PHYSICS

Singapore-Cambridge General Certificate of Education Advanced Level Higher 3 (2021)

(Syllabus 9814)

CONTENTS

Singapore Examinations and Assessment Board

Cambridge Assessment International Education

INTRODUCTION

The H3 Physics syllabus has been designed to build on and extend the knowledge, understanding and skills acquired from the H2 Physics (9749) syllabus. It caters to students of strong ability and keen interest in physics, and is designed with a strong emphasis on independent and self-directed learning. Students should simultaneously offer H2 Physics. The H3 Physics syllabus is meant to provide greater depth and rigour in the subject for students pursuing further studies in physics-related fields.

AIMS

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

1 provide students an experience that deepens their knowledge and skills, and foster attitudes necessary for further studies in related fields

2 develop in students their appreciation of the practice, value and rigour of physics as a discipline

3 develop in students the skills to analyse physical situations, and to apply relevant concepts and techniques, including calculus, to solve problems.

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 this syllabus to allow teachers to embed them as learning objectives in their lessons. 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 evidence-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 application of scientific knowledge to problem solving is influenced by other considerations such as economic, social, environmental and ethical factors

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

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 scale 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 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 to study and make sense 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 *system* under study (by specifying its *boundaries* and making explicit a *model* of that system) 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.

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 being 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. reaching constant temperature at thermal equilibrium when objects of different temperature interact, an object returning to its equilibrium position after undergoing damped oscillatory motion).

1.8 Simplified *microscopic* models can 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. electrons' movement in a wire resulting in the 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 include:

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

3.7.2 conservation of energy to calculate 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 curriculum framework for H3 Physics (**Fig. 1**) builds on the framework for H2 Physics, and guides the development of the H3 Physics curriculum.

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.

