GCE A LEVEL

eduqas
Part of WJEC

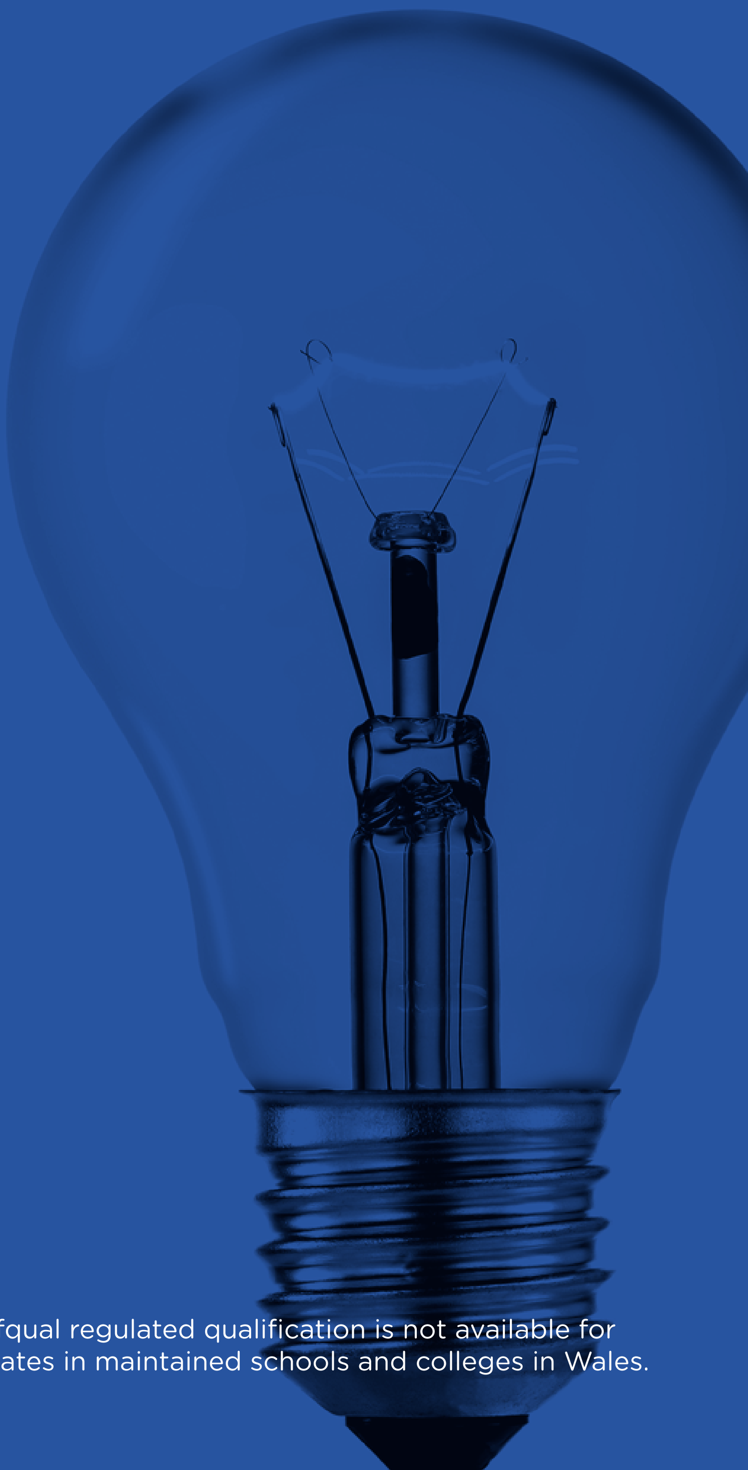
WJEC Eduqas GCE A LEVEL in PHYSICS

ACCREDITED BY OFQUAL

SPECIFICATION

Teaching from 2015
For award from 2017

Version 2 January 2019



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This Ofqual regulated qualification is not available for candidates in maintained schools and colleges in Wales.

SUMMARY OF AMENDMENTS

Version	Description	Page number
2	‘Arrangements for non-exam assessment' section has been amended to clarify requirements.	60 – 62
	'Making entries' section has been amended to clarify resit rules and carry forward of NEA endorsement grade.	63

WJEC Eduqas GCE A LEVEL in PHYSICS

For teaching from 2015
For award from 2017

A LEVEL PHYSICS

SUMMARY OF ASSESSMENT

Component 1: Newtonian Physics
Written examination : **2 hours 15 minutes (100 marks)**
31.25% of qualification

Section A: 80 marks
A mix of short answer and extended answer questions with some set in a practical context.

Section B: 20 marks - one comprehension question.

Component 2: Electricity and the Universe
Written examination : **2 hours (100 marks)**
31.25% of qualification

A mix of short answer and extended answer questions with some set in a practical context.

Component 3: Light, Nuclei and Options
Written examination : **2 hours 15 minutes (120 marks)**
37.5% of qualification

Section A: 100 marks
A mix of short answer and extended answer questions with some set in a practical context.

Section B: 20 marks - choice of 1 out of 4 options: Alternating Currents, Medical Physics, The Physics of Sports, Energy and the Environment.

Practical Endorsement
Non-exam assessment

Assessment of practical competency.
Reported separately and not contributing to final grade.

This linear qualification will be available in the months of May and June of each year. It will be awarded for the first time in Summer 2017.

Qualification Accreditation Number: 601/5522/X

A LEVEL PHYSICS

1 INTRODUCTION

1.1 Aims and objectives

The WJEC Eduqas A level in Physics provides a broad, coherent, satisfying and worthwhile course of study. It encourages learners to develop confidence in, and a positive attitude towards, physics and to recognise its importance in their own lives and to society.

Studying this A level in Physics encourages learners to:

- develop essential knowledge and understanding of different areas of the subject and how they relate to each other
- develop and demonstrate a deep appreciation of the skills, knowledge and understanding of scientific methods
- develop competence and confidence in a variety of practical, mathematical and problem solving skills
- develop their interest in and enthusiasm for the subject, including developing an interest in further study and careers associated with the subject
- understand how society makes decisions about scientific issues and how the sciences contribute to the success of the economy and society.

This specification is intended to promote a variety of styles of teaching and learning so that the course is enjoyable for all participants. Learners will be introduced to a wide range of physics principles which will allow them to enjoy a positive learning experience whilst gaining an understanding of how nature operates at both microscopic and macroscopic scales. The optional topics have been developed to allow learners to gain an insight into topics in the world of work which use physics on a daily basis.

Practical work is an intrinsic part of physics, and is highly valued by higher education. It is imperative that practical skills are developed throughout this course and that an investigatory approach is promoted.

1.2 Prior learning and progression

Any requirements set for entry to a course following this specification are at the discretion of centres. It is reasonable to assume that many learners will have achieved qualifications equivalent to Level 2 at KS4. Skills in Numeracy/Mathematics, Literacy/English and Information Communication Technology will provide a good basis for progression to this Level 3 qualification.

This specification builds on the skills, knowledge and understanding set out in the GCSE criteria/content for science. Some learners will have already gained knowledge, understanding, and skills through their study of physics at GCSE or AS.

Mathematical requirements are specified in the subject criteria and repeated in Appendix C of this specification.

This specification provides a suitable foundation for the study of physics or a related area through a range of higher education courses, progression to the next level of vocational qualifications or employment. In addition, the specification provides a coherent, satisfying and worthwhile course of study for learners who do not progress to further study in this subject.

This specification is not age specific and, as such, provides opportunities for learners to extend their life-long learning.

1.3 Equality and fair assessment

This specification may be followed by any learner, irrespective of gender, ethnic, religious or cultural background. It has been designed to avoid, where possible, features that could, without justification, make it more difficult for a learner to achieve because they have a particular protected characteristic.

The protected characteristics under the Equality Act 2010 are age, disability, gender reassignment, pregnancy and maternity, race, religion or belief, sex and sexual orientation.

The specification has been discussed with groups who represent the interests of a diverse range of learners, and the specification will be kept under review.

Reasonable adjustments are made for certain learners in order to enable them to access the assessments (e.g. candidates are allowed access to a Sign Language Interpreter, using British Sign Language). Information on reasonable adjustments is found in the following document from the Joint Council for Qualifications (JCQ): *Access Arrangements and Reasonable Adjustments: General and Vocational Qualifications.*

This document is available on the JCQ website (www.jcq.org.uk). As a consequence of provision for reasonable adjustments, very few learners will have a complete barrier to any part of the assessment.

2 SUBJECT CONTENT

This section outlines the knowledge, understanding and skills to be developed by learners studying A level Physics.

Learners should be prepared to apply the knowledge, understanding and skills specified in a range of theoretical, practical, industrial and environmental contexts. Learners' understanding of the connections between the different elements of the subject and their holistic understanding of the subject is a requirement of all A level specifications. In practice, this means that in each component learners will be required to demonstrate their ability to draw together different areas of knowledge and understanding from across the full course of study.

Practical work is an intrinsic part of this specification. It is vitally important in developing a conceptual understanding of many topics and it enhances the experience and enjoyment of physics. The practical skills developed are also fundamentally important to learners going on to further study in physics and related subjects, and are transferable to many careers.

This section includes **specified practical work** that **must** be undertaken by learners in order that they are suitably prepared for the written examinations. The completion of this practical work will develop the practical skills listed in Appendix A. The requirements of the Practical Endorsement are detailed in Section 3.2. Appendix B lists the practical technique requirements with exemplification in the context of A level Physics.

Appendix C lists the mathematical requirements with exemplification in the context of A level Physics.

All content in the specification should be introduced in such a way that it develops learners' ability to:

- use theories, models and ideas to develop scientific explanations
- use knowledge and understanding to pose scientific questions, define scientific problems, present scientific arguments and scientific ideas
- use appropriate methodology, including information and communication technology (ICT), to answer scientific questions and solve scientific problems
- carry out experimental and investigative activities, including appropriate risk management, in a range of contexts
- analyse and interpret data to provide evidence, recognising correlations and causal relationships
- evaluate methodology, evidence and data, and resolve conflicting evidence
- know that scientific knowledge and understanding develops over time
- communicate information and ideas in appropriate ways using appropriate terminology
- consider applications and implications of science and evaluate their associated benefits and risks
- consider ethical issues in the treatment of humans, other organisms and the environment
- evaluate the role of the scientific community in validating new knowledge and ensuring integrity
- evaluate the ways in which society uses science to inform decision making.

Appendix D exemplifies the areas of the specification where these skills can be developed.

2.1 Component 1

NEWTONIAN PHYSICS

Written examination: 2 hours 15 minutes
31.25% of qualification

This component covers the following areas of study:

1. Basic physics
2. Kinematics
3. Dynamics
4. Energy concepts
5. Circular motion
6. Vibrations
7. Kinetic theory
8. Thermal physics

1. BASIC PHYSICS

Overview

This topic covers units, dimensions, basic ideas on scalar and vector quantities and the differences between them. The basic physics in this unit gives learners the ideas and skills they need to progress to further study of Newtonian mechanics, kinetic theory and thermal physics.

Working Scientifically

The specified practical work in this topic gives learners the opportunity to use apparatus to record a range of measurements and to interpolate between scale readings. Learners also have the opportunity to follow written instructions, to make and record observations, keep appropriate records and present information and data in a scientific way.

Mathematical Skills

There are a number of opportunities for the development of mathematical skills in this unit. These include identifying the correct units for physical quantities; using physical constants expressed in standard form; using ratios, fractions and percentages; using calculators to handle trigonometrical expressions; calculating mean values for repeated experimental readings.

How Science Works

There are opportunities within this topic for learners to carry out experimental and investigative activities, including appropriate risk management, in a range of contexts.

Learners should be able to demonstrate and apply their knowledge and understanding of:

(a) the 6 essential base SI units (kg, m, s, A, mol, K)

(b) representing units in terms of the 6 base SI units and their prefixes

(c) checking equations for homogeneity using units

(d) the difference between scalar and vector quantities and to give examples of each – displacement, velocity, acceleration, force, speed, time, density, pressure etc

(e) the addition and subtraction of coplanar vectors, and perform mathematical calculations limited to **two** perpendicular vectors

(f) how to resolve a vector into two perpendicular components

(g) the concept of density and how to use the equation $\rho = \frac{m}{V}$ to calculate mass, density and volume

(h) what is meant by the turning effect of a force

(i) the use of the principle of moments

(j) the use of centre of gravity, for example in problems including stability: identify its position in a cylinder, sphere and cuboid (beam) of uniform density

(k) when a body is in equilibrium the resultant force is zero and the net moment is zero, and be able to perform simple calculations

SPECIFIED PRACTICAL WORK

- Measurement of the density of solids
- Determination of unknown masses by using the principle of moments

2. KINEMATICS

Overview

This topic covers rectilinear and projectile motion. Learners study accelerated motion in a straight line; the motion of bodies falling in a gravitational field; the independence of vertical and horizontal motion of a body moving freely under gravity.

Working Scientifically

This unit contains opportunities for learners to use stopwatches or light gates for timing; to use analogue apparatus to record a range of measurements; to make and record observations; to keep appropriate records and to present data in a scientific way.

Mathematical Skills

There are a number of opportunities for the development of mathematical skills in this unit. These include recognising and making use of appropriate units in calculations; using expressions in decimal and standard form; changing the subject of an equation; substituting numerical values into algebraic equations using appropriate units for physical quantities.

How Science Works

There are opportunities within this topic for learners to use appropriate methodology, including ICT to answer scientific questions and solve scientific problems; to analyse and interpret data to provide evidence, recognise correlations and causal evidence. Learners can carry out experimental and investigative activities using air tracks, light gates, data loggers and photographic or video techniques to investigate factors affecting terminal velocity, stopping distances and the measuring of the speed of moving objects. Learners can apply these factors to consider the possibility of increasing the legal motorway speed limit to 80 mph by analysing data to provide them with evidence to be able to make an informed judgement of whether to support this possibility, or not.

