SIGNED OFF by Cambridge International and approved by the NEACB. For final submission to Cambridge international

20 November 2020

Republic of Namibia

MINISTRY OF EDUCATION, ARTS AND CULTURE

NAMIBIA SENIOR SECONDARY CERTIFICATE (NSSC)

PHYSICS SYLLABUS

ADVANCED SUBSIDIARY LEVEL

SYLLABUS CODE: 8225

GRADE 12

FOR IMPLEMENTATION IN 2021
FOR FIRST EXAMINATION IN 2021

Ministry of Education, Arts and Culture
National Institute for Educational Development (NIED)
Private Bag 2034
Okahandja
Namibia

© Copyright NIED, Ministry of Education, Arts and Culture 2019
Physics Syllabus Advanced Subsidiary Level Grade 12

ISBN: 978-99945-2-244-6

Printed by NIED
Website: http://www.nied.edu.na

Publication date: December 2020

TABLE OF CONTENTS

1. INTRODUCTION

The Namibia Senior Secondary Certificate Advanced Subsidiary (NSSCAS) level syllabus is designed as a one-year course leading to examination after completion of the Namibia Senior Secondary Certificate Ordinary (NSSCO) level. The syllabus is designed to meet the requirements of the *National Curriculum for Basic Education (NCBE)* and has been approved by the National Examination, Assessment and Certification Board (NEACB).

The Namibia National Curriculum Guidelines for Basic Education, applicable at the stage of senior secondary education (Grade 12) and at equivalent stages of non-formal education, as a part of life-long learning, recognise the uniqueness of the learner and adhere to the philosophy of learner-centred education.

The Namibia National Curriculum Guidelines:

- recognise that learning involves developing values and attitudes as well as knowledge and skills
- promote self-awareness and an understanding of the attitudes, values and beliefs of others in a multilingual and multicultural society
- encourage respect for human rights and freedom of speech
- provide insight and understanding of crucial “global” issues in a rapidly changing world which affects quality of life: the AIDS pandemic, global warming, environmental degradation, distribution of wealth, expanding and increasing conflicts, the technological explosion and increased connectivity
- recognise that as information in its various forms becomes more accessible, learners need to develop higher cognitive skills of analysis, interpretation and evaluation to use information effectively
- seek to challenge and to motivate learners to reach their full potential and to contribute positively to the environment, economy and society

Thus the Namibia National Curriculum Guidelines should provide opportunities for developing essential skills across the various fields of study. Such skills cannot be developed in isolation and they may differ from context to context according to a field of study. The skills marked with an * are relevant to this syllabus.

The skills are:

- communication skills*
- numeracy skills*
- information skills*
- problem-solving skills*
- self-management and competitive skills*
- social and cooperative skills
- physical skills
- work and study skills*
- critical and creative thinking*

2. RATIONALE

This syllabus describes the intended learning and assessment for Physics in the NSSCAS phase. As a subject, Physics is within the natural science area/areas of learning in the curriculum, but has thematic links to other subjects across the curriculum.

The subject Physics places strong emphasis on the learners' understanding of the physical and biological world around them at the local, regional and international levels. It thus includes how societies use natural resources to satisfy their needs, and how the environment may be changed in ecologically sustainable ways. At this phase and subject area, the application of scientific knowledge and attitudes to health is of special relevance for the individual, the family, and society as a whole as well as the environment around us including the sustainability of our natural resources. Critical thinking, investigating phenomena, interpreting data, and applying knowledge to practical (experimental and investigative) skills and abilities are essential to understanding the value and limitations of natural scientific knowledge and methods, and their application to daily life. This requires advanced technology through the efficient and effective usage of equipment, materials and processes. Modern technology is required in order to assist our learners and society to solve problems through planning, design, realisation, and evaluation of activities and goals.

3. AIMS

The aims of the syllabus are the same for all learners. These are set out below and describe the educational purposes of a course in Physics for the NSSCAS examination. They are not listed in order of priority.

Physics promotes the following aims in the curriculum:

1. Provide, through well designed studies of theoretical and practical science, a worthwhile educational experience for all learners, whether or not they go on to study science beyond this level and in particular, enables learners to acquire sufficient understanding and knowledge to:
   - become confident citizens in a technological world, able to take or develop an informed interest in scientific matters;
   - recognise the usefulness and limitations of scientific method and to appreciate its applicability in other disciplines and in everyday life;
   - be suitably prepared for employment and/or further studies beyond the NSSCAS in Physics.

2. Develop abilities and skills that:
   - are relevant to the study and practice of Physics
   - are useful in everyday life
   - encourage efficient and safe practice
   - encourage effective communication

3. Develop attitudes relevant to Physics such as: concern for accuracy and precision; objectivity, integrity, enquiry, initiative and inventiveness.

4. Stimulate interest in, and care for, the environment.

5. Promote an awareness that:
    - scientific theories and methods have developed, and continue to do so, as a result of the co-operative activities of groups and individuals
    - the study and practice of science is subject to social, economic, technological, ethical and cultural influences and limitations
    - the applications of science may be both beneficial and detrimental to the individual, the community and the environment
    - science transcends national boundaries and that the language of science, correctly and rigorously applied, is universal

4. ADDITIONAL INFORMATION

4.1 Guided learning hours

The NSSCAS level syllabuses are designed on the assumption that learners have about 180 guided learning hours per subject over the duration of one year, but this is for guidance only. The number of hours required to gain the qualification may vary according to local conditions and the learners' prior experience of the subject. *The National Curriculum for Basic Education (NCBE)* indicates that this subject will be taught for 9 periods of 40 minutes each per 7-day cycle over one year.

4.2 Prior learning

It is recommended that learners who are beginning this course should have previously studied Physics at Namibia Senior Secondary Certificate Ordinary (NSSCO) level.

4.3 Progression

NSSCAS level Physics provides a suitable foundation for the study of physics or related courses in higher education. It is also suitable for candidates intending to pursue careers or further study in science, or as part of a course of general education.

4.4 Grading and reporting

NSSCAS results are shown by one of the grades a, b, c, d or e indicating the standard achieved, grade a being the highest and grade e the lowest. 'Ungraded' indicates that the candidate has failed to reach the standard required for a pass at NSSCAS level.

4.5 Support materials and approved textbooks

NSSCAS syllabuses, recent specimen material, question papers and examiners reports are sent to all schools. Assessment manuals in subjects, where applicable are sent to schools. Approved learning support materials are available on the Senior Secondary Textbook Catalogue for Schools. The Senior Secondary Textbook Catalogue is available on the institution's (NIED) website (http://www.nied.edu.na).

5. LEARNING CONTENT

The content is divided into themes and topics as follow:

Mathematical requirements

Theme 1: General physics

1.1 Physical quantities and units
1.2 Measurement techniques
1.3 Kinematics
1.4 Dynamics
1.5 Forces, density and pressure
1.6 Work, energy and power
1.7 Deformation of solids

Theme 2: Waves

2.1 Progressive waves
2.2 Transverse and longitudinal waves
2.3 Determination of frequency and wavelength of sound waves
2.4 Doppler effect
2.5 Electromagnetic spectrum
2.6 Superposition
2.6.1 Stationary waves
2.6.2 Diffraction
2.6.4 Diffraction gratings
2.6.3 Interference, two-source interference

Theme 3: Electricity

3.1 Electric fields
3.2 Current of electricity
3.3 DC circuits

Theme 4: Modern physics

4.1 Atoms, nuclei and radiation
4.2 Fundamental particles

MATHEMATICAL REQUIREMENTS

Arithmetic

- recognise and use expressions in decimal and standard form (scientific) notation
- use an electronic calculator for addition, subtraction, multiplication and division
- find arithmetic means, powers (including reciprocals and square roots), sines, cosines, tangents (and the inverse functions)
- take account of accuracy in numerical work and handle calculations so that significant figures are neither lost unnecessarily nor carried beyond what is justified
- make approximate evaluations of numerical expressions (e.g. $\pi^2 \approx 10$) and use such approximations to check the magnitude of calculated results