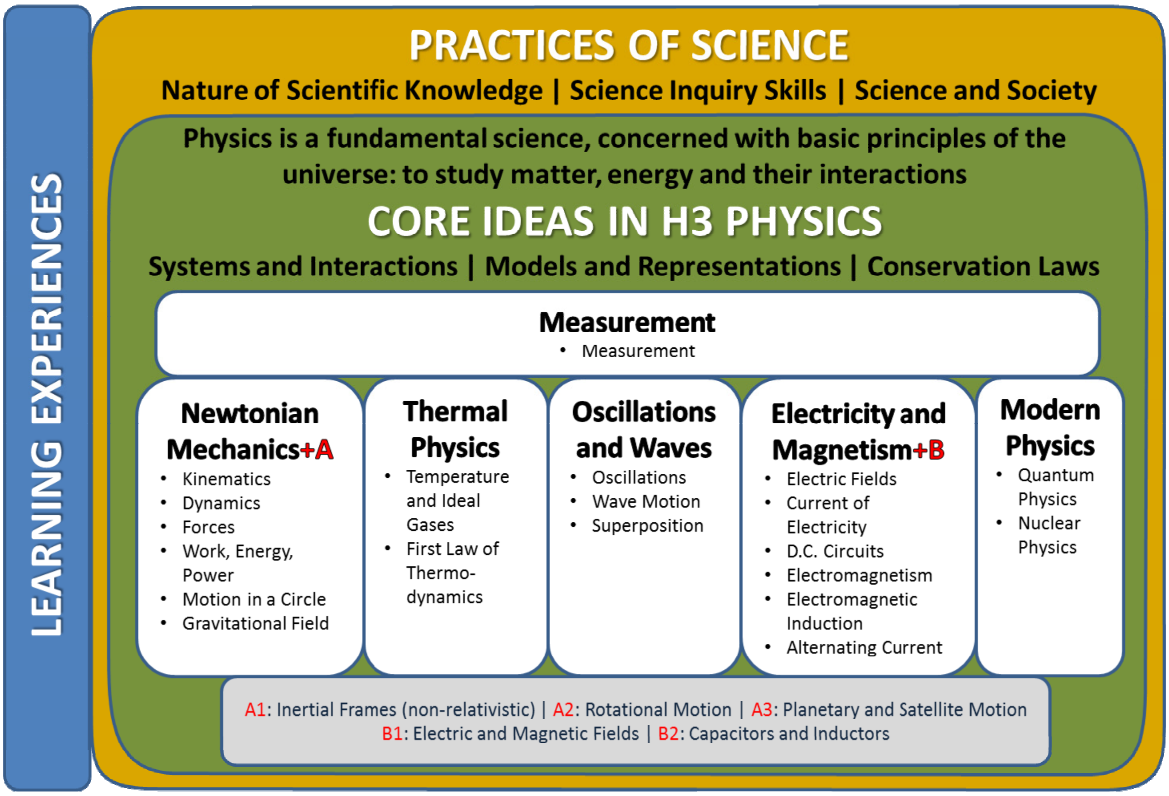

Fig. 1: H3 Physics Curriculum Framework

[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 in the examination.

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.

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.

SCHEME OF ASSESSMENT

There is one paper of 3 hours duration for this subject. This paper will consist of two sections and will include questions which require candidates to integrate knowledge and understanding from different areas of the syllabus.

Section A (60 marks)
This section will consist of a variable number of compulsory structured questions. The last of these will be a stimulus-based question which will constitute 15–20 marks.

Section B (40 marks)
This section will consist of a choice of two from three 20-mark longer structured questions. Questions will be set in which knowledge of differential and/or integral calculus will be advantageous.

Weighting of Assessment Objectives

Assessment Objectives		Weighting (%)
A	**Knowledge with understanding**	25
B	**Handling, applying and evaluating information**	75

ADDITIONAL INFORMATION

Mathematical Requirements

The mathematical requirements are given on pages 14 to 16.

Data and Formulae

Data and Formulae, as printed on pages 22 to 24, will appear as pages 2 and 3 in the examination paper.

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 kW h, atmosphere, eV and unified atomic mass unit (u) may be used in examination papers without further explanation.

Required Subject Combinations

Candidates should simultaneously offer H2 Physics.

SUBJECT CONTENT

The syllabus for H3 Physics builds on that for H2 Physics, and includes the whole of the H2 Physics (9749) syllabus. Only content that is not already part of the H2 Physics syllabus is specifically set out here. Candidates who offer H3 Physics should have a strong foundation in H2 Physics, through the three core ideas of models and representations, systems and interactions, and conservation laws.

There are six broad sections of the H2 Physics syllabus. The H3 Physics syllabus introduces additional content in two of these sections, namely “Newtonian Mechanics” and “Electricity and Magnetism”. The additional content has been selected to highlight basic principles in physics and to strengthen the focus on applications. The topics chosen as extensions to the H2 syllabus expand the scope for students to engage in solving challenging problems, while allowing a deeper appreciation of the unity, cohesion and beauty of the discipline of physics.

Candidates who offer H3 Physics are expected to tackle more sophisticated problems than other candidates who only offer H2 Physics, especially because of the expanded scope. Furthermore, the mathematical requirements for H3 Physics are higher than for H2 Physics, from the introduction of calculus, etc. (see pages 14 to 16 for the mathematical requirements).

Additional content areas

In addition to the physics content specified in the H2 Physics (9749) syllabus, the H3 Physics syllabus will also include additional content in two main sections.

SECTION A NEWTONIAN MECHANICS

As part of the H2 Physics syllabus, candidates should understand and apply concepts involving the statics and classical dynamics of point masses, and the statics of extended objects.

1 Inertial Frames (non-relativistic)

In the H3 Physics syllabus, building on the understanding of collisions and the significance of the centre of mass in equilibrium situations, candidates should understand and apply concepts related to non-relativistic dynamics viewed from different inertial frames.

