PHYSICS

Higher 2 (2017)

(Syllabus 9749)

CONTENTS

Singapore Examinations and Assessment Board

CAMBRIDGE International Examinations

INTRODUCTION

The syllabus has been designed to build on and extend the content coverage at O-Level. Candidates will be assumed to have knowledge and understanding of Physics at O-Level, either as a single subject or as part of a balanced science course.

AIMS

The aims of a course based on this syllabus should be to:

1. provide students with an experience that develops their interest in Physics and builds the knowledge, skills and attitudes necessary for further studies in related fields

2. enable students to become scientifically literate citizens who are well-prepared for the challenges of the 21st century

3. develop in students the understanding, skills, ethics and attitudes relevant to the *Practices of Science,* including the following:

   3.1 understanding the nature of scientific knowledge

   3.2 demonstrating science inquiry skills

   3.3 relating science and society

4. develop in students an understanding that a small number of basic principles and core ideas can be applied to explain, analyse and solve problems in a variety of systems in the physical world.

PRACTICES OF SCIENCE

Science as a discipline is more than the acquisition of a body of knowledge (e.g. scientific facts, concepts, laws, and theories) it is a way of knowing and doing. It includes an understanding of the nature of scientific knowledge and how this knowledge is generated, established and communicated. Scientists rely on a set of established procedures and practices associated with scientific inquiry to gather evidence and test their ideas on how the natural world works. However, there is no single method and the real process of science is often complex and iterative, following many different paths. While science is powerful, generating knowledge that forms the basis for many technological feats and innovations, it has limitations.

The *Practices of Science* are explicitly articulated in the syllabus to allow teachers to embed them as learning objectives in their lessons. The students' understanding of the nature and the limitations of science and scientific inquiry are developed effectively when the practices are taught in the context of relevant science content. Attitudes relevant to science such as inquisitiveness, concern for accuracy and precision, objectivity, integrity and perseverance should be emphasised in the teaching of these practices where appropriate. For example, students learning science should be introduced to the use of technology as an aid in practical work or as a tool for the interpretation of experimental and theoretical results.

The *Practices of Science* comprise three components:

1. Understanding the Nature of Scientific Knowledge

1.1 Understand that science is an evidenced-based, model-building enterprise concerned with the natural world

1.2 Understand that the use of both logic and creativity is required in the generation of scientific knowledge

1.3 Recognise that scientific knowledge is generated from consensus within the community of scientists through a process of critical debate and peer review

1.4 Understand that scientific knowledge is reliable and durable, yet subject to revision in the light of new evidence

2. Demonstrating Science Inquiry Skills

2.1. Identify scientific problems, observe phenomena and pose scientific questions/hypotheses

2.2 Plan and conduct investigations by selecting appropriate experimental procedures, apparatus and materials, with due regard for accuracy, precision and safety

2.3 Obtain, organise and represent data in an appropriate manner

2.4 Analyse and interpret data

2.5 Construct explanations based on evidence and justify these explanations through reasoning and logical argument

2.6 Use appropriate models[1] to explain concepts, solve problems and make predictions

2.7 Make decisions based on evaluation of evidence, processes, claims and conclusions

2.8 Communicate scientific findings and information using appropriate language and terminology

3. Relating Science and Society

3.1. Recognise that the application of scientific knowledge to problem solving could be influenced by other considerations such as economic, social, environmental and ethical factors

3.2 Demonstrate an understanding of the benefits and risks associated with the application of science to society

3.3 Use scientific principles and reasoning to understand, analyse and evaluate real-world systems as well as to generate solutions for problem solving

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[1] A model is a representation of an idea, an object, a process or a system that is used to describe and explain phenomena that cannot be experienced directly. Models exist in different forms from the concrete, such as physical, scale models to abstract representations, such as diagrams or mathematical expressions. The use of models involves the understanding that all models contain approximations and assumptions limiting their validity and predictive power.

CORE IDEAS IN PHYSICS

- Physics encompasses the study of systems spanning a wide range of distances and times: from 10^{-15} m (e.g. sub-atomic particles) to larger than 10^{30} m (e.g. galaxies); from near-instantaneous events, such as the current flow with a flick of a switch, to slow-evolving phenomenon, such as the birth and death of a star.

- A small number of basic principles and laws can be applied in the study and interpretation of this wide variety of simple and complex systems. Similarly, a few core ideas that cut across traditional content boundaries can be introduced in the curriculum to provide students with a broader way of thinking about the physical world.

- These *Core Ideas* are fundamental in the study of Physics and help students integrate knowledge and link concepts across different topics. They provide powerful analytical tools which can explain phenomena and solve problems.

1. Systems and Interactions

1.1. Defining the *systems* under study (by specifying their *boundaries* and making explicit *models* of the systems) provides tools for understanding and testing ideas that are applicable throughout physics.

1.2. *Objects* can be treated as having no *internal structure* or an internal structure that can be ignored. A *system*, on the other hand, is a collection of objects with an internal structure which may need to be taken into account.

1.3. Physical events and phenomena can be understood by studying the *interactions* between objects in a system and with the environment.

1.4. Students should be able to identify *causal relationships* when analysing interactions and *changes* in a system.

1.5. Interactions between objects in a system can be modelled using *forces* (e.g. a system of forces applied to move a mass; a system of two masses colliding; a system of the moon orbiting around the Earth; a system of electrical charges; a system of current in a straight wire placed in a magnetic field).

1.6. Fields existing in space are used to explain interactions between objects that are not in contact. Forces at a distance are explained by fields that can transfer *energy* and can be described in terms of the arrangement and properties of the interacting objects. These forces can be used to describe the relationship between electrical and magnetic fields.

1.7. *Equilibrium* is a unique state where the relevant physical properties of a system are balanced (e.g. the attainment of constant temperature at thermal equilibrium when objects of different temperatures interact, or an object returning to its equilibrium position after undergoing damped oscillatory motion).

1.8. Simplified *microscopic* models can be used to explain *macroscopic* properties observed in systems with complex and random interactions between a large number of objects:

1.8.1. Microscopic models are applied in the study of electricity, thermodynamics and waves. Macroscopic properties (e.g. current, temperature and wave speed) are used to investigate interactions and changes in these systems.

1.8.2. These macroscopic properties can be linked to complex interactions at the microscopic level, for example: the motion of electrons giving rise to current in a circuit, the random motion of atoms and molecules of an object giving rise to its thermal energy and the oscillatory motion of many particles giving rise to a wave motion.

1.8.3. Such complex systems may also be better characterised by *statistical averages* (e.g. drift velocity, temperature) as these quantities may be more meaningful than the properties and behaviours of individual components (e.g. electron movement in a wire resulting in current).

2. Models and Representations

2.1. *Models* use reasonable *approximations* to simplify real-world phenomena in order to arrive at useful ways to explain or analyse systems.

2.2. The awareness of the approximations used in a proposed model allows one to estimate the *validity* and *reliability* of that model.

2.3. Models are tested through observations and experiments and should be *consistent with available evidence*. Models can evolve and be refined in the light of new evidence.

2.4. The assumptions made in defining a system will determine how interactions are described and analysed. Understanding the limits of these assumptions is a fundamental aspect of modelling.

2.5. The use of *representations* is inherent in the process of constructing a model. Examples of representations are pictures, motion diagrams, graphs, energy bar charts and mathematical equations.

2.6. Mathematics is an important tool in Physics. It is used as a *language* to describe the relationships between different physical quantities and to solve numerical problems.

2.7. Representations and models help in analysing phenomena, solving problems, making predictions and communicating ideas.

3. Conservation Laws

3.1. *Conservation laws* are fundamental among the principles in physics used to understand the physical world.