Learners should be able to demonstrate and apply their knowledge and understanding of:

(a) what is meant by displacement, mean and instantaneous values of speed, velocity and acceleration

(b) the representation of displacement, speed, velocity and acceleration by graphical methods

(c) the properties of displacement-time graphs, velocity-time graphs, and interpret speed and displacement-time graphs for non-uniform acceleration

(d) how to derive and use equations which represent uniformly accelerated motion in a straight line

(e) how to describe the motion of bodies falling in a gravitational field with and without air resistance - terminal velocity

(f) the independence of vertical and horizontal motion of a body moving freely under gravity

(g) the explanation of the motion due to a uniform velocity in one direction and uniform acceleration in a perpendicular direction, and perform simple calculations

SPECIFIED PRACTICAL WORK

- Measurement of g by freefall

3. DYNAMICS

Overview

This topic covers the concept of force and free body diagrams. Learners study Newton's laws of motion and the concept of linear momentum. The principle of conservation of momentum is used to solve problems involving both elastic and inelastic collisions.

Working Scientifically

The specified practical work within this unit contains opportunities for learners to use appropriate analogue instruments to record a range of measurements; to make and record observations; keep appropriate records; to follow written instructions and to apply investigative approaches to practical work.

Mathematical Skills

There are a number of opportunities for the development of mathematical skills in this unit. These include recognising and making use of appropriate units in calculations; using an appropriate number of significant figures; understanding and using mathematical symbols; changing the subject of an equation; solving algebraic equations; plotting two variables from experimental or other data.

How Science Works

There are opportunities within this topic for learners to carry out experimental and investigative activities, including risk management to analyse and interpret data to provide evidence. Learners can use and apply the concept of change in momentum to investigate the importance of crumple zones in car bonnets and air bags, and evaluate their benefits for the safety of passengers.

Learners should be able to demonstrate and apply their knowledge and understanding of:

(a) the concept of force and Newton's 3rd law of motion

(b) how free body diagrams can be used to represent forces on a particle or body

(c) the use of the relationship $\sum F = ma$ in situations where mass is constant

(d) the idea that linear momentum is the product of mass and velocity

(e) the concept that force is the rate of change of momentum, applying this in situations where mass is constant

(f) the principle of conservation of momentum and use it to solve problems in one dimension involving elastic collisions (where there is no loss of kinetic energy) and inelastic collisions (where there is a loss of kinetic energy)

SPECIFIED PRACTICAL WORK

- Investigation of Newton's 2nd law

4. ENERGY CONCEPTS

Overview

This topic covers the relationship between work, energy and power. It develops the conservation of energy, and the link between work and energy via the work-energy relationship.

Working Scientifically

This unit contains opportunities for learners to apply scientific knowledge to practical contexts.

Mathematical Skills

There are a number of opportunities for the development of mathematical skills in this unit. These include recognising and making use of appropriate units in calculations; using expressions in decimal and standard form; using ratios, fractions and percentages; using calculators to find and use power functions; solving algebraic equations.

How Science Works

There are opportunities within this topic for learners to use theories, models and ideas to develop scientific explanations; to analyse and interpret data to provide evidence, recognise correlations and causal relationships. Learners can apply the principle of conservation of energy to many different situations, including investigating data to be able to compare the efficiency of power stations and the comparison of the different methods of generating electrical power and evaluate their impact on the consumer.

Learners should be able to demonstrate and apply their knowledge and understanding of:

(a) the idea that work is the product of a force and distance moved in the direction of the force when the force is constant

(b) the calculation of the work done for constant forces, when the force is not along the line of motion (work done = $Fx\cos\theta$)

(c) the principle of conservation of energy including knowledge of gravitational potential energy $(mg\Delta h)$, elastic potential energy $(\frac{1}{2}kx^2)$ and kinetic energy $(\frac{1}{2}mv^2)$

(d) the work-energy relationship: $Fx = \frac{1}{2}mv^2 - \frac{1}{2}mu^2$

(e) power being the rate of energy transfer

(f) dissipative forces for example, friction and drag cause energy to be transferred from a system and reduce the overall efficiency of the system

(g) the equation efficiency = $\frac{\text{useful energy transfer}}{\text{total energy input}} \times 100\%$

5. CIRCULAR MOTION

Overview

This topic covers the idea that centripetal force is the resultant force that acts on a body moving at constant speed in a circle, and that it acts towards the centre of the circle. Defining terms for circular motion are introduced and the equations relating to circular motion are derived.

Working Scientifically

This unit contains opportunities for learners to apply scientific knowledge to practical contexts.

Mathematical Skills

There are a number of opportunities for the development of mathematical skills in this unit. These include using calculators to find and use power expressions; making order of magnitude calculations; understanding and using the symbols: =, <, <<, >>, >, ∝, ≈, Δ; changing the subject of an equation, including non-linear equations; using angles in regular 2D and 3D structures.

Learners should be able to demonstrate and apply their knowledge and understanding of:

(a) the terms period of rotation, frequency

(b) the definition of the unit radian as a measure of angle

(c) the use of the radian as a measure of angle

(d) the definition of angular velocity, ω, for an object performing circular motion and performing simple harmonic motion

(e) the idea that the centripetal force is the resultant force acting on a body moving at constant speed in a circle

(f) the centripetal force and acceleration are directed towards the centre of the circular motion

(g) the use of the following equations relating to circular motion

$$v = \omega r, \quad a = \omega^2 r, \quad a = \frac{v^2}{r}, \quad F = \frac{mv^2}{r}, \quad F = m\omega^2 r$$

6. VIBRATIONS

Overview

This topic covers the physical and mathematical treatment of undamped simple harmonic motion. It investigates the energy interchanges which occur during simple harmonic motion.

Working Scientifically

The specified practical work in this unit contains opportunities for learners to safely and correctly use a range of practical equipment and materials; to follow written instructions; to make and record observations; to present information and data in a scientific way; to use methods to increase accuracy of measurements, such as timing over multiple oscillations, or use of a fiduciary marker, set square or plumb line.

Mathematical Skills

There are a number of opportunities for the development of mathematical skills in this unit. These include recognising and making use of appropriate units in calculations; using calculators to handle $\sin x$, $\cos x$, $\tan x$ when x is expressed in degrees or radians; finding arithmetic means; identifying uncertainties in measurements and using simple techniques to determine uncertainty when data are combined; translating information between graphical, numerical and algebraic forms; determining the slope and intercept of a linear graph.

How Science Works

There are opportunities within this topic for learners to use theories, models and ideas to develop scientific explanations; to use appropriate methodology, including ICT, to answer scientific questions and solve scientific problems; to carry out experimental and investigative activities, including appropriate risk management, in a range of contexts; to consider applications and implications of science and evaluate their associated benefits and risks. Learners can investigate the rise and fall of tides and the consequences of resonance. They can consider different methods of preventing vibratory systems resonating and relate this to the design of bridges and the suspension systems of cars.

Learners should be able to demonstrate and apply their knowledge and understanding of:

(a) the definition of simple harmonic motion as a statement in words

(b) $a = -\omega^2 x$ as a mathematical defining equation of simple harmonic motion

(c) the graphical representation of the variation of acceleration with displacement during simple harmonic motion

(d) $x = A\cos(\omega t + \varepsilon)$ as a solution to $-\omega^2 x$

(e) the terms frequency, period, amplitude and phase

(f) period as $\frac{1}{f}$ or $\frac{2\pi}{\omega}$

(g) $v = -A\omega \sin(\omega t + \varepsilon)$ for the velocity during simple harmonic motion

(h) the graphical representation of the changes in displacement and velocity with time during simple harmonic motion

(i) the equation $T = 2\pi\sqrt{\frac{m}{k}}$ for the period of a system having stiffness (force per unit extension) k and mass m

(j) the equation $T = 2\pi\sqrt{\frac{l}{g}}$ for the period of a simple pendulum

(k) the graphical representation of the interchange between kinetic energy and potential energy during undamped simple harmonic motion, and perform simple calculations on energy changes

(l) free oscillations and the effect of damping in real systems

(m) practical examples of damped oscillations

(n) the importance of critical damping in appropriate cases such as vehicle suspensions

(o) forced oscillations and resonance, and to describe practical examples

(p) the variation of the amplitude of a forced oscillation with driving frequency and that increased damping broadens the resonance curve

(q) circumstances when resonance is useful for example, circuit tuning, microwave cooking and other circumstances in which it should be avoided for example, bridge design

SPECIFIED PRACTICAL WORK

- Measurement of g with a pendulum
- Investigation of the damping of a spring

7. KINETIC THEORY

Overview

This topic covers the ideal gas law and the equation of state. It develops the kinetic theory of gases and leads to the kinetic theory of pressure of a perfect gas.

Mathematical Skills

There are a number of opportunities for the development of mathematical skills in this unit. These include recognising and using expressions in decimal and standard form; using ratios, fractions and percentages; making order of magnitude calculations; changing the subject of an equation, including non-linear equations; sketching relationships which are modelled by $y = \frac{k}{x}$.

How Science Works

There are opportunities within this topic for learners to use theories, models and ideas to develop scientific explanations. They can investigate how Newton's laws of motion can be applied to the behaviour of an ideal gas to produce a model which links the pressure of an ideal gas to its density and the root mean square speed of its molecules.

Learners should be able to demonstrate and apply their knowledge and understanding of:

(a) the equation of state for an ideal gas expressed as $pV = nRT$ where R is the molar gas constant and $pV = NkT$ where k is the Boltzmann constant

(b) the assumptions of the kinetic theory of gases which includes the random distribution of energy among the molecules

(c) the idea that molecular movement causes the pressure exerted by a gas, and use $p = \frac{1}{3}\rho\overline{c^2} = \frac{1}{3}\frac{N}{V}m\overline{c^2}$ where N is the number of molecules

(d) the definition of Avogadro constant N_A and hence the mole

(e) the idea that the molar mass M is related to the relative molecular mass M_r by $M\,/\,\text{kg} = \frac{M_r}{1000}$, and that the number of moles n is given by $\frac{\text{total mass}}{\text{molar mass}}$

(f) how to combine $pV = \frac{1}{3}Nm\overline{c^2}$ with $pV = nRT$ and show that the total translational kinetic energy of a mole of a monatomic gas is given by $\frac{3}{2}RT$ and the mean kinetic energy of a molecule is $\frac{3}{2}kT$ where $k = \frac{R}{N_A}$ is the Boltzmann constant, and that T is proportional to the mean kinetic energy

8. THERMAL PHYSICS

Overview

This topic introduces the idea that the internal energy of a system is the sum of the potential and kinetic energy of its molecules. It considers the internal energy of an ideal gas and discusses energy transfer between a gas and its surroundings. The first law of thermodynamics is introduced in the form $\Delta U = Q - W$.

Working Scientifically

The specified practical work within this unit contains opportunities for learners to plot and interpret graphs; to process and analyse data using appropriate mathematical skills; to apply investigative approaches to practical work; to follow written instructions; to make and record observations; to keep appropriate records of experimental activities; to use appropriate analogue apparatus and digital instruments to record a range of measurements.

Mathematical Skills

There are a number of opportunities for the development of mathematical skills in this unit. These include using ratios, fractions and percentages; estimating results; making order of magnitude calculations; understanding and using the symbols =, <, <<, >>, >, ∝, ≈; translating information between graphical, numerical and algebraic forms; plotting two variables from experimental/other data.

How Science Works

There are opportunities within this topic for learners to use their knowledge and understanding to pose scientific questions, define scientific problems, present scientific arguments and scientific ideas; to analyse and interpret data to provide evidence, recognise correlations and causal relationships; to communicate information and ideas in appropriate ways using appropriate terminology. Learners can be given the opportunity to carry out experimental work to investigate the specific heat capacity of different materials and use their findings together with data about the thermal conductivity of materials to investigate methods of insulating buildings to produce optimum heat retention.

Learners should be able to demonstrate and apply their knowledge and understanding of:

(a) the idea that the internal energy of a system is the sum of the potential and kinetic energies of its molecules

(b) absolute zero being the temperature of a system when it has minimum internal energy

(c) the internal energy of an ideal monatomic gas being wholly kinetic so it is given by $U = \frac{3}{2}nRT$

(d) the idea that heat enters or leaves a system through its boundary or container wall, according to whether the system's temperature is lower or higher than that of its surroundings, so heat is energy in transit and not contained within the system

(e) the idea that if no heat flows between systems in contact, then they are said to be in thermal equilibrium, and are at the same temperature

(f) the idea that energy can enter or leave a system by means of work, so work is also energy in transit

(g) the equation $W = p\Delta V$ can be used to calculate the work done by a gas under constant pressure

(h) the idea that even if p changes, W is given by the area under the $p - V$ graph

(i) the use of the first law of thermodynamics, in the form $\Delta U = Q - W$ and know how to interpret negative values of ΔU, Q, and W

(j) the idea that for a solid (or liquid), W is usually negligible, so $Q = \Delta U$

(k) $Q = mc\Delta\theta$, for a solid or liquid, and this is the defining equation for specific heat capacity, c

SPECIFIED PRACTICAL WORK

- Estimation of absolute zero by use of the gas laws
- Measurement of the specific heat capacity for a solid

2.2 Component 2

ELECTRICITY AND THE UNIVERSE

Written examination: 2 hours
31.25% of qualification

This component covers the following areas of study:

1. Conduction of electricity
2. Resistance
3. D.C. circuits
4. Capacitance
5. Solids under stress
6. Electrostatic and gravitational fields of force
7. Using radiation to investigate stars
8. Orbits and the wider universe

1. CONDUCTION OF ELECTRICITY

Overview

This topic covers the basic ideas of electric charge and electric current. The nature of charge carriers in conductors is explored.

Mathematical Skills

There are a number of opportunities for the development of mathematical skills in this unit. These include recognising and using expressions in decimal and standard form; using ratios, fractions and percentages; making order of magnitude calculations; calculating areas of circles, surface areas and volumes of rectangular blocks and cylinders.

How Science Works

There are opportunities within this topic for learners to use theories, models and ideas to develop scientific explanations.

Learners should be able to demonstrate and apply their knowledge and understanding of:

(a) the fact that the unit of charge is the coulomb (C), and an electron's charge, e, is a very small fraction of a coulomb

(b) the fact that charge can flow through certain materials, called conductors

(c) electric current being the rate of flow of charge

(d) the use of the equation $I = \frac{\Delta Q}{\Delta t}$

(e) current being measured in ampères (A), where A = C s^{-1}

(f) the mechanism of conduction in metals as the drift of free electrons

(g) the derivation and use of the equation $I = nAve$ for free electrons

2. RESISTANCE

Overview

This topic covers the relationship between current and potential difference and develops the ideas of resistance and resistivity. The heating effect of an electric current is explored and the variation of resistance with temperature of metals is investigated.