Algebra

- change the subject of an equation to the required variable. Most relevant equations involve only the simpler operations but may include positive and negative indices and square roots.
- solve simple algebraic equations. Most relevant equations are linear but some may involve inverse and inverse square relationships. Linear simultaneous equations and the use of the formula to obtain the solutions of quadratic equations are required.
- substitute physical quantities into physical equations using consistent units and check the dimensional consistency of such equations
- set up simple algebraic equations as mathematical models of physical situations, and identify inadequacies of such models
- express small changes or uncertainties as percentages and vice versa
- understand and use the symbols $<$, $>$, $\leq$; $\geq$; $\ll$, $\gg$; $\approx$; /, $\propto$, $\langle X \rangle$, $(= \overline{X})$, $\sum$, Δx, δx, $\surd$

Geometry and trigonometry

- calculate areas of right-angled and isosceles triangles, circumference and area of circles, areas and volumes of cuboids, cylinders and spheres
- use Pythagoras' theorem, similarity of triangles, the angle sum of a triangle
- use sines, cosines and tangents of angles (especially for 0°, 30°, 45°, 60°, 90°)

Vectors

- find the resultant of two coplanar vectors, recognising situations where vector addition is appropriate
- obtain expressions for components of a vector in perpendicular directions, recognising situations where vector resolution is appropriate

Graphs

- translate information between graphical, numerical, algebraic and verbal forms
- select appropriate variables and scales for graph plotting
- determine the gradient, intercept and intersection of linear graphs
- choose, by inspection, a straight line which will serve as the line of best fit through a set of data points presented graphically
- draw a curved trend line through a set of data points presented graphically, when the arrangement of these data points is clearly indicative of a non-linear relationship
- recall standard linear form $y = mx + c$ and rearrange relationships into linear form where appropriate
- sketch and recognise the forms of plots of common simple expressions like $\frac{1}{x}$; x^2; $\frac{1}{x^2}$; $\sin x$; $\cos x$; e^{-x}
- draw a tangent to a curve, and understand and use the gradient of the tangent as a means to obtain the gradient of the curve at a point
- understand and use the area below a curve where the area has physical significance
- apply the conventions for labelling graph axes and table columns (*see Annexe A, A2, graph layout, plotting of points, trend line*)

THEME 1: GENERAL PHYSICS

TOPIC	GENERAL OBJECTIVES *Learners will:*	SPECIFIC OBJECTIVES *Learners should be able to:*
1.1 Physical quantities and units *The measurement and recording of quantities is central to the whole of physics. The skills of estimating a physical quantity and having a feeling for which quantities are reasonable and which are unreasonable are very useful for any physicist. This topic introduces the SI system of units, which provides a universal framework of measurement that is common to all scientists internationally. Learners should be aware of the nature of a physical measurement, in terms of a magnitude and a unit. They should have experience of making and recording measurements in the laboratory.*		
1.1.1 Physical quantities	• show understanding of physical quantities included within the syllabus	• recall that all physical quantities consist of a numerical magnitude and a unit • make reasonable estimates of physical quantities included within the syllabus
1.1.2 SI units	• know the SI units for various physical quantities included within the syllabus	• recall and use the following SI base quantities and their units: mass (kg), length (m), time (s), current (A), temperature (K), amount of substance (mol) • express derived units as products or quotients of the SI base units and use the named units listed in this syllabus as appropriate • use SI base units to check the homogeneity of physical equations • use the following prefixes and their symbols to indicate decimal submultiples or multiples of both base and derived units: pico (p), nano (n), micro (μ), milli (m), centi (c), deci (d), kilo (k), mega (M), giga (G), tera (T)
1.1.3 Scalars and vectors	• know scalar and vector quantities including calculations and representations	• distinguish between scalar and vector quantities – a scalar as a quantity which has a magnitude, but no direction – a vector as a quantity which has both magnitude and direction • state examples of scalar (e.g. mass) and vector (e.g. velocity) quantities • add and subtract coplanar vectors (vectors in the same plane) • represent a vector as two perpendicular components

TOPIC	GENERAL OBJECTIVES *Learners will:*	SPECIFIC OBJECTIVES *Learners should be able to:*
1.2 Measurement techniques *Measurement is essential to the study of physics. Physicists need to be familiar with a wide range of measuring instruments. Measurements themselves may be misleading and result in inappropriate conclusions as a result of errors and uncertainties. This topic develops an understanding of errors and uncertainties in measured and derived physical quantities.*		
1.2.1 Measurements	• know measuring instruments and apply them in physical quantities	• use techniques for the measurement of length, volume, angle, mass, time, temperature and electrical quantities appropriate to the ranges of magnitude implied by the relevant parts of the syllabus. In particular, learners should be able to: – measure lengths using rulers, calipers and micrometers – measure weight and hence mass using balances – measure an angle using a protractor – measure time intervals using clocks, stopwatches and the calibrated time-base of a cathode-ray oscilloscope (c.r.o.) – measure temperature using a thermometer – use ammeters and voltmeters with appropriate scales – use a galvanometer in null methods – use a cathode-ray oscilloscope (c.r.o.) – use both analogue scales and digital displays – use calibration curves
1.2.2 Errors and uncertainties	• understand errors and uncertainties and the effects thereof in measurements	• explain the effects of systematic errors (including zero errors) and random errors in measurements • distinguish between precision and accuracy – precise measurements are all close to one another – an accurate measurement is close to the true value • assess the uncertainty in a derived quantity by simple addition of absolute, fractional or percentage uncertainties (a rigorous statistical treatment is not required)

TOPIC	GENERAL OBJECTIVES *Learners will:*	SPECIFIC OBJECTIVES *Learners should be able to:*
1.3 Kinematics *Kinematics is the study of motion. Movement is part of everyday experience, so it is important to be able to analyse and predict the way in which objects move. The behaviour of moving objects is studied both graphically and through equations of motion.*		
1.3.1 Equations of motion	• understand the concepts distance, displacement, speed, velocity and acceleration, including equations of motion	• define and use distance, displacement, speed, velocity and acceleration – distance as a measure of how far an object travels along a particular path (without considering direction) – displacement as a vector which has a magnitude equal to the shortest distance between the initial and final points and a direction from the initial to the final point – speed as a rate of change of distance – instantaneous velocity as a 'rate of change of displacement' or speed in a given direction – average velocity as the total displacement divided by the total time taken – acceleration as the rate of change of velocity • use graphical methods to represent distance, displacement, speed, velocity and acceleration • determine displacement from the area under a velocity-time graph • determine velocity using the gradient of a displacement-time graph • determine acceleration using the gradient of a velocity-time graph • recall and use the equations of uniformly accelerated motion: $v = u + at$; $a = \frac{v - u}{\Delta t}$; $s = \frac{v + u}{2}t$ • derive, from the definitions of velocity and acceleration, equations that represent uniformly accelerated motion in a straight line • solve problems using equations that represent uniformly accelerated (constant acceleration) motion in a straight line, including the motion of bodies falling in a uniform gravitational field without air resistance • describe an experiment to determine the acceleration of free fall using a falling body • describe and explain motion due to a uniform velocity in one direction and a uniform acceleration in a perpendicular direction

TOPIC	GENERAL OBJECTIVES *Learners will:*	SPECIFIC OBJECTIVES *Learners should be able to:*
1.4 Dynamics *The motion of any object is governed by forces that act on the object. This topic introduces Newton's laws of motion, which are fundamental to understanding the connection between forces and motion. The concept of momentum and the use of momentum conservation to analyse interactions are also studied.*		
1.4.1 Momentum and Newton's laws of motion	• understand momentum and newton's laws of motion and its application	• state that mass is the property of a body that resists change in motion • recall the relationship $F = ma$ and solve problems using it, appreciating that acceleration and resultant force are always in the same direction • define and use linear momentum as the product of mass and velocity (recall $p = mv$) • define and use force as rate of change of momentum • state and apply each of Newton's laws of motion: – Newton's first law (the law of inertia): an object at rest continues in a state of rest or if moving continues moving with constant velocity unless it is acted on by a resultant force – Newton's second law: the resultant force exerted on a body is directly proportional to the rate of change of linear momentum of that body; and recall use ($\Sigma F = \frac{\Delta p}{\Delta t}$) – Newton's third law: when two bodies interact, they exert forces on each other, these forces have the same magnitude but are in opposite directions
1.4.2 Non-uniform motion	• understand non-uniform motion and its application	• describe and use the concept of weight as the effect of a gravitational field on a mass and recall that the weight of a body is equal to the product of its mass and the acceleration of free fall • describe and explain qualitatively the motion of bodies falling in a uniform gravitational field with air resistance (including reference to terminal velocity) • recall that acceleration may be constant even when the motion is non-uniform