3.2. When analysing physical events or phenomena, the choice of system and associated conservation laws provides a powerful set of tools to use to predict the possible outcome of an interaction.

3.3. Conservation laws *constrain* the possible behaviours of objects in a system, or the outcome of an interaction or process.

3.4. Associated with every conservation law in classical physics is a physical quantity, a scalar or a vector, which characterises a system.

3.5. In a *closed* system, the associated physical quantity has a constant value independent of interactions between objects in the system. In an *open* system, the changes of the associated physical quantity are always equal to the transfer of that quantity to or from the system by interactions with other systems.

3.6. In Physics, charge, momentum, mass-energy and angular momentum are conserved.

3.7. Examples of how conservation laws are used in our syllabus:

3.7.1. Conservation of momentum in collisions and explosions allowing the prediction of subsequent motion of the objects or particles.

3.7.2. Conservation of energy to calculate the change in total energy in systems that are open to energy transfer due to external forces (work is done), thermal contact processes (heating occurs), or the emission or absorption of photons (radiative processes)

3.7.3. Conservation of mass-energy, charge and nucleon number in nuclear reactions to enable the calculation of relevant binding energies and identification of the resulting nuclides.

CURRICULUM FRAMEWORK

The *Practices of Science, Core Ideas* in physics and *Learning Experiences* are put together in a framework (**Fig. 1**) to guide the development of the H2 Physics curriculum.

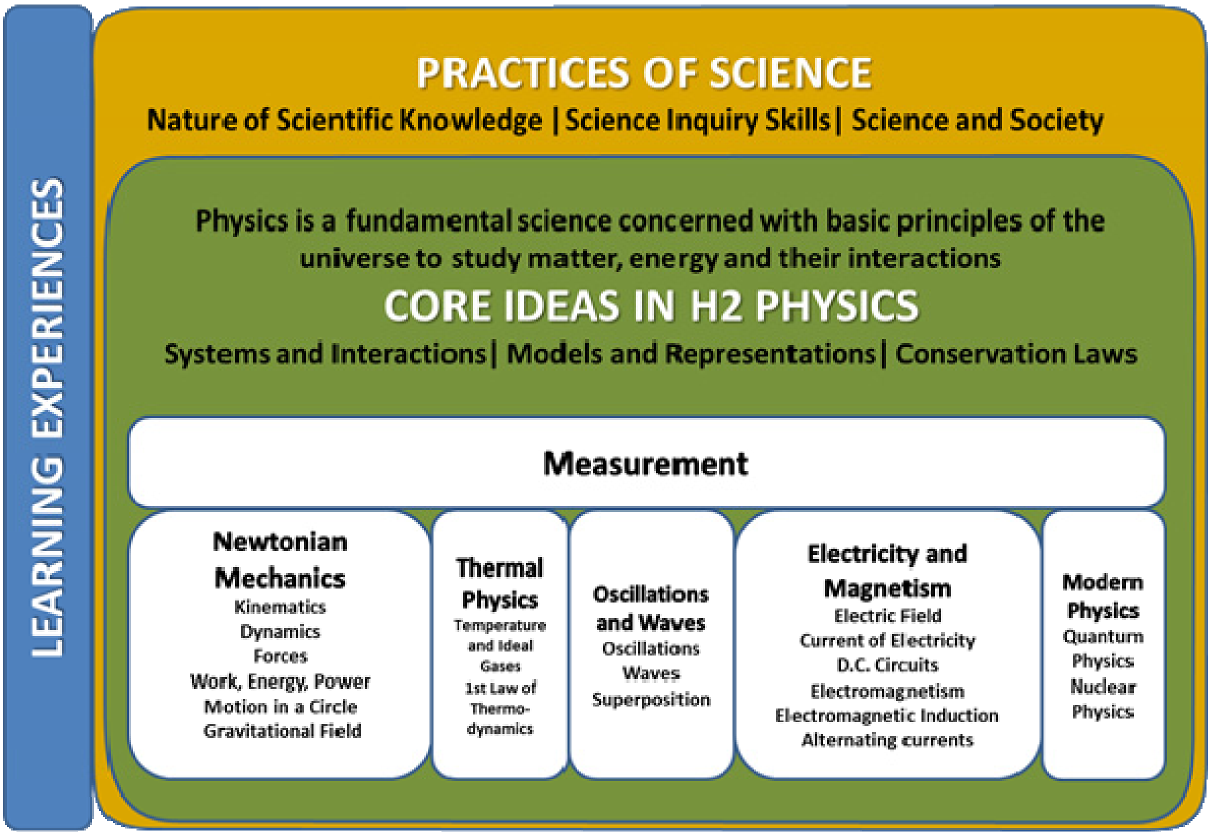

Fig. 1: H2 Physics Curriculum Framework

The *Practices of Science* are common to the natural sciences of Physics, Chemistry and Biology. These practices highlight the ways of thinking and doing that are inherent in the scientific approach, with the aim of equipping students with the understanding, skills, and attitudes shared by the scientific disciplines, including an appropriate approach to ethical issues.

The *Core Ideas* help students to integrate knowledge and link concepts across different topics, and highlight important themes that recur throughout the curriculum. The syllabus content is organised into sections according to the main branches and knowledge areas of Physics, i.e. *Newtonian Mechanics*, *Thermal Physics*, *Oscillations and Waves*, *Electricity and Magnetism* and *Modern Physics*. This allows for a focussed, systematic and in-depth treatment of topics within each section.

The *Learning Experiences*[2] refer to a range of learning opportunities selected by teachers to link the Physics content with the *Core Ideas* and the *Practices of Science* to enhance students' learning of the concepts. Rather than being mandatory, teachers are encouraged to incorporate *Learning Experiences* that match the interests and abilities of their students and provide opportunities to illustrate and exemplify the Practices of Science, where appropriate. Real-world contexts can help illustrate the concepts in Physics and their applications. Experimental activities and ICT tools can also be used to build students' understanding.

[2] The *Learning Experiences* can be found in the Teaching and Learning Syllabus.

ASSESSMENT OBJECTIVES

The assessment objectives listed below reflect those parts of the *aims* and *Practices of Science* that will be assessed.

A Knowledge with understanding

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

1. scientific phenomena, facts, laws, definitions, concepts, theories
2. scientific vocabulary, terminology, conventions (including symbols, quantities and units)
3. scientific instruments and apparatus, including techniques of operation and aspects of safety
4. scientific quantities and their determination
5. scientific and technological applications with their social, economic and environmental implications.

The syllabus content defines the factual knowledge that candidates may be required to recall and explain. Questions testing these objectives will often begin with one of the following words: *define*, *state*, *describe*, *explain* or *outline* (see the *Glossary of Terms*).

B Handling, applying and evaluating information

Candidates should be able (in words or by using symbolic, graphical and numerical forms of presentation) to:

1. locate, select, organise and present information from a variety of sources
2. handle information, distinguishing the relevant from the extraneous
3. manipulate numerical and other data and translate information from one form to another
4. use information to identify patterns, report trends, draw inferences and report conclusions
5. present reasoned explanations for phenomena, patterns and relationships
6. make predictions and put forward hypotheses
7. apply knowledge, including principles, to novel situations
8. bring together knowledge, principles and concepts from different areas of physics, and apply them in a particular context
9. evaluate information and hypotheses
10. demonstrate an awareness of the limitations of physical theories and models.

These assessment objectives cannot be precisely specified in the syllabus content because questions testing such skills may be based on information that is unfamiliar to the candidate. In answering such questions, candidates are required to use principles and concepts that are within the syllabus and apply them in a logical, reasoned or deductive manner to a novel situation. Questions testing these objectives will often begin with one of the following words: *predict*, *suggest*, *deduce*, *calculate* or *determine* (see the *Glossary of Terms*).

