Singapore Examinations and Assessment Board

CAMBRIDGE International Education

Singapore–Cambridge General Certificate of Education Advanced Level Higher 3 (2026)

Physics (Syllabus 9814)

(First year of examination in 2026)

CONTENTS

INTRODUCTION

The H3 Physics syllabus has been designed to build on and extend the knowledge, understanding and skills acquired from the H2 Physics (9478) 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 with an experience that deepens their knowledge and skills in physics, 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 Demonstrating Ways of Thinking and Doing (WOTD)

The Ways of Thinking and Doing in Science illustrate a set of established procedures and practices associated with scientific inquiry to gather evidence and test ideas on how the natural world works. There are three broad, iterative domains of scientific activity: investigating, evaluating and reasoning, and developing explanations and solutions.

1.1 Posing questions and defining problems
1.2 Designing investigations
1.3 Conducting experiments and testing solutions
1.4 Analysing and interpreting data
1.5 Communicating, evaluating and defending ideas with evidence
1.6 Making informed decisions and taking responsible actions
1.7 Using and developing models[1]
1.8 Constructing explanations and designing solutions

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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.*

2 Understanding the Nature of Scientific Knowledge (NOS)
Science is an epistemic endeavour to build a better understanding of reality.

2.1 Science is an evidence-based, model-building enterprise to understand the real world.
2.2 Science assumes natural causes, order and consistency in natural systems.
2.3 Scientific knowledge is generated through established procedures and critical debate.
2.4 Scientific knowledge is reliable, durable and open to change in light of new evidence.

3 Relating Science-Technology-Society-Environment (STSE)
Science is not done completely independently of the other spheres of human activity. The relationships and connections to these areas are important as students learn science in context.

3.1 There are risks and benefits associated with the applications of science in society.
3.2 Applications of science often have ethical, social, economic and environmental implications.
3.3 Applications of new scientific discoveries often drive technological advancements while advances in technology enable scientists to make new or deeper inquiry.

CURRICULUM FRAMEWORK

The *Values, Ethics, Attitudes*, the *Practices of Science,* the *Disciplinary Content* and *Learning Experiences* are put together in a framework (**Figure 1**) to guide the development of the A-Level Physics curriculum.