TOPIC	**GENERAL OBJECTIVES** *Learners will:*	**SPECIFIC OBJECTIVES** *Learners should be able to:*
1.4.3 Linear momentum and its conservation	• understand linear momentum and its conversation	• define impulse as $F\Delta t$ • relate impulse to change in momentum ($F\Delta t = \Delta p$) • use the relationship between impulse and change in momentum to calculate the force exerted, time for which the force is applied and change in momentum for a variety of situations involving the motion of an object in one dimension • apply the concept of impulse to safety considerations in everyday life, e.g. airbags, seatbelts and arrestor beds • state the principle of conservation of momentum, that when bodies in a system interact, the total momentum remains constant (momentum is always conserved) provided that no external force acts on the system • apply the principle of conservation of momentum to solve simple problems, including elastic and inelastic interactions between bodies in both one and two dimensions (knowledge of the concept of coefficient of restitution is not required) – in elastic interactions, kinetic energy is conserved – in inelastic interactions, kinetic energy is not conserved • recognise that, for a perfectly elastic collision, the relative speed of approach is equal to the relative speed of separation • explain that, while momentum of a system is always conserved in interactions between bodies, some change in kinetic energy may take place

TOPIC	**GENERAL OBJECTIVES** *Learners will:*	**SPECIFIC OBJECTIVES** *Learners should be able to:*
1.5 Forces, density and pressure *In this topic, the natures of some different types of force are studied, including how forces give rise to both translational and rotational equilibrium. The concept of pressure is introduced.*		
1.5.1 Types of forces	• know different types of forces	• describe the force on a mass in a uniform gravitational field and on a charge in a uniform electric field • explain the origin of the up-thrust acting on a body in a fluid (due to the difference in hydrostatic pressure) • explain frictional forces and viscous forces including air resistance (no treatment of the coefficients of friction and viscosity is required) • apply the concept that the weight of a body may be taken as acting at a single point known as its centre of gravity
1.5.2 Turning effects of forces	• know and apply turning effects of forces	• define moment as the product of force and perpendicular distance through the line of action from the pivot • apply the moment of a force to everyday examples such as crowbar, wheelbarrow, pliers, scissors, tweezers or tongs • state that a couple is a pair of (equal but opposite) forces (acting along parallel but different lines) that tends to produce rotation only • define and apply the torque of a couple (torque as the product of the magnitude of one of the forces and the perpendicular distance of separation)
1.5.3 Equilibrium of forces	• understand equilibrium of forces	• state and apply the principle of moments • recall and apply the principle that, when there is no resultant force and no resultant torque, a system is in equilibrium • use a vector triangle to represent three coplanar forces in equilibrium
1.5.4 Density and pressure	• understand density and pressure and apply these in calculations	• define and use density (density as the mass per unit volume) • define and use pressure (pressure as the perpendicular force per unit area) • derive, from the definitions of pressure and density, the equation $\Delta p = \rho g \Delta h$ • use the equation for hydrostatic pressure $\Delta p = \rho g \Delta h$

TOPIC	GENERAL OBJECTIVES *Learners will:*	SPECIFIC OBJECTIVES *Learners should be able to:*
1.6 Work, energy and power *This topic introduces different forms of energy in both qualitative and quantitative terms. The concept of energy and its conservation provide useful accounting tools that help to understand the behaviour of physical systems. The concepts of power and efficiency are also studied.*		
1.6.1 Energy conversion and conservation	• understand energy conversions and its conversation	• give examples of energy in different forms, its conversion and conservation, and apply the principle of conservation of energy to simple examples (e.g. the kinetic energy changing to potential energy in a pendulum and the sum of the two is constant if air resistance is negligible)
1.6.2 Work and efficiency	• understand work and its efficiency including implications of energy loss	• explain the concept of work in terms of the product of a force and displacement in the direction of the force • calculate the work done in a number of situations including the work done by a gas that is expanding against a constant external pressure: $W = p\Delta V$ • recall and apply that the efficiency of a system is the ratio (which can be expressed as percentage) of useful energy output from the system to the total energy input • discuss the implications of energy losses in practical devices and use the concept of efficiency to solve problems
1.6.3 Potential energy and kinetic energy	• understand the relationship between potential and kinetic energy	• derive, from the equations of motion, the formula for kinetic energy $E_k = \frac{1}{2}mv^2$ • recall and apply the formula $E_k = \frac{1}{2}mv^2$ • distinguish between gravitational potential energy and elastic potential energy – gravitational potential energy as energy of a mass due to its position in a gravitational field – elastic potential energy as energy stored in an object as a result of reversible (elastic) deformation • apply the relationship between force and potential energy in a uniform field to solve problems • derive, from the defining equation $W = Fs$, the formula $\Delta Ep = mg\Delta h$ for gravitational potential energy changes near the Earth's surface • recall and use the formula $\Delta E_p = mg\Delta h$ for gravitational potential energy changes near the Earth's surface

TOPIC	**GENERAL OBJECTIVES** *Learners will:*	**SPECIFIC OBJECTIVES** *Learners should be able to:*
1.6.4 Power	• understand power and its calculations	• define power as work done per unit time • derive power as the product of force and velocity • recall and use the relationships $P = \frac{W}{t}$ and $P = Fv$

TOPIC	GENERAL OBJECTIVES *Learners will:*	SPECIFIC OBJECTIVES *Learners should be able to:*
1.7 Deformation of solids *Solids change their shape under the action of forces. This change may be large in the case of springs or hardly noticeable in some structures such as buildings. The study of the deformation of solids is an important aspect of engineering. This topic provides an introduction to both elastic and plastic deformation of materials.*		
1.7.1 Stress and strain	• compare stress and strain and apply these concepts in deformation of solids	• outline that deformation is caused by a force and that, in one dimension, the deformation can be tensile or compressive • use the terms load, extension and compression • explain and use the terms limit of proportionality, elastic limit, yield point and the spring constant (i.e. force per unit extension) • obtain and draw force-extension, force-compression, and tensile/compressive stress-strain graphs • recall and use Hooke's law ($F = kx$) • define and use the terms stress, strain and the Young modulus: – stress as the force per unit area of a material – strain as extension per unit length – Young modulus as the ratio of stress to strain • describe an experiment to determine the Young modulus of a metal in the form of a wire
1.7.2 Elastic and plastic behaviour	• understand elastic and plastic behaviour	• distinguish between elastic and plastic deformation of a material – elastic deformation being reversible when the stress is removed – plastic deformation being permanent as a result of dislocations • relate the area under the force-extension graph to the work done (the area under the force-extension graph = work done) • determine the elastic potential (strain) energy in a deformed material from the area under the force-extension graph • recall and use $E_p = \frac{1}{2}Fx = \frac{1}{2}kx^2$ for a material deformed within its limit of proportionality

THEME 2: WAVES

This topic introduces the basic properties of transverse and longitudinal progressive waves, including the determination of the frequency and speed of sound waves. The electromagnetic spectrum is also introduced. These basic properties of waves are developed further into a study of the Doppler effect. The ideas of simple wave behaviour, such as reflection and refraction of light, would be useful prior knowledge.		
2.1 Progressive waves	• understand progressive waves including properties of waves	• describe what is meant by wave motion (propagation), an oscillation which transfers energy from one place to another without any net movement of the medium, as illustrated by vibration in ropes, springs and by experiments using water waves • describe and use the terms displacement, amplitude, phase difference, period, frequency, wavelength and speed • derive, from the definitions of speed, frequency and wavelength, the wave equation $v = f\lambda$ • recall and use the equations $v = f\lambda$ and $f = \frac{1}{T}$ • describe that energy is transferred by a progressive wave • recall and use the relationship $intensity = \frac{power}{area}$ and $intensity \propto (amplitude)^2$
2.2 Transverse and longitudinal waves	• know the differences between transverse and longitudinal waves	• compare transverse and longitudinal waves – for a transverse wave, the oscillations are perpendicular to the direction of travel of the energy of the wave – for a longitudinal wave, the oscillations are parallel to the direction of travel of the energy of the wave • analyse and interpret graphical representations of transverse and longitudinal waves
2.3 Determination of frequency and wavelength of sound waves	• know how to determine frequency and wavelength of sound using a cathode ray or PC oscilloscope	• determine the frequency of sound using a calibrated cathode-ray or PC oscilloscope • determine the wavelength of sound using stationary waves (e.g. use of sonometer, resonance tubes, tuning forks)