C Experimental skills and investigations

Candidates should be able to:

1. follow a detailed set or sequence of instructions and use techniques, apparatus and materials safely and effectively
2. make, record and present observations and measurements with due regard for precision and accuracy
3. interpret and evaluate observations and experimental data
4. identify a problem, design and plan investigations
5. evaluate methods and techniques, and suggest possible improvements.

SCHEME OF ASSESSMENT

All candidates are required to enter for Papers 1, 2, 3 and 4.

Paper	Type of Paper	Duration	Weighting (%)	Marks
1	**Multiple Choice**	1 h	15	30
2	**Structured Questions**	2 h	30	80
3	**Longer Structured Questions**	2 h	35	80
4	**Practical**	2 h and 30 min	20	55

Paper 1 (1 h, 30 marks)

This paper will consist of 30 compulsory multiple-choice questions. All questions will be of the direct choice type with 4 options.

Paper 2 (2 h, 80 marks)

This paper will consist of a variable number of structured questions plus one or two data-based questions and will include questions which require candidates to integrate knowledge and understanding from different areas of the syllabus. All questions are compulsory and answers will be written in spaces provided on the Question Paper. The data-based question(s) will constitute 20–25 marks.

Paper 3 (2 h, 80 marks)

This paper will consist of 2 sections and will include questions which require candidates to integrate knowledge and understanding from different areas of the syllabus. All answers will be written in spaces provided on the Question Paper.

- Section A worth 60 marks consisting of a variable number of structured questions, all compulsory.
- Section B worth 20 marks consisting of a choice of one from two 20-mark questions.

Paper 4 (2 h 30 min, 55 marks)

This paper will assess appropriate aspects of objectives C1 to C5 in the following skill areas:

- Planning (P)
- Manipulation, measurement and observation (MMO)
- Presentation of data and observations (PDO)
- Analysis, conclusions and evaluation (ACE)

The assessment of Planning (P) will have a weighting of 5%. The assessment of skill areas MMO, PDO and ACE will have a weighting of 15%.

The assessment of PDO and ACE may also include questions on data-analysis which do not require practical equipment and apparatus. Candidates would be allocated a specified time for access to apparatus and materials of specific questions (See page 27).

Candidates will **not** be permitted to refer to books and laboratory notebooks during the assessment.

Weighting of Assessment Objectives

Assessment Objectives		Weighting (%)	Assessment Components
A	**Knowledge with understanding**	32	Papers 1, 2, 3
B	**Handling, applying and evaluating information**	48	Papers 1, 2, 3
C	**Experimental skills and investigations**	20	Paper 4

ADDITIONAL INFORMATION

Mathematical Requirements

The mathematical requirements are given on pages 30 and 31.

Data and Formulae

Data and Formulae, as printed on pages 36 and 37, will appear as pages 2 and 3 in Papers 1, 2 and 3.

Symbols, Signs and Abbreviations

Symbols, signs and abbreviations used in examination papers will follow the recommendations made in the Association for Science Education publication *Signs, Symbols and Systematics* (The ASE Companion to 16–19 Science, 2000). The units kWh, atmosphere, eV and unified atomic mass unit (u) may be used in examination papers without further explanation.

Disallowed Subject Combinations

Candidates may not simultaneously offer Physics at H1 and H2 levels.

SUBJECT CONTENT

SECTION I MEASUREMENT

1. Measurement

Content

- Physical quantities and SI units
- Scalars and vectors
- Errors and uncertainties

Learning Outcomes

Candidates should be able to:

(a) recall the following base quantities and their SI units: mass (kg), length (m), time (s), current (A), temperature (K), amount of substance (mol)

(b) express derived units as products or quotients of the base units and use the named units listed in ‘Summary of Key Quantities, Symbols and Units’ as appropriate

(c) use SI base units to check the homogeneity of physical equations

(d) show an understanding of and use the conventions for labelling graph axes and table columns as set out in the ASE publication *Signs, Symbols and Systematics (The ASE Companion to 16–19 Science, 2000)*

(e) use the following prefixes and their symbols to indicate decimal sub-multiples 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)

(f) make reasonable estimates of physical quantities included within the syllabus

(g) distinguish between scalar and vector quantities, and give examples of each

(h) add and subtract coplanar vectors

(i) represent a vector as two perpendicular components

(j) show an understanding of the distinction between systematic errors (including zero error) and random errors

(k) show an understanding of the distinction between precision and accuracy

(l) assess the uncertainty in a derived quantity by addition of actual, fractional, percentage uncertainties or by numerical substitution (a rigorous statistical treatment is not required).

SECTION II NEWTONIAN MECHANICS

2. Kinematics

Content

- Rectilinear motion
- Non-linear motion

Learning Outcomes

Candidates should be able to:

(a) define and use displacement, speed, velocity and acceleration

(b) use graphical methods to represent distance, displacement, speed, velocity and acceleration

(c) identify and use the physical quantities from the gradients of displacement-time graphs and areas under and gradients of velocity-time graphs, including cases of non-uniform acceleration

(d) derive, from the definitions of velocity and acceleration, equations which represent uniformly accelerated motion in a straight line

(e) solve problems using equations which represent uniformly accelerated motion in a straight line, including the motion of bodies falling in a uniform gravitational field without air resistance

(f) describe qualitatively the motion of bodies falling in a uniform gravitational field with air resistance

(g) describe and explain motion due to a uniform velocity in one direction and a uniform acceleration in a perpendicular direction.

3. Dynamics

Content

- Newton's laws of motion
- Linear momentum and its conservation

Learning Outcomes

Candidates should be able to:

(a) state and apply each of Newton's laws of motion

(b) show an understanding that mass is the property of a body which resists change in motion (inertia)

(c) describe and use the concept of weight as the effect of a gravitational field on a mass

(d) define and use linear momentum as the product of mass and velocity

(e) define and use impulse as the product of force and time of impact

(f) relate resultant force to the rate of change of momentum

(g) recall and solve problems using the relationship $F = ma$, appreciating that resultant force and acceleration are always in the same direction

(h) state the principle of conservation of momentum

(i) apply the principle of conservation of momentum to solve simple problems including inelastic and (perfectly) elastic interactions between two bodies in one dimension (knowledge of the concept of coefficient of restitution is not required)

(j) show an understanding that, for a (perfectly) elastic collision between two bodies, the relative speed of approach is equal to the relative speed of separation

(k) show an understanding that, whilst the momentum of a closed system is always conserved in interactions between bodies, some change in kinetic energy usually takes place.

4. Forces

Content

- Types of force
- Centre of gravity
- Turning effects of forces
- Equilibrium of forces
- Upthrust

Learning Outcomes

Candidates should be able to:

(a) recall and apply Hooke's law ($F = kx$, where k is the force constant) to new situations or to solve related problems

(b) describe the forces on a mass, charge and current-carrying conductor in gravitational, electric and magnetic fields, as appropriate

(c) show a qualitative understanding of normal contact forces, frictional forces and viscous forces including air resistance (no treatment of the coefficients of friction and viscosity is required)

(d) show an understanding that the weight of a body may be taken as acting at a single point known as its centre of gravity

(e) define and apply the moment of a force and the torque of a couple

(f) show an understanding that a couple is a pair of forces which tends to produce rotation only

(g) apply the principle of moments to new situations or to solve related problems

(h) show an understanding that, when there is no resultant force and no resultant torque, a system is in equilibrium

(i) use a vector triangle to represent forces in equilibrium

(j) derive, from the definitions of pressure and density, the equation $p = \rho gh$

(k) solve problems using the equation $p = \rho gh$

(l) show an understanding of the origin of the upthrust acting on a body in a fluid

(m) state that upthrust is equal to the weight of the fluid displaced by a submerged or floating object

(n) calculate the upthrust in terms of the weight of the displaced fluid

(o) recall and apply the principle that, for an object floating in equilibrium, the upthrust is equal to the weight of the object to new situations or to solve related problems.