Content

- Inertial frames of reference
- Centre of mass frame

Learning Outcomes

Candidates should be able to:

(a) show an understanding of what is meant by a frame of reference

(b) recall and apply the Galilean transformation equations to solve problems relating observations in different frames of reference

(c) show an understanding of what is meant by an inertial frame of reference, in the context of Newton’s laws of motion

(d) show an understanding that the centre of mass moves as though the total mass is concentrated at that point and is acted upon by the net external force on the system

(e) solve two-dimensional collision problems by considering velocities relative to the centre of mass of the system.

2 Rotational Motion

In the H3 Physics syllabus, building on the study of linear motion and motion in a circle, as well as on the understanding of the significance of the centre of mass in statics and dynamics, candidates should understand and apply concepts related to the rotational dynamics of classical objects about an axis of fixed orientation.

Content

- Kinematics of angular motion
- Dynamics of angular motion
- Rigid body rotation about an axis of fixed orientation

Learning Outcomes

Candidates should be able to:

(a) show an understanding of and use the terms angular displacement, angular velocity, and angular acceleration of a rigid body with respect to a fixed axis

(b) solve problems using the equations of motion for uniform angular acceleration that are analogous to the equations of motion for uniform linear acceleration

(c) show an understanding of and use the terms angular momentum and moment of inertia of a rotating rigid body

(d) calculate the moment of inertia about an axis for simple objects by using calculus, the parallel-axis theorem or otherwise (knowledge of the perpendicular-axis theorem is not required)

(e) show an understanding of torque produced by a force relative to a reference point and apply the principle that torque is related to the rate of change of angular momentum to solve problems, such as those involving point masses, rigid bodies, or bodies with a variable moment of inertia e.g. an ice-skater

(f) derive, from the equations of motion, and apply the formula $E_{\mathrm{K,rot}} = \frac{1}{2}I\omega^2$ for the rotational kinetic energy of a rigid body

(g) recall and apply the result that the motion of a rigid body can be regarded as translational motion of its centre of mass with rotational motion about an axis through the centre of mass to solve related problems, including situations where the frictional force between surfaces heuristically takes a limiting value governed by a coefficient of friction and the normal contact force (no distinction is made between the coefficient of static and kinetic friction).

3 Planetary and Satellite Motion

In the H3 Physics syllabus, building on the study of circular motion and gravitation fields, candidates should understand and apply concepts related to the motion of planets and satellites in elliptical orbits, where the central body is much more massive than the orbiting body.

Content

- Kepler’s laws of planetary motion
- Gravitational potential energy of a spherical shell
- Elliptical orbits and orbital transfers
- Concept of an effective radial potential

Learning Outcomes

Candidates should be able to:

(a) show an understanding of Kepler's laws of planetary motion, and

(i) recall and apply Kepler's first law that the planets move in elliptical orbits with the Sun at one focus of the ellipse (knowledge of the eccentricity parameter is not required)

(ii) show an understanding of how Kepler's second law (that an imaginary line from the Sun to a moving planet sweeps out equal areas in equal intervals of time) is related to the conservation of angular momentum and apply this law to solve related problems

(iii) recall and apply Kepler's third law that the ratio of the square of a planet's period of revolution to the cube of the semi-major axis of its orbit around the Sun is a constant and that this constant is the same for all planets

(b) derive expressions for the gravitational potential energy of a point mass inside and outside a uniform spherical shell of mass, and relate these expressions to the justification for treating large spherical objects as point masses

(c) solve problems involving elliptical orbits and orbital transfers e.g. when a satellite fires its thrusters (knowledge of parabolic and hyperbolic trajectories is not required)

(d) derive, from energy considerations, an expression for the effective radial potential $U_{\text{eff}} = -\frac{GMm}{r} + \frac{L^2}{2mr^2}$ for a mass m interacting gravitationally with a large mass $M \gg m$ whose own motion is negligible, where L is the angular momentum of the mass m relative to the stationary mass M

(e) discuss how the effective radial potential allows the determination of bound and unbound states, as well as turning points in the motion, and apply this to solve related problems.