Working Scientifically

The specified practical work in this topic gives learners the opportunity to apply investigative approaches and methods to practical work; to safely and correctly use a range of practical equipment and materials; to keep appropriate records of experimental activities; to correctly construct circuits from circuit diagrams using D.C. power supplies, cells and a range of circuit components.

Mathematical Skills

There are a number of opportunities for the development of mathematical skills in this unit. These include recognising and using expressions in decimal and standard form; estimating results; using calculators to find and use power functions; using an appropriate number of significant figures; finding arithmetic means; making order of magnitude calculations; changing the subject of an equation, including non-linear equations; translating information between graphical , numerical and algebraic forms; drawing and using the slope of a tangent to a curve as a measure of rate of change.

How Science Works

There are opportunities within this topic for learners to use theories, models and ideas to develop scientific explanations; to use appropriate methodology, including ICT to answer scientific questions and solve scientific problems; to know that scientific knowledge and understanding develops over time. Learners can carry out experimental and investigative activities, such as the comparison of the I-V characteristics of metal wires, filament lamps, LED lamps and diodes and use spreadsheets to analyse and evaluate their data. They can then make informed decisions on the use of energy saving devices in their homes.

Learners should be able to demonstrate and apply their knowledge and understanding of:

(a) the definition of potential difference

(b) the idea that potential difference is measured in volts (V) where V = J C^{-1}

(c) the characteristics of $I - V$ graphs for the filament of a lamp, and a metal wire at constant temperature

(d) Ohm's law, the equation $V = IR$ and the definition of resistance

(e) resistance being measured in ohms (Ω), where Ω = V A^{-1}

(f) the application of $P = IV = I^2R = \frac{V^2}{R}$

(g) collisions between free electrons and ions gives rise to electrical resistance, and electrical resistance increases with temperature

(h) the application of $R = \frac{\rho l}{A}$, the equation for resistivity

(i) the idea that the resistance of metals varies almost linearly with temperature over a wide range

(j) the idea that ordinarily, collisions between free electrons and ions in metals increase the random vibration energy of the ions, so the temperature of the metal increases

(k) what is meant by superconductivity, and superconducting transition temperature

(l) the fact that most metals show superconductivity, and have transition temperatures a few degrees above absolute zero (–273 °C)

(m) certain materials (high temperature superconductors) having transition temperatures above the boiling point of nitrogen (–196 °C)

(n) some uses of superconductors for example, MRI scanners and particle accelerators

SPECIFIED PRACTICAL WORK

- Investigation of the I-V characteristics of the filament of a lamp and a metal wire at constant temperature
- Determination of resistivity of a metal
- Investigation of the variation of resistance with temperature for a metal wire

3. D.C. CIRCUITS

Overview

This topic covers series and parallel electrical circuits including resistor combinations. The use of a potential divider in circuits is investigated. The terms electromotive force and the internal resistance of a source are introduced.

Working Scientifically

The specified practical work in this topic gives learners the opportunity to evaluate results and draw conclusions with reference to measurement uncertainties and errors; to present data in appropriate ways; to make and record observations; to keep appropriate records of experimental activities; to design, construct and check circuits using D.C. power supplies, cells and a range of circuit components.

Mathematical Skills

There are a number of opportunities for the development of mathematical skills in this unit. These include recognising and making use of appropriate units in calculations; using ratios, fractions and percentages; finding arithmetic means; identifying uncertainties in measurements and using simple techniques to determine uncertainty; solving algebraic equations, including quadratic equations; translating information between graphical, numerical and algebraic forms; understanding that $y = mx + c$ represents a linear relationship.

How Science Works

There are opportunities within this topic for learners to carry out experimental and investigative activities, including appropriate risk management: to analyse and interpret data to provide evidence, recognise correlations and causal relationships. Learners can investigate electrical circuits and use this experience to learn about the risk management issues involved when handling sources of power. The opportunity to design circuits and carry out fault finding techniques will enable them to evaluate their methodology and to resolve conflicting evidence.

Learners should be able to demonstrate and apply their knowledge and understanding of:

(a) the idea that the current from a source is equal to the sum of the currents in the separate branches of a parallel circuit, and that this is a consequence of conservation of charge

(b) the sum of the potential differences across components in a series circuit is equal to the potential difference across the supply, and that this is a consequence of conservation of energy

(c) potential differences across components in parallel are equal

(d) the application of equations for the combined resistance of resistors in series and parallel

(e) the use of a potential divider in circuits (including circuits which contain LDRs and thermistors)

(f) what is meant by the emf of a source

(g) the unit of emf is the volt (V), which is the same as that of potential difference

(h) the idea that sources have internal resistance and to use the equation $V = E - Ir$

(i) how to calculate current and potential difference in a circuit containing one cell or cells in series

SPECIFIED PRACTICAL WORK

- Determination of the internal resistance of a cell

4. CAPACITANCE

Overview

This unit introduces the concept of capacitance and the factors affecting it. Capacitors connected in series and parallel are studied together with the factors affecting the energy stored in them. The mechanism by which a capacitor charges and discharges through a resistor is examined.

Working Scientifically

The specified practical work in this topic gives learners the opportunity to apply investigative approaches and methods to practical work; to follow written instructions; to make and record observations; to present information and data in a scientific way; to use electrical multimeters to obtain a range of measurements; to correctly construct circuits from circuit diagrams using D.C. power supplies, cells and a range of circuit components, including those where polarity is important.

Mathematical Skills

There are a number of opportunities for the development of mathematical skills in this unit. These include recognising and using expressions in decimal and standard form; using calculators to find and use power, exponential and logarithmic functions; using an appropriate number of significant figures; finding arithmetic means; making order of magnitude calculations; changing the subject of an equation, including non-linear equations; using logarithms in relation to quantities that range over several orders of magnitude; plotting two variables from experimental data; determining the slope and the intercept of a linear graph; understanding the possible physical significance of the area between a curve and the x-axis and being able to calculate or estimate it by graphical methods; interpreting logarithmic plots.

How Science Works

There are opportunities within this topic for learners to use appropriate methodology, including ICT to answer scientific questions and to solve scientific problems; to carry out experimental and investigative activities, including appropriate risk management, in a range of contexts. Learners can investigate the use of capacitors to store charge, in time delay circuits and use risk management appropriately when dealing with power supplies. Opportunities exist to study electrostatic precipitation and devices such as photocopiers.

Learners should be able to demonstrate and apply their knowledge and understanding of:

(a) the idea that a simple parallel plate capacitor consists of a pair of equal parallel metal plates separated by a vacuum or air

(b) a capacitor storing energy by transferring charge from one plate to the other, so that the plates carry equal but opposite charges (the net charge being zero)

(c) the definition of capacitance as $C = \frac{Q}{V}$

(d) the use of $C = \frac{\varepsilon_o A}{d}$ for a parallel plate capacitor, with no dielectric

(e) the idea that a dielectric increases the capacitance of a vacuum-spaced capacitor

(f) the E field within a parallel plate capacitor being uniform and the use of the equation $E = \frac{V}{d}$

(g) the equation $U = \frac{1}{2}QV$ for the energy stored in a capacitor

(h) the equations for capacitors in series and in parallel

(i) the process by which a capacitor charges and discharges through a resistor

(j) the equations: $Q = Q_0\left(1 - e^{-\frac{t}{RC}}\right)$ and $Q = Q_0 e^{-\frac{t}{RC}}$ where RC is the time constant

SPECIFIED PRACTICAL WORK

- Investigation of the charging and discharging of a capacitor to determine the time constant
- Investigation of the energy stored in a capacitor

5. SOLIDS UNDER STRESS

Overview

This topic introduces the behaviour of different solids under stress and introduces the concepts of stress, strain and Young modulus. The work done deforming a solid is related to the strain energy stored. The behaviour under stress for metals, brittle materials and rubber are compared.

Working Scientifically

The specified practical work in this topic gives learners the opportunity to know and understand how to use a wide range of experimental and practical instruments, equipment and techniques appropriate to the knowledge and understanding included in this specification; to safely and correctly use a range of practical equipment and materials; to make and record observations; to present information and data in a scientific way; to use appropriate analogue apparatus to record a range of measurements of length and to interpolate between scale markings; to use callipers and micrometers, using digital or vernier scales.

Mathematical Skills

There are a number of opportunities for the development of mathematical skills in this unit. These include recognising and making use of appropriate units in calculations; using an appropriate number of significant figures; making order of magnitude calculations; identifying uncertainties in measurements and using simple techniques to determine uncertainty; translating information between graphical, numerical and algebraic forms; determining the slope and intercept of a linear graph; understanding the possible physical significance of the area between a curve and the x-axis and to be able to calculate it or estimate it by graphical means; calculating areas of triangles, circumferences and areas of circles and volumes of cylinders.

How Science Works

There are opportunities within this topic for learners to use theories, models and ideas to develop scientific explanations; to use appropriate methodology, including ICT to answer scientific questions and solve scientific problems; to communicate information and ideas in appropriate ways using appropriate terminology; to consider applications and implications of science and evaluate their associated benefits and risks. Learners can investigate the behaviour of different solids under stress, for example, metals, rubber, polythene and consider such practical applications as adding carbon to rubber tyres, pre-stressing concrete and the behaviour of building materials under compression and tension.

Learners should be able to demonstrate and apply their knowledge and understanding of:

(a) Hooke's law and use $F = kx$ where the spring constant k is the force per unit extension

(b) the ideas that for materials the tensile stress, $\sigma = \frac{F}{A}$ and the tensile strain, $\varepsilon = \frac{\Delta l}{l}$ and the Young modulus, $E = \frac{\sigma}{\varepsilon}$ when Hooke's law applies

(c) the work done in deforming a solid being equal to the area under a force-extension graph, which is $\frac{1}{2}Fx$ if Hooke's law is obeyed

(d) the classification of solids as crystalline, amorphous (to include glasses and ceramics) and polymeric

(e) the features of a force-extension (or stress-strain) graph for a metal such as copper, to include
- elastic and plastic strain
- the effects of dislocations, and the strengthening of metals by introducing barriers to dislocation movement, such as foreign atoms, other dislocations, and more grain boundaries
- necking and ductile fracture

(f) the features of a force-extension (or stress-strain) graph for a brittle material such as glass, to include
- elastic strain and obeying Hooke's law up to fracture
- brittle fracture by crack propagation, the effect of surface imperfections on breaking stress, and how breaking stress can be increased by reducing surface imperfections (as in thin fibres) or by putting surface under compression (as in toughened glass or pre-stressed concrete)

(g) the features of a force-extension (or stress-strain) graph for rubber, to include
- Hooke's law only approximately obeyed, low Young modulus and the extension due to straightening of chain molecules against thermal opposition
- hysteresis

SPECIFIED PRACTICAL WORK

- Determination of Young modulus of a metal in the form of a wire
- Investigation of the force-extension relationship for rubber

6. ELECTROSTATIC AND GRAVITATIONAL FIELDS OF FORCE

Overview

This topic examines the similarities and differences between electrostatic and gravitational fields. The ideas of potential and potential energy in fields of force are introduced.

Mathematical Skills

There are a number of opportunities for the development of mathematical skills in this unit. These include recognising and making use of appropriate units in calculations; recognising and using expressions in decimal and standard form; using calculators to find and use power, exponential and logarithmic functions; using calculators to handle $\sin x$, $\cos x$, $\tan x$ when x is expressed in degrees or radians; making order of magnitude calculations; changing the subject of an equation; translating information between graphical, numerical and algebraic forms; drawing and using the slope of a tangent to a curve as a measure of rate of change; interpreting logarithmic plots; using Pythagoras' theorem, and the angle sum of a triangle; using $\sin$, $\cos$ and $\tan$ in physical problems, using small angle approximations including $\sin\theta \approx \theta$, $\tan\theta \approx \theta$, $\cos\theta \approx 1$ for small θ where appropriate.

How Science Works

There are opportunities within this topic for learners to analyse and interpret data to provide evidence, recognise correlations and causal relationships. Learners can be given the opportunity to use theories and models to predict the motion of satellites and planets. Applications and uses such as geostationary satellites can be studied and their benefits and risk evaluated as well as the ethical issues involved in their use.

Learners should be able to demonstrate and apply their knowledge and understanding of:

(a) the features of electric and gravitational fields as specified in the **table on page 30**

(b) the idea that the gravitational field outside spherical bodies such as the Earth is essentially the same as if the whole mass were concentrated at the centre

(c) field lines (or lines of force) giving the direction of the field at a point, thus, for a positive point charge, the field lines are radially outward

(d) equipotential surfaces joining points of equal potential and are therefore spherical for a point charge

(e) how to calculate the net potential and resultant field strength for a number of point charges or point masses

(f) the equation $\Delta U_P = mg\Delta h$ for distances over which the variation of g is negligible

ELECTRIC FIELDS	GRAVITATIONAL FIELDS
Electric field strength, E, is the force per unit charge on a small positive test charge placed at the point	Gravitational field strength, g, is the force per unit mass on a small test mass placed at the point
Inverse square law for the force between two electric charges in the form $F = \frac{1}{4\pi\varepsilon_0}\frac{Q_1Q_2}{r^2}$ (Coulomb's law)	Inverse square law for the force between two masses in the form $F = G\frac{M_1M_2}{r^2}$ (Newton's law of gravitation)
F can be attractive or repulsive	F is attractive only
$E = \frac{1}{4\pi\varepsilon_o}\frac{Q}{r^2}$ for the field strength due to a point charge in free space or air	$g = \frac{GM}{r^2}$ for the field strength due to a point mass
Potential at a point due to a point charge in terms of the work done in bringing a unit positive charge from infinity to that point	Potential at a point due to a point mass in terms of the work done in bringing a unit mass from infinity to that point
$V_E = \frac{1}{4\pi\varepsilon_0}\frac{Q}{r}$ and $PE = \frac{1}{4\pi\varepsilon_0}\frac{Q_1Q_2}{r}$	$V_g = -\frac{GM}{r}$ and $PE = -\frac{GM_1M_2}{r}$
Change in potential energy of a point charge moving in any electric field $= q\Delta V_E$	Change in potential energy of a point mass moving in any gravitational field $= m\Delta V_g$
Field strength at a point is given by E = - slope of the $V_E - r$ graph at that point	Field strength at a point is given by g = - slope of the $V_g - r$ graph at that point
Note that $\frac{1}{4\pi\varepsilon_0} \approx 9 \times 10^9\ \text{F}^{-1}\text{m}$ is an acceptable approximation	

7. USING RADIATION TO INVESTIGATE STARS

Overview

This topic studies the continuous emission and line absorption spectra of the Sun. It uses Wien's displacement law, Stefan's law, and the inverse square law to also investigate properties of stars, such as luminosity, size, temperature and distance.