5. Work, Energy and Power

Content

- Work
- Energy conversion and conservation
- Efficiency
- Potential energy and kinetic energy
- Power

Learning Outcomes

Candidates should be able to:

(a) show an understanding of the concept of work in terms of the product of a force and displacement in the direction of the force

(b) calculate the work done in a number of situations including the work done by a gas which is expanding against a constant external pressure: $W = p\Delta V$

(c) give examples of energy in different forms, its conversion and conservation, and apply the principle of energy conservation

(d) show an appreciation for the implications of energy losses in practical devices and use the concept of efficiency to solve problems

(e) derive, from the equations for uniformly accelerated motion in a straight line, the equation $E_k = ½mv^2$

(f) recall and use the equation $E_k = ½mv^2$

(g) distinguish between gravitational potential energy, electric potential energy and elastic potential energy

(h) deduce that the elastic potential energy in a deformed material is related to the area under the force-extension graph

(i) show an understanding of and use the relationship between force and potential energy in a uniform field to solve problems

(j) derive, from the definition of work done by a force, the equation $E_p = mgh$ for gravitational potential energy changes near the Earth's surface

(k) recall and use the equation $E_p = mgh$ for gravitational potential energy changes near the Earth's surface

(l) define power as work done per unit time and derive power as the product of a force and velocity in the direction of the force.

6. Motion in a Circle

Content

- Kinematics of uniform circular motion
- Centripetal acceleration
- Centripetal force

Learning Outcomes

Candidates should be able to:

(a) express angular displacement in radians

(b) show an understanding of and use the concept of angular velocity to solve problems

(c) recall and use $v = r\omega$ to solve problems

(d) describe qualitatively motion in a curved path due to a perpendicular force, and understand the centripetal acceleration in the case of uniform motion in a circle

(e) recall and use centripetal acceleration $a = r\omega^2$, and $a = v^2/r$ to solve problems

(f) recall and use centripetal force $F = mr\omega^2$, and $F = mv^2/r$ to solve problems.

7. Gravitational Field

Content

- Gravitational field
- Gravitational force between point masses
- Gravitational field of a point mass
- Gravitational field near to the surface of the Earth
- Gravitational potential
- Circular orbits

Learning Outcomes

Candidates should be able to:

(a) show an understanding of the concept of a gravitational field as an example of field of force and define the gravitational field strength at a point as the gravitational force exerted per unit mass placed at that point

(b) recognise the analogy between certain qualitative and quantitative aspects of gravitational and electric fields

(c) recall and use Newton's law of gravitation in the form $F = \dfrac{Gm_1m_2}{r^2}$

(d) derive, from Newton's law of gravitation and the definition of gravitational field strength, the equation $g = \dfrac{GM}{r^2}$ for the gravitational field strength of a point mass

(e) recall and apply the equation $g = \dfrac{GM}{r^2}$ for the gravitational field strength of a point mass to new situations or to solve related problems

(f) show an understanding that near the surface of the Earth g is approximately constant and equal to the acceleration of free fall

(g) define the gravitational potential at a point as the work done per unit mass in bringing a small test mass from infinity to that point

(h) solve problems using the equation $\phi = -\dfrac{GM}{r}$ for the gravitational potential in the field of a point mass

(i) analyse circular orbits in inverse square law fields by relating the gravitational force to the centripetal acceleration it causes

(j) show an understanding of geostationary orbits and their application.

SECTION III THERMAL PHYSICS

8. Temperature and Ideal Gases

Content

- Thermal equilibrium
- Temperature scales
- Equation of state
- Kinetic theory of gases
- Kinetic energy of a molecule

Learning Outcomes

Candidates should be able to:

(a) show an understanding that regions of equal temperature are in thermal equilibrium

(b) explain how empirical evidence leads to the gas laws and to the idea of an absolute scale of temperature (i.e. the thermodynamic scale that is independent of the property of any particular substance and has an absolute zero)

(c) convert temperatures measured in kelvin to degrees Celsius: $T/\mathrm{K} = T/°\mathrm{C} + 273.15$

(d) recall and use the equation of state for an ideal gas expressed as $pV = nRT$, where n is the amount of gas in moles

(e) state that one mole of any substance contains 6.02×10^{23} particles and use the Avogadro number $N_A = 6.02 \times 10^{23}\ \mathrm{mol}^{-1}$

(f) state the basic assumptions of the kinetic theory of gases

(g) explain how molecular movement causes the pressure exerted by a gas and hence derive the relationship $pV = \frac{1}{3} Nm\langle c^2 \rangle$, where N is the number of gas molecules (a simple model considering one-dimensional collisions and then extending to three dimensions using $\frac{1}{3}\langle c^2 \rangle = \langle c_x^2 \rangle$ is sufficient)

(h) recall and apply the relationship that the mean kinetic energy of a molecule of an ideal gas is proportional to the thermodynamic temperature (i.e. $\frac{1}{2} m\langle c^2 \rangle = \frac{3}{2} kT$) to new situations or to solve related problems.

9. First Law of Thermodynamics

Content

- Specific heat capacity and specific latent heat
- Internal energy
- First law of thermodynamics

Learning Outcomes

Candidates should be able to:

(a) define and use the concepts of specific heat capacity and specific latent heat

(b) show an understanding that internal energy is determined by the state of the system and that it can be expressed as the sum of a random distribution of kinetic and potential energies associated with the molecules of a system

(c) relate a rise in temperature of a body to an increase in its internal energy

(d) recall and use the first law of thermodynamics expressed in terms of the increase in internal energy, the heat supplied to the system and the work done on the system.

SECTION IV OSCILLATION AND WAVES

10. Oscillations

Content

- Simple harmonic motion
- Energy in simple harmonic motion
- Damped and forced oscillations, resonance

Learning Outcomes

Candidates should be able to:

(a) describe simple examples of free oscillations

(b) investigate the motion of an oscillator using experimental and graphical methods

(c) show an understanding of and use the terms amplitude, period, frequency, angular frequency and phase difference and express the period in terms of both frequency and angular frequency

(d) recall and use the equation $a = -\omega^2 x$ as the defining equation of simple harmonic motion

(e) recognise and use $x = x_0 \sin \omega t$ as a solution to the equation $a = -\omega^2 x$

(f) recognise and use the equations $v = v_0 \cos \omega t$ and $v = \pm\omega\sqrt{\left(x_o^2 - x^2\right)}$

(g) describe, with graphical illustrations, the changes in displacement, velocity and acceleration during simple harmonic motion

(h) describe the interchange between kinetic and potential energy during simple harmonic motion

(i) describe practical examples of damped oscillations with particular reference to the effects of the degree of damping and to the importance of critical damping in applications such as a car suspension system

(j) describe practical examples of forced oscillations and resonance

(k) describe graphically how the amplitude of a forced oscillation changes with driving frequency near to the natural frequency of the system, and understand qualitatively the factors which determine the frequency response and sharpness of the resonance

(l) show an appreciation that there are some circumstances in which resonance is useful, and other circumstances in which resonance should be avoided.