TOPIC	GENERAL OBJECTIVES *Learners will:*	SPECIFIC OBJECTIVES *Learners should be able to:*
2.4 Doppler effect	• understand the Doppler effect	• explain that when a source (of waves) moves relative to a stationary observer, there is a change in observed frequency • use the expression $f_o = \frac{f_s v}{(v \pm v_s)}$ for the observed frequency when a source of sound waves moves relative to a stationary observer • explain that Doppler shift is observed with all waves, including sound and light
2.5 Electromagnetic spectrum	• understand the electromagnetic spectrum	• state that all electromagnetic waves are transverse waves that travel with the same speed in free space • recall the orders of magnitude of the wavelengths of the principal regions of the electromagnetic spectrum from radio waves to gamma rays

TOPIC	**GENERAL OBJECTIVES** *Learners will:*	**SPECIFIC OBJECTIVES** *Learners should be able to:*
2.6 Superposition *Superposition is used to develop the concept of stationary waves. Diffraction and interference are then studied, including two-source interference and the diffraction grating.*		
2.6.1 Stationary waves	• show an understanding of stationary waves	• explain and use the principle of superposition in simple application • describe experiments that demonstrate stationary waves using microwaves, stretched strings and air columns • explain the formation of a stationary wave using a graphical method and identify nodes and antinodes
2.6.2 Diffraction	• develop an understanding of diffraction	• explain the meaning of the term diffraction • describe experiments that demonstrate diffraction, including the qualitative effect of the gap width relative to the wavelength of the wave, for example diffraction of water waves in a ripple tank
2.6.3 Interference, two-source interference	• know the two-source interference	• define the terms interference and coherence – coherence - when two waves both have the same frequency (and wavelength) and a constant phase difference – interference - when two or more waves overlap/superpose, the resultant displacement is the sum of the displacements of each wave • describe experiments that demonstrate two-source interference using water ripples, light (monochromatic light source e.g. laser) and microwaves • discuss the conditions required if two-source interference fringes are to be observed • recall and solve problems using the equation $\lambda = \frac{ax}{D}$ for double-slit interference using light
2.6.4 Diffraction gratings	• know diffraction gratings	• recall and solve problems using the formula $d\sin\theta = n\lambda$ • describe the use of a diffraction grating to determine the wavelength of light (the structure and use of the spectrometer are not included)

THEME 3: ELECTRICITY

TOPIC	**GENERAL OBJECTIVES** *Learners will:*	**SPECIFIC OBJECTIVES** *Learners should be able to:*
3.1 Electric fields *In this topic, the concept of an electric field is introduced. Awareness of the two types of charge and the processes of charging by friction and by induction are useful prior knowledge.*		
3.1.1 Concept of an electric field	• understand the concept of an electric field	• define and use electric field strength as force per unit positive charge (point charge) ($E = \frac{F}{Q}$) • explain the concept of an electric field as an example of a field of force (a region in which an electric charge experiences a force due to another charge) • represent an electric field by means of field lines
3.1.2 Uniform electric fields	• know uniform electric fields	• recall and use $E = \frac{\Delta V}{\Delta d}$ to calculate the field strength of the uniform field between charged parallel plates in terms of potential difference and separation • calculate the forces on charges in uniform electric fields • describe the effect of a uniform electric field on the motion of charged particles

TOPIC	**GENERAL OBJECTIVES** *Learners will:*	**SPECIFIC OBJECTIVES** *Learners should be able to:*
3.2 Current of electricity *Electric current, potential difference, resistance and power in electrical circuits are introduced. The concept of resistivity is included. Some electrical components may be used to sense environmental changes.*		
3.2.1 Electric current	• understand electric current and its calculations	• explain that electric current is a flow of charge carriers • recall that the charge on charge carriers is quantised • define the coulomb as the SI unit of electric charge, equal to the quantity of charge conveyed in one second by a current of one ampere • recall and use $Q = It$ • derive and use, for a current-carrying conductor, the expression $I = Anvq$, where A is the cross sectional area, n is the number density of charge carriers (number of charge carriers per unit volume), v is drift velocity and q is the charge carried by the individual charge carrier
3.2.2 Potential difference and power	• show an understanding of potential difference and power including their calculations	• define potential difference and the volt – potential difference *(p.d) [V]* as energy transferred (work done)per unit charge – the volt (the SI unit for of both potential difference and electromotive force) as the ratio of joule to coulomb • recall and use $V = \frac{W}{Q}$ • recall and use $P = VI, P = \frac{V^2}{R}$ *and* $P = I^2R$

TOPIC	GENERAL OBJECTIVES *Learners will:*	SPECIFIC OBJECTIVES *Learners should be able to:*
3.2.3 Resistance and resistivity	• understand resistance and resistivity including their calculations	• define resistance of a conductor as the ratio of the potential difference across it to the current through it • define the ohm (the SI unit for of electrical resistance) as the ratio of volt to ampere, transmitting a current of one ampere when subjected to a potential difference of one volt • recall and use $V = IR$ • sketch and discuss the I-V characteristics of a metallic conductor at constant temperature, a semiconductor diode and a filament lamp • explain that the resistance of a filament lamp increases as current increases because its temperature increases • explain that the resistance of a light-dependent resistor (LDR) decreases as the light intensity increases • explain that the resistance of a thermistor decreases as temperature increases (negative temperature coefficient [NTC] thermistor only) • state and use Ohm's law • define resistivity of a material as a product of the resistance and cross-sectional area per length of the specimen • recall and use $\rho = \frac{RA}{l}$, where R is the resistance, ρ is the resistivity of the material, l is the length of the conductor and A is the cross sectional area

TOPIC	GENERAL OBJECTIVES *Learners will:*	SPECIFIC OBJECTIVES *Learners should be able to:*
3.3 DC circuits *In this topic, practical circuits are considered. Circuit diagrams are studied with particular reference to Kirchhoff's laws and the consequences of internal resistance. The use of potential divider circuits for monitoring environmental conditions is studied.*		
3.3.1 Practical circuits	• understand practical circuits including calculations	• recall and use appropriate circuit symbols (see Annexe C) • draw and interpret circuit diagrams containing sources, switches, resistors, ammeters, voltmeters, and/or any other type of component referred to in the syllabus • define electromotive force (e.m.f.) of a source as energy transferred per unit charge in driving charge round a complete circuit • distinguish between e.m.f. and potential difference • discuss the effects of the internal resistance of a source of e.m.f. on the terminal potential difference and output power • recall and use the equation $V = E - Ir$, where V is the $p.d.$, E is the $e.m.f$, I is the current and r is the internal resistance
3.3.2 Kirchhoff's laws	• apply Kirchhoff's laws in calculations	• recall Kirchhoff's first law and appreciate the link to conservation of charge • recall Kirchhoff's second law and appreciate the link to conservation of energy • derive, using Kirchhoff's laws, a formula for the combined resistance of two or more resistors in series • solve problems using the formula for the combined resistance of two or more resistors in series • derive, using Kirchhoff's laws, a formula for the combined resistance of two or more resistors in parallel • solve problems using the formula for the combined resistance of two or more resistors in parallel • apply Kirchhoff's laws to solve simple circuit problems

TOPIC	**GENERAL OBJECTIVES** *Learners will*:	**SPECIFIC OBJECTIVES** *Learners should be able to*:
3.3.3 Potential dividers	• understand potential dividers and calculations	• explain the principle of a potential divider circuit as a source of variable p.d • recall and use $V_{out} = V_{in} \frac{R_2}{(R_1 + R_2)}$ • solve problems using the principle of the potentiometer as a means of comparing potential differences • explain the use of thermistors (negative temperature coefficient [NTC] thermistors only) and light-dependent resistors (LDR) in potential dividers to provide a potential difference that is dependent on the temperature (NTC) and illumination (LDR)