Mathematical Skills

There are a number of opportunities for the development of mathematical skills in this unit. These include recognising and using expressions in decimal and standard form; estimating results; making order of magnitude calculations; solving algebraic equations, including quadratic equations; calculating surface areas of spheres.

How Science Works

There are opportunities within this topic for learners to use knowledge and understanding to pose scientific questions, define scientific problems, present scientific arguments and scientific ideas; to analyse and interpret data to provide evidence, recognise correlations and causal relationships; to know that scientific knowledge and understanding develops over time.

Learners should be able to demonstrate and apply their knowledge and understanding of:

(a) the idea that the stellar spectrum consists of a continuous emission spectrum, from the dense gas of the surface of the star, and a line absorption spectrum arising from the passage of the emitted electromagnetic radiation through the tenuous atmosphere of the star

(b) the idea that bodies which absorb all incident radiation are known as black bodies and that stars are very good approximations to black bodies

(c) the shape of the black body spectrum and that the peak wavelength is inversely proportional to the absolute temperature (defined by: T (K) = θ (°C) + 273.15)

(d) Wien's displacement law, Stefan's law and the inverse square law to investigate the properties of stars – luminosity, size, temperature and distance [N.B. stellar brightness in magnitudes will not be required]

(e) the meaning of multiwavelength astronomy and that by studying a region of space at different wavelengths (different photon energies) the different processes which took place there can be revealed

8. ORBITS AND THE WIDER UNIVERSE

Overview

This topic covers Kepler's laws of planetary motion and circular orbits of satellites, planets and stars. It explores the evidence for the existence of dark matter and examines the Doppler shift of spectral lines. It discusses how the Hubble constant relates galactic radial velocity to distance and how a knowledge of the Hubble constant can give an approximation to the age of the universe.

Mathematical Skills

There are a number of opportunities for the development of mathematical skills in this unit. These include estimating results; making order of magnitude calculations; understanding and using the symbols: =, <, <<, >>, >, ∝, ≈, Δ; changing the subject of an equation, including non-linear equations; solving algebraic equation, including quadratic equations; translating information between graphical, numerical and algebraic forms.

How Science Works

There are opportunities within this topic for learners to use theories, models and ideas to develop scientific explanations; to use knowledge and understanding to pose scientific questions, define scientific problems, present scientific arguments and scientific ideas; to analyse and interpret data to provide evidence, recognise correlations and causal relationships; to know that scientific knowledge and understanding develops over time; to communicate information and ideas in appropriate ways using appropriate terminology. Learners can be given the opportunity to understand how scientific knowledge and understanding developed over time and how the Big Bang Theory developed until its acceptance. Learners can use astronomical data to show how the orbital speeds of objects in spiral galaxies implied the existence of dark matter and evaluate the role of the scientific community in validating the recently discovered Higgs boson.

Learners should be able to demonstrate and apply their knowledge and understanding of:

(a) Kepler's three laws of planetary motion

(b) Newton's law of gravitation $F = G\frac{M_1 M_2}{r^2}$ in simple examples, including the motion of planets and satellites

(c) how to derive Kepler's 3rd law, for the case of a circular orbit from Newton's law of gravity and the formula for centripetal acceleration

(d) how to use data on orbital motion, such as period or orbital speed, to calculate the mass of the central object

(e) how the orbital speeds of objects in spiral galaxies implies the existence of dark matter

(f) how the recently discovered Higgs boson may be related to dark matter

(g) how to determine the position of the centre of mass of two spherically symmetric objects, given their masses and separation, and calculate their mutual orbital period in the case of circular orbits

(h) the Doppler relationship in the form $\frac{\Delta\lambda}{\lambda} = \frac{v}{c}$

(i) how to determine a star's radial velocity (i.e. the component of its velocity along the line joining it and an observer on the Earth) from data about the Doppler shift of spectral lines

(j) the use of data on the variation of the radial velocities of the bodies in a double system (for example, a star and orbiting exo-planet) and their orbital period to determine the masses of the bodies for the case of a circular orbit edge on as viewed from the Earth

(k) how the Hubble constant (H_0) relates galactic radial velocity (v) to distance (D) and it is defined by $v = H_0 D$

(l) why $\frac{1}{H_0}$ approximates the age of the universe

(m) how the equation $\rho_c = \frac{3{H_0}^2}{8\pi G}$ for the critical density of a 'flat' universe can be derived very simply using conservation of energy

2.3 Component 3

LIGHT, NUCLEI AND OPTIONS

Written examination: 2 hours 15 minutes
37.5% of qualification

This component covers the following areas of study:

1. The nature of waves
2. Wave properties
3. Refraction of light
4. Photons
5. Lasers
6. Nuclear decay
7. Particles and nuclear structure
8. Nuclear energy
9. Magnetic fields
10. Electromagnetic induction

Choice of 1 option from 4:

A: Alternating currents

B: Medical physics

C: The physics of sports

D: Energy and the environment

1. THE NATURE OF WAVES

Overview

This topic covers the basic properties of transverse and longitudinal waves and the differences between them. It introduces the wave equation and gives learners the basic ideas and skills they need to study both electromagnetic and sound waves.

Working Scientifically

Questions set on this unit will assess learners' abilities to apply scientific knowledge to practical contexts; to present data in appropriate ways; to evaluate results and draw conclusions; to plot and interpret graphs. The specified practical work in this topic gives learners the opportunity to make and record observations; to keep appropriate records of experimental activities; to generate and measure waves using a microwave source.

Mathematical Skills

There are a number of opportunities for the development of mathematical skills in this unit. These include recognising and using expressions in decimal and standard form; finding arithmetic means; changing the subject of an equation, including non-linear equations.

How Science Works

There are opportunities within this topic for learners to carry out experimental and investigative activities, including appropriate risk management, in a range of contexts.

Learners should be able to demonstrate and apply their knowledge and understanding of:

(a) the idea that a progressive wave transfers energy without any transfer of matter

(b) the difference between transverse and longitudinal waves

(c) the term polarisation

(d) the terms in phase and in antiphase

(e) the terms displacement, amplitude, wavelength, frequency, period and velocity of a wave

(f) graphs of displacement against time, and displacement against position for transverse waves only

(g) the equation $c = f\lambda$

(h) the idea that all points on wavefronts oscillate in phase, and that wave propagation directions (rays) are at right angles to wavefronts

SPECIFIED PRACTICAL WORK

- Measurement of the intensity variations for polarisation

2. WAVE PROPERTIES

Overview

This topic introduces the wave properties of diffraction and interference. Investigation of two source interference patterns and the diffraction grating are carried out. The topic deals with coherent and incoherent sources and the conditions needed for two source interference to be observed. Stationary waves are introduced, and the differences between stationary and progressive waves investigated.

Working Scientifically

The specified practical work in this topic gives learners the opportunity to safely and correctly use a range of practical equipment and materials; to make and record observations; to present information and data in a scientific way; to use a wide range of experimental and practical instruments, equipment and techniques; to generate and measure waves, using a microphone and loudspeaker; to use a laser/light source to investigate interference/diffraction.

Mathematical Skills

There are a number of opportunities for the development of mathematical skills in this unit. These include recognising and using expressions in decimal and standard form; using calculators to handle $\sin x$, $\cos x$, $\tan x$ when x is expressed in degrees or radians; using an appropriate number of significant figures; making order of magnitude calculations; understanding and using the symbols: =, <, <<, >>, >, ∝, ≈, Δ; substituting numerical values into algebraic equations using appropriate units for physical quantities; plotting two variables from experimental or other data; using angles in regular 2D structures; visualising and representing 2D forms; using Pythagoras' theorem, and the angle sum of a triangle; using small angle approximations including $\sin\theta \approx \theta$, $\tan\theta \approx \theta, \cos\theta \approx 1$ for small θ where appropriate.

How Science Works

There are opportunities within this topic for learners to use appropriate methodology, including ICT to answer scientific questions and to solve scientific problems; to evaluate methodology, evidence and data, and resolve conflicting evidence; to know that scientific knowledge and understanding develops over time; to communicate information and ideas in appropriate ways using appropriate terminology. Learners can be given the opportunity to understand that scientific knowledge and understanding develops over time by considering the historical importance of Young's experiment and how it demonstrated the wave nature of light. Learners can be given the opportunity to carry out investigational activities to determine the wavelength of light using Young's double slits and a diffraction grating and evaluate the relative merits of both methods.

Learners should be able to demonstrate and apply their knowledge and understanding of:

(a) diffraction occuring when waves encounter slits or obstacles

(b) the idea that there is little diffraction when λ is much smaller than the dimensions of the obstacle or slit

(c) the idea that if λ is equal to or greater than the width of a slit, waves spread as roughly semicircular wavefronts, but if λ is less than the slit width the main beam spreads through less than 180°

(d) how two source interference occurs

(e) the historical importance of Young's experiment

(f) the principle of superposition, giving appropriate sketch graphs

(g) the path difference rules for constructive and destructive interference between waves from in phase sources

(h) the use of $\lambda = \frac{a\Delta y}{D}$

(i) the derivation and use of $d\sin\theta = n\lambda$ for a diffraction grating

(j) the idea that for a diffraction grating a very small d makes beams ("orders") much further apart than in Young's experiment, and that the large number of slits makes the bright beams much sharper

(k) the idea that coherent sources are monochromatic with wavefronts continuous across the width of the beam and, (when comparing more than one source) with a constant phase relationship

(l) examples of coherent and incoherent sources

(m) the idea that for two source interference to be observed, the sources must have a zero or constant phase difference and have oscillations in the same direction

(n) the differences between stationary and progressive waves

(o) the idea that a stationary wave can be regarded as a superposition of two progressive waves of equal amplitude and frequency, travelling in opposite directions, and that the internodal distance is $\frac{\lambda}{2}$

SPECIFIED PRACTICAL WORK

- Determination of wavelength using Young's double slits
- Determination of wavelength using a diffraction grating
- Determination of the speed of sound using stationary waves

3. REFRACTION OF LIGHT

Overview

This topic covers refraction of light, and how Snell's law relates to the wave model of light propagation. The concept of total internal reflection is studied and its application to multimode optical fibres. This topic also looks at how the introduction of monomode optical fibres has allowed for greater transmission rates and distances.

Working Scientifically

The specified practical work for this topic gives learners the opportunity to make and record observations; to keep appropriate records of experimental activities; to use appropriate analogue and digital apparatus to record a range of measurements; to use laser or light sources to investigate refraction.

Mathematical Skills

There are a number of opportunities for the development of mathematical skills in this unit. These include recognising and making use of appropriate units in calculations; estimating results; using calculators to handle $\sin x$, $\cos x$, $\tan x$ when x is expressed in degrees or radians; using an appropriate number of significant figures; changing the subject of an equation, including non-linear equations; solving algebraic equations; translating information between graphical, numerical and algebraic form; determining the slope and intercept of a linear graph; using angles in regular 2D structures; using $\sin$, $\cos$ and $\tan$ in physical problems.

How Science Works

There are opportunities within this topic for learners to consider applications and implications of science and evaluate their associated risks. Learners can be given the opportunity to apply the concept of total internal reflection in optical fibres and use optical fibres to investigate the problem of multimode dispersion.

Learners should be able to demonstrate and apply their knowledge and understanding of:

(a) the refractive index, n, of a medium being defined as $\frac{c}{v}$, in which v is the speed of light in the medium and c is the speed of light in a vacuum

(b) the use of the equations: $n_1 v_1 = n_2 v_2$ and $n_1 \sin\theta_1 = n_2 \sin\theta_2$ (regarded as Snell's law)

(c) how Snell's law relates to the wave model of light propagation and for diagrams of plane waves approaching a plane boundary obliquely, and being refracted

(d) the conditions for total internal reflection

(e) the derivation and use of the equation for the critical angle $n_1 \sin\theta_C = n_2$

(f) how to apply the concept of total internal reflection to multimode optical fibres

(g) the problem of multimode dispersion with optical fibres in terms of limiting the rate of data transfer and transmission distance

(h) how the introduction of monomode optical fibres has allowed for much greater transmission rates and distances

SPECIFIED PRACTICAL WORK

- Measurement of the refractive index of a material

4. PHOTONS

Overview

This topic covers the properties of photons and the photoelectric effect. Learners study the electromagnetic spectrum and how to produce line emission and line absorption spectra from atoms. The wave-like behaviour of particles is studied using electron diffraction and de Broglie's relationship is applied to both particles of matter and to photons.

Working Scientifically

The specified practical work in this topic gives learners the opportunity to use a wide range of experimental and practical instruments, equipment and techniques appropriate to the knowledge and understanding included in this topic; to use appropriate digital instruments, including electrical multimeters, to obtain a range of measurements; to correctly construct circuits from circuit diagrams using D.C. power supplies, cells, and a range of circuit components, including those where polarity is important.

Mathematical Skills

There are a number of opportunities for the development of mathematical skills in this unit. These include recognising and using expressions in decimal and standard form; using an appropriate number of significant figures; understanding simple probability; making order of magnitude calculations; translating information between graphical, numerical and algebraic forms; plotting two variables from experimental or other data; determining the slope and the intercept of a linear graph.

How Science Works

There are opportunities within this topic for learners to use theories, models and ideas to develop scientific explanations; to use knowledge and understanding to pose scientific questions, define scientific problems, present scientific arguments and scientific ideas; to carry out experimental and investigative activities, including appropriate risk management, in a range of contexts; to analyse and interpret data to provide evidence, recognise correlations and causal relationships; to know that scientific knowledge and understanding develops over time. Learners can research the difficulties encountered by trying to use the wave theory of light to explain the photoelectric effect and how the photon model of light was developed. Learners can also investigate how the Planck constant can be determined using light emitting diodes.