11. Wave Motion

Content

- Progressive waves
- Transverse and longitudinal waves
- Polarisation
- Determination of frequency and wavelength of sound waves

Learning Outcomes

Candidates should be able to:

(a) show an understanding of and use the terms displacement, amplitude, period, frequency, phase difference, wavelength and speed

(b) deduce, from the definitions of speed, frequency and wavelength, the equation $v = f\lambda$

(c) recall and use the equation $v = f\lambda$

(d) show an understanding that energy is transferred due to a progressive wave

(e) recall and use the relationship, $intensity \propto (amplitude)^2$

(f) show an understanding of and apply the concept that a wave from a point source and travelling without loss of energy obeys an inverse square law to solve problems

(g) analyse and interpret graphical representations of transverse and longitudinal waves

(h) show an understanding that polarisation is a phenomenon associated with transverse waves

(i) recall and use Malus' law ($intensity \propto \cos^2\theta$) to calculate the amplitude and intensity of a plane polarised electromagnetic wave after transmission through a polarising filter

(j) determine the frequency of sound using a calibrated oscilloscope

(k) determine the wavelength of sound using stationary waves.

12. Superposition

Content

- Principle of superposition
- Stationary waves
- Diffraction
- Two-source interference
- Single slit and multiple slit diffraction

Learning Outcomes

Candidates should be able to:

(a) explain and use the principle of superposition in simple applications

(b) show an understanding of the terms interference, coherence, phase difference and path difference

(c) show an understanding of experiments which demonstrate stationary waves using microwaves, stretched strings and air columns

(d) explain the formation of a stationary wave using a graphical method, and identify nodes and antinodes

(e) explain the meaning of the term diffraction

(f) show an understanding of experiments which demonstrate diffraction including the diffraction of water waves in a ripple tank with both a wide gap and a narrow gap

(g) show an understanding of experiments which demonstrate two-source interference using water waves, sound waves, light and microwaves

(h) show an understanding of the conditions required for two-source interference fringes to be observed

(i) recall and solve problems using the equation $\lambda = ax / D$ for double-slit interference using light

(j) recall and use the equation $\sin\theta = \lambda / b$ to locate the position of the first minima for single slit diffraction

(k) recall and use the Rayleigh criterion $\theta \approx \lambda / b$ for the resolving power of a single aperture

(l) recall and use the equation $d\sin\theta = n\lambda$ to locate the positions of the principal maxima produced by a diffraction grating

(m) describe the use of a diffraction grating to determine the wavelength of light (the structure and use of a spectrometer are not required).

SECTION V ELECTRICITY AND MAGNETISM

13. Electric Fields

Content

- Concept of an electric field
- Electric force between point charges
- Electric field of a point charge
- Uniform electric fields
- Electric potential

Learning Outcomes

Candidates should be able to:

(a) show an understanding of the concept of an electric field as an example of a field of force and define electric field strength at a point as the electric force exerted per unit positive charge placed at that point

(b) represent an electric field by means of field lines

(c) recognise the analogy between certain qualitative and quantitative aspects of electric field and gravitational field

(d) recall and use Coulomb's law in the form $F = Q_1Q_2 / 4\pi\varepsilon_0 r^2$ for the electric force between two point charges in free space or air

(e) recall and use $E = Q / 4\pi\varepsilon_0 r^2$ for the electric field strength of a point charge in free space or air

(f) calculate the electric field strength of the uniform field between charged parallel plates in terms of the potential difference and plate separation

(g) calculate the forces on charges in uniform electric fields

(h) describe the effect of a uniform electric field on the motion of charged particles

(i) define the electric potential at a point as the work done per unit positive charge in bringing a small test charge from infinity to that point

(j) state that the field strength of the electric field at a point is numerically equal to the potential gradient at that point

(k) use the equation $V = Q / 4\pi\varepsilon_0 r$ for the electric potential in the field of a point charge, in free space or air.

14. Current of Electricity

Content

- Electric current
- Potential difference
- Resistance and resistivity
- Electromotive force

Learning Outcomes

Candidates should be able to:

(a) show an understanding that electric current is the rate of flow of charge

(b) derive and use the equation $I = nAvq$ for a current-carrying conductor, where n is the number density of charge carriers and v is the drift velocity

(c) recall and solve problems using the equation $Q = It$

(d) recall and solve problems using the equation $V = W / Q$

(e) recall and solve problems using the equations $P = VI$, $P = I^2R$ and $P = V^2 / R$

(f) recall and solve problems using the equation $V = IR$

(g) sketch and explain the I–V characteristics of various electrical components such as an ohmic resistor, a semiconductor diode, a filament lamp and a negative temperature coefficient (NTC) thermistor

(h) sketch the resistance-temperature characteristic of an NTC thermistor

(i) recall and solve problems using the equation $R = \rho l / A$

(j) distinguish between electromotive force (e.m.f.) and potential difference (p.d.) using energy considerations

(k) show an understanding of the effects of the internal resistance of a source of e.m.f. on the terminal potential difference and output power.

15. D.C. Circuits

Content

- Circuit symbols and diagrams
- Series and parallel arrangements
- Potential divider
- Balanced potentials

Learning Outcomes

Candidates should be able to:

(a) recall and use appropriate circuit symbols as set out in the ASE publication *Signs, Symbols and Systematics (The ASE Companion to 16–19 Science, 2000)*

(b) draw and interpret circuit diagrams containing sources, switches, resistors, ammeters, voltmeters, and/or any other type of component referred to in the syllabus

(c) solve problems using the formula for the combined resistance of two or more resistors in series

(d) solve problems using the formula for the combined resistance of two or more resistors in parallel

(e) solve problems involving series and parallel circuits for one source of e.m.f.

(f) show an understanding of the use of a potential divider circuit as a source of variable p.d.

(g) explain the use of thermistors and light-dependent resistors in potential divider circuits to provide a potential difference which is dependent on temperature and illumination respectively

(h) recall and solve problems by using the principle of the potentiometer as a means of comparing potential differences.

16. Electromagnetism

Content

- Concept of a magnetic field
- Magnetic fields due to currents
- Force on a current-carrying conductor
- Force between current-carrying conductors
- Force on a moving charge

Learning Outcomes

Candidates should be able to:

(a) show an understanding that a magnetic field is an example of a field of force produced either by current-carrying conductors or by permanent magnets

(b) sketch flux patterns due to currents in a long straight wire, a flat circular coil and a long solenoid

(c) use $B = \mu_0 I / 2\pi d$, $B = \mu_0 NI / 2r$ and $B = \mu_0 nI$ for the flux densities of the fields due to currents in a long straight wire, a flat circular coil and a long solenoid respectively

(d) show an understanding that the magnetic field due to a solenoid may be influenced by the presence of a ferrous core

(e) show an understanding that a current-carrying conductor placed in a magnetic field might experience a force

(f) recall and solve problems using the equation $F = BIl\sin\theta$, with directions as interpreted by Fleming's left-hand rule

(g) define magnetic flux density and the tesla

(h) show an understanding of how the force on a current-carrying conductor can be used to measure the flux density of a magnetic field using a current balance

(i) explain the forces between current-carrying conductors and predict the direction of the forces

(j) predict the direction of the force on a charge moving in a magnetic field

(k) recall and solve problems using the equation $F = BQv\sin\theta$

(l) describe and analyse deflections of beams of charged particles by uniform electric and uniform magnetic fields

(m) explain how electric and magnetic fields can be used in velocity selection for charged particles.

17. Electromagnetic Induction

Content

- Magnetic flux
- Laws of electromagnetic induction

Learning Outcomes

Candidates should be able to:

(a) define magnetic flux and the weber

(b) recall and solve problems using $\Phi = BA$

(c) define magnetic flux linkage

(d) infer from appropriate experiments on electromagnetic induction:

i. that a changing magnetic flux can induce an e.m.f.
ii. that the direction of the induced e.m.f. opposes the change producing it
iii. the factors affecting the magnitude of the induced e.m.f.