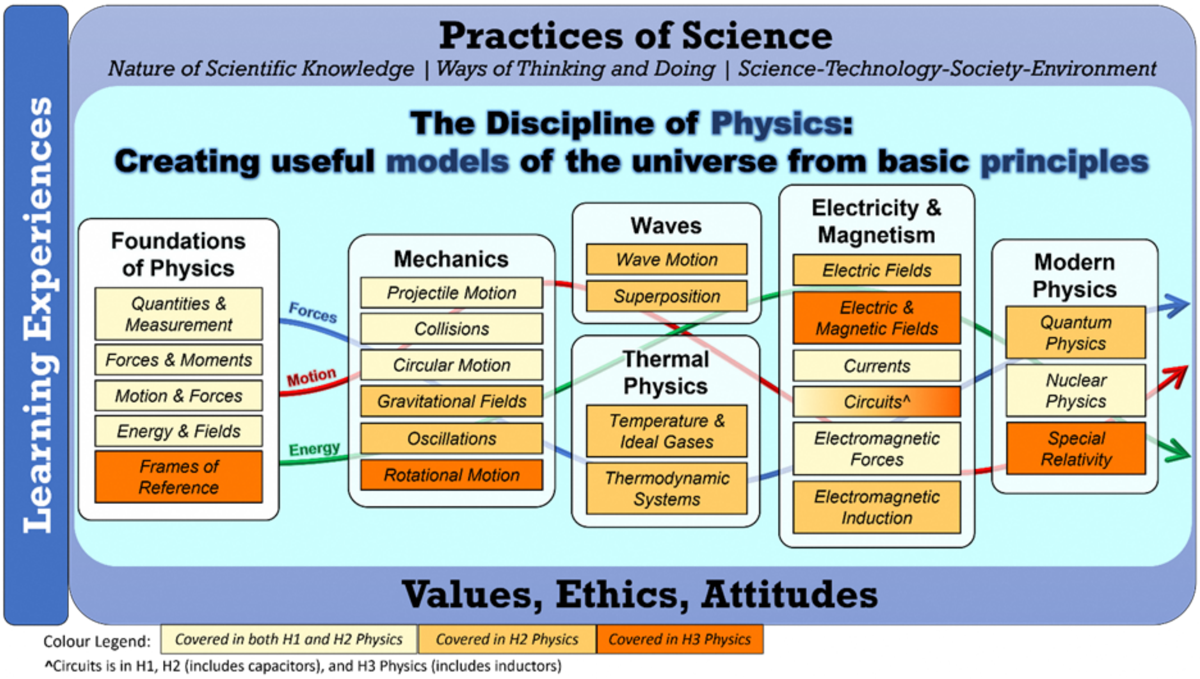

Figure 1: A-Level Physics Curriculum Framework

The *Practices of Science* 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 *Disciplinary Content* is organised around conceptual strands that are explored in different contexts. This content is coherently developed with a consideration of conceptual progression and framed by *Core Ideas in Physics* to help students integrate knowledge and link concepts across different topics.

The *Values, Ethics, Attitudes* undergird the study of science and the use of related knowledge and skills to make a positive contribution to humanity.

The *Learning Experiences*[2] refer to a range of learning opportunities that enhance students' learning of physics. Real-world contexts can help illustrate the application of physics concepts and bring the subject to life. These *Learning Experiences* would include experimental (practical work) activities and ICT tools that can be used to build students' understanding and model-making. The *Learning Experience*s are not meant to be prescriptive or exhaustive but serve as examples of the range of learning experiences that can enhance students' learning of physics.

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* or *explain* (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).

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

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.

<u>Section A (60 marks)</u>
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.

<u>Section B (40 marks)</u>
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 necessary.

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 15.

Data and Formulae

Data and Formulae, as printed on pages 21 and 22 will appear as pages 2 and 3 in the examination paper.

Conventions, Symbols, Signs and Abbreviations

Conventions, 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 kilowatt hour (kWh), atmosphere (atm), electron volt (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.

CONTENT OVERVIEW

Light escapes from a giant ball of hydrogen gas and radiates through free space. The sky is blue, we think, as our neurons process the signals generated from photons activating retinal cells. The Sun is white, yet may appear yellow while the sky appears blue…

'Nobody ever figures out what life is all about, and it doesn't matter. Explore the world. Nearly everything is really interesting if you go into it deeply enough.' – Richard P. Feynman

In physics, we create useful **models** of the universe and attempt to make sense of nature. Starting from a small number of basic principles, we work out their implications and compare them against observations. As a natural science, physics ultimately relies on empirical evidence obtained through careful observations and experimentation.

Several revolutionary paradigms have emerged in the historical development of the discipline of physics. While each paradigm considers a different set of principles as fundamental, the older paradigms like *Newtonian Mechanics* remain relevant – coherent[3] application of its principles produces excellent agreement between theory and experiment in many cases.

Still, the universe is a tremendously complex place. Science and physics are not 'finished' as no paradigm has yet proven fully satisfactory as a 'theory of everything'. There is much we know, and much more to find out. Stay curious – there is never a better time to be alive!

The core content selected for the Singapore Advanced-Level Physics Curriculum is organised into six sections[4], which provide rich contexts and applications to spark the joy of learning:

- Foundations of Physics. This introductory section is designed to strengthen the framework and approach to physics that learners bring along from secondary school. An appreciation for measurement and uncertainty anchors the *Ways of Thinking and Doing* articulated in the *Practices of Science*. Physical quantities are modelled as mathematical objects like scalars and vectors, and simple examples are used to illustrate the key conceptual strands of **motion**, **forces**, and **energy** that thread through the syllabus. In **H3 Physics**, learners wonder about the role of the observer.