SECTION B ELECTRICITY AND MAGNETISM

As part of the H2 Physics syllabus, candidates should understand and apply concepts involving the statics and dynamics of point charges in electric and magnetic fields. Candidates should also understand and apply concepts involving electrical circuits with resistance and voltage sources (both direct current and alternating current).

4 Electric and Magnetic Fields

In the H3 Physics syllabus, building on the study of Coulomb's law and uniform electric fields, candidates should understand and apply concepts related to continuous distributions of charge in both conductors and insulators. Similarly, building on the study of magnetic flux patterns and Faraday's law, candidates should understand and apply concepts related to Ampère's law and magnetic dipole moments.

Content

- Electric fields in a conductor
- Gauss's law for electric and magnetic fields
- Ampère's law for magnetic fields
- Electric and magnetic dipoles

Learning Outcomes

Candidates should be able to:

(a) show an understanding that ideal conductors form an equipotential volume and that the electric field within an ideal conductor is zero

(b) show an understanding that electric charge accumulates on the surfaces of a conductor and that the electric field at the surface of a conductor is normal to the surface

(c) recall and apply Gauss's law[3] for electric and magnetic fields (knowledge of the differential form of Gauss's law is not required) and

(i) solve problems involving symmetric charge distributions by relating the electric flux (in a vacuum) through a closed surface with the charge enclosed by that surface

(ii) show an understanding of the non-existence of "magnetic charge" expressed by Gauss's law for magnetism

(d) recall and apply Ampère's law[4] relating the line integral of the magnetic field (in a vacuum) around a closed loop with the electric current enclosed by the loop to solve problems involving symmetric field configurations (knowledge of the differential form of Ampère's law is not required).
[Note further that candidates are not required to know Maxwell's generalisation of Ampère's law including the term related to the rate of change of electric flux, nor the Biot-Savart law]

(e) define the magnitude of the electric dipole moment as the product of the charge and the separation

(f) show an understanding of and use the torque on an electric dipole and the potential energy of an electric dipole to solve related problems

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[3] Note that the mathematical concepts and notation for integrating over a surface should be introduced as necessary in the context of Gauss's law and are not general mathematical requirements in other contexts.

[4] Note that the mathematical concepts and notation for integrating along a contour should be introduced as necessary in the context of Ampère's law and are not general mathematical requirements in other contexts.

(g) define the magnitude of the magnetic dipole moment for a current loop as the product of the current and the area of the loop

(h) show an understanding of and use the torque on a magnetic dipole and the potential energy of a magnetic dipole to solve related problems

(i) appreciate that while electric and magnetic dipoles behave analogously, the theoretical framework at this level of study does not admit the possibility of magnetic monopoles.

5 Capacitors and Inductors

In the H3 Physics syllabus, building on the study of conductors in electric fields, candidates should understand and apply concepts related to the charging and discharging of capacitors. Similarly, building on the study of Faraday's law, candidates should understand and apply concepts related to the inclusion of inductors in electrical circuits.

Content

- Capacitance and inductance
- Dielectrics and ferromagnetic materials
- Energy in a capacitor and in an inductor
- Circuits with capacitors and inductors

Learning Outcomes

Candidates should be able to:

(a) define capacitance and the farad

(b) define mutual inductance, self-inductance and the henry

(c) show an understanding that the self-inductance (inductance) of a circuit can result in a self-induced e.m.f.

(d) show a qualitative understanding that dielectric materials enhance capacitance and that dielectric breakdown can occur when the electric field is sufficiently strong (knowledge of the quantitative modification of electric fields in matter through the permittivity is not required)

(e) show a qualitative understanding that ferromagnetic materials enhance inductance and that this enhancement is non-linear especially near saturation (knowledge of the quantitative modification of magnetic fields in matter through the permeability is not required)

(f) derive, from the definition of work done by a force, that the potential energy stored in a capacitor is $U = \frac{1}{2}CV^2$ and apply this to solve related problems

(g) derive, from the definition of work done by a force, that the potential energy stored in an inductor is $U = \frac{1}{2}LI^2$ and apply this to solve related problems