Learners should be able to demonstrate and apply their knowledge and understanding of:

(a) the fact that light can be shown to consist of discrete packets (photons) of energy

(b) how the photoelectric effect can be demonstrated

(c) how a vacuum photocell can be used to measure the maximum kinetic energy, $E_{k\,\mathrm{max}}$, of emitted electrons in eV and hence in J

(d) the graph of $E_{k\,\mathrm{max}}$ against frequency of illuminating radiation

(e) how a photon picture of light leads to Einstein's equation, $E_{k\,max} = hf - \phi$, and how this equation correlates with the graph of $E_{k\,max}$ against frequency

(f) the fact that the visible spectrum runs approximately from 700 nm (red end) to 400 nm (violet end) and the orders of magnitude of the wavelengths of the other named regions of the electromagnetic spectrum

(g) typical photon energies for these radiations

(h) how to produce line emission and line absorption spectra from atoms

(i) the appearance of such spectra as seen in a diffraction grating

(j) simple atomic energy level diagrams, together with the photon hypothesis, line emission and line absorption spectra

(k) how to determine ionisation energies from an energy level diagram

(l) the demonstration of electron diffraction and that particles have a wave-like aspect

(m) the use of the relationship $p = \frac{h}{\lambda}$ for both particles of matter and photons

(n) the calculation of radiation pressure on a surface absorbing or reflecting photons

SPECIFIED PRACTICAL WORK

- Determination of h using LEDs

5. LASERS

Overview

This topic covers the process of stimulated emission and how this leads to coherent light emission. The structure of lasers is studied, including how a population inversion is attained. The advantages and disadvantages of different types of laser are compared.

Working Scientifically

Question set on this unit will assess learner's abilities to apply scientific knowledge to practical contexts; to process and analyse data using appropriate mathematical skills; to present data in appropriate ways.

Mathematical Skills

There are a number of opportunities for the development of mathematical skills in this unit. These include; visualising and representing 2D and 3D forms including 2D representations of 3D objects.

How Science Works

There are opportunities within this topic for learners to communicate information and ideas in appropriate ways using appropriate terminology; to consider applications and implications of science and evaluate their associated benefits and risks.

Learners should be able to demonstrate and apply their knowledge and understanding of:

(a) the process of stimulated emission and how this process leads to light emission that is coherent

(b) the idea that a population inversion ($N_2 > N_1$) is necessary for a laser to operate

(c) the idea that a population inversion is not (usually) possible with a 2-level energy system

(d) how a population inversion is attained in 3 and 4-level energy systems

(e) the process of pumping and its purpose

(f) the structure of a typical laser i.e. an amplifying medium between two mirrors, one of which partially transmits light

(g) the advantages and uses of a semiconductor laser i.e. small, cheap, far more efficient than other types of laser, and it is used for CDs, DVDs, telecommunication etc

6. NUCLEAR DECAY

Overview

This topic covers the spontaneous nature of nuclear decay and the nature of alpha, beta and gamma radiation. It introduces the concept of half-life, activity and decay constant. Learners study the exponential decay law in both graphical and algebraic form.

Working Scientifically

There are opportunities within this topic for learners to plot and interpret graphs; to process and analyse data using appropriate mathematical skills; to safely and correctly use a range of practical equipment and materials; to make and record observations; to use ionising radiation, including detectors.

Mathematical Skills

There are a number of opportunities for the development of mathematical skills in this unit. These include recognising and making use of appropriate units in calculations; recognising and using expressions in decimal and standard form; using an appropriate number of significant figures; finding arithmetic means; understanding simple probability; making order of magnitude calculations; changing the subject of an equation including non-linear equations; solving algebraic equations, including quadratic equations, using logarithms in relation to quantities that range over several orders of magnitude; plotting two variables from experimental or other data; sketching relationships which are modelled by: $y = e^{\pm x}$; applying the concepts underlying calculus (but without requiring the explicit use of derivatives or integrals) by solving equations involving rates of change, for example $\frac{\Delta x}{\Delta t} = -\lambda x$ using a graphical method or spreadsheet modelling.

How Science Works

There are opportunities within this topic for learners to use appropriate methodology, including ICT, to answer scientific questions and to solve scientific problems; to evaluate methodology, evidence and data, and resolve conflicting evidence to consider ethical issues in the treatment of humans and the environment, to evaluate the ways in which society uses science to inform decision making.

Learners should be able to demonstrate and apply their knowledge and understanding of:

(a) the spontaneous nature of nuclear decay; the nature of α, β and γ radiation, and equations to represent the nuclear transformations using the $^{A}_{Z}\mathrm{X}$ notation

(b) different methods used to distinguish between α, β and γ radiation and the connections between the nature, penetration and range for ionising particles

(c) how to make allowance for background radiation in experimental measurements

(d) the concept of the half-life, $T_{½}$

(e) the definition of the activity, A, and the Becquerel

(f) the decay constant, λ, and the equation $A = \lambda N$

(g) the exponential law of decay in graphical and algebraic form,
$N = N_o e^{-\lambda t}$ and $A = A_o e^{-\lambda t}$

or $N = \frac{N_o}{2^x}$ and $A = \frac{A_o}{2^x}$

where x is the number of half-lives elapsed – not necessarily an integer

(h) the derivation and use of $\lambda = \frac{\ln 2}{T_{\frac{1}{2}}}$

SPECIFIED PRACTICAL WORK

- Investigation of radioactive decay – a dice analogy
- Investigation of the variation of intensity of gamma radiation with distance

7. PARTICLES AND NUCLEAR STRUCTURE

Overview

This topic covers the nuclear atom and the idea that matter is composed of quarks and leptons. Learners study the quark composition of the neutron and the proton and the idea that quarks and antiquarks are never observed in isolation. The properties of the four interactions experienced by particles are discussed and learners are shown how to apply the conservation of charge, lepton number and quark number to given reactions.

Working Scientifically

There are opportunities within this topic for learners to present data in appropriate ways; to process and analyse using appropriate mathematical skills.

Mathematical Skills

There is an opportunity for learners to use ratios and fractions in this unit.

How Science Works

There are opportunities within this topic for learners to use theories, models and ideas to develop scientific explanations; to analyse and interpret data to provide evidence, recognise correlations and causal relationships; to evaluate methodology, evidence and data, and resolve conflicting evidence; to know that scientific knowledge and understanding develops over time; to evaluate the role of the scientific community in validating new knowledge and ensuring integrity.

Learners should be able to demonstrate and apply their knowledge and understanding of:

(a) the significance of the results of the Rutherford alpha particle scattering experiment

(b) how to approximate the maximum size of the Coulomb repulsion force between an alpha particle and a gold atom / nucleus for both the plum pudding model and the Rutherford model

(c) the idea that matter is composed of quarks and leptons and that there are three generations of quarks and leptons, although no questions will be set involving second or third generations

	leptons		quarks	
particle (symbol)	electron (e^-)	electron neutrino (ν_e)	up (u)	down (d)
charge (e)	1	0	$+\frac{2}{3}$	$-\frac{1}{3}$

(d) the idea that antiparticles exist for the particles given in the table above, that the properties of an antiparticle are identical to those of its corresponding particle apart from having opposite charge, and that particles and antiparticles annihilate

(e) symbols for a positron and for antiparticles of quarks and hadrons

(f) the idea that quarks and antiquarks are never observed in isolation, but are bound into composite particles called hadrons, or three types of baryon (combinations of 3 quarks), or antibaryons (combinations of 3 antiquarks) or mesons (quark-antiquark pairs)

(g) the quark compositions of the neutron and proton

(h) how to use data in the **table on page 45** to suggest the quark make-up of less well known first generation baryons and of charged pions

(i) the properties of the four forces or interactions experienced by particles as summarized in the table below

Interaction	Experienced by	Range	Comments
gravitational	all matter	infinite	very weak – negligible except between large objects such as planets
weak	all leptons, all quarks, so all hadrons	very short	only significant when the e-m and strong interactions do not operate
electromagnetic (e-m)	all charged particles	infinite	also experienced by neutral hadrons, as these are composed of quarks
strong	all quarks, so all hadrons	short	

(j) how to apply conservation of charge, lepton number and baryon number (or quark number) to given simple reactions

(k) the idea that neutrino involvement and quark flavour changes are exclusive to weak interactions

8. NUCLEAR ENERGY

Overview

This topic discusses the relationship between mass and energy and learners use the equation $E = mc^2$. Learners are shown how to calculate the binding energy per nucleon of a nucleus and relate this to the stability of the nucleus. The conservation of mass/energy is applied to particle interactions and the physics of fission and fusion is explored.

Working Scientifically

There are opportunities within this topic for learners to comment on experimental design and evaluate scientific methods; to present data in appropriate ways; to process and analyse data using appropriate experimental skills.

Mathematical Skills

There is an opportunity for learners to understand simple probability in this topic.

How Science Works

There are opportunities within this topic for learners to use knowledge and understanding to pose scientific questions, define scientific problems, present scientific arguments and scientific ideas; to consider applications and implications of science and evaluate their associated benefits and risks; to evaluate the ways in which society uses science to inform decision making. Learners can be given the opportunity to consider and evaluate the benefits and risks to society of the commissioning, building and siting of nuclear power stations. The ethical issues involved in the treatment of the surrounding environment can be considered and the way in which society uses the knowledge and understanding of science to inform decision making.

Learners should be able to demonstrate and apply their knowledge and understanding of:

(a) the association between mass and energy and that $E = mc^2$

(b) the binding energy for a nucleus and hence the binding energy per nucleon, making use, where necessary, of the unified atomic mass unit (u)

(c) how to calculate binding energy and binding energy per nucleon from given masses of nuclei

(d) the conservation of mass / energy to particle interactions – for example: fission, fusion

(e) the relevance of binding energy per nucleon to nuclear fission and fusion making reference when appropriate to the binding energy per nucleon versus nucleon number curve

9. MAGNETIC FIELDS

Overview

This topic covers the concept of magnetic fields and investigates the forces on current carrying conductors and moving charges in magnetic fields. The magnetic fields due to currents and the force between current carrying conductors is investigated. Learners also study the deflection of beams of charged particles in electric and magnetic fields.

Working Scientifically

The specified practical work in this topic gives learners the opportunity to plot and interpret graphs; process and analyse data using appropriate mathematical skills; make and record observations; keep appropriate records of experimental activities; to use online and offline research skills including websites, textbooks and other printed scientific sources of information; to use a data logger with a sensor to collect information.

Mathematical Skills

There are a number of opportunities for the development of mathematical skills in this unit. These include recognising and using expressions in decimal and standard form; using an appropriate number of significant figures; identifying uncertainties in measurements and using simple techniques to determine uncertainty; substituting numerical values into algebraic equations using appropriate units for physical quantities; plotting two variables from experimental or other data; determining the slope and intercept of a linear graph; calculating rate of change from a graph showing a linear relationship; using angles in regular 2D and 3D structures; visualising and representing 2D and 3D forms; using $\sin$, $\cos$ and $\tan$ in physical problems.

How Science Works

There are opportunities within this topic for learners to communicate information and ideas in appropriate ways using appropriate terminology; to consider applications and implications of science and evaluate their associated benefits and risks. Learners can study the motion of charged particles in magnetic fields to develop an understanding of how scientific knowledge and understanding develops over time. This understanding can lead to an appreciation, for example, of how charged particles behave in linear accelerators, cyclotrons and synchrotrons. This can help evaluate the role of the scientific community in validating new knowledge, for example, using the large hadron collider to reproduce the conditions which existed immediately after the Big Bang.

Learners should be able to demonstrate and apply their knowledge and understanding of:

(a) how to determine the direction of the force on a current carrying conductor in a magnetic field

(b) how to calculate the magnetic field, B, by considering the force on a current carrying conductor in a magnetic field i.e. understand how to use $F = BIl\sin\theta$

(c) how to use $F = Bqv\sin\theta$ for a moving charge in a magnetic field

(d) the processes involved in the production of a Hall voltage and understand that $V_H \propto B$ for constant I

(e) the shapes of the magnetic fields due to a current in a long straight wire and a long solenoid

(f) the equations $B = \frac{\mu_o I}{2\pi a}$ and $B = \mu_o nI$ for the field strengths due to a long straight wire and in a long solenoid

(g) the fact that adding an iron core increases the field strength in a solenoid

(h) the idea that current carrying conductors exert a force on each other and to predict the directions of the forces

(i) quantitatively, how ion beams of charged particles, are deflected in uniform electric and magnetic fields

(j) the motion of charged particles in magnetic and electric fields in linear accelerators, cyclotrons and synchrotrons

SPECIFIED PRACTICAL WORK

- Investigation of the force on a current in a magnetic field
- Investigation of magnetic flux density using a Hall probe

10. ELECTROMAGNETIC INDUCTION

Overview

This topic begins by defining magnetic flux and then explores the laws of Faraday and Lenz. Learners will apply these laws to determine the emf induced in a linear conductor moving at right angles to a magnetic field. The topic concludes with the derivation of the instantaneous emf induced in a coil rotating in a magnetic field.

Working Scientifically

There are opportunities within this topic for learners to solve problems set in practical contexts; to apply scientific knowledge to practical contexts; to present data in appropriate ways; to plot and interpret graphs.

Mathematical Skills

There are a number of opportunities for the development of mathematical skills in this unit. These include understanding and using the symbols: =, <, <<, >>, >, ∝, ≈; applying the concepts underlying calculus (but without requiring the explicit use of derivatives or integrals) by solving equations involving rates of change, for example $\frac{\Delta x}{\Delta t} = -\lambda x$ using a graphical method or spreadsheet modelling; visualising and representing 2D and 3D forms, including representations of 3D objects.

How Science Works

There is an opportunity within this topic for learners to use theories, models and ideas to develop scientific explanations. Learners can consider the applications and implications of science and the associated benefits to society by studying the application of Faraday's law to the case of a rotating coil in a magnetic field. They can consider how the invention of devices such as the a.c. generator has benefitted society. Lenz's law gives learners the opportunity to answer scientific questions and solve scientific problems.