- Mechanics. Each topic in mechanics is built around real-world contexts to deepen learners' understanding of **motion**, **forces**, and **energy**. Learners will sharpen their quantitative and analytical skills as they bridge real-world observations and theory by conducting investigations and experiments to study the mechanics of **systems**. Think about how gravity affects the vertical motion but not the horizontal motion of a thrown ball. In collisions, careful consideration of *before* and *after* allows us to **model** and extract information about the dramatic and short-lived impact event. Why does the Earth maintain a circular orbit around the Sun? Is there acceleration when moving with constant speed? In **H2 Physics**, learners encounter oscillatory perturbations from stable equilibrium, which also recalls the regularity and **pattern** of circular motion. In **H3 Physics**, learners unlock possibilities for modelling rigid bodies by realising the analogy between translational and rotational motion.

- Waves. In **H2 Physics**, the collective behaviour of synchronised oscillators is modelled as **waves**. These ripples in space and time can transfer **energy** without transferring **matter**. To describe and represent wave motion, learners first need to pick up the necessary mathematical language and terminology, focusing initially on visualising waves in one spatial and one temporal dimension. Using the principle of linear superposition, a wide range of phenomena involving wave interference can be explained, predicting complex **patterns** with the aid of geometric reasoning.

- Thermal Physics. In **H2 Physics**, the everyday concepts of heat and temperature are re-examined. Single-particle mechanics is applied to **model** an ideal gas, which is one of the simplest many-body **systems**. A crucial purpose of this section is to connect the **microscopic** behaviour of individual constituents with the **macroscopic** properties of the collective **system**, for learners to *simultaneously* see the forest *and* the trees. The strand of **energy** provides insight into physical processes like melting and

[3] This coherence owes a large part to the use of logical reasoning and mathematics. For an extended discussion, see Wigner, E.P. (1960), The unreasonable effectiveness of mathematics in the natural sciences. Richard courant lecture in mathematical sciences delivered at New York University, May 11, 1959. *Comm. Pure Appl. Math.*, 13: 1-14. https://doi.org/10.1002/cpa.3160130102
[4] For H1 Physics, the sections on Waves and Thermal Physics are omitted in view of the reduced syllabus scope.

boiling for material substances generalised beyond ideal gases. The overlap with what learners might have encountered in chemistry provides opportunities for teachers to discuss cross-curricular connections.

- Electricity & Magnetism. In this section, learners explore the **diversity** of phenomena related to the fundamental physical property of (electric) charge, which experiences **forces** when interacting with electric and magnetic **fields**. There is a close analogy between mass in a gravitational field and charge in an electric field. Electromagnetic forces can cause the kinds of **motion** studied in the earlier mechanics topics, and the **microscopic** behaviour of individual charges is connected to the **macroscopic** property of current in circuit **systems**. The principle of **conservation** of **energy** guides the analysis of circuits containing resistors and e.m.f. sources. In **H2 Physics**, the consideration of charge storage in capacitors deepens learners' appreciation of applications in electronics. The mathematics of oscillations and **waves** proves useful here for describing alternating currents in the electrical grid. In **H3 Physics**, the laws of electromagnetism are recast in integral form, which emphasises their geometrical nature, and allows characterisation of more complex field **patterns**. Learners explore the rotational **motion** of electric and magnetic dipoles, as well as the modification of electromagnetic fields in dielectric and ferromagnetic media, which is crucial for technological applications. In electrical circuits, the analogy with mechanical oscillations is established when inductive components are added to resistive and capacitive components.