THEME 4: MODERN PHYSICS

TOPIC	GENERAL OBJECTIVES *Learners will:*	SPECIFIC OBJECTIVES *Learners should be able to:*
Alpha-particle scattering is studied as evidence for the structure of the atom. Nuclear composition, in terms of nucleons, leads to an appreciation of mass defect and binding energy. Nuclear processes including radioactive decay, fission and fusion are studied. An introduction to fundamental particles is included.		
4.1 Atoms, nuclei and radiation	• show an understanding of the concepts of atoms, nuclei in relationship to radiation	• describe and explain the simple structure of the nucleus • recall that radioactive decay is the random and spontaneous emission of particles and/or electromagnetic radiation from an unstable nucleus • recall the nature and properties of of α, β and γ radiations (both β– and β+ are included) • distinguish between proton number and nucleon number (mass number) and proton number (atomic number) and use standard nuclide notation ($^{A}_{Z}X$) - proton number (atomic number), denoted by Z - nucleon number (mass number), denoted by A • state that an element can exist in various isotopic forms each with a different number of neutrons • describe and explain the transformation of nuclei when they emit radiation • appreciate that nucleon number proton number and energy are all conserved in nuclear processes • represent simple alpha and beta decay by equations of the form $^{234}_{92}U \rightarrow {}^{230}_{90}Th + {}^{4}_{2}\alpha$ $\quad$ $^{214}_{82}Pb \rightarrow {}^{214}_{83}Bi + {}^{0}_{-1}\beta$

TOPIC	**GENERAL OBJECTIVES** *Learners will:*	**SPECIFIC OBJECTIVES** *Learners should be able to:*
4.1 Atoms, nuclei and radiation (continued)	• show an understanding of the concepts of atoms, nuclei in relationship to radiation	• deduce the mass number and proton number of the daughter and granddaughter products in a decay series • recall that during beta decay that beta particles are emitted with a range of kinetic energies • recognise the effects of a uniform electric field on the path of alpha and beta particles and gamma rays • calculate the force on alpha and beta particles when passing through a uniform electric field (e.g using $F = EQ$; $E = \frac{\Delta V}{\Delta d}$) • use the unified atomic mass unit and/or the mass of an electron in calculations involving forces on alpha and beta particles (e.g. using $F = ma$ and equations of motion) • deduce from the results of the α particle scattering experiment the existence and small size of the nucleus • state that (electron) antineutrinos and (electron) neutrinos are produced during β^- and β^+ decay
4.2 Fundamental particles	• show an understanding of the fundamental particles	• appreciate that protons and neutrons are not fundamental particles since they consist of quarks • describe a simple quark model of hadrons in terms of up, down and strange quarks and their respective antiquarks • describe protons and neutrons in terms of a simple quark model • appreciate that there is a weak interaction between quarks, giving rise to β decay • describe β^- and β^+ decay in terms of a simple quark model • appreciate that electrons and neutrinos are leptons

6. ASSESSMENT OBJECTIVES

The assessment will include, wherever appropriate, personal, social, environmental, economic and technological applications of Physics in modern society. Learners are required to demonstrate the Assessment Objectives in the context of the content and skills prescribed. Within each of the Assessment Objectives the assessment must take account of the learners' ability to communicate clearly and logically and apply conventions where appropriate.

The three Assessment Objectives in Physics are:

A Knowledge with understanding
B Handling information, application and solving problems
C Practical (experimental and investigative) skills and abilities

Following is a description of each Assessment Objective:

A Knowledge with understanding

Learners should be able to demonstrate knowledge and understanding in relation to:

A1 scientific phenomena, facts, laws, definitions, concepts and theories
A2 scientific vocabulary, terminology and conventions, (including symbols, quantities, units)
A3 scientific instruments and apparatus, including techniques of operation and aspects of safety
A4 scientific quantities and their determination
A5 scientific and technological applications with their social, economic and environmental implications

The Learning Content defines what learners may be required to recall and explain. Questions testing assessment objectives will often begin with one of the following words: *define, name, list, indicate, give examples, state, describe, compare, explain, distinguish, outline and give reasons.* (see glossary of terms).

B Handling information, application and solving problems

Learners should be able to, in word or using other written forms of presentation (i.e. symbolic, graphical and numerical) to:

B1 locate, select, organise and present information from a variety of sources
B2 handle information, distinguishing the relevant from the extraneous
B3 manipulate numerical and other data and translate information from one form to another
B4 analyse and evaluate information so as to identify patterns, report trends and draw inferences
B5 construct arguments to support hypotheses or to justify a course of action
B6 evaluate information and hypotheses
B7 apply knowledge, including principles, to new situations
B8 reasoned explanations of phenomena, patterns and relationships

These skills cannot be precisely specified in the Learning Content, because questions testing such skills are often based on information that is unfamiliar to the learner. In answering such questions, learners are required to use principles and concepts that are within the syllabus and apply them in a logical, deductive manner to a novel situation.

Questions testing these objectives will often begin with one of the following words: discuss, deduce, compare and discuss, find, estimate, interpret, evaluate, sketch, predict, identify, relate, suggest and calculate or determine. (see glossary of terms)

C Practical (experimental and investigative) skills and abilities

Learners should be able to:

C1 collect, record and present observations, measurements and estimates

C2 analyse and interpret data to reach conclusions

C3 evaluate methods and quality of data to reach conclusions

7. SCHEME OF ASSESSMENT

All learners should be entered for **Papers 1, 2 and 3** which are compulsory papers.

Paper	Description of paper and types of questions	Duration of paper	Marks
Paper 1: Theory: Multiple choice questions	This paper consists of forty multiple-choice items of the four-choice type. The questions will be based on the content described as specific objectives and will test abilities in assessment objectives A and B.	1 hour 15 minutes	40
Paper 2: Theory: Structured questions	This paper will consist of six (6) to ten (10) compulsory short-answer, structured and free-response questions. The questions will test skills and abilities in Assessment Objectives A and B. Learners will answer all questions on the question paper [booklet].	1 hour 15 minutes	60
Paper 3: Advanced practical skills	This paper requires learners to carry out practical work in timed conditions. Learners will be expected to collect, record, analyse and evaluate data so that they can answer questions related to the activity. The paper will consist of two experiments, each of one hour duration, drawn from different areas of Physics. Learners will answer all questions. Learners will answer on the question paper.	2 hours	40
		TOTAL	**140**

Weighting of papers

All learners will be entered for Papers 1, 2 and 3 specified below.

Learners will be graded from a - e depending on their abilities and achievements. **Paper 1 and 2 will constitute 77% of the final assessment while Paper 3 will constitute 23%.**

Papers	Weighting of papers
Paper 1	31%
Paper 2	46%
Paper 3	23%

8. SPECIFICATION GRID

The specification grid gives a general idea of how marks are allocated to assessment objectives in the different components. However, the balance on each paper may vary slightly.

The approximate weightings allocated to each of the Assessment Objectives across the papers are summarised in the table:

	Assessment objective	Weighting across all components	Paper 1 (marks)	Paper 2 (marks)	Paper 3 (marks)
A	Knowledge with understanding	38.5%	20	30	0
B	Handling information, application and solving problems	38.5%	20	30	0
C	Practical (experimental and investigative) skills and abilities	23.0%	0	0	40
			40 marks	**60 marks**	**40 marks**

Teachers should note that there is a greater weighting of 61.5 % for skills (including handling information, solving problems, experimental skills and investigations) compared to 38.5 % for knowledge and understanding. Teachers should make sure that their **schemes of work** and the **sequence of learning activities** reflect this balance so that the aims of the syllabus are met and the candidates are suitably prepared for the assessment.

9. GRADE DESCRIPTIONS

The scheme of assessment is intended to encourage positive achievement by all learners. Grade descriptions are therefore provided for judgmental Grades a, c and e to give a general indication of the standards of achievement likely to have been shown by learners awarded particular grades. The description must be interpreted in relation to the content specified by the Physics syllabus but are not designed to define that content. The grade awarded will depend in practice upon the extent to which the learner has met the assessment objective overall. Shortcomings in some aspects of the assessment may be balanced by better performance in others. Grade descriptions for Science Subjects will range from a to e.

At ***Grade a*** *- the learner is expected to:*

- show mastery of curriculum content;
- demonstrate the ability to interpret relatively complex data with precision;
- demonstrate the ability to discuss physics topics with depth and breadth of understanding, bringing together ideas from various areas of the curriculum and from the learner's own experience;
- communicate with clarity, by means of words, diagrams and other forms of presentation;
- be able to link his or her theoretical and practical studies in Physics with applications relating to society and to the environment;
- show a clear understanding of scientific method, and be able to design, carry out and evaluate experiments with confidence and competence.