(h) solve problems using the formulae for the combined capacitance of two or more capacitors in series and/or parallel

(i) solve problems using the formulae for the combined inductance of two or more inductors in series and/or parallel

(j) solve problems involving circuits with resistors, capacitors, and sources of constant e.m.f. (includes solving first-order differential equations). *[RC series circuits with constant e.m.f. source]*

(k) solve problems involving circuits with resistors, inductors, and sources of constant e.m.f. (includes solving first-order differential equations). *[RL series circuits with constant e.m.f. source]*

(l) solve problems involving circuits with inductors and capacitors only (includes solving second-order differential equations). *[LC series circuits without e.m.f. source]*

(m) solve problems involving circuits with resistors, inductors and capacitors only (candidates are not expected to solve the general second-order differential equations, though they can be asked to show that particular solutions work). *[RLC series circuits without e.m.f. source]*

MATHEMATICAL REQUIREMENTS

Additional requirements not found in the H2 Physics (9749) syllabus are marked with an asterisk (*).

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 and 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:

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

(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

*(c) use column vector notation for vectors and unit vector notation (such as $\hat{x}$)

*(d) use concepts and properties of scalar (dot) products and vector (cross) products, excluding triple products.

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 line of best fit 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

*(j) describe ellipses mathematically, in Cartesian coordinates.

Calculus

Candidates should be able to:

*(a) perform differentiation of simple functions, including trigonometric, exponential and logarithmic functions, and the use of product rule and chain rule

*(b) perform integration of simple functions, including trigonometric, exponential and logarithmic functions, and area integrals of circularly symmetric distributions and volume integrals of spherically and cylindrically symmetric distributions[5] (knowledge of integration by parts is not required)

*(c) evaluate definite integrals

*(d) solve first-order differential equations of the form $\mathrm{d}y / \mathrm{d}x = \mathrm{f}(x)$

*(e) solve second-order differential equations of the form $\mathrm{d}^2y / \mathrm{d}x^2 = \mathrm{f}(x)$.

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

[5] Candidates are only expected to be able to perform one-dimensional radial integrals that do not involve any non-trivial angular dependence.

GLOSSARY OF TERMS USED IN PHYSICS PAPERS

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.

REFERENCES

Teachers and students may find the following textbooks helpful:

Adams, S and Allday, J (2000). *Advanced Physics*. Oxford: Oxford University Press.

Breithaupt, J (2015). *Physics*. London New York, NY: Palgrave.

Feynman, R, Leighton, R and Sands, M (2010). *The Feynman Lectures on Physics*. New York: Basic Books.

Giancoli, D (2014). *Physics : Principles with Applications*. Boston: Pearson.

Hutchings, R (2000). *Physics*. Cheltenham: Nelson Thornes.

Jones, E and Childers, R (2001). *Contemporary College Physics*. Boston: McGraw Hill.

Muncaster, R (1993). *A-level Physics*. Cheltenham: Thornes.

Serway, R, Jewett, J and Peroomian, V (2016). *Physics for Scientists and Engineers with Modern Physics*. Boston, MA: Brooks/Cole, Cengage Learning.

Tipler, P and Mosca, G (2008). *Physics for Scientists and Engineers*. New York, NY: W.H. Freeman.

Wolfson, R (2015). *Essential University Physics + MasteringPhysics with eText-Access Card*. Addison-Wesley.

Students might also enjoy the following list of books related to physics (which is in no way exhaustive!):

Abbott, E and Banchoff, T (2015). *Flatland: A Romance of Many Dimensions*. Princeton: Princeton University Press.

Feynman, R and Zee, A (2014). *QED: The Strange Theory of Light and Matter*. Princeton, NJ: Princeton University Press.

Hawking, S (2016). *The Illustrated A Brief History of Time/The Universe in a Nutshell*. London: Bantam.

MacKay, D (2009). *Sustainable Energy – Without The Hot Air*. Cambridge, England: UIT.