Learners should be able to demonstrate and apply their knowledge and understanding of:

(a) the definition of magnetic flux as $\phi = AB\cos\theta$ and flux linkage $= N\phi$

(b) the laws of Faraday and Lenz

(c) how to apply the laws of Faraday and Lenz (i.e. emf = - rate of change of flux linkage)

(d) the idea that an emf is induced in a linear conductor moving at right angles to a uniform magnetic field

(e) qualitatively, how the instantaneous emf induced in a coil rotating at right angles to a magnetic field is related to the position of the coil, flux density, coil area and angular velocity

OPTIONS (Choice of 1 option from 4)

OPTION A: ALTERNATING CURRENTS

Overview

This topic begins by using Faraday's law to derive an expression for the induced emf in a coil rotating in a B-field and then develops the idea of the rms value of an alternating current or voltage. The phase relationships between current and voltage for capacitors and inductors in a.c. circuits are studied. The terms phase angle and impedance are discussed and the phenomenon of resonance in an LCR circuit is introduced.

Working Scientifically

There are opportunities within this topic for learners to solve problems set in practical contexts; to apply scientific knowledge to practical contexts; to plot and interpret graphs; to process and analyse data using appropriate mathematical skills.

Mathematical Skills

There are a number of opportunities for the development of mathematical skills in this unit. These include estimating results; changing the subject of an equation, including non-linear equations; substituting numerical values into algebraic equations using appropriate units for physical quantities; using angles in regular 2D and 3D structures.

How Science Works

There is an opportunity within this topic for learners to communicate information and ideas in appropriate ways using appropriate technology to consider applications and implications of science and evaluate their associated benefits and risks.

Learners should be able to demonstrate and apply their knowledge and understanding of:

(a) using Faraday's law, the principle of electromagnetic induction applied to a rotating coil in a magnetic field

(b) the idea that the flux linkage of a rotating flat coil in a uniform magnetic B-field is $BAN\cos\omega t$ because the angle between the coil normal and the field can be expressed as $\theta = \omega t$

(c) the equation $V = \omega BAN \sin\omega t$ for the induced emf in a rotating flat coil in a uniform B-field

(d) the terms frequency, period, peak value and rms value when applied to alternating potential differences and currents

(e) the idea that the rms value is related to the energy dissipated per cycle, and use the relationships
$I = \frac{I_0}{\sqrt{2}}$ and $V = \frac{V_0}{\sqrt{2}}$, (including $V_{\text{rms}} = \frac{\omega BAN}{\sqrt{2}}$)

(f) the idea that the mean power dissipated in a resistor is given by $P = IV = I^2R = \frac{V^2}{R}$ where V and I are the rms values

(g) the use of an oscilloscope (CRO or PC based via USB or sound card) to measure
- a.c. and d.c. voltages and currents
- frequencies

(h) the 90° phase lag of current behind potential difference for an inductor in a sinusoidal a.c. circuit

(i) the idea that $X_L = \frac{V_{\text{rms}}}{I_{\text{rms}}}$ is called the reactance, X_L, of the inductor, and to use the equation $X_L = \omega L$

(j) the 90° phase lead of current ahead of potential difference for a capacitor in a sinusoidal a.c. circuit, and to use the equation $X_C = \frac{V_{\text{rms}}}{I_{\text{rms}}}$, where $X_C = \frac{1}{\omega C}$

(k) the idea that the mean power dissipation in an inductor or a capacitor is zero

(l) how to add potential differences across series RC, RL and RCL combinations using phasors

(m) how to calculate phase angle and impedance, Z, (defined as $Z = \frac{V_{\text{rms}}}{I_{\text{rms}}}$ for such circuits)

(n) how to derive an expression for the resonance frequency of an RCL series circuit

(o) the idea that the Q factor of a RCL circuit is the ratio $\frac{V_L}{V_R}\left(=\frac{V_C}{V_R}\right)$ at resonance

(p) the idea that the sharpness of the resonance curve is determined by the Q factor of the circuit

OPTION B: MEDICAL PHYSICS

Overview

This topic begins by studying the nature and properties of X-rays and the uses of X-rays in imaging soft tissue. Techniques of radiography are studied together with the use of a rotating beam X-ray computed tomography scanner. The generation and detection of ultrasound, its use for diagnosis and the study of blood flow are introduced. The principles of magnetic resonance are discussed together with the use of MRI in obtaining diagnostic information. The uses of radionuclides as tracers is covered, together with the use of the gamma camera and positron emission tomography scanning.

Working Scientifically

There are opportunities within this topic for learners to solve problems set in practical contexts; to apply scientific knowledge to practical contexts; to plot and interpret graphs; to process and analyse data using appropriate mathematical skills.

Mathematical Skills

There are a number of opportunities for the development of mathematical skills in this unit. These include estimating results; using calculators to find and use power, exponential and logarithmic functions; making order of magnitude calculations; substituting numerical values into algebraic equations using appropriate units for physical quantities; using angles in regular 2D and 3D structures.

How Science Works

There are opportunities within this topic for learners to consider applications and implications of science and evaluate their associated benefits and risks; to consider ethical issues in the treatment of humans; to evaluate the role of the scientific community in validating new knowledge and ensuring integrity; to evaluate the ways in which society uses science to inform decision making.

Learners should be able to demonstrate and apply their knowledge and understanding of:

(a) the nature and properties of X-rays

(b) the production of X-ray spectra including methods of controlling the beam intensity and photon energy

(c) the use of high energy X-rays in the treatment of patients (therapy) and low energy X-rays in diagnosis

(d) the equation $I = I_0 \exp(-\mu x)$ for the attenuation of X-rays

(e) the use of X-rays in imaging soft tissue, and fluoroscopy to produce real time X-rays using image intensifiers

(f) techniques of radiography including using digital image receptors

(g) the use of a rotating beam X-ray computed tomography (CT) scanner

(h) the generation and detection of ultrasound using piezoelectric transducers

(i) scanning with ultrasound for diagnosis including A-scans and B-scans incorporating examples and applications

(j) the significance of acoustic impedance, defined by $Z = c\rho$ for the reflection and transmission of sound waves at tissue boundaries, including the need for a coupling medium

(k) the use of the Doppler equation $\frac{\Delta f}{f_0} = \frac{2v}{c}\cos\theta$ to study blood flow using an ultrasound probe

(l) the principles of magnetic resonance with reference to precession nuclei, resonance and relaxation time, and to apply the equation $f = 42.6 \times 10^6 B$ for the Lamour frequency

(m) the use of MRI in obtaining diagnostic information about internal structures

(n) the advantages and disadvantages of ultrasound imaging, X-ray imaging and MRI in examining internal structures

(o) the effects of α, β, and γ radiation on living matter

(p) the Gray (Gy) as the unit of absorbed dose and the Sievert (Sv) as the unit of equivalent dose and effective dose. Define absorbed dose as energy per kilogram

(q) the use of the equations
- equivalent dose = absorbed dose × (radiation) weighting factor $H = DW_R$ and
- effective dose = equivalent dose × tissue weighting factor $E = HW_T$

(r) the uses of radionuclides as tracers to image body parts with particular reference to technetium-99m (Tc-99m)

(s) the use of the gamma camera including the principles of the collimator, scintillation counter and photomultiplier / CCD

(t) positron emission tomography (PET) scanning and its use in detecting tumours

OPTION C: THE PHYSICS OF SPORTS

Overview

This topic studies the use of the centre of gravity in explaining how stability and toppling is achieved in various sporting contexts. The concept of moment of inertia is introduced together with the principle of conservation of angular momentum and their application to different sporting contexts is studied. Projectile motion and the Bernouilli equation and their application to sporting events is also studied.

Working Scientifically

There are opportunities within this topic for learners to solve problems set in practical contexts; to apply scientific knowledge to practical contexts; to plot and interpret graphs; to process and analyse data using appropriate mathematical skills.

Mathematical Skills

There are a number of opportunities for the development of mathematical skills in this unit. These include making order of magnitude calculations; substituting numerical values into algebraic equations using appropriate units for physical quantities; solving algebraic equations, including quadratic equations; visualising and representing 2D and 3D forms, including 2D representations of 3D objects; calculating areas of triangles, circumferences and areas of circles, surface areas and volumes of rectangular blocks, cylinders and spheres.

How Science Works

There are opportunities within this topic for learners to use appropriate methodology, including ICT, to answer scientific questions and to solve scientific problems; to communicate information and ideas in appropriate ways using appropriate terminology; to consider applications and implications of science and evaluate their associated benefits and risks.

Learners should be able to demonstrate and apply their knowledge and understanding of:

(a) how to use the centre of gravity to explain how stability and toppling is achieved in various sporting contexts

(b) how to use the principle of moments to determine forces within
- various muscle systems in the human body and
- other sporting contexts, for example, sailing

(c) how to use Newton's 2nd law in the form $Ft = mv - mu$ in various sporting contexts

(d) the coefficient of restitution as

$e = \dfrac{\text{Relative speed after collision}}{\text{Relative speed before collision}}$ and also use it in the form $e = \sqrt{\dfrac{h}{H}}$ where h is the bounce height and H is the drop height

(e) what is meant by the moment of inertia of a body

(f) how to use equations to determine the moment of inertia, I, for example

- a solid sphere $I = \frac{2}{5}mr^2$
- a thin spherical shell $I = \frac{2}{3}mr^2$ where m is the mass and r is the radius

(g) the idea that angular acceleration, α , is defined as the rate of change of angular velocity, ω, and how to use the equation $\alpha = \frac{\omega_2 - \omega_1}{t}$

(h) the idea that torque, τ, is given as $\tau = I\alpha$

(i) angular momentum, L, is given as $L = I\omega$ where ω is the angular velocity

(j) the principle of conservation of angular momentum and use it to solve problems in sporting contexts

(k) how to use the equation for the rotational kinetic energy, rotational $KE = \frac{1}{2}I\omega^2$

(l) how to use the principle of conservation of energy including the use of linear and rotational kinetic energy as well as gravitational and elastic potential energy in various sporting contexts

(m) how to use projectile motion theory in sporting contexts

(n) how to use Bernoulli's equation $p = p_0 - \frac{1}{2}\rho v^2$ in sporting contexts

(o) how to determine the magnitude of the drag force using $F_D = \frac{1}{2}\rho v^2 A C_D$ where C_D is the drag coefficient

OPTION D: ENERGY AND THE ENVIRONMENT

Overview

In this topic, learners will consider different factors which affect the rate at which the temperature of the Earth rises. Common sources of renewable and non-renewable energy are discussed and their development as sources of energy, both in the UK and internationally are compared. Learners study the effect of insulation on thermal energy loss and perform quantitative calculations on comparative uses of energy transfer.

Working Scientifically

There are opportunities within this topic for learners to solve problems set in practical contexts; to apply scientific knowledge to practical contexts; to plot and interpret graphs; to process and analyse data using appropriate mathematical skills.

Mathematical Skills

There are a number of opportunities for the development of mathematical skills in this unit. These include estimating results; substituting numerical values into algebraic equations using appropriate units for physical quantities; solving algebraic equations, including quadratic equations.

How Science Works

There are opportunities within this topic for learners to use knowledge and understanding to pose scientific questions, define scientific problems, present scientific arguments and scientific ideas; to communicate information and ideas in appropriate ways using appropriate terminology, to consider applications and implications of science and evaluate their associated benefits and risks; to consider ethical issues in the treatment of the environment; to evaluate the role of the scientific community invalidating new knowledge and ensuring integrity; to evaluate the ways in which society uses science to inform decision making.

Learners should be able to demonstrate and apply their knowledge and understanding of:

(a) how the following affect the rate at which the temperature of the Earth rises including:

- (i) the need for thermal equilibrium: that is the balance between energy inflow from the Sun and energy re-radiated from the Earth in the context of global energy demand and the effect of CO_2 levels in the atmosphere

- (ii) the origin and means of transmission of solar energy and the form of the Sun's power spectrum including the idea that wavelengths are converted into the near infrared in the atmosphere

- (iii) the use of Wien's law ($\lambda_{max} T$ = constant) and Stefan-Boltzman T^4 law in the context of solar power

- (iv) use of the density equation and Archimedes' principle to explain why rising sea levels are due to melting ice caps and that the melting of ice on land increases sea levels but melting icebergs do not

(b) the common sources of renewable and non-renewable energy and be able to compare their development and use both in the UK and internationally

(i) solar power:
- the idea that the main branch of the proton-proton chain is the main energy production mechanism in the Sun
- the intensity of power from the Sun $I = \frac{P}{A}$ and the inverse square law for a point source
- how to perform energy conversions using photovoltaic cells (including efficiency calculations)

(ii) wind power:
- the power available from a flowing fluid $= \frac{1}{2} A\rho v^3$
- the factors affecting the efficiency of wind turbines

(iii) tidal barrages, hydroelectric power and pumped storage:
- the principles of energy conversion (E_p to E_k) in tidal barrage, hydroelectric and pumped storage schemes and be able to carry out energy and power calculations related to these schemes and compare with the energy produced from wind

(iv) nuclear fission and fusion:
- the principles underlying breeding and enrichment in nuclear fission applications
- the difficulties in producing sustained fusion power - fusion triple product

(c) the principles of fuel cell operation and the benefits of fuel cells particularly regarding greenhouse gas emissions

(d) the thermal conduction equation in the form

$$\frac{\Delta Q}{\Delta t} = -AK \frac{\Delta \theta}{\Delta x}$$

(e) the effect of insulation on thermal energy loss and be able to calculate the heat loss for parallel surfaces using the rate of energy transfer $= UA\Delta\theta$ including cases where different materials are in contact

3 ASSESSMENT

3.1 Assessment objectives and weightings

Below are the assessment objectives for this specification. Learners must:

AO1
Demonstrate knowledge and understanding of scientific ideas, processes, techniques and procedures

AO2
Apply knowledge and understanding of scientific ideas, processes, techniques and procedures:
- in a theoretical context
- in a practical context
- when handling qualitative data
- when handling quantitative data

AO3
Analyse, interpret and evaluate scientific information, ideas and evidence, including in relation to issues, to:
- make judgements and reach conclusions
- develop and refine practical design and procedures

The table below shows the weighting of each assessment objective for each component and for the qualification as a whole.