(e) recall and solve problems using Faraday's law of electromagnetic induction and Lenz's law

(f) explain simple applications of electromagnetic induction.

18. Alternating Current

Content

- Characteristics of alternating currents
- The transformer
- Rectification with a diode

Learning Outcomes

Candidates should be able to:

(a) show an understanding of and use the terms period, frequency, peak value and root-mean-square (r.m.s.) value as applied to an alternating current or voltage

(b) deduce that the mean power in a resistive load is half the maximum (peak) power for a sinusoidal alternating current

(c) represent an alternating current or an alternating voltage by an equation of the form $x = x_0 \sin \omega t$

(d) distinguish between r.m.s. and peak values and recall and solve problems using the relationship $I_{rms} = I_o / \sqrt{2}$ for the sinusoidal case

(e) show an understanding of the principle of operation of a simple iron-core transformer and recall and solve problems using $N_s / N_p = V_s / V_p = I_p / I_s$ for an ideal transformer

(f) explain the use of a single diode for the half-wave rectification of an alternating current.

SECTION VI MODERN PHYSICS

19. Quantum Physics

Content

- Energy of a photon
- The photoelectric effect
- Wave-particle duality
- Energy levels in atoms
- Line spectra
- X-ray spectra
- The uncertainty principle

Learning Outcomes

Candidates should be able to:

(a) show an appreciation of the particulate nature of electromagnetic radiation

(b) recall and use the equation $E = hf$

(c) show an understanding that the photoelectric effect provides evidence for the particulate nature of electromagnetic radiation while phenomena such as interference and diffraction provide evidence for the wave nature

(d) recall the significance of threshold frequency

(e) recall and use the equation $\frac{1}{2} mv_{max}^2 = eV_s$, where V_s is the stopping potential

(f) explain photoelectric phenomena in terms of photon energy and work function energy

(g) explain why the stopping potential is independent of intensity whereas the photoelectric current is proportional to intensity at constant frequency

(h) recall, use and explain the significance of the equation $hf = \Phi + \frac{1}{2} mv_{max}^2$

(i) describe and interpret qualitatively the evidence provided by electron diffraction for the wave nature of particles

(j) recall and use the relation for the de Broglie wavelength $\lambda = h / p$

(k) show an understanding of the existence of discrete electronic energy levels in isolated atoms (e.g. atomic hydrogen) and deduce how this leads to the observation of spectral lines

(l) distinguish between emission and absorption line spectra

(m) recall and solve problems using the relation $hf = E_2 - E_1$

(n) explain the origins of the features of a typical X-ray spectrum

(o) show an understanding of and apply $\Delta p \Delta x \gtrsim h$ as a form of the Heisenberg position-momentum uncertainty principle to new situations or to solve related problems.

20. Nuclear Physics

Content

- The nucleus
- Isotopes
- Nuclear processes
- Mass defect and nuclear binding energy
- Radioactive decay
- Biological effects of radiation

Learning Outcomes

Candidates should be able to:

(a) infer from the results of the Rutherford α-particle scattering experiment the existence and small size of the atomic nucleus

(b) distinguish between nucleon number (mass number) and proton number (atomic number)

(c) show an understanding that an element can exist in various isotopic forms each with a different number of neutrons in the nucleus

(d) use the usual notation for the representation of nuclides and represent simple nuclear reactions by nuclear equations of the form ${}^{14}_{7}\mathrm{N} + {}^{4}_{2}\mathrm{He} \rightarrow {}^{17}_{8}\mathrm{O} + {}^{1}_{1}\mathrm{H}$

(e) state and apply to problem solving the concept that nucleon number, charge and mass-energy are all conserved in nuclear processes.

(f) show an understanding of the concept of mass defect

(g) recall and apply the equivalence relationship between energy and mass as represented by $E = mc^2$ to solve problems

(h) show an understanding of the concept of nuclear binding energy and its relation to mass defect

(i) sketch the variation of binding energy per nucleon with nucleon number

(j) explain the relevance of binding energy per nucleon to nuclear fusion and to nuclear fission

(k) show an understanding of the spontaneous and random nature of nuclear decay

(l) infer the random nature of radioactive decay from the fluctuations in count rate

(m) show an understanding of the origin and significance of background radiation

(n) show an understanding of the nature of α, β and γ radiations (knowledge of positron emission is not required)

(o) show an understanding of how the conservation laws for energy and momentum in β decay were used to predict the existence of the neutrino (knowledge of antineutrino and antiparticles is not required)

(p) define the terms activity and decay constant and recall and solve problems using the equation $A = \lambda N$

(q) infer and sketch the exponential nature of radioactive decay and solve problems using the relationship $x = x_0\exp(-\lambda t)$ where x could represent activity, number of undecayed particles and received count rate

(r) define half-life

(s) solve problems using the relation $\lambda = \dfrac{\ln 2}{t_{\frac{1}{2}}}$

(t) discuss qualitatively the effects, both direct and indirect, of ionising radiation on living tissues and cells.

PRACTICAL ASSESSMENT

Scientific subjects are, by their nature, experimental. It is therefore important that, wherever possible, the candidates carry out appropriate practical work to support the learning of this subject and to develop the expected practical skills.

Paper 4 Practical

This paper is designed to assess a candidate's competence in those practical skills which can realistically be assessed within the context of a formal practical assessment.
Candidates will be assessed in the following skill areas:

(a) Planning (P)

Candidates should be able to:

- define a question/problem using appropriate knowledge and understanding
- give a clear logical account of the experimental procedure to be followed
- describe how the data should be used in order to reach a conclusion
- assess the risks of the experiment and describe precautions that should be taken to keep risks to a minimum.

(b) Manipulation, measurement and observation (MMO)

Candidates should be able to:

- demonstrate a high level of manipulative skills in all aspects of practical activity
- make and record accurate observations with good details and measurements to an appropriate degree of precision
- make appropriate decisions about measurements or observations
- recognise anomalous observations and / or measurements (where appropriate) with reasons indicated.

(c) Presentation of data and observations (PDO)

Candidates should be able to:

- present all information in an appropriate form
- manipulate measurements effectively in order to identify trends / patterns
- present all quantitative data to an appropriate number of decimal places / significant figures.

(d) Analysis, conclusions and evaluation (ACE)

Candidates should be able to:

- analyse and interpret data or observations appropriately in relation to the task
- draw conclusion(s) from the interpretation of experimental data or observations and underlying principles
- make predictions based on their data and conclusions
- identify significant sources of errors, limitations of measurements and / or experimental procedures used, explaining how they affect the final result(s)
- state and explain how significant errors / limitations may be overcome or reduced, as appropriate, including how experimental procedures may be improved.

The assessment of skill area P will be set in the context of the content syllabus, requiring candidates to apply and integrate knowledge and understanding from different sections of the syllabus. It may also require treatment of given experimental data to draw a relevant conclusion and in the analysis of a proposed plan.

The assessment of skill areas MMO, PDO and ACE will be set in the context of the syllabus. The assessment of PDO and ACE may also include questions on data analysis which do not require practical equipment and apparatus.

Within the Scheme of Assessment Paper 4 is weighted to 20% of the Higher 2 assessment. It is therefore recommended that the schemes of work include learning opportunities that apportion a commensurate amount of time for the development and acquisition of practical skills. The guidance material for practical work, which is published separately, will provide examples of appropriate practical activities.

Candidates are **not** allowed to refer to notebooks, textbooks or any other information in the Practical examination.

Apparatus List

This list below gives guidance to Centres concerning the apparatus and items that are expected to be generally available for examination purposes. The list is not intended to be exhaustive. To instil some variation in the questions set, some novel items are usually required.