- Modern Physics. This final section interrogates the **structure** of atoms – peering past their vast electronic shells into their central cores, the incredibly dense nuclear regions. In that secret heart of atoms, the electrical repulsion of like charges is overwhelmed by mysterious nuclear **forces**, which act as an invisible hand causing random and spontaneous disintegration for radioactive substances. **Conservation** laws also guide the analysis of nuclear reactions such as fusion and fission, which humanity has exploited in times of peace but also in times of war. In **H2 Physics**, learners catch glimpses into a paradigm shift that famously rocked the foundations of physics – the quantum revolution. **Waves** are particle-like, particles are wave-like; nature at its smallest scales does not behave in accordance with a deterministic classical clockwork conception, requiring a new framework to harmonise both particle-like and wave-like properties into a coherent theory expressed in terms of probability, complex numbers, and linear algebra. In **H3 Physics**, learners are challenged with yet another paradigm shift – the theory of relativity that questioned accepted wisdom about the absolute nature of space and time. Space and time do not exist independently of each other, and the relative **motion** of observers distorts their assignments of space and time coordinates. Simultaneity is not as obvious as we naïvely expect because of the universal limiting speed of light.

'Everything should be made as simple as possible, but no simpler.' – Albert Einstein[5]

To truly appreciate physical reality, we need the courage and tenacity to experiment, the humility and skepticism to question even our most basic assumptions, and the creativity and imagination to build alternative theories…

[5] The actual line from a 1933 lecture by Einstein is 'It can scarcely be denied that the supreme goal of all theory is to make the irreducible basic elements as simple and as few as possible without having to surrender the adequate representation of a single datum of experience.' [Source: Nature 557, 30 (2018). doi: https://doi.org/10.1038/d41586-018-05004-4]

SUBJECT CONTENT

The syllabus for H3 Physics builds on that for H2 Physics and includes the whole of the H2 Physics (9478) 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 into four of these sections, as shown in the table below. 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 15 for the mathematical requirements).

Additional content areas

The five additional topics in H3 Physics are layered into four of the six main sections in H2 Physics as shown.

Sections	Topics
A Foundations of Physics	1 Frames of Reference
B Mechanics	2 Rotational Motion
C Electricity and Magnetism	3 Electric and Magnetic Fields 4 RLC Circuits
D Modern Physics	5 Special Relativity

SECTION A FOUNDATIONS OF PHYSICS

1 Frames of Reference

Content

- Reference frames
- Inertial frames
- Centre of mass frame

Learning Outcomes

Candidates should be able to:

(a) state that a frame of reference is a set of coordinates that can be used to determine positions and times of events in that frame

(b) show an understanding that Newton's laws of motion are obeyed in all inertial frames of reference

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

(d) show an understanding that the centre of mass frame (or zero momentum frame) is the inertial frame in which the total linear momentum of the system is zero

(e) solve one-dimensional collision problems by considering velocities relative to the centre of mass of the system (i.e. in the zero-momentum frame).

SECTION B MECHANICS

2 Rotational Motion

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 bodies by using calculus, the parallel-axis theorem or otherwise (knowledge of the perpendicular-axis theorem and mathematical derivation of the moment of inertia for spheres are 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 problems, including the use of $F \leqslant \mu N$ for solid surfaces in no-slip contact (no distinction is made between the coefficient of static and kinetic friction).

SECTION C ELECTRICITY AND MAGNETISM

3 Electric and Magnetic Fields

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[6] 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 that the magnetic flux through a closed surface is always zero, suggesting the non-existence of magnetic monopoles

(d) recall and apply Ampère's law[7] 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

(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.

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[6] 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.
[7] 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.