Munroe, R (2014). *what if?* New York: Houghton Mifflin Harcourt

Povey, T (2015). *Professor Povey's Perplexing Problems: Pre-University Physics and Maths Puzzles with Solutions*. London: Oneworld Publications.

Randall, L (2015). *Dark Matter and the Dinosaurs: The Astounding Interconnectedness of the Universe*. New York, NY: Ecco, an imprint of HarperCollins Publishers.

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	τ	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}

Quantity	***Usual symbols***	***Usual unit***
angular velocity	ω	rad s^{-1}
*angular acceleration	α	rad s^{-2}
*moment of inertia	I	kg m^2
*angular momentum	L	kg m^2 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, Q	C
*electric charge (surface) density	σ	C m^{-2}
elementary charge	e	C
electric potential	V	V
electric potential difference	V	V
electromotive force	E	V
resistance	R	Ω
resistivity	ρ	Ω m
*electric dipole moment	p	C m
electric field strength	E	N C^{-1}, V m^{-1}
*electric flux	Φ	V m
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}
*magnetic dipole moment	μ, m	A m^2
*capacitance	C	F
*inductance	L	H
force constant	k	N m^{-1}
Celsius temperature	θ	°C
specific heat capacity	c	J K^{-1} kg^{-1}
molar gas constant	R	J K^{-1} mol^{-1}
Boltzmann constant	k	J K^{-1}
Avogadro constant	N_A	mol^{-1}
number	N, n, m	
number density (number per unit volume)	n	m^{-3}
Planck constant	h	J s
work function energy	Φ	J
activity of radioactive source	A	Bq
decay constant	λ	s^{-1}

Quantity	***Usual symbols***	***Usual unit***
half-life	$t_{\frac{1}{2}}$	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

Additional data and formulae not found in the H2 Physics (9749) syllabus are marked with an asterisk (*).

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	=	$u^2 + 2as$
*moment of inertia of rod through one end	I	=	$\frac{1}{3}ML^2$
*moment of inertia of hollow cylinder through axis	I	=	$\frac{1}{2}M\left(r_1^2 + r_2^2\right)$
*moment of inertia of solid sphere through centre	I	=	$\frac{2}{5}MR^2$
*moment of inertia of hollow sphere through centre	I	=	$\frac{2}{3}MR^2$
work done on/by a gas	W	=	$p\Delta V$
hydrostatic pressure	p	=	ρgh
gravitational potential	ϕ	=	$-Gm/r$
*Kepler's third law of planetary motion	T^2	=	$\frac{4\pi^2 a^3}{GM}$

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	=	$v_0 \cos \omega t$
		=	$\pm\omega\sqrt{\left(x_0^2 - x^2\right)}$
electric current	I	=	$Anvq$
resistors in series	R	=	$R_1 + R_2 + \ldots$
resistors in parallel	$1/R$	=	$1/R_1 + 1/R_2 + \ldots$
*capacitors in series	$1/C$	=	$1/C_1 + 1/C_2 + \ldots$
*capacitors in parallel	C	=	$C_1 + C_2 + \ldots$
*energy in a capacitor	U	=	$\frac{1}{2}CV^2$
electric potential	V	=	$\frac{Q}{4\pi\varepsilon_0 r}$
*electric field strength due to a long straight wire	E	=	$\frac{\lambda}{2\pi\varepsilon_0 r}$
*electric field strength due to a large sheet	E	=	$\frac{\sigma}{2\varepsilon_0}$
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	=	$\mu_0 nI$
*energy in an inductor	U	=	$\frac{1}{2}LI^2$
*RL series circuits	τ	=	$\frac{L}{R}$

*RLC series circuits (underdamped)	ω	=	$\sqrt{\frac{1}{LC}-\frac{R^2}{4L^2}}$
radioactive decay	x	=	$x_0 \exp(-\lambda t)$
decay constant	λ	=	$\frac{\ln 2}{t_{\frac{1}{2}}}$