Unless otherwise stated, the rate of allocation is “per candidate”. The number of sets of apparatus assembled for each experiment should be at least sufficient for half the candidates to undertake that particular experiment at the same time; some spare sets should also be provided.

Candidates will be told that they will have access to the apparatus and materials for specific questions for a specified time. Candidates will be told which question(s) to attempt first.

Electrical	**Mechanics and General Items**
Ammeter (analogue): f.s.d 500 mA and 1 A	Pendulum bob
Digital ammeter - minimum ranges: 0–10 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 0–200 μA reading to 0.1 μA or better. (digital multimeters are suitable)	Stand, boss and clamp: × 3 (Rod length: 2 × 60 cm, 1 × 90 cm)
	G-clamp × 2
	Pivot
	Pulley
Voltmeter (analogue): f.s.d 3 V	Tuning forks (1 set of 8 pieces per 4–6 candidates)
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)	Newton-meter: 1 N, 10 N
	Rule with millimeter scale (2 × 1 m, 1 × 0.5 m, 1 × 300 mm)
	Micrometer screw gauge (1 per 4–6 candidates)
Galvanometer (analogue): centre-zero, f.s.d. ±35 mA, reading to 1 mA or better	Vernier calipers (1 per 4–6 candidates)
Power supply: 12 V d.c. (low resistance)	Stopwatch (reading to 0.1 s or better)
Cells: 2 × 1.5 V with holder, 2 V	Protractor
Lamp and holder: 6 V, 300 mA; 2.5 V, 0.3 A	Balance to 0.01 g (1 per 8–12 candidates)
Rheostat: Max resistance: 22 Ω, Rating: at least 3.3 A	Beaker: 100 cm^3, 2 × 250 cm^3
Switch	Plasticine
Jockey	Blu-Tack
Leads and crocodile clips	Wire cutters
Wire: constantan 26, 28, 30, 32, 36, 38 s.w.g. or metric equivalents	Bare copper wire: 18, 26 s.w.g.
	Springs
Magnets and mounting: 2 × magnadur magnets plus small iron yoke for mounting, 2 × bar magnets	Spirit level (1 per 4–6 candidates)
	Stout pin or round nail
Compasses: 2 × small	Optical pin
Heat	Slotted masses: 1 each 5 and 10 g; 2 × 20 g; 4 × 50 g; 1 × 50 g hanger
Long stem thermometer: –10 °C to 110 °C at 1 °C	Slotted masses: 4 × 100 g; 1 × 100 g hanger
Metal calorimeter	Cork
Measuring cylinder: 50 cm^3, 100 cm^3	String/thread/twine
Plastic or polystyrene cup 200 cm^3	Scissors
Means to heat water safely to boiling	Adhesive tape
Heating mat	Card (assorted sizes)
Stirrer	Sand and tray
	Wood (assorted sizes, for various uses, e.g. support)
	Bricks: 2 × (approx. 22 cm × 10 cm × 7 cm)

The apparatus and material requirements for Paper 4 will vary year on year. Centres will be notified in advance of the details of the apparatus and materials required for each practical examination.

MATHEMATICAL REQUIREMENTS

Arithmetic

Candidates should be able to:

(a) recognise and use expressions in decimal and standard form (scientific) notation

(b) use appropriate calculating aids (electronic calculator or tables) for addition, subtraction, multiplication and division. Find arithmetic means, powers (including reciprocals and square roots), sines, cosines, tangents (and the inverse functions), exponentials and logarithms (lg and ln)

(c) take account of accuracy in numerical work and handle calculations so that significant figures are neither lost unnecessarily nor carried beyond what is justified

(d) make approximate evaluations of numerical expressions (e.g. $\pi^2 \approx 10$) and use such approximations to check the magnitude of machine calculations.

Algebra

Candidates should be able to:

(a) change the subject of an equation. Most relevant equations involve only the simpler operations but may include positive and negative indices and square roots

(b) 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 included

(c) substitute physical quantities into physical equations using consistent units and check the dimensional consistency of such equations

(d) formulate simple algebraic equations as mathematical models of physical situations, and identify inadequacies of such models

(e) recognise and use the logarithmic forms of expressions like ab, a/b, x^n, e^{kx}; understand the use of logarithms in relation to quantities with values that range over several orders of magnitude

(f) manipulate and solve equations involving logarithmic and exponential functions

(g) express small changes or errors as percentages and *vice versa*

(h) comprehend and use the symbols $<$, $>$, $\ll$, $\gg$, $\approx$, $/$, $\propto$, $\langle x \rangle$ ($= \overline{x}$), Σ, Δx, δx, $\sqrt{}$.

Geometry and trigonometry

Candidates should be able to:

(a) calculate areas of right-angled and isosceles triangles, circumference and area of circles, areas and volumes of rectangular blocks, cylinders and spheres

(b) use Pythagoras' theorem, similarity of triangles, the angle sum of a triangle

(c) use sines, cosines and tangents (especially for 0°, 30°, 45°, 60°, 90°). Use the trigonometric relationships for triangles:

$$\frac{a}{\sin A} = \frac{b}{\sin B} = \frac{c}{\sin C}; \qquad a^2 = b^2 + c^2 - 2bc\cos A$$

(d) use $\sin\theta \approx \tan\theta \approx \theta$ and $\cos\theta \approx 1$ for small θ; $\sin^2\theta + \cos^2\theta = 1$

(e) understand the relationship between degrees and radians (defined as arc / radius), translate from one to the other and use the appropriate system in context.

Vectors

Candidates should be able to:

(a) find the resultant of two coplanar vectors, recognising situations where vector addition is appropriate

(b) obtain expressions for components of a vector in perpendicular directions, recognising situations where vector resolution is appropriate.

Graphs

Candidates should be able to:

(a) translate information between graphical, numerical, algebraic and verbal forms

(b) select appropriate variables and scales for graph plotting

(c) for linear graphs, determine the slope, intercept and intersection

(d) choose, by inspection, a straight line which will serve as the best straight line through a set of data points presented graphically

(e) recall standard linear form $y = mx + c$ and rearrange relationships into linear form where appropriate

(f) sketch and recognise the forms of plots of common simple expressions like $1/x$, x^2, $1/x^2$, $\sin x$, $\cos x$, e^{-x}

(g) use logarithmic plots to test exponential and power law variations

(h) understand, draw and use the slope of a tangent to a curve as a means to obtain the gradient, and use notation in the form dy/dx for a rate of change

(i) understand and use the area below a curve where the area has physical significance.

Any calculator used must be on the Singapore Examinations and Assessment Board list of approved calculators.

GLOSSARY OF TERMS

It is hoped that the glossary will prove helpful to candidates as a guide, although it is not exhaustive. The glossary has been deliberately kept brief not only with respect to the number of terms included but also to the descriptions of their meanings. Candidates should appreciate that the meaning of a term must depend in part on its context. They should also note that the number of marks allocated for any part of a question is a guide to the depth of treatment required for the answer.

1. *Define* (*the term(s)* ...) is intended literally. Only a formal statement or equivalent paraphrase, such as the defining equation with symbols identified, being required.

2. *What is meant by ...* 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.

3. *Explain* may imply reasoning or some reference to theory, depending on the context.

4. *State* implies a concise answer with little or no supporting argument, e.g. a numerical answer that can be obtained 'by inspection'.

5. *List* requires a number of points with no elaboration. Where a given number of points is specified, this should not be exceeded.

6. *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. In the former instance, the term usually implies that the answer should include reference to (visual) observations associated with the phenomena. The amount of description intended should be interpreted in the light of the indicated mark value.

7. *Discuss* requires candidates to give a critical account of the points involved in the topic.

8. *Deduce/Predict* implies that candidates are 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.