	AO1	**AO2**	**AO3**
Component 1	9.4%	14.1%	7.8%
Component 2	9.4%	14.1%	7.8%
Component 3	11.2%	16.8%	9.4%
Overall weighting	30%	45%	25%

For each series:

- The weighting for the assessment of mathematical skills will be a minimum of 40%.
- The weighting for the indirect assessment of practical skills will be a minimum of 15%.

The ability to select, organise and communicate information and ideas coherently using appropriate scientific conventions and vocabulary will be tested across the assessment objectives.

3.2 Arrangements for non-exam assessment

PRACTICAL ENDORSEMENT

The assessment of practical skills is a compulsory requirement of the course of study for A level qualifications in Physics. It will appear on all learners' certificates as a separately reported result, alongside the overall grade for the qualification. The arrangements for the assessment of practical skills will be common to all awarding organisations. These arrangements will include:

- A minimum of 12 practical activities to be carried out by each learner which, together, meet the requirements of Appendix A part (b) (Practical skills identified for direct assessment and developed through teaching and learning) and Appendix A part (c) (Use of apparatus and techniques) from the prescribed subject content, published by the Department for Education.

- Teachers will assess learners against Common Practical Assessment Criteria (CPAC) issued by the awarding organisations. The CPAC (see pages 61 and 62) are based on the requirements of Appendix A parts (b) and (c) of the subject content requirements published by the Department for Education, and define the minimum standard required for the achievement of a pass.

- Each learner will keep an appropriate record of their assessed practical activities.

- Learners who demonstrate the required standard across all the requirements of the CPAC will receive a 'pass' grade.

- The practical activities prescribed in this specification (the specified practicals) provide opportunities for demonstrating competence in all the skills identified, together with the use of apparatus and techniques for each subject. However, learners can also demonstrate these competences in any additional practical activity undertaken throughout the course of study which covers the requirements of Appendix A part (c).

- There will be no separate assessment of practical skills for AS qualifications.

- Learners will answer questions in the AS and A level examination papers that assess the requirements of Appendix A part (a) (Practical skills identified for indirect assessment and developed through teaching and learning) from the prescribed subject content, published by the Department for Education.

Criteria for the assessment of practical competency in A level Physics (CPAC)	
Competency	**Practical Mastery:** In order to achieve a **pass,** learners will need to have met the following expectations. Learners will be expected to develop these competencies through the acquisition of the technical skills specified in Appendix A part (c). Learners can demonstrate these competencies in any practical activity undertaken throughout the course of study. The practical activities prescribed in the subject specification, which cover the requirements of Appendix A part (c), will provide opportunities for demonstrating competence in all the skills identified together with the use of apparatus and practical techniques for each subject. Learners may work in groups but must be able to demonstrate and record independent evidence of their competency. This must include evidence of independent application of investigative approaches and methods to practical work. Teachers who award a pass to their learners need to be confident that the learner consistently and routinely exhibits the competencies listed below before completion of the A level course.
1. Follows written procedures	Correctly follows written instructions to carry out the experimental techniques or procedures.
2. Applies investigative approaches and methods when using instruments and equipment	Correctly uses appropriate instrumentation, apparatus and materials (including ICT) to carry out investigative activities, experimental techniques and procedures with minimal assistance or prompting. Carries out techniques or procedures methodically, in sequence and in combination, identifying practical issues and making adjustments when necessary. Identifies and controls significant quantitative variables where applicable, and plans approaches to take account of variables that cannot readily be controlled. Selects appropriate equipment and measurement strategies in order to ensure suitably accurate results.

3.	Safely uses a range of practical equipment and materials	Identifies hazards and assesses risks associated with these hazards, making safety adjustments as necessary, when carrying out experimental techniques and procedures in the lab or field. Uses appropriate safety equipment and approaches to minimise risks with minimal prompting.
4.	Makes and records observations	Makes accurate observations relevant to the experimental or investigative procedure. Obtains accurate, precise and sufficient data for experimental and investigative procedures and records this methodically using appropriate units and conventions.
5.	Researches, references and reports	Uses appropriate software and/or tools to process data, carry out research and report findings. Cites sources of information are cited demonstrating that research has taken place, supporting planning and conclusions.

Marking and Standardisation
The practical work is assessed by teachers. WJEC Eduqas will support teachers in making judgements against the criteria for assessment.

In co-ordination with other exam boards, WJEC Eduqas will monitor how centres provide learners with opportunities to develop and demonstrate the required practical skills and how they mark the assessments.

Every centre will be monitored at least once in a two-year period in respect of at least one of the A level science subjects.

In common with other exam boards, WJEC Eduqas will require centres to provide a statement annually confirming they have taken reasonable steps to ensure that learners:

- have undertaken the minimum number of practical activities, and
- have made a contemporaneous record of their work.

If a centre fails to provide a statement, or provides a false statement, this will be treated as malpractice and/or maladministration. Learners will only get a certificate for the practical endorsement if they achieve at least a grade E in the examined part of the qualification.

Practical endorsement results for each learner need to be submitted by centres to WJEC Eduqas by 15 May each year.

4 TECHNICAL INFORMATION

4.1 Making entries

This is a linear qualification in which all assessments must be taken at the end of the course. Assessment opportunities will be available in the months of May and June each year, from 2017, until the end of the life of this specification.

A qualification may be taken more than once. Candidates must resit all examination components in the same series.

The endorsement grade for NEA may be carried forward for the life of the specification, even if it was awarded by a different awarding body. If a candidate resits an NEA component (rather than carrying forward the previous NEA endorsement grade), it is the new grade that will be used, even if this is 'Not Classified'.

Where a candidate has certificated on two or more previous occasions, the most recent NEA endorsement grade is carried forward, even if this is 'Not Classified'.

The entry code appears below.

WJEC Eduqas A level Physics: A420QS

The current edition of our *Entry Procedures and Coding Information* gives up-to-date entry procedures.

4.2 Grading, awarding and reporting

A level qualifications are reported as a grade from A* to E. Results not attaining the minimum standard for the award will be reported as U (unclassified).

APPENDIX A

WORKING SCIENTIFICALLY

The practical skills can be split into those which can be assessed indirectly through written examinations (part (a)) and those that will be assessed directly by teachers through appropriate practical activities (part (b)).

Part (a) - Practical skills identified for indirect assessment and developed through teaching and learning

Question papers will assess learners' abilities to:

Independent thinking

- solve problems set in practical contexts
- apply scientific knowledge to practical contexts

Use and application of scientific methods and practices

- comment on experimental design and evaluate scientific methods
- present data in appropriate ways
- evaluate results and draw conclusions with reference to measurement uncertainties and errors
- identify variables including those that must be controlled

Numeracy and the application of mathematical concepts in a practical context

- plot and interpret graphs
- process and analyse data using appropriate mathematical skills as exemplified in the mathematical appendix (see Appendix C)
- consider margins of error, accuracy and precision of data

Instruments and equipment

- know and understand how to use a wide range of experimental and practical instruments, equipment and techniques appropriate to the knowledge and understanding included in the specification

Part (b) - Practical skills identified for direct assessment and developed through teaching and learning

Practical work carried out throughout the course will enable learners to develop the following skills.

Independent thinking

- apply investigative approaches and methods to practical work

Use and apply scientific methods and practices

- safely and correctly use a range of practical equipment and materials
- follow written instructions
- make and record observations
- keep appropriate records of experimental activities
- present information and data in a scientific way
- use appropriate software and tools to process data, carry out research and report findings

Research and referencing

- use online and offline research skills including websites, textbooks and other printed scientific sources of information
- correctly cite sources of information

Instruments and equipment

- use a wide range of experimental and practical instruments, equipment and techniques appropriate to the knowledge and understanding included in the specification

Part (c) – Use of apparatus and techniques

The practical work specified in the subject content section has been chosen to facilitate learners in developing the skills and acquiring the techniques listed below.

Practical techniques to be gained by learners

- use appropriate analogue apparatus to record a range of measurements (to include length/distance, temperature, pressure, force, angles, volume) and to interpolate between scale markings
- use appropriate digital instruments, including electrical multimeters, to obtain a range of measurements (to include time, current, voltage, resistance, mass)
- use methods to increase accuracy of measurements, such as timing over multiple oscillations, or use of fiducial marker, set square or plumb line
- use stopwatch or light gates for timing
- use calipers and micrometers for small distances, using digital or vernier scales
- correctly construct circuits from circuit diagrams using D.C. power supplies, cells, and a range of circuit components, including those where polarity is important
- design, construct and check circuits using D.C. power supplies, cells, and a range of circuit components
- use signal generator and oscilloscope, including volts/division and time-base
- generate and measure waves, using microphone and loudspeaker, or ripple tank, or vibration transducer, or microwave / radio wave source
- use laser or light source to investigate characteristics of light, including interference and diffraction
- use ICT such as computer modelling, or data logger with a variety of sensors to collect data, or use of software to process data
- use ionising radiation, including detectors

APPENDIX B

PRACTICAL TECHNIQUE REQUIREMENTS AND EXEMPLIFICATION

Practical Technique	Component	Topic	Specified practical work which exemplify the practical technique
Use appropriate analogue apparatus to record a range of measurements (to include length/distance, temperature, pressure, force, angles, volume) and to interpolate between scale markings	1	Basic physics	Measurement of the density of solids
	1	Basic physics	Determination of unknown masses by using the principle of moments
	1	Kinematics	Measurement of g by freefall
	1	Dynamics	Investigation of Newton's 2nd Law
	2	Resistance	Determination of resistivity of a metal
	2	Resistance	Investigation of the variation of resistance with temperature for a metal wire
	2	Solids under stress	Determination of Young modulus of a metal in the form of a wire
	2	Solids under stress	Investigation of the force-extension relationship for rubber
	3	Wave properties	Determination of wavelength using Young's double slits
	3	Wave properties	Determination of wavelength using a diffraction grating
	3	Wave properties	Determination of the speed of sound using stationary waves
	3	Refraction of light	Measurement of the refractive index of a material
Use appropriate digital instruments, including electrical multimeters, to obtain a range of measurements (to include time, current, voltage, resistance, mass)	1	Basic physics	Measurement of the density of solids
	1	Kinematics	Measurement of g by freefall
	1	Dynamics	Investigation of Newton's 2nd Law
	2	Resistance	Investigation of the I-V characteristics of the filament of a lamp and metal wire at constant temperature
	2	Resistance	Determination of resistivity of a metal
	2	Resistance	Investigation of the variation of resistance with temperature for a metal wire
	2	D.C. circuits	Determination of the internal resistance of a cell
Use methods to increase accuracy of measurements, such as timing over multiple oscillations, or use of fiducial marker, set square or plumb line	1	Kinematics	Measurement of g by freefall
	2	Solids under stress	Investigation of the force-extension relationship for rubber
Use stopwatch or light gates for timing	1	Kinematics	Measurement of g by freefall
	1	Dynamics	Investigation of Newton's 2nd Law

Use calipers and micrometers for small distances, using digital or vernier scales	2	Resistance	Determination of resistivity of a metal
	2	Solids under stress	Determination of Young modulus of a metal in the form of a wire
	2	Resistance	Investigation of the I-V characteristics of the filament of a lamp and metal wire at constant temperature
	2	Resistance	Determination of resistivity of a metal
	2	Resistance	Investigation of the variation of resistance with temperature for a metal wire
	2	D.C. circuits	Determination of the internal resistance of a cell
	3	Lasers	Determination of h using LEDs
Correctly construct circuits from circuit diagrams using D.C. power supplies, cells, and a range of circuit components, including those where polarity is important	2	Resistance	Investigation of the I-V characteristics of the filament of a lamp and metal wire at constant temperature
	2	Resistance	Determination of resistivity of a metal
	2	Resistance	Investigation of the variation of resistance with temperature for a metal wire
	2	D.C. circuits	Determination of the internal resistance of a cell
	3	Lasers	Determination of h using LEDs
	3	Magnetic fields	Investigation of the force on a current in a magnetic field
Use signal generator and oscilloscope, including volts/division and time-base	3	Wave properties	Determination of the speed of sound using stationary waves
	3	Magnetic fields	Investigation of magnetic flux density using a Hall probe
	2	Capacitance	Investigating the charging and discharging of a capacitor to determine the time constant
	2	Capacitance	Investigation of the energy stored in a capacitor
Generate and measure waves, using microphone and loudspeaker, or ripple tank, or vibration transducer, or microwave / radio wave source	3	The nature of waves	Measurement of the intensity variations for polarisation
	3	Wave properties	Determination of the speed of sound using stationary waves
Use laser or light source to investigate characteristics of light, including interference and diffraction	3	Wave properties	Determination of wavelength using Young's double slits
	3	Wave properties	Determination of wavelength using a diffraction grating
	3	Refraction of light	Measurement of the refractive index of a material

Use ICT such as computer modelling, or data logger with a variety of sensors to collect data, or use of software to process data	1	Kinematics	Measurement of g by freefall
	1	Dynamics	Investigation of Newton's 2nd Law
	1	Vibrations	Measurement of g with a pendulum
	1	Vibrations	Investigation of the damping of a spring
	1	Thermal physics	Estimation of absolute zero by use of the gas laws
	1	Thermal physics	Measurement of the specific heat capacity for a solid
	2	Resistance	Determination of resistivity of a metal
	2	Resistance	Investigation of the variation of resistance with temperature for a metal wire
	2	D.C. circuits	Determination of the internal resistance of a cell
	2	Capacitance	Investigation of the charging and discharging of a capacitor to determine the time constant
	2	Capacitance	Investigation of the energy stored in a capacitor
	2	Solids under stress	Determination of Young modulus of a metal in the form of a wire
	2	Solids under stress	Investigation of the force-extension relationship for rubber
	3	Lasers	Determination of h using LEDs
	3	Nuclear decay	Investigation of radioactive decay – a dice analogy
	3	Nuclear decay	Investigation of the variation of intensity of gamma radiation with distance
	3	Magnetic fields	Investigation of the force on a current in a magnetic field
	3	Magnetic fields	Investigation of magnetic flux density using a Hall probe
Use ionising radiation, including detectors	3	Nuclear decay	Investigation of the variation of intensity of gamma radiation with distance