At ***Grade c*** *- the learner is expected to:*

- show reasonable competence of curriculum content;
- demonstrate the ability to interpret relatively simple data with precision;
- demonstrate the ability to discuss Physics topics, with some success at bringing together ideas from different areas of the curriculum and the learners' experience;
- communicate effectively, by words, diagrams and other forms of presentation;
- show some ability to link his or her Physics studies with applications relating to society and the environment;
- show a reasonable understanding of scientific method and be able to design, carry out and evaluate experiments with reasonable confidence and competence.

At ***Grade e*** *- the learner is expected to:*

- show a limited range of competence of curriculum content;
- demonstrate the ability to interpret simple data with reasonable precision;
- demonstrate some ability to discuss Physics topics;
- communicate effectively, by words, diagrams and other forms of presentation;
- show some ability to link his or her Physics studies with applications relating to society and the environment;
- show a reasonable understanding of scientific method, and be able to design, carry out and evaluate simple experiments with some confidence and competence.

10. GLOSSARY OF COMMAND WORDS

This glossary of terms is intendent to serve as a guide to learners, although it is not exhaustive and it has deliberately been kept brief. Learners should understand that the meaning of a term must depend in part on its context. The number of marks allocated for any part of a question is a guide to the depth required for the answer.

Define (the term(s)...).	is intended literally. Only a formal statement or equivalent paraphrase is required
What do you understand by/What is meant by (the term(s)...)	normally implies that a definition should be given, together with some relevant comment on the significance or context of the term(s) concerned, especially where two or more terms are included in the question. The amount of supplementary comment intended should be interpreted in the light of the indicated mark value.
State	implies a concise answer with little or no supporting argument, e.g. a numerical answer that can be obtained 'by inspection'.
List	requires a number of points with no elaboration. If a specific number of points is requested, this number should not be exceeded.
Explain	may imply reasoning or some reference to theory, depending on the context.
Describe	requires candidates to state in words (using diagrams where appropriate) the main points of the topic. It is often used with reference either to particular phenomena or to particular experiments. For particular phenomena, the term usually implies that the answer should include reference to (visual) observations associated with the phenomena. In other contexts, **describe and give an account of** should be interpreted more generally, i.e. the candidate has greater discretion about the nature and the organisation of the material to be included in the answer. **Describe and explain** may be coupled in a similar way to **state and explain**.
Discuss	requires candidates to give a critical account of the points involved in the topic.
Outline	implies brevity, i.e. restricting the answer to giving essentials.
Deduce/ predict	implies that the candidate is not expected to produce the required answer by recall but by making a logical connection between other pieces of information. Such information may be wholly given in the question or may depend on answers extracted in an earlier part of the question.
Comment	is intended as an open-ended instruction, inviting candidates to recall or infer points of interest relevant to the context of the question, taking account of the number of marks available.
Suggest	is used in two main contexts. It may imply either that there is no unique answer (e.g. in chemistry, two or more substances may satisfy the given conditions describing an 'unknown'), or that candidates are expected to apply their general knowledge to a new situation (one that may not formally be in the syllabus).
Find	is a general term that may variously be interpreted as calculate, measure, determine, etc.

Calculate	is used when a numerical answer is required. In general, working should be shown, especially where two or more steps are involved.
Measure	implies that the quantity concerned can be directly obtained from a suitable measuring instrument, e.g. length, using a rule, or angle, using a protractor.
Determine	often implies that the quantity concerned cannot be measured directly but is obtained by calculation, substituting measured or known values of other quantities into a standard formula, e.g. relative molecular mass.
Estimate	implies a reasoned order of magnitude statement or calculation of the quantity concerned. Candidates should make any necessary simplifying assumptions about points of principle and about the values of quantities not otherwise included in the question.
Sketch	when applied to graph work, implies that the shape and/or position of the curve need only be qualitatively correct, but candidates should be aware that, depending on the context, some quantitative aspects may be looked for, e.g. passing through the origin, having an intercept, asymptote or discontinuity at a particular value. In diagrams, sketch implies that a simple, freehand drawing is acceptable though care should be taken over proportions and the clear exposition of important details.
Construct	is often used in relation to chemical equations where a candidate is expected to write a balanced equation, not by factual recall but by analogy or by using information in the question.
Compare	requires candidates to provide both the similarities and differences between things or concepts.
Classify	requires candidates to group things based on common characteristics.

In all questions, the number of marks is shown on the examination paper and candidates should use this as a guide to how much detail to give. When describing a process, the candidate should use the number of marks to decide how many steps to include. When explaining why something happens, the candidate should use the number of marks to decide how many reasons to give, or how much detail to give for each reason

ANNEXE A: Assessment criteria for Paper 3 (Advanced practical skills)

Scientific subjects are, by their nature, experimental. It is, accordingly, important that an assessment of a learner's knowledge and understanding of Physics should contain a component relating to practical work and experimental skills (as identified by assessment objective C). Teachers should ensure that learners practise experimental skills throughout the whole period of their course of study. As a guide, learners should expect to spend at least 20% of their time doing practical work individually or in small groups. This 20% does not include the time spent observing teacher demonstrations of experiments.

The practical work that learners do during their course should aim to:

- provide learning opportunities so that they develop the skills they need to carry out experimental and
- investigative work
- reinforce their learning of the theoretical subject content of the syllabus
- instil an understanding of the interplay of experiment and theory in scientific method
- prove enjoyable, contributing to the motivation of learners.

Learners' experimental skills will be assessed in Paper 3. In each of these papers, the questions may be based on physics not included in the syllabus content, but learners will be assessed on their practical skills rather than their knowledge of theory. Where appropriate, learners will be told exactly what to do and how to do it.

Paper 3 will be a timetabled, laboratory-based practical paper focusing on the following experimental skills:

- manipulation, measurement and observation
- presentation of data and observations
- analysis, conclusions and evaluation.

Each paper will consist of two questions, each of 1 hour and each of 20 marks.

The first question will be an experiment requiring learners to collect data, to plot a graph and to draw conclusions.

The second question will be an experiment requiring learners to collect data and to draw conclusions, but may or may not include the plotting of a graph. In the second question, the experimental method to be followed will be inaccurate, and learners will be required to evaluate the method and suggest improvements.

The two questions will be set in different areas of physics. No prior knowledge of the theory will be required.

A1: Mark scheme for Paper 3
Paper 3 will be marked using the generic mark scheme below. The expectations for each mark category are listed in the sections that follow.

Question 1 [20 marks]

Skill	Minimum mark allocation*	Breakdown of skills	Minimum mark allocation*
Manipulation, measurement and observation (MMO)	7 marks	Successful collection of data and observations	5 marks
		Range of distribution of values	1 mark
		Quality of data	1 mark
Presentation of data and observations (PDO)	6 marks	Table of results	1 mark
		Recording data, observations and calculations	2 marks
		Graph	3 marks
Analysis, conclusions and evaluation (ACE)	4 marks	Interpretation of graph	2 marks
		Drawing conclusions	2 marks

*The remaining 3 marks will be allocated across the skills in this grid and their allocation may vary from paper to paper.

Question 2 [20 marks]

Skill	Minimum mark allocation*	Breakdown of skills	Minimum mark allocation*
Manipulation, measurement and observation	5 marks	Successful collection of data and observations	4 marks
		Quality of data	1 mark
Presentation of data and observations	2 marks	Recording data, observations and calculations	2 marks
Analysis, conclusions and evaluation (ACE)	10 marks	Drawing conclusions	1 mark
		Estimating uncertainties	1 mark
		Identifying limitations	4 marks
		Suggesting improvements	4 marks

*The remaining 3 marks will be allocated across the skills in this grid and their allocation may vary from paper to paper.

A2: Expectations for each mark category (Paper 3)

Manipulation, measurement and observation

Successful collection of data

Candidates should be able to:

- set up apparatus correctly without assistance from the Supervisor
- follow instructions given in the form of written instructions, diagrams or circuit diagrams
- use their apparatus to collect an appropriate quantity of data
- repeat readings where appropriate
- make measurements using common laboratory apparatus, such as millimetre scales, protractors, top pan balances, newton-meters, analogue or digital electrical meters, measuring cylinders, calipers*****, micrometer screw gauges and thermometers
- use a stopwatch to measure intervals of time, including the period of an oscillating system by timing an appropriate number of consecutive oscillations
- use both analogue scales and digital displays.

