topics learned previously. Use of industry standard mounts and components is recommended. An alternative to interferometry is the investigation of fibre optics. This should include how to launch a light source into a fibre, measurements of losses and a look at fibre types.

D1 relates to the use of multi-layered coatings on a surface. This can be an extension of M1. The need for multi-layer coatings and an example of its application should be included. The coating materials should be included as well as the ideal refractive index of a coating. An experiment or analysis should be included to demonstrate the effect of coating a lens. Evidence such as transmission vs frequency plots should be drawn and explained.

D2 builds on experience gained in M3 and should ideally be a practical-based exercise which looks at the construction and operation of an interferometer. This should draw on several topics learned previously. Discussion of the building of the system and setting up and testing should be included as well as the measurements made. Use of industry standard mounts and components is recommended. The leaner should undertake a wider study of the use of interferometry eg metrology, inspection techniques etc.

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

This unit relates strongly to *Unit 4: Mathematics for Technicians* and also *Unit 126: Principle of Photonics*. It would be useful to study the maths unit concurrently as this unit has a reliance on strong mathematical skills involving problem solving and graphical plots. Data from experiments within this unit can be manipulated mathematically and so provide evidence for both units.

The unit should be delivered to meet the underpinning knowledge in the Photonics Engineering pathway in the Mechanical Manufacturing Engineering National Occupational Standards.

Essential resources

It is essential that learners have access to a well-equipped optics laboratory with up-to-date resources and instruments such as lenses, class II laser diodes (<1mW), 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.

Indicative reading for learners

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

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

Kingslake, R — *Lens Design Fundamentals* (Academic Press, 1978) ISBN 9780124086500

Kingslake, R — *Optical Systems Design* (Academic Press, 1983) ISBN 9780124086609

O'Shea, DC — *Elements of Modern Optical Design* (John Wiley & Sons, 1985) ISBN 9780471077961

Smith, W — *Modern Optical Engineering: The Design of Optical Systems* (McGraw Hill, 2000) ISBN 9780071363600

Key skills

Achievement of key skills is not a requirement of this qualification but it is encouraged. Suggestions of opportunities for the generation of Level 3 key skills evidence are given here. Staff should check that learners have produced all the evidence required by part B of the key skills specifications when assessing this evidence. Learners may need to develop additional evidence elsewhere to fully meet the requirements of the key skills specifications.

Application of number Level 3	
When learners are:	**They should be able to develop the following key skills evidence:**
• planning and presenting their descriptions and explanations when comparing practical and theoretical information • solving problems and interpreting results in any of the four learning outcomes using conventional methods and/or computer-based software packages.	N3.1 Plan an activity and get relevant information from relevant sources. N3.2 Use this information to carry out multi-stage calculations to do with: a amounts or sizes b scales or proportion c handling statistics d using formulae. N3.3 Interpret the results of your calculations, present your findings and justify your methods.
Information and communication technology Level 3	
When learners are:	**They should be able to develop the following key skills evidence:**
• researching and using a variety of different sources for product/component information • developing and presenting information on electrical and electronic principles to meet the unit criteria/content eg description of capacitors, magnetic field etc.	ICT3.1 Search for information, using different sources, and multiple search criteria in at least one case. ICT3.2 Enter and develop the information and derive new information. ICT3.3 Present combined information such as text with image, text with number, image with number.

Problem solving Level 3	
When learners are:	**They should be able to develop the following key skills evidence:**
• solving problems in DC and AC circuits using conventional methods and computer-based software analysis and simulation packages.	PS3.1 Explore a problem and identify different ways of tackling it. PS3.2 Plan and implement at least one way of solving the problem. PS3.3 Check if the problem has been solved and review your approach to problem solving.