APPENDIX C

MATHEMATICAL REQUIREMENTS AND EXEMPLIFICATION

Mathematical skills	Exemplification of mathematical skill in the context of A level Physics (assessment is not limited to the examples given below)	Areas of the specification which exemplify the mathematical skill (assessment is not limited to the examples below)
Arithmetic and numerical computation		
Recognise and make use of appropriate units in calculations	Learners may be tested on their ability to • identify the correct units for physical properties such as m s^{-1}, the unit for velocity • convert between units with different prefixes for example, cm^3 to m^3	1.1(c) 1.2(c) 1.2(d) 1.3(f) 1.4(c) 1.6(d) 1.7(e) 2.3(i) 2.4(j) 2.5(b) 2.6(a) 2.8(d) 3.3(b) 3.4(c) 3.6(g) 3.9(f)
Recognise and use expressions in decimal and standard form	Learners may be tested on their ability to • use physical constants expressed in standard form such as c = 3.00 x 10^8 m s^{-1}	1.1(k) 1.2(g) 1.3(f) 1.4(c) 1.7(a) 2.1(g) 2.2(h) 2.4(j) 2.6(a) 2.7(d) 3.1(g) 3.2(h) 3.4(m) 3.6(g) 3.9(b)
Use ratios, fractions and percenges	Learners may be tested on their ability to • calculate efficiency of devices • calculate percentage uncertainties in measurements	1.4(c) 1.7(f) 1.8(c) 2.1(g) 2.3(d) 2.4(h)
Estimate results	Learners may be tested on their ability to • estimate the effect of changing experimental parameters on measurable values	1.8(k) 2.2(i) 2.2(m) 2.3(h) 2.7(c) 2.8(l) 3.3(d) 3.A(p) 3.B(q) 3.D(b)(ii)
Use calculators to find and use power, exponential and logarithmic functions	Learners may be tested on their ability to • solve for unknowns in decay problems such as $N = N_o e^{-\lambda t}$	1.4(d) 1.5(g) 2.2(f) 2.4(j) 2.6(a) 3.6(g)(h) 3.B(d)

Use calculators to handle $\sin x$, $\cos x$, $\tan x$ when x is expressed in degrees or radians	Learners may be tested on their ability to • calculate the direction of resultant vectors	1.1(e) 1.6(d) 3.3(b) 1.1(f) 1.6(g) 1.1(j) 2.6(e) 1.4(e) 3.2(i)
Handling data		
Use an appropriate number of significant figures	Learners may be tested on their ability to • report calculations to an appropriate number of significant figures given raw data quoted to varying numbers of significant figures • understand that calculated results can only be reported to the limits of the least accurate measurement	1.1(i) 3.6(b) 1.3(c) 3.9(b) 1.6(j) 1.8(b) 2.2(c) 2.2(h) 2.4(g) 2.5(b) 3.2(o) 3.3(a) 3.4(c)
Find arithmetic means	Learners may be tested on their ability to • calculate a mean value for repeated experimental readings	1.1(g) 2.3(h) 1.2(a) 2.4(i) 1.6(i) 3.1(e) 2.2(c) 3.6(g)
Understand simple probability	Learners may be tested on their ability to • understand probability in the context of radioactive decay	3.4(b) 3.6(d) – (h) 3.8(d)
Make order of magnitude calculations	Learners may be tested on their ability to • evaluate equations with variables expressed in different orders of magnitude	1.5(g) 2.4(d) 3.2(h) 1.7(c) 2.5(b) 3.4(e) 1.8(c) 2.6(a) 3.6(g) 2.1(g) 2.7(d) 3.B(k) 2.2(h) 2.8(b) 3.C(i)
Identify uncertainties in measurements and use simple techniques to determine uncertainty when data are combined by addition, subtraction, multiplication, division and raising to powers	Learners may be tested on their ability to • determine the uncertainty where two readings for length need to be added together	1.1(i) 1.6(j) 2.2(c) 2.3(i) 2.4(g) 2.5(b) 3.2(i) 3.3(a) 3.9(b)
Algebra		
Understand and use the symbols: =, <, <<, >>, >, ∝, ≈, Δ	Learners may be tested on their ability to • recognise the significance of the symbols in the expression: $F \propto \frac{\Delta p}{\Delta t}$	1.1(c) 2.5(b) 1.3(e) 2.6(f) 1.5(g) 2.8(h) 1.6(d) 3.2(h) 1.8(g) 3.6(g) 2.1(d) 3.9(b) 2.4(j) 3.10(c)

Change the subject of an equation, including non-linear equations	Learners may be tested on their ability to • rearrange $E = mc^2$ to make m the subject	1.2(d) 2.2(f) 3.1(g) 1.3(c) 2.4(f) 3.3(e) 1.5(g) 2.6(a) 3.6(h) 1.7(f) 2.8(k) 3.A(e)
Substitute numerical values into algebraic equations using appropriate units for physical quantities	Learners may be tested on their ability to • calculate the momentum p of an object by substituting the values for mass m and velocity v into the equation $p = mv$	1.1(g) 2.6(a) 3.10(a) 1.2(g) 2.8(m) 3.A(i) 1.3(d) 3.2(h) 3.B(k) 1.4(c) 3.3(b) 3.C(d) 1.6(f) 3.6(f) 3.D(d) 2.4(c) 3.9(c)
Solve algebraic equations, including quadratic equations	Learners may be tested on their ability to • solve kinematic equations for constant acceleration such as: $v = u + at$ and $s = ut + \frac{1}{2}at^2$	1.3(e) 2.3(h) 3.2(o) 1.4(d) 2.4(g) 3.3(b) 1.6(b) 2.5(a) 3.6(h) 1.7(a) 2.7(d) 3.C(g) 1.8(c) 2.8(k) 3.D(b)
Use logarithms in relation to quantities that range over several orders of magnitude	Learners may be tested on their ability to • recognise and interpret real world examples of logarithmic scales	2.4(j) 3.6(g)
Graphs		
Translate information between graphical, numerical and algebraic forms	Learners may be tested on their ability to • calculate Young modulus for materials using stress-strain graphs	1.2(c) 2.3(h) 3.4(d) 1.6(c) 2.5(c) 1.6(k) 2.6(a) 1.8(h) 2.8(l) 2.2(h) 3.3(a)
Plot two variables from experimental or other data	Learners may be tested on their ability to • plot graphs of extension of a wire against force applied	1.3(c) 2.5(g) 3.9(b) 1.8(k) 3.2(h) 3.9(d) 1.2(c) 3.4(e) 2.4(g) 3.6(b)
Understand that $y = mx + c$ represents a linear relationship	Learners may be tested on their ability to • rearrange and compare $v = u + at$ with $y = mx + c$ for a velocity-time graph in constant acceleration problems	1.2(c) 3.4(e) 1.3(c) 3.9(b) 1.8(k) 2.2(h) 2.3(h) 2.5(a)
Determine the slope and intercept of a linear graph	Learners may be tested on their ability to • read off and interpret the intercept point from a graph for example, the initial velocity in a velocity-time graph	1.2(b) 2.5(b) 1.3(c) 3.3(a) 1.6(i) 3.4(d) 2.2(h) 3.9(b) 2.3(h) 2.4(g)
Calculate rate of change from a graph showing a linear relationship	Learners may be tested on their ability to • calculate acceleration from a linear velocity-time graph	1.2(b) 3.3(a) 1.3(c) 3.9(b) 1.6(c) 2.2(h)

Draw and use the slope of a tangent to a curve as a measure of rate of change	Learners may be tested on their ability to • draw a tangent to the curve of a displacement–time graph and use the gradient to approximate the velocity at a specific time	1.2(c) 1.6(h) 2.2(c) 2.6(a)
Distinguish between instantaneous rate of change and mean rate of change	Learners may be tested on their ability to • understand that the gradient of the tangent of a displacement–time graph gives the velocity at a point in time which is a different measure to the mean velocity	1.2(c) 1.6(h)
Understand the possible physical significance of the area between a curve and the x-axis and be able to calculate it or estimate it by graphical methods as appropriate	Learners may be tested on their ability to • recognise that for a capacitor the area under a voltage-charge graph is equivalent to the energy stored	1.8(h) 2.4(g) 2.5(c)
Apply the concepts underlying calculus (but without requiring the explicit use of derivatives or integrals) by solving equations involving rates of change, for example $\frac{\Delta x}{\Delta t} = -\lambda x$ using a graphical method or spreadsheet modelling	Learners may be tested on their ability to • determine g from a distance-time plot, projectile motion	1.2(e) 1.2(g) 1.6(c) 1.6(h) 3.6(g) 3.10(c)
Interpret logarithmic plots	Learners may be tested on their ability to • obtain time constant for capacitor discharge by interpreting plot of $\log V$ against time	2.4(j) 2.6(g)
Use logarithmic plots to test exponential and power law variations.	Learners may be tested on their ability to • use logarithmic plots with the decay law of radioactivity / charging and discharging of a capacitor	2.4(j) 2.6(g)

Sketch relationships which are modelled by: $y=\frac{k}{x}$, $y=kx^2$, $y=\frac{k}{x^2}$, $y=kx$, $y=\sin x$, $y=\cos x$, $y=e^{\pm x}$ and $y=\sin^2 x$, $y=\cos^2 x$ as applied to physical relationships	Learners may be tested on their ability to • sketch relationships between pressure and volume for an ideal gas	1.2(e) 1.6(h) 1.7(a) 2.2(c) 2.6(a) 3.6(g)
Geometry and trigonometry		
Use angles in regular 2D and 3D structures	Learners may be tested on their ability to • interpret force diagrams to solve problems	1.1(f) 3.2(i) 3.10(a) 1.1(k) 3.3(b) 3.A(b) 1.4(b) 3.3(d) 3.B(k) 1.5(c) 3.9(b) 1.6(g) 3.9(c)
Visualise and represent 2D and 3D forms including 2D representations of 3D objects	Learners may be tested on their ability to • draw force diagrams to solve mechanics problems	1.1(j) 3.3(f) 1.1(k) 3.5(f) 1.4(c) 3.9(i) 1.6(b) 3.10(e) 3.2(g) 3.C(b)
Calculate areas of triangles, circumferences and areas of circles, surface areas and volumes of rectangular blocks, cylinders and spheres	Learners may be tested on their ability to • calculate the area of the cross section to work out the resistance of a conductor given its length and resistivity	1.1(g) 3.A(e) 2.1(g) 3.C(o) 2.2(h) 3.D(b) 2.4(d) 2.5(b) 2.7(d) 3.10(a)
Use Pythagoras' theorem, and the angle sum of a triangle	Learners may be tested on their ability to • calculate the magnitude of a resultant vector, resolving forces into components to solve problems	1.1(e) 1.1(k) 2.6(a) 3.2(g) 3.3(b)
Use $\sin$, $\cos$ and $\tan$ in physical problems	Learners may be tested on their ability to • resolve forces into components	1.1(f) 1.4(b) 3.2(i) 1.1(j) 1.6(d) 3.3(e) 1.1(k) 2.6(a) 3.9(c)
Use of small angle approximations including $\sin\theta \approx \theta$, $\tan\theta \approx \theta$, $\cos\theta \approx 1$ for small θ where appropriate	Learners may be tested on their ability to • calculate fringe separations in interference patterns	1.4(b) 2.6(a) 3.2(i)

Understand the relationship between degrees and radians and translate from one to the other	Learners may be tested on their ability to: • convert angle in degrees to angle in radians	1.5(b) 1.5(c) 1.6(d) 1.6(g) 3.3(b)

APPENDIX D

HOW SCIENCE WORKS

How science works skill	Areas of the specification which exemplify the how science works skill (assessment is not limited to the examples below)
Use theories, models and ideas to develop scientific explanations	1.4(f) 1.6(q) 1.7(c) 2.1(f) 2.2(k) 2.5(e) 2.8(f) 3.4(m) 3.7(a)
Use knowledge and understanding to pose scientific questions, define scientific problems, present scientific arguments and scientific ideas	1.8(e) 2.2(n) 2.7(e) 2.8(e) 2.8(b) 3.4(e) 3.7(h) 3.8(e) 3.D(c)
Use appropriate methodology, including information and communication technology (ICT), to answer scientific questions and solve scientific problems	1.2(f) 1.6(j) 1.8(k) 2.2(i) 2.4(i) 2.5(b) 3.2(f) 3.6(g) 3.C(d)
Carry out experimental and investigative activities, including appropriate risk management, in a range of contexts	1.1(g) 1.1(i) 1.6(i) 2.2(h) 2.3(c) 2.4(i) 3.1(c) 3.2(o) 3.4(c)
Analyse and interpret data to provide evidence, recognising correlations and causal relationships	1.2(c) 1.4(d) 1.6(k) 1.8(i) 2.2(l) 2.3(h) 2.6(a) 2.7(e) 2.8(d) 3.1(f) 3.4(j) 3.7(a)
Evaluate methodology, evidence and data, and resolve conflicting evidence	2.8(l) 3.2(e) 3.4(m) 3.6(c) 3.7(a) 3.A(a)
Know that scientific knowledge and understanding develops over time	2.2(k) – (n) 2.7(a) – (e) 2.8(e)(f) 3.2(e) 3.4(e) 3.4(m) 3.7(a) – (k)
Communicate information and ideas in appropriate ways using appropriate terminology	1.6(l) 1.8(i) 2.2(j) 2.5(e) – (g) 2.8(m) 3.2(i) 3.5 3.9(d) 3.A(a) 3.C(l) 3.D(a)
Consider applications and implications of science and evaluate their associated benefits and risks	1.6(o) 1.8(i) 2.5(e) – (g) 3.3(f) 3.5(a) – (g) 3.8(d) 3.9(j) 3.A 3.B 3.C 3.D
Consider ethical issues in the treatment of humans, other organisms and the environment	3.6(a)(b)(d) 3.B(c)(o)(r) 3.D
Evaluate the role of the scientific community in validating new knowledge and ensuring integrity	2.2(e)(f) 3.4(m) 3.7 3.D(a)(b)
Evaluate the ways in which society uses science to inform decision making	1.6(n) 1.8(d)(f) 2.2(n) 3.6(a)(b) 3.8(e) 3.B(n)(o) 3.D