***** Where calipers are required in the examination, Centres may provide either vernier or digital calipers. Candidates should be familiar with the type of calipers provided.

Some candidates will be unable to set up their apparatus without help and may ask for assistance from the Supervisor. Supervisors will be given clear instructions on what assistance may be given to candidates, but this assistance should never go beyond the minimum necessary to enable candidates to take some readings: under no circumstances should help be given with the presentation of data, analysis or evaluation sections. All assistance must be reported to the Examiners by recording details of the help given on the Supervisor's Report Form, and candidates who require assistance will not be able to score full marks for the successful collection of data.

Range and distribution of values

Candidates should be able to:

- make measurements that span the largest possible range of values within the limits either of the equipment provided or of the instructions given
- make measurements whose values are appropriately distributed within this range.

In most experiments, including those involving straight-line graphs, a regularly-spaced set of measurements will be appropriate. For other experiments, such as those requiring the peak value of a curved graph to be determined, it may be appropriate for the measurements to be concentrated in one part of the range investigated. Candidates will be expected to be able to identify the most appropriate distribution of values.

Quality of data

Candidates should be able to:

- make and record accurate measurements.

Marks will be awarded for measured data in which the values obtained are reasonable. In some cases, the award of the mark will be based on the scatter of points on a graph; in other cases, the candidate's data may be compared with information supplied by the Supervisor or known to the Examiners. The Examiners will only consider the extent to which the candidate has affected the quality of the data: allowances will be made where the quality of data is limited by the experimental method required or by the apparatus used.

Presentation of data and observations
Table of results
Candidates should be able to:

- present numerical data and values in a single table of results
- record all data in the table
- draw up the table in advance of taking readings so that they do not have to copy up their results
- include in the table of results columns for raw data and for values calculated from them
- use column headings that include both the quantity and the unit and that conform to accepted scientific conventions.

As an example of accepted practice in column headings, if the quantity being measured is current in milliamperes, then '*I* / mA' would be the usual way to write the column heading, but '*I* in mA' or '*I* (mA)' or 'current / mA' would be allowed. Headings such as '*I* mA' or just 'mA' are not acceptable. The quantity or the unit or both may be written in words rather than symbols. Conventional symbols or abbreviations (such as p.d.) may be used without explanation.

Recording of data, observations and calculations
Candidates should be able to:

- record raw readings of a quantity to the same degree of precision
- calculate other quantities from their raw data
- show their working in calculations, and the key steps in their reasoning
- use and justify the correct number of significant figures in calculated quantities.

For example, if one measurement of length in a column of raw data is given to the nearest millimetre, then all the lengths in that column should be given to the nearest millimetre. The degree of precision used should be compatible with the measuring instrument used: it would be inappropriate to record a distance measured on a millimetre scale as either '2 cm' or '2.00 cm'. Except where they are produced by addition or subtraction, calculated quantities should be given to the same number of significant figures (or one more than) the measured quantity of least accuracy. For example, if values of a potential difference and of a current are measured to 2 and 4 significant figures respectively, then the corresponding resistance should be given to 2 or 3 significant figures, but not 1 or 4. The number of significant figures may, if necessary, vary down a column of values for a calculated quantity.

Graph
Layout
Candidates should be able to:

- plot the independent variable on the *x*-axis and the dependent variable on the *y*-axis, except where the variables are conventionally plotted the other way around
- clearly label graph axes with both the quantity and the unit, following accepted scientific conventions
- choose scales for graph axes such that the data points occupy at least half of the graph grid in both *x*- and *y*-directions
- use a false origin where appropriate
- choose scales for the graph axes that allow the graph to be read easily, such as 1, 2 or 5 units to a 2 cm square
- place regularly-spaced numerical labels along the whole of each axis.

The accepted scientific conventions for labelling the axes of a graph are the same as for the column headings in a table of results.

Plotting of points
Candidates should be able to:

- plot all their data points on their graph grid to an accuracy of better than 1 mm. Points should be finely drawn with a sharp pencil, but must still be visible. A fine cross or an encircled dot is suitable; a thick pencil blob is not.

Trend line
Candidates should be able to:

- identify when the trend of a graph is linear or curved
- draw straight lines of best fit or curves to show the trend of a graph
- draw tangents to curved trend lines.

The trend line should show an even distribution of points on either side of the line along its whole length. Lines should be finely drawn and should not contain kinks or breaks.

Analysis, conclusions and evaluation
Interpretation of graph
Candidates should be able to:

- relate straight-line graphs to equations of the form $y = mx + c$, and derive expressions that equate to the gradient and/or the y-intercept of their graphs
- read the co-ordinates of points on the trend line of a graph
- determine the gradient of a straight-line graph or of a tangent to a curve
- determine the y-intercept of a straight-line graph or of a tangent to a curve, including where these are on graphs with a false origin.

When a gradient is to be determined, the points on the line chosen for the calculation should be separated by at least half of the length of the line drawn. In cases where the y-intercept cannot be read directly from the y-axis, it is expected that the co-ordinates of a point on the line and the gradient will be substituted into $y = mx + c$.

Drawing conclusions
Candidates should be able to:

- draw conclusions from an experiment, including determining the values of constants, considering whether experimental data supports a given hypothesis, and making predictions.

Estimating uncertainties
Candidates should be able to:

- estimate, quantitatively, the uncertainty in their measurements
- determine the uncertainty in a final result
- express the uncertainty in a measurement as an absolute, fractional or percentage uncertainty, and translate between these forms
- express the uncertainty in a repeated measurement as half the range of the repeated readings.

Identifying limitations
Candidates should be able to:

- identify and describe the limitations in an experimental procedure
- identify the most significant sources of uncertainty in an experiment
- show an understanding of the distinction between systematic errors (including zero errors) and random errors.

Suggesting improvements
Candidates should be able to:

- suggest modifications to an experimental arrangement that will improve the accuracy of the experiment or to extend the investigation to answer a new question
- describe these modifications clearly in words or diagrams.

Candidates' suggestions should be realistic, so that in principle they are achievable in practice in a school laboratory. The suggestions may relate either to the apparatus used or to the experimental procedure followed. Candidates may include improvements that they have actually made while carrying out the experiment. The suggested modifications may relate to sources of uncertainty identified by the candidate. Improvements that could have been made with the apparatus provided while following the instructions in the question will not normally gain credit.

A3: Administration of Paper 3

Detailed regulations on the administration of Cambridge practical examinations are contained in the *DNEA Handbook*. Details of the specific requirements for apparatus and materials for a particular examination are given in the Confidential Instructions which are sent to Centres several weeks prior to the examination. Centres should contact the DNEA if they believe the Confidential Instructions have not been received.

Access to the question paper itself is not permitted in advance of the examination.
It is essential that absolute confidentiality be maintained in advance of the examination date: the contents of the Confidential Instructions must not be revealed either directly or indirectly to candidates. The Confidential Instructions describe information required by the Examiners. This will include a set of numerical results for the experiments, which the Supervisor should obtain out of sight of the candidates. A Supervisor's Report Form is included in the Confidential Instructions. Centres must complete this form and enclose a copy in each envelope of scripts. If any assistance is given to candidates, the Supervisor's Report Form must include full details of this assistance. The marking process may be delayed and candidates may be disadvantaged if the Supervisor's Report Form or sample results are missing or do not contain the information required. If there is any doubt about the interpretation of the Confidential Instructions document or the suitability of the apparatus available, enquiries should be sent to the DNEA.

A4: Apparatus that is used regularly

Below is a list of items that are regularly used in Paper 3. The list is not exhaustive: other items are usually required, to allow for a variety in the questions set.