9. *Suggest* is used in two main contexts. It may either imply that there is no unique answer or that candidates are expected to apply their general knowledge to a 'novel' situation, one that formally may not be 'in the syllabus'.

10. *Calculate* is used when a numerical answer is required. In general, working should be shown.

11. *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.

12. *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.

13. *Show* is used when an algebraic deduction has to be made to prove a given equation. It is important that the terms being used by candidates are stated explicitly.

14. *Estimate* implies a reasoned order of magnitude statement or calculation of the quantity concerned. Candidates should make such simplifying assumptions as may be necessary about points of principle and about the values of quantities not otherwise included in the question.

15. *Sketch,* when applied to graph work, implies that the shape and/or position of the curve need only be qualitatively correct. However, 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. On a sketch graph it is essential that candidates clearly indicate what is being plotted on each axis.

16. *Sketch,* when applied to diagrams, implies that a simple, freehand drawing is acceptable: nevertheless, care should be taken over proportions and the clear exposition of important details.

17. *Compare* requires candidates to provide both similarities and differences between things or concepts.

TEXTBOOKS

Teachers may find reference to the following books helpful.

Practice in Physics (4th Edition), by Akrill et al, published by Hodder Education, ISBN 1-444-12125-1

New Understanding Physics for Advanced Level (4th Edition), by J Breithaupt, published by Nelson Thornes, ISBN 0-748-74314-6

Advanced Physics (5th Edition), by T Duncan, published by Hodder Education, ISBN 0-719-57669-5

Physics for Scientists and Engineers with Modern Physics (9th Edition), by R Serway and J Jewett, published by Brooks/Cole, ISBN 1-133-95399-9

Fundamental of Physics (10th Edition), by R Resnick, D Halliday & J Walker, published by Wiley, ISBN 1-118-23071-X

Physics: Principles with Applications (7th Edition), by DC Giancoli, published by Addison-Wesley, ISBN 0-321-62592-2

College Physics, by PP Urone, published by Brooks/Cole, ISBN 0-534-37688-6

AS/A-Level Physics – Essential Word Dictionary by Mike Crundell, ISBN: 0860033775

Advanced Physics by Steve Adams and Jonathan Allday, Oxford University Press, ISBN: 978-0-19-914680-2

Cambridge International AS and A Level Physics Coursebook by Sang, Janoes, Woodside and Chandha, Cambridge University Press, ISBN: 9781107697690

Teachers are encouraged to choose texts for class use that they feel will be of interest to their students and will support their own teaching style.

SUMMARY OF KEY QUANTITIES, SYMBOLS AND UNITS

The following list illustrates the symbols and units that will be 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		
distance	d	m
displacement	s, x	m
area	A	m^2
volume	V, v	m^3
density	ρ	$kg\,m^{-3}$
speed	u, v, w, c	$m\,s^{-1}$
velocity	u, v, w, c	$m\,s^{-1}$
acceleration	a	$m\,s^{-2}$
acceleration of free fall	g	$m\,s^{-2}$
force	F	N
weight	W	N
momentum	p	N s
work	w, W	J
energy	E,U,W	J
potential energy	E_p	J
kinetic energy	E_k	J
heating	Q	J
change of internal energy	ΔU	J
power	P	W
pressure	p	Pa
torque	T	N m
gravitational constant	G	$N\,kg^{-2}\,m^2$
gravitational field strength	g	$N\,kg^{-1}$
gravitational potential	ϕ	$J\,kg^{-1}$
angle	θ	°, rad
angular displacement	θ	°, rad
angular speed	ω	$rad\,s^{-1}$
angular velocity	ω	$rad\,s^{-1}$
period	T	s
frequency	f	Hz
angular frequency	ω	$rad\,s^{-1}$
wavelength	λ	m
speed of electromagnetic waves	c	$m\,s^{-1}$
electric charge	Q	C
elementary charge	e	C
electric potential	V	V
electric potential difference	V	V
electromotive force	E	V
resistance	R	Ω
resistivity	ρ	$\Omega\,m$
electric field strength	E	$N\,C^{-1}$, $V\,m^{-1}$
permittivity of free space	ε_0	$F\,m^{-1}$
magnetic flux	Φ	Wb
magnetic flux density	B	T
permeability of free space	μ_0	$H\,m^{-1}$
force constant	k	$N\,m^{-1}$

Quantity	***Usual symbols***	***Usual unit***
Celsius temperature	θ	°C
specific heat capacity	c	$\mathrm{J\,K^{-1}\,kg^{-1}}$
molar gas constant	R	$\mathrm{J\,K^{-1}\,mol^{-1}}$
Boltzmann constant	k	$\mathrm{J\,K^{-1}}$
Avogadro constant	N_A	$\mathrm{mol^{-1}}$
number	N, n, m	
number density (number per unit volume)	n	$\mathrm{m^{-3}}$
Planck constant	h	J s
work function energy	Φ	J
activity of radioactive source	A	Bq
decay constant	λ	$\mathrm{s^{-1}}$
half-life	$t_{1/2}$	s
relative atomic mass	A_r	
relative molecular mass	M_r	
atomic mass	m_a	kg, u
electron mass	m_e	kg, u
neutron mass	m_n	kg, u
proton mass	m_p	kg, u
molar mass	M	kg
proton number	Z	
nucleon number	A	
neutron number	N	

DATA AND FORMULAE

Data

speed of light in free space	c	=	3.00×10^{8} m s^{-1}
permeability of free space	μ_0	=	$4\pi \times 10^{-7}$ H m^{-1}
permittivity of free space	ε_0	=	8.85×10^{-12} F m^{-1}
			$(1/(36\pi)) \times 10^{-9}$ F m^{-1}
elementary charge	e	=	1.60×10^{-19} C
the Planck constant	h	=	6.63×10^{-34} J s
unified atomic mass constant	u	=	1.66×10^{-27} kg
rest mass of electron	m_e	=	9.11×10^{-31} kg
rest mass of proton	m_p	=	1.67×10^{-27} kg
molar gas constant	R	=	8.31 J K^{-1} mol^{-1}
the Avogadro constant	N_A	=	6.02×10^{23} mol^{-1}
the Boltzmann constant	k	=	1.38×10^{-23} J K^{-1}
gravitational constant	G	=	6.67×10^{-11} N m^{2} kg^{-2}
acceleration of free fall	g	=	9.81 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	p	=	ρgh
gravitational potential	ϕ	=	$-Gm/r$
temperature	T/K	=	T/°C + 273.15
pressure of an ideal gas	p	=	$\frac{1}{3}\frac{Nm}{V}\langle c^2 \rangle$
mean translational kinetic energy of an ideal gas molecule	E	=	$\frac{3}{2}kT$
displacement of particle in s.h.m.	x	=	$x_0 \sin \omega t$
velocity of particle in s.h.m.	v	=	$v_0 \cos \omega t$
		=	$\pm \omega \sqrt{(x_o^2 - x^2)}$
electric current	I	=	$Anvq$
resistors in series	R	=	$R_1 + R_2 + \ldots$
resistors in parallel	$1/R$	=	$1/R_1 + 1/R_2 + \ldots$
electric potential	V	=	$\frac{Q}{4\pi\varepsilon_0 r}$
alternating current/voltage	x	=	$x_0 \sin \omega t$
magnetic flux density due to a long straight wire	B	=	$\frac{\mu_0 I}{2\pi d}$
magnetic flux density due to a flat circular coil	B	=	$\frac{\mu_0 NI}{2r}$

magnetic flux density due to a long solenoid	B	=	$\mu_0 n I$
radioactive decay	x	=	$x_0 \exp(-\lambda t)$
decay constant	λ	=	$\dfrac{\ln 2}{t_{\frac{1}{2}}}$