4 RLC Circuits

Content

- Inductance
- Dielectrics and ferromagnetic materials
- Energy in an inductor
- Circuits with capacitors and inductors

Learning Outcomes

Candidates should be able to:

(a) define self-inductance as the ratio of the e.m.f. induced in an electrical circuit / component to the rate of change of current causing it and use $V = L\frac{dI}{dt}$ to solve problems

(b) show an understanding that mutual inductance is the tendency of an electrical circuit / component to oppose a change in the current in a nearby electrical circuit / component

(c) 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)

(d) 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)

(e) derive, by considering work done on charges, the expression for potential energy stored in an inductor, $U = \frac{1}{2}LI^2$, and use this to solve problems

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

(g) 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]*

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

(i) 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 verify and use particular solutions). *[RLC series circuits without e.m.f. source]*

SECTION D MODERN PHYSICS

5 Special Relativity

Content

- Michelson-Morley experiment
- Inertial frames and universal light speed
- Lorentz transformations
- Length contraction and time dilation
- Velocity addition
- Energy–momentum relation

Learning Outcomes

Candidates should be able to:

(a) discuss qualitatively the results of the Michelson–Morley interferometer experiment and its implications on the ether theory (knowledge of the details of the experiment is not required)

(b) state the postulates of the special theory of relativity, that in all inertial frames, the laws of physics are the same and the speed of light in free space is the same regardless of the motion of the light source or observer

(c) appreciate the failure of Galilean transformation equations when applied to a moving source of light

(d) discuss the concept of simultaneity

(e) show an understanding of the terms proper time and proper length

(f) apply the Lorentz transformation equations to solve one-dimensional problems

(g) derive the time dilation formula and length contraction formula, making use of the Lorentz factor

(h) apply the time dilation formula and the length contraction formula in related situations (e.g. the lifetime of fast-moving muons) or to solve problems

(i) use the one-dimensional relativistic velocity addition formula to calculate velocities in different inertial frames or to solve problems

(j) use the relativistic energy–momentum relation $E^2 = (pc)^2 + (mc^2)^2$ to solve problems, and show that it reduces, in the appropriate limits, to:

1 $E = pc$ (for massless particles); or

2 $E = mc^2 + \frac{1}{2}mv^2$ (for particles moving at low speeds $v \ll c$).

MATHEMATICAL REQUIREMENTS

Additional requirements not found in the H2 Physics (9478) 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 $<$, $>$, $\ll$, $\gg$, $\approx$, $/$, $\propto$, $\langle x \rangle$ (= $\bar{x}$), Σ, Δx, δx, $\surd$.

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.

*(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[8] (knowledge of integration by parts is not required).

*(c) evaluate definite integrals.

*(d) solve first-order differential equations of the form $dy / dx = f(x)$.

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

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

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[8] 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. & Allday, J. (2000). *Advanced physics*. Oxford: Oxford University Press.

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

Feynman, R., Leighton, R. & Sands, M. (2010). *The Feynman lectures on physics*. New York: Basic Books.

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Jones, E. & Childers, R. (2001). *Contemporary college physics*. Boston: McGraw Hill.

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

Serway, R., Jewett, J. & Peroomian, V. (2016). *Physics for scientists and engineers with modern physics*.

Boston, MA: Brooks/Cole, Cengage Learning.

Tipler, P. & 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. & Banchoff, T. (2015). *Flatland: a romance of many dimensions*. Princeton: Princeton University Press.

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

Hawking, S. (2010). *The illustrated a brief history of time; The universe in a nutshell*. New York: Bantam Books.

MacKay, D. (2009). *Sustainable energy--without the hot air*. Cambridge, England: UIT.

Munroe, R. (2015). *What if*. Place of publication not identified: John Murray Publishers Lt.

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. Quantities not listed in H2 Physics are marked with an asterix (*).

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
capacitance	C	F
*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 dipole moment	μ	A m^2
magnetic flux	Φ	Wb
magnetic flux density	B	T
permeability of free space	μ_0	H m^{-1}
*inductance	L	H
force constant	k	N m^{-1}
Celsius temperature	θ, T	°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

Quantity	***Usual symbols***	***Usual unit***
activity of radioactive source	A	Bq
radioactive decay constant	λ	s^{-1}
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 mol^{-1}
proton number	Z	
nucleon number	A	
neutron number	N	

DATA AND FORMULAE

Additional data and formulae not found in the H2 Physics (9478) syllabus are marked with an asterisk (*).