- Cells: 1.5 V
- Connecting leads and crocodile clips
- Digital ammeter, minimum ranges 0–1 A reading to 0.01 A or better, 0–200 mA reading to 0.1 mA or better, 0–20 mA reading to 0.01 mA or better (digital multimeters are suitable)
- Digital voltmeter, minimum ranges 0–2 V reading to 0.001 V or better, 0–20 V reading to 0.01 V or better (digital multimeters are suitable)
- Lamp and holder: 6 V 60 mA; 2.5 V 0.3 A
- Power supply: variable up to 12 V d.c. (low resistance)
- Rheostat (with a maximum resistance of at least 8 Ω, capable of carrying a current of at least 4 A)
- Switch
- Wire: constantan 26, 28, 30, 32, 34, 36, 38 s.w.g. or similar metric sizes
- Long stem thermometer: –10 °C to 110 °C × 1 °C
- Means to heat water safely to boiling (e.g. an electric kettle)
- Plastic or polystyrene cup 200 cm^3
- Stirrer
- Adhesive putty (e.g. Blu-Tack)
- Adhesive tape (e.g. Sellotape)
- Balance to 0.1 g (this item may often be shared between sets of apparatus)
- Bar magnet
- Bare copper wire: 18, 20, 26 s.w.g. or similar metric sizes
- Beaker: 100 cm^3, 200 cm^3 or 250 cm^3
- Card
- Expendable steel spring (spring constant approx. 25 N m^{-1}; unstretched length approx. 2 cm)
- G-clamp
- Magnadur ceramic magnets
- Mass hanger
- Micrometer screw gauge (this item may often be shared between sets of apparatus)
- Modelling clay (e.g. Plasticine)
- Newton-meter (1 N, 10 N)
- Pendulum bob
- Protractor
- Pulley
- Rule with a millimetre scale (1 m, 0.5 m, 300 mm)
- Scissors
- Slotted masses (100 g, 50 g, 20 g, 10 g) or alternative
- Stand, boss and clamp
- Stopwatch (learners may use their wristwatches), reading to 0.1 s or better
- Stout pin or round nail
- String/thread/twine
- Tuning fork (range 256 – 512 Hz)
- Vernier or digital calipers (this item may often be shared between sets of apparatus)
- Wire cutters

A5: Summary of key quantities, symbols and units

The list below is intended as a guide to the more important quantities which might be encountered in teaching and used in question papers.

Quantity	Usual symbols	Usual unit
Base quantities		
mass	m	kg
length	l	m
time	t	s
electric current	I	A
thermodynamic temperature	T	K
amount of substance	n	mol
Other quantities		
acceleration	a	ms^{-2}
acceleration of free fall	g	ms^{-2}
activity of radioactive source	A	Bq
amplitude	x_0	m
angle	θ	°, rad
angular displacement	θ	°, rad
angular frequency	ω	rad s^{-1}
angular speed	ω	rad s^{-1}
angular velocity	ω	rad s^{-1}
area	A	m^2
atomic mass	m_a	kg, u
attenuation/absorption coefficient	μ	m^{-1}
Avogadro constant	N_A	mol^{-1}
Boltzmann constant	k	JK^{-1}
capacitance	C	F
Celsius temperature	θ	℃
decay constant	λ	s^{-1}
density	ρ	kgm^{-3}
displacement	s, x	m
distance	d	m
efficiency	η	
electric charge	q, Q	C
electric field strength	E	NC^{-1}, Vm^{-1}
electric potential	V	V
electric potential difference	V	V
electromotive force	E	V
electron mass	m_e	kg, u
elementary charge	e	C
energy	E, U, W	J
force	F	N
frequency	f	Hz
gravitational constant	G	$Nm^2\ kg^{-2}$
gravitational field strength	g	N kg^{-1}
gravitational potential	ϕ	N kg^{-1}
half-life	$t_{\frac{1}{2}}$	s
Hall voltage	V_H	V
heating	q,Q	J

intensity	$\boldsymbol{I}$	Wm^{-2}
internal energy change	ΔU	J
kinetic energy	E_k	J
magnetic flux	Φ	Wb
magnetic flux density	B	T
mean-square speed	$\langle c^2 \rangle$	m^2s^{-2}
molar gas constant	R	$Jmol^{-1}K^{-1}$
molar mass	M	$kgmol^{-1}$
moment of force	T	Nm
momentum	p	Ns
neutron mass	m_n	kg, u
neutron number	N	
nucleon number	A	
number	N, m, n	
number density (number per unit volume)	n	m^{-3}
period	T	s
permeability of free space	μ_0	Hm^{-1}
permittivity of free space	ε_0	Fm^{-1}
phase difference	ϕ	°, rad
Plank constant	h	Js
potential energy	E_p	J
power	P	W
pressure	p	Pa
proton mass	m_p	kg, u
proton number	Z	
ratio of powers		dB
relative atomic mass	A_r	
relative molecular mass	M_r	
resistance	R	Ω
resistivity	ρ	Ωm
specific acoustic impedance	Z	$kgm^{-2}s^{-1}$
specific heat capacity	c	$J\ kg^{-1}K^{-1}$
specific latent heat	l	$J\ kg^{-1}$
speed	u, v, w, c	ms^{-1}
speed of electromagnetic waves	c	ms^{-1}
spring constant	k	Nm^{-1}
strain	ε	
stress	σ	Pa
torque	T	Nm
velocity	u, v, w, c	ms^{-1}
volume	V, v	m^3
wavelength	λ	m
weight	W	N
work	w, W	J
work function energy	Φ	J
Young modulus	E	Pa

ANNEXE B: DATA AND FORMULAE

The following data and formulae will appear as pages 2 and 3 in Papers 1 and 2.

Data

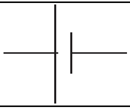
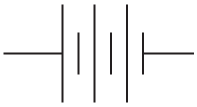
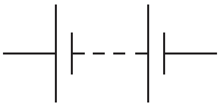
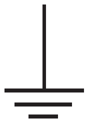
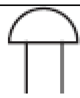
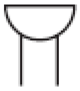
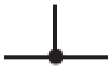
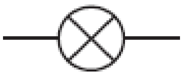
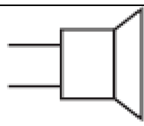
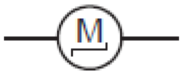
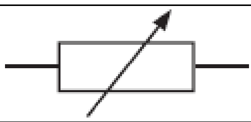
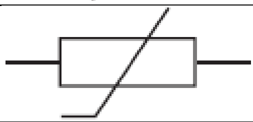
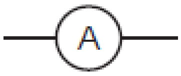
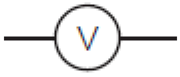
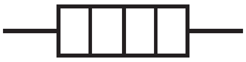
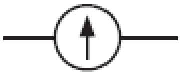
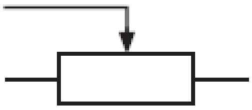
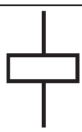
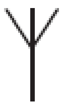
speed of light in free space	$c = 3.00 \times 10^{8}\,\mathrm{m\,s^{-1}}$
elementary charge	$e = 1.60 \times 10^{-19}\,\mathrm{C}$
unified atomic mass unit	$1\,\mathrm{u} = 1.66 \times 10^{-27}\,\mathrm{kg}$
rest mass of electron	$m_e = 9.11 \times 10^{-31}\,\mathrm{kg}$
rest mass of proton	$m_p = 1.67 \times 10^{-27}\,\mathrm{kg}$
acceleration of free fall	$g = 9.81\,\mathrm{m\,s^{-2}}$

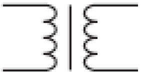
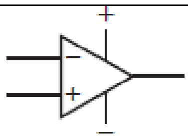
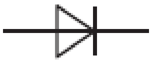
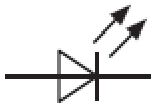
Formulae

uniformly accelerated motion	$s = ut + \frac{1}{2}at^2$
	$v^2 = u^2 + 2as$
work done on / by a gas	$W = p\Delta V$
hydrostatic pressure	$\Delta p = \rho g \Delta h$
Doppler effect	$f_o = \frac{f_s V}{(v \pm v_s)}$
electric current	$I = Anvq$
resistors in series	$R = R_1 + R_2 + \ldots$
resistors in parallel	$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \ldots$

ANNEXE C: CIRCUIT SYMBOLS

The following table gives a guide to the circuit symbols that may be used in examination papers.

cell		switch	
battery of cells	 or 	earth	
power supply		electric bell	
a.c. power supply		buzzer	
junction of conductors		microphone	
lamp		loudspeaker	
fixed resistor		motor	
variable resistor		generator	
thermistor		ammeter	
light-dependent resistor (LDR)		voltmeter	
heater		galvanometer	
potentiometer		oscilloscope	
relay coil		antenna	

transformer		operational amplifier	
diode		light-emitting diode	

The National Institute for Educational Development
Private Bag 2034
Okahandja
NAMIBIA

Telephone: +264 62 509000
Facsimile: +264 62 509073

Website: http://www.nied.edu.na

© NIED 2020