Data

speed of light in free space	c	$= 3.00 \times 10^{8}$ m s^{-1}
permeability of free space	μ_0	$= 4\pi \times 10^{-7}$ H m^{-1}
permittivity of free space	ε_0	$= 8.85 \times 10^{-12}$ F m^{-1}
	$(\frac{1}{4\pi\varepsilon_0}$	$= 8.99 \times 10^{9}$ m F^{-1})
elementary charge	e	$= 1.60 \times 10^{-19}$ C
Planck constant	h	$= 6.63 \times 10^{-34}$ J s
unified atomic mass constant	u	$= 1.66 \times 10^{-27}$ kg
rest mass of electron	m_e	$= 9.11 \times 10^{-31}$ kg
rest mass of proton	m_p	$= 1.67 \times 10^{-27}$ kg
molar gas constant	R	$= 8.31$ J K^{-1} mol^{-1}
Avogadro constant	N_A	$= 6.02 \times 10^{23}$ mol^{-1}
Boltzmann constant	k	$= 1.38 \times 10^{-23}$ J K^{-1}
gravitational constant	G	$= 6.67 \times 10^{-11}$ 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	$I = \frac{1}{2}M(r_1^{\,2} + r_2^{\,2})$
*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	$W = p\Delta V$
pressure	$p = \frac{F}{A}$
gravitational potential	$\phi = -\frac{GM}{r}$
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 particle	$E = \frac{3}{2}kT$

displacement of particle in s.h.m.	$x = x_0 \sin \omega t$
velocity of particle in s.h.m.	$v = v_0 \cos \omega t$
	$= \pm \omega \sqrt{(x_0^2 - x^2)}$
electric current	$I = nAvq$
resistors in series	$R = R_1 + R_2 + \ldots$
resistors in parallel	$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \ldots$
capacitors in series	$\frac{1}{C} = \frac{1}{C_1} + \frac{1}{C_2} + \ldots$
capacitors in parallel	$C = C_1 + C_2 + \ldots$
energy in a capacitor	$U = \frac{1}{2} QV$
	$= \frac{1}{2} \frac{Q^2}{C}$
	$= \frac{1}{2} CV^2$
charging a capacitor	$Q = Q_0 \left[1 - e^{-\frac{t}{\tau}}\right]$
discharging a capacitor	$Q = Q_0 \, e^{-\frac{t}{\tau}}$
RC time constant	$\tau = RC$
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	$B = \frac{\mu_0 N I}{2r}$
magnetic flux density due to a long solenoid	$B = \mu_0 n I$
*energy in an inductor	$U = \frac{1}{2} L I^2$
*RL series circuits	$\tau = \frac{L}{R}$
*RLC series circuits (underdamped)	$\omega = \sqrt{\frac{1}{LC} - \frac{R^2}{4L^2}}$
energy states for quantum particle in a box	$E_n = \frac{h^2}{8mL^2} n^2$
radioactive decay	$x = x_0 e^{-\lambda t}$
radioactive decay constant	$\lambda = \frac{\ln 2}{t_{\frac{1}{2}}}$
*Lorentz factor	$\gamma = \frac{1}{\sqrt{1 - \left(\frac{v}{c}\right)^2}}$
*Length contraction	$L = \frac{L_0}{\gamma}$
*time dilation	$T = \gamma T_0$
*Lorentz transformation equations (1 dimension)	$x' = \gamma(x - vt)$
	$t' = \gamma\left(t - \frac{vx}{c^2}\right)$
velocity addition	$u' = \frac{(u - v)}{\left(1 - \frac{uv}{c^2}\right)}$
*mass–energy equivalence	$E^2 = (pc)^2 + (mc^